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Seminar on Short-term and Area-wide Evaluation of Safety Measures

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CONTENTS

BACKGROUND PAPER

SHORT TERM AND AREA WIDE EVALUATION OF SAFETY-MEASURES

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1. INTRODUCTION

In this seminar we will restrict ourselves to safety measures. Thus only countermeasures that are intended to reduce accidents and the consequences of these accidents will be regarded. Of course it is of interest to know how safety measures are related to countermeasures that have been taken for other reasons but also have an impact on safety.
Furthermore it is important to know the limitations with regard to goals of higher priority. We can ask ourselves if there are countermeasures on a higher level, such as town planning, traffic distribution, energy consumption etc., that influence safety or the safety measures that have been taken. Or, given these priorities, whether or not the safety measures are optimal with regard to safety or with regard to cost/benefit, cost/effectiveness etc.
We can also investigate the side effects of the safety measures on other subjects such as noise, air pollution and comfort.
However, we propose to restrict ourselves to the evaluation of safety-measures with regard to safety.
A second limitation is concerned with the addition of "area wide".
In those cases where traffic circulation has been changed it is always advisable not to restrict the evaluation of countermeasures to the locations where they are implemented. E.g. signalisation of intersections may result in changes in traffic flow and finally in a shift of accidents rather than a reduction. However, here we are concerned with a different thing.

Area-wide investigations

Recently more and more attention has been paid to area-wide traffic plans and proper evaluation studies for these plans. Specific methodological and statistical problems result from this situation. Uncertainties about the effects of new traffic management or environmental schemes result in experimentation and evaluation. The uncertainties arise from the implementation of various different types of countermeasures in "unique" situations. Short-term evaluations are therefore of interest not only for the policy-makers

but also for the investigators themselves. A second, rather cynical reason for evaluation is that it is sometimes easy to bypass the public participation process by promising such an evaluation study.
In general, however, the reason behind these studies is to improve an implemented scheme or at least specific countermeasures that are part of it. Therefore, it is necessary to understand why changes do appear. Global studies which result in some percentage of accident reduction do not satisfy the investigator completely. To understand the effects of countermeasures it is inevitable to detect the relevant conditions and to describe quite precisely how these conditions are related to the effects. Furthermore it is important to know how the results of the evaluation studies can be generalized in order to design new schemes.
Finally, two practical problems with regard to area-wide evaluation studies are important. The first one is the definition of the experimental area, the area that is not experimental itself but is influenced by the countermeasures and the control area.
The second problem is how to cope with behavioural studies in small streets with low traffic volumes without influencing the traffic process.
Two main reasons for evaluation are mentioned: evaluation of the product of these countermeasures (decrease in unsafety) and evaluation of the changes in the process of traffic behaviour that are initiated with the safety measures. The product is of major concern for policy makers, the process for the investigators, although this distinction is not absolute. The question whether or not these countermeasures are effective, mostly stated in terms of hypothesis testing, is mainly concerned with the product. If explanations are wanted for the presence or absence of effects, mostly stated in terms of parameter estimation, one is mainly concerned with the process. If one is concerned with the product then questions arise such as: "Is this specific conflict measure an acceptable surrogate measure for accidents?". To test such a hypothesis, one investigates whether or not the correlation between the number of accidents and that conflict measure departs from 0. If an investigator regards a conflict to be a behavioural determinant of accidents, then he might ask himself to what extent this aspect of

behaviour is related to unsafety, e.g. by asking how much the correlation between this conflict measure and the number of accidents deviates from 0. In this context we may find here all kinds of relational studies, with regard to a large number of behavioural aspects, road conditions and circumstances.

In view of product evaluation, short-term evaluation has the advantage that the influence of disturbing factors is reduced. However, the time for evaluation may be too short to collect sufficient data, especially when residential areas are investigated. Furthermore, if we want information about the effect of countermeasures on specific aspects of safety, such as pedestrian-accidents with children involved, then the problem of insufficient data becomes even more important.

2. PRODUCT EVALUATION

2.1. Safety data

If we want to evaluate the effects of countermeasures, we will measure unsafety before and after the countermeasure and see to what extent there is a reduction in unsafety due to these. If we define unsafety in terms of the probability of accidents and the resulting damage to persons and properties, then the only way to measure unsafety directly, is to count accidents and registrate their effects. We have to estimate probabilities from counts and even with well defined probabilistic models, such as the model of Poisson-distributed accidents, it is very difficult to detect differences in probabilities. In Figure 1, we find an example of the expected number of observations needed to detect various percentages of reduction of accidents. These data result from exact tests applied to Poisson-distributed accidents. A reduction of 20% of the accidents is not significant anymore at a 5%-level, with less than 80 accidents. A reduction of 30% is only significant with more than 35 accidents. We have to wait for years to get these figures in most situations, both because the kind of countermeasures result in us

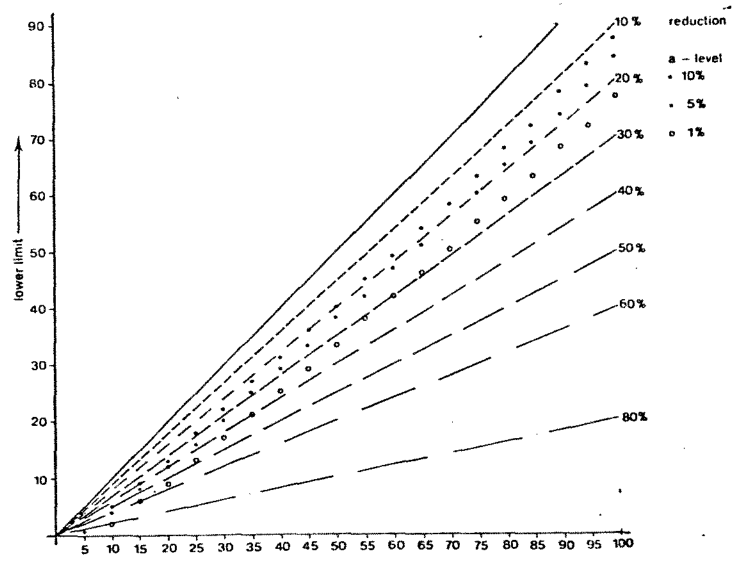

Figure 1

Figure 1 shows the numbers of observations necessary to detect significant reductions in those numbers for values of zero to hundred observations. It is assumed that the number of observations is Poisson-distributed. When the number of observations is 100, a reduction of 13% (87 observations) is already indicative (at a 10%-level of significance). A reduction of 16% is already significant at a 5%-level and a reduction of 23% is significant at a 1%-level of significance. A reduction of 20% is not significant anymore at a 5%-level if the number of observations is less than 80. With numbers of observations lower than 50, this reduction is not even indicative.

A reduction of 30% can only be detected at a 1%-level of significance when the number of observations is larger than 60. At a 5%-level with numbers larger than 35. If the number of observations is smaller than 25, a reduction of 30% is not indicative anymore.

A reduction of 40% can only be detected at a 1%-level if the number is greater than 35 and if the level is 5% then only with numbers greater than 20.

If the number of observations is smaller than or equal to 10 even a reduction of 60% is not significant anymore at a 5%-level.

larger reduction, are very rare and the areas involved have low traffic volumes and therefore low accident numbers (although these numbers may be relatively high as compared to situations with high traffic volumes). There seems to be no way out of this problem that is stated over and over again.

Apart from this fundamental problem there are many methodological problems related to the comparison of accident figures. The OECD-report from OECD Road Research group TS4 (OECD, 1981) gives an excellent survey of problems such as the definition of the correct control group, finding the correct sampling procedure etc. We shall not go into detail on this here.

There are also modern techniques that improve the possibilities of comparing data. E.g. De Leeuw & Oppe (1976) describe a log-linear model in which it is possible to compare accident rates of multi-way tables by means of various kinds of hypotheses.

Recently it is even possible to use exact tests to test larger tables than 2x2 designs more efficiently.

However, for each comparison that is stated by means of counts or measures such as accident rates deduced from counts, the problem of insufficient data remains the most important problem once the effect of safety measures is evaluated.

The only way to improve statistics is to increase the counts.

One way to do this is to extend sample time. However, with short-term evaluation this seems to be hardly the answer. Furthermore there are difficulties resulting from the increased variation in circumstances that disturb the comparison if time of observation is extended.

Another way out is to enlarge the area or increase the number of areas. However, this presumes careful comparisons of situations in order to see if this justifiable. We will return to this in section 3.

Finally, we can use surrogate measures of safety, e.g. counting conflicts instead of accidents.

2.2. Conflict data

If we want to know how unsafe a particular area is, we really want to

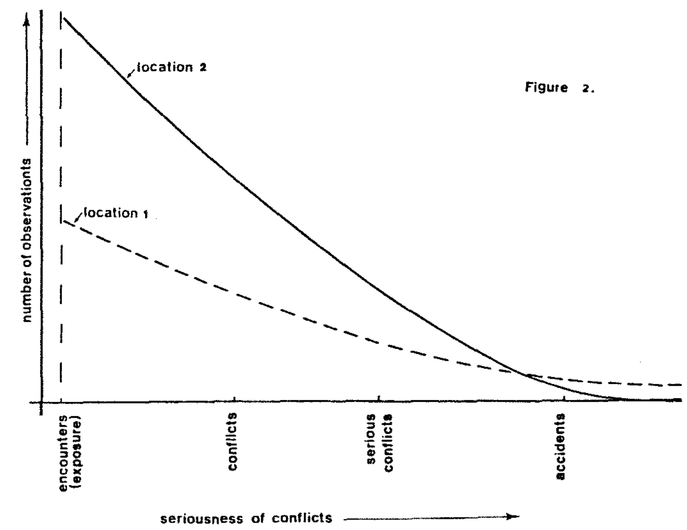

Figure 2.

establish the accident potential and not just how many accidents have already occurred there. Especially if these areas of concern have very new and drastic designs. Sometimes, we try to estimate accident potential by means of other indicators of unsafety than the accidents themselves. Sometimes the number of traffic conflicts is used as an indicator of traffic unsafety.

Experimental evidence shows that the "serious-conflict" measure is a better predictor for accidents than the total number of conflicts. Therefore, the definition of conflicts with regard to seriousness is very important in order to improve the validity of the conflict technique. Figure 2 demonstrates an imaginary comparison between two locations. If we choose a definition with regard to the seriousness of conflicts, we select a point on the x-axis. On the surface underneath the curve, right from this point, we find for each location the number of conflicts. If we select the point marked "conflicts" we see that the estimated number of accidents is larger for location A than for location B. If we choose serious conflicts, then both numbers are more or less equal, while, using the number of accidents, this number is smaller for A than for B. The use of accident rates as a measure of unsafety instead of accidents totals is implicitly based on the assumption that the curves are not parallel. If the curves were decreasing at exactly the same rate for all locations, the correlation between accidents and accident rates would be perfect. In this case the denominator (some measure of exposure that is used in the accident rate) would give us the best estimation of the potential danger at the locations, because we can measure exposure the most reliably. We know that this is not the case; the accident rate gives us extra information. We have to study the curves in detail before we know if these rates give us sufficient information.

2.3. Accidents, conflicts and exposure

If we look again at Figure 2 we must realise that we use rather far going assumptions in trying to predict the small surface area at the right of the accident point, from the large surface at the right of the conflict or serious conflict point. At least the shape of the curve seems relevant. The accident rate gives us information about this shape. If we define a conflict rate in the same way, using conflicts as some measure of exposure and serious conflicts as a measure of unsafety, then we have some information about the shape of the curve. If well defined, both measures will be more reliable than accident counts, because of the larger number of counts. One problem does limit the relevance of both measures of exposure and unsafety, namely, the problem of the validity of the conflict measures. If we ask for the "content validity" of the conflict measure using conflicts as a measure of exposure we need an operational definition of exposure in each particular case.
Exposure measures deduced from gross traffic volume data, such as exposure data for pedestrians deduced from time spent in traffic or distance travelled, seem to be insufficient. Especially in situations we are interested in, e.g. residential areas. It seems better to define first situations that are relevant such as the number of encounters between road users, in order to detect which of these

situations are critical.
However, it will be even more difficult to find a correct operational definition for serious conflicts, for the detection of critical situations. Content validity seems to be the (very important) first step. Only the "predictive validity" with regard to accidents can inform us about the relevance of the serious-conflict measure as a measure of unsafety. The content validity can inform us only about the "face value" of the method, or in other words, how relevant the definition looks at first sight.
The face value of the existing conflict measures with regard to situations that are special for residential areas is not high. Many techniques are being developed for dense traffic arterials and/or car-to-car conflicts. It is important to know the relevant cues for accidents between cars and other road users such as pedestrians and bicyclists.
Improving the content validity of the conflict measure will be the necessary link between the conflict technique used as a surrogate measure of unsafety and the conflict-analysis technique. This technique regards conflicts as behavioural aspects of the traffic process amongst (and related to) other aspects of behaviour, such as speeds, manoeuvres etc., under various conditions, in order to find explanations for the hazard of specific traffic situations.

3. PROCESS EVALUATION

The effectiveness of countermeasures that have been taken to improve safety, results from the extent to which it is possible to reduce unsafe behaviour or to improve conditions that cause unsafety. If one wants to know if a measure is indeed effective (or as effective as has been assumed), the question arises whether that measure has the intended effect on behaviour or conditions. This answers the question whether or not the measure can have an effect on safety. The next question then is: "Does this change in behaviour or conditions reduce unsafety as was supposed?", or: "Is the measure relevant with regard to safety?"
We can skip the first question and only look at the impact of the

countermeasure on safety as has been described as product evaluation. But if such evaluation is not possible, because there are not enough accident data to test these effects, we can ask ourselves whether it is still the best procedure to evaluate the assumed effect on safety by means of surrogate measures instead of evaluating whether or not the countermeasures have the expected impact on traffic behaviour and traffic conditions. Especially in case knowledge about the effectiveness of a particular countermeasure is scarce, it is of great importance to register, apart from the effect on behaviour and conditions that are supposed to be directly influenced in the other conditions and circumstances that existed in that situation and to measure the effect of the countermeasure on the relevant traffic characteristics. We can ask ourselves in what way the characteristics that are supposed to change, are influenced by the countermeasures and which conditions are relevant for this change.

This asks for relational studies in complex situations, especially if the countermeasures that have been taken are compounds of various area-wide countermeasures. For this kind of investigations it is necessary that the results of various situations are collected in order to find relations that are stable and can be generalised for other situations. For example, if we want to evaluate the usefulness of humps in streets, we have to determine under what conditions and in which situations a sufficient reduction in speed will result and how we can cope with dangerous side effects in various situations.

We can possibly find a way of applying a countermeasure which is optimal for a moderate range of situations, but it is of great importance to know the results outside this range. A large-scale evaluation of countermeasures applied to a diversity of small-scale situations is needed to collect this kind of knowledge.

The registration of conditions is primarily important if we want to compare results from other studies, especially in different countries. Furthermore the registration of discrepancies between the data that is wanted for optimal investigation and the data that were available at the moment of investigation can help to improve future investigations.

If conflict techniques are used to analyse conflicts, in order to get

a greater insight in to the relation between various countermeasures and conditions on the one hand and the impact of these on the behaviour of road users on the other, this will also result in a better content validity of this technique as a surrogate measure of unsafety.

However, the conflict-analysis technique is only one method of investigation.

All kinds of behavioural measures are available, ranging from sophisticated registration of eye movements and galvanic skin responses to the measuring of velocities or observation of the crossing behaviour of pedestrians.

Because not much is known about the influence of various traffic conditions on the behaviour of road users, the expectations about the effectiveness of measures are based on rather vague theories.

Also little is known about the relation between the estimated risk of situations and feelings of unsafety of road users and the effect of these on their behaviour in traffic or their participation in traffic, vehicle choice or choice of routes. Although these feelings of unsafety may not be direct criteria for the evaluation of safety measures, they are relevant to investigate the relation between the behaviour of road users and safety or the effectiveness of safety measures.

A major problem in the study of this kind of relations is the fact that many characteristics are of a qualitative nature. However, there are recently developed techniques (Gifi, 1981) which can be used to analyse relations between qualitative characteristics as well.

At last, in order to give a complete evaluation of countermeasures and to find an adequate evaluation procedure, the purpose of the measure has to be stated explicitly, together with the means by which one tries to realise this purpose, the expectation about the effectiveness of the measure and its side effects.

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SESSION 1:
Research policy

SESSION 1

Chairman: Gressier (France)

Theme: Research-policy

F.G. Ephraim (U.S.A.)	:	Community traffic safety: an evaluation challenge
J.J. Lawson (Canada)	:	Some experience in Canada with problems of short-term evaluation of safety measures
R.C. Matthews (France)	:	Short-term evaluation and decisionmaking
N. Muhlrad (France)	:	Why an evaluation of traffic safety measures?
M. Roine (Finland)	:	Principles in short-term evaluation of safety measures
D.T. Silcock and R.T. Walker (U.K.)	:	The potential for area-wide application of accident measures in residential areas

COMMUNITY TRAFFIC SAFETY: AN EVALUATION CHALLENGE

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1.0 Introduction

Given the state of the art of safety evaluation this seminar addresses a necessary yet difficult task. The evaluation of short-term and area-wide safety measures presents a challenge to the seminar participants by directing their collective abilities toward exploring ways to better design and apply evaluative analyses.

This paper draws on selected U.S. experience thought to be relevant to the topic and attempts, through interpretation, to focus on certain problems that confront the evaluator. It does not deal in detail with statistical methodology.

1.1 Trends in Traffic Safety Direction

In the United States, the Federal role in traffic and motor vehicle safety stems from legislation adopted in 1966. It encompasses leadership, research, information and regulation. While the regulation of safety performance for vehicles is not specifically relevant to this seminar, it offers evaluation opportunities from which useful experience has been gained to illustrate certain points later on. For traffic safety the emphasis is on driver, pedestrian and road safety research, local and area (State, county, city) demonstrations to test and evaluate safety measures, and grants to States for safety programs. A considerable amount of evaluation work has been done at all government levels, some of which has been included or referenced in previous OECD reports.

In the early seventies, the National Highway Traffic Safety Administration (NHTSA) funded 35 Alcohol Safety Action Projects (ASAPS) - in as many States. Each ran for three years, was managed by a local or State agency, and required evaluations of countermeasures. The overall direction was at the Federal level. It was hoped that local governments would continue those measures found to be both effective and affordable. The results were mixed. Twelve of the projects appeared to have reduced the number of fatal accidents where alcohol was a contributing factor. Local authorities did, in several instances, continue certain programs, but as national statistics have shown, alcohol continues to be a factor in more than half of our fatalities.

The problem of drunk driving is probably the best indicator of the trend in government roles. A more acute awareness and willingness to intercede has emerged in communities, accompanied by the view at the national level, that safety problems can be better addressed by localities whose elected and appointed officials are responsible for public service and who can take or encourage action. The last few years have seen more local initiatives to curb drunk driving, such as mandatory jail sentences upon conviction and roadblock patrol interdiction. In some areas hardly a week goes by without several television and radio editorials on the subject of drunk drivers.

Displeasure over the way the Federal Government has performed and interceded as well as questions about benefits from increasing expenditures at all government levels are the likely motivation for the public to assure themselves that what is planned and implemented does indeed work. Such is the growing concern at the local level.

The implication for our topic is clear. We wish to explore how one might approach the evaluation of safety measures so that the product is useful to local decision makers and to members of a community. If the trends in the U.S. are a guide, there is little doubt that our undertaking is worthwhile.

1.2 Discussion Topics

This paper begins with a brief discussion of some impediments to evaluation. Two cases, which are considered good examples of scientific evaluations in the short-term, area-wide category are presented next. Both use speed reduction as an intermediate measure. A number of issues, relating to speed reduction as a criterion of safety, the use of observations, measurement of public awareness and the transferability of results are discussed. A multiple countermeasure program which is underway is described.

The potential for developing causal factors, such as unsafe driving acts, as surrogate measures is presented. The paper concludes with a call for developing, and exploring the use of exposure measures.

2.0 Impediments to Evaluation

The impediments to evaluation are particularly relevant to short-term, area-wide evaluations. While they cover many situations, the two cases that are described next illustrate some of our experience.

2.1 "Small" Numbers Are Not Always Small

One of the key problems in short-term, area-wide evaluation is the lack of sufficient accident data. A short commentary entitled "Use and Misuse of Small Samples in Traffic Safety Problem Analysis" by Waller [1] discusses the problem.

During January 1980, there were 17 fatalities in the State of Vermont, which was higher than the average of seven which had occurred that month in each of the previous five years. The month of February 1980 continued at the high level. Top executive and legislative officials were, of course, very concerned. On the one hand it was possible to contemplate that here was a case of small sample deviation when the annual number of traffic deaths could vary from 117 to 166, strictly by chance alone. On the other hand, the small number for January shows a statistically significant increase, a legitimate cause for concern. By March of 1980 fatalities dropped and remained down for the rest of the year. One could have left it at that and concluded that the annual statistics fell within the "small sample deviation" category.

The small numbers did yield some information. The January 1978 and 1979 totals (14 fatalities) included only one fatal single-vehicle crash, but in January 1980 nearly half of the 17 fatal crashes were single-vehicle.

Early 1980 was a disappointing skiing period - there was no snow, and single vehicles going off the road ran into solid obstacles, instead of the cushioning snow banks! People could also drive more - and faster. In March when fresh snow again lay deep, fatal crashes returned to the expected level.

Dr. Waller's parting thought was: "simply because you have small numbers doesn't preclude analysis and problem identification."1/ We should at least resolve not to assume, a priori, that the numbers are too small for an evaluation.

2.2 Evaluations Are Not Always Welcome

Many years ago a medium-sized city police department employed a selective enforcement countermeasure to reduce observable traffic violations. On the assumption that these lead to traffic accidents, particularly at intersections, they employed a method by which police patrol cars cruised through or were stationed at certrain intersections. A separate set of intersections served as a control group. Violations were observed before and after the countermeasure. After a relatively short time -- about three months -- large reductions in intersection accidents were recorded at the experimental sites, compared to control areas. The results received wide publicity. When the project was reviewed some disturbing facts emerged. An elevated roadway across the city had been opened not long before, and traffic to a distant resort area no longer had to wind its way through the city. A number of experimental intersections lay along the old route. No traffic counts were available. In addition, a one-way street plan had been put into effect, and polarized traffic signals were being installed. The nearby resort area was going through an economic "down", thus very likely reducing traffic volume through - or rather over - the city.

While this may appear to be a blatant case of "poor design" coupled with the desire to show that funds were spent effectively, it is by no means unique. The urge to prove success for safety measures is based on a simple reality. A failure by local officials to improve a situation is much worse than doing nothing. While this might tempt one to pursue research on the evaluation process in relative isolation from the political and economic environment, this too can lead to illusory results of little value. In their study on impediments to safety program evaluation, Griffin, et al., state [2]:

> Evaluations should be seen as a synthesis between pure science and the politics of public administration. A certain combination of both will allow for clear statements of project goals, good measurements, logical inferences and subjective explanations for why things are the way they are and how they can be profitably changed. Objectivity in measurement, logic and common sense in inference, and subjective, qualitative prescriptions in conclusions are the essence of good evaluations."2/

1/Based on comments made by Julian Waller, M.D., at the Symposium on Traffic Safety Effectiveness (Impact) Evaluation projects conducted by the National Safety Council, Chicago, Illinois, 1981, p. 293.

2/Lindsay I. Griffin, III, Brian Powers and Catherine Mallen. Impediments to the Evaluation of Highway Safety Programs. (Chapel Hill: University of North Carolina Highway Safety Research Center, 1975), p.47.

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Working within an environment of competing interests should not be new to seasoned evaluators. It is still not the most pleasant task to point out faults to committed and often adamant special interests as we had to do in the case just mentioned. The "success" in reducing accidents continued to be cited for years thereafter. This case was an example of a situation where an evaluation was impractical in the first place. The evaluation was not welcome, nor could it be properly designed.

3.0 A Review of Case Studies - The Scientific Evaluations

There are many examples in the United States of scientific evaluations which could be classified as short-term, area-wide. Two have been selected for discussion to illustrate public administration conditions and especially to explore the use of intermediate measures.

3.1 The School Speed Zone Study

This example is drawn from a paper published in Transportation Research Record 811 [3]. It begins with the request, by a group of citizens, to the mayor of a Mid-western city, to establish 15-mile per hour speed zones near school crossings located on streets with posted 35 mile per hour speed limits. The mayor first appointed a committee to determine the need for such zones and to offer recommendations about their use. The committee went to work analyzing local pedestrian accidents, and school speed zone effects in 25 cities throughout the United States. The committee reported that:

- During the previous four years, six children were struck while crossing a street next to their school where a speed limit over 25 mph prevailed. This is out of a total of 156 children (aged 5 to 14) involved in pedestrian accidents in the city.
- Radar surveys from ten of the 25 cities showed that none were able to reduce speeds to the level proposed, even with police enforcement.
- Accident experience did not differ significantly between cities with and without school speed zones.

The committee then recommended against establishing school speed zones.

The public administrator - in this case, the mayor - did what others have done so many times. When in doubt appoint a committee. This achieves two purposes: it does not cost anything since members serve voluntarily and it fends off decisions without appearing arbitrary. The committee used accident statistics which are inadequate to prove or disprove effects - as any experienced safety evaluator could have known. Their second finding was based on 10 of 25 cities and reflected - very likely - expected speed reductions of 10 or more miles per hour. Such effectiveness levels are rarely derived from the countermeasures employed even against such popular targets as speeds. A three or four mile per hour reduction, under the circumstances is probably more typical, as found in numerous field tests conducted by the Federal Highway Administration.

3.1.1 Conducting the Study

The recommendation of the committee however, was not unanimous. Some members expressed the following views:

- It is not necessary to prove that lower speed limits will reduce accidents since the "potential" conflict between school children and cars is itself sufficient reason for lower speed limits.

- That speeds could be brought down by enforcement and publicity.

After continuing to support the need for school speed zones and drawing the support of parents, the city over the subsequent three years had set up 15 speed zones, and more were requested. The committee, which by now appeared to have been institutionalized and renamed the School Crossing Protection Committee, remained unconvinced about crossing zone effectiveness. They even felt that such measures could have the effect of giving parents and children a false sense of safety.

At this point a study of the effects of school speed zones, and their enforcement, on speeds was commissioned. It was performed by the State university in cooperation with the city's transportation and police departments.

Four existing school crossings were selected that were similar in traffic and pedestrian volume, previous enforcement levels and road condition. Two crossings were within school speed zones and two were not. The speed zones were marked by 25 mile per hour speed limit signs with flashing yellow lights which operated only during crossing periods. The posted speed limits on the streets containing the school crossings were 35 miles per hour.

Speed studies were conducted at each of the four crossings over a five-week period. Six spot speed measurement "units", conducted at one week intervals, at each site, were collected. Each unit consisted of speed measurements in one direction, with free-flowing traffic, during the 45 minutes when students used the crossing and for one hour thereafter. The presence of students in the crossing vicinity was noted as each speed was recorded. At two of the school crossings - one within and one not within a school speed zone - a police officer in a radar-equipped patrol car was stationed during the 45-minute crossing period. This type of enforcement was employed one day a week during the first week, and increased to three days during the second week and five days during the third week of the experiment. During the last two weeks no enforcement was used.

Each crossing had a traffic signal which could be actuated by pedestrians and two of the crossings were manned by student crossing guards during a 10 to 15 minute peak period. The crossing guards were counted as "pedestrians present" during speed measurements. All together, 8100 individual speeds were observed. The speed data were stratified into four sets

- Speeds during the hour after the 45-minute crossing period, without students present.

- Speeds during the 45-minute crossing period without students present, and

- Speeds for both above, except <u>with</u> students present.

The influence of school speed zones and their enforcement was based on comparisons of the 85th percentile speeds and a computation of the error in the estimate (of the 85th percentile speed), at the 95 percent level of confidence, provided the degree of statistical accuracy deemed sufficient for this study.

3.1.2 Results of the Study

Traffic speeds were reduced when pedestrians were visible at school crossings and during the 45-minute crossing period. The 25 mile per hour speed zone together with the presence of enforcement when combined with the effect of the presence of pedestrians, reduced speeds by about seven miles per hour. As expected, the experiment showed a diminution of speed compliance once enforcement had been removed. The conclusions were that speed zones plus enforcement improve the achievement of speed reduction above that created by the presence of pedestrians and the normal 45-minute crossing period. The researchers recommended that since enforcement is necessary if there is to be compliance with the reduced speed, school speed zones should not be established unless such enforcement will be provided.

3.1.3 Some Observations Based on the School Speed Zone Study

The conduct of the study was a serious effort by researchers to measure the effects of speed zones and enforcement, the presence of pedestrians, and school crossing periods on the driving speed of individuals operating cars along a road with a normal posted speed limit of 35 miles per hour. The study was well designed and executed and it is not the purpose here to dissect or otherwise critique the analysis. The case serves as one benchmark for our discussion.

The primary issue is the use of speed as an intermediate measure in a case where the questions were about accident reduction and the reduction of potential conflict between schoolchildren and cars. Were it not for the modern technology that produced the radar speed gun, fewer examples would be in hand. We might even raise the point that the very reason for the popularity of speed reduction as an intermediate or proxy measure is the fact that it is now so easy to establish! Had we a practical device which would record (and interpret) the motivation of drivers during vehicle operation, or the reactive impulses of schoolchildren preparing to cross a street, our studies would undoubtedly be full of interesting data.

The bottom line - accidents, injuries and fatalities - are the measures of highway safety, but as we recognize, these data are often not present in sufficient quantity to conduct an evaluation. Speed reduction, per se, is frequently an acceptable intermediate effect, yet this depends on the subjective judgement of how much of a reduction is required to produce an improvement in safety. Is it necessary to reduce speeds, say from 35 to 15 miles per hour, before we agree that it has an effect? Or is a five m.p.h. drop adequate? Is there any way we can accumulate the experience of the many speed reduction studies done in circumscribed areas and derive an expected pedestrian accident reduction - at crossings - for a range of speed reductions?

If we are to at least tentatively accept conflict reduction as an objective, we are confronted with complex observation criteria and techniques. Multiangle video monitors are the immediate devices that come to mind, yet here the technology is but a relatively minor component. Scoring and classifying such conflicts, given many possible contributing factors preceding and accompanying the "conflict" such as a loud noise, sudden wind gusts, or distraction for either or both entities presents some serious problems.

To digress for a moment and pursue the capture of conflict data, a recent evaluation of the U.S. automobile bumper regulation [4], involved a survey of unreported, low speed collisions [5]. The regulation required damage protection at impact speeds of five miles per hour. Of interest is the finding that about one in five cars on the road (22 percent) is involved in a low speed collision each year. "Low speed" was defined as a collision where there were no injuries and the cars were driveable after contact. Fourteen out of 22 percent of the drivers do not report such incidents to either the police or an insurance company. Insurance claims are filed by another seven percent. In unreported incidents, half of the cars were damaged. That is, some seven percent of the cars on the road, each year, incur some property damage which is not reported.

One would expect a "potential" conflict situation to arise more frequently than a low speed collision thus providing a substantial data base even for an evaluation of safety measures in an "area". There are limitations and criticisms which we have to consider. The ability of a respondent to recall an incident, particulars about the incident, and when it took place. In the low speed accident case actual collisions (though many with no damage) were solicited. If incidents such as near misses, or other noncontact conflicts (perceived risks) were sought one might expect far more dissipation of retained facts. There are techniques to improve recall and validate the response, which were employed in the survey. The use of a survey or interview technique, however, still leaves the many questions of conflict definition and classification unanswered.

We will return to these issues again, but before proceeding further, another case study is introduced and described. It is an evaluation of a safety measure where the objective is quite similar to the previous example. There are, however, important differences ranging from the political environment to the data used for analysis.

3.2 The Model Ice Cream Truck Ordinance - An Experimental Field Test [6]

Vendor-related accidents involving young children, aged two to ten years of age, were identified as a type of "dart-out" accident. While they are shown to represent only two to three percent of pedestrian accidents in such cities as Los Angeles and Detroit, they are likely to be underreported since the presence of an ice cream vending truck is not always recorded by police investigators.

3.2.1 Conduct of the Field Test

The field test required that a city adopt a special ordinance applicable to ice cream vending trucks which, in brief, stipulated that these vehicles be equipped with a horizontal swing out stop signal arm

containing two alternately flashing lights. Additional signal lamps were required to be mounted on the truck, visible for 500 feet. Drivers of cars approaching the truck, when in its vending mode with signal arm swung out and lights flashing, were to stop before reaching the truck. Thereafter they could proceed at a reasonable speed not exceeding 15 miles per hour, yielding the right of way to pedestrians.

After reviewing accident statistics in several cities, the researchers approached the City of Detroit, which also met other requirements for the test in terms of the vending season and size of ice cream vendor operations. The city recorded more than 40 accidents of the target type each year.

The entry environment was supportive. The governing body, a City Council, had held a public meeting to hear views by all interested parties on the problem. Not long after the city officials were approached by the research team, a resolution was passed by the City Council which authorized the conduct of a field test. It did take another seven months to adopt the model ordinance - mainly to specify front amber rather than red flashing lights (the latter were only allowed on emergency vehicles and school buses).

More than codification was required since the support of vending businesses, who would have to spend $150 per truck for modifications was necessary to pass the ordinance.

Accident frequency reduction was to be the criterion measure of effectiveness. Although the number of vendor accidents was small, it was expected to be sufficient for statistical accuracy. As in the previous case, speed was to be an intermediate measure - that is, speed in the approach, at and beyond the vending truck. Four variables were controlled: truck type, whether brand name or independent vendors; police enforcement level; socioeconomic area; and day of week - the inclusion of both a week and weekend day for radar speed readings. Chicago served as the comparison city.

Another feature in this field test was an effort at public education through radio and television messages. In addition a telephone survey to assess the public's awareness and reaction to the model ice cream truck ordinance was planned. The survey was not administered since the number of surveys allowed under Federally sponsored projects at that time was curtailed to reduce the burden on the public. To wait until this survey could be approved under revised guidelines was not feasible.

Speed measurements were made at ten sites in each city, five within the central city area, and five within outlying city areas. Measurements were made to equally represent morning and afternoon vending periods, weekend and week days, independent and brand name ice cream vending trucks. Common factors were: residential areas, street segments (not intersections), two way streets, parking on both sides, a 25 mile per hour speed limit and traffic flow between one and two cars per minute.

Three speed measurements were made for each car: one at the block "entrance", one at the block "exit" and one at the truck. Radar measurements were recorded over a 15 minute span - the vending period.

The field test speed data collection was conducted in seven waves, each covering two days. The baseline wave began in September 1975 and test data were obtained during July, August and September 1976. The last three waves were conducted over three months in the following year.

3.2.2 The Results of the Field Test

Speed was reduced at the ice cream vending truck, from an average of 28.10 to 15.65 miles per hour pre to post field test, during the three month period in 1976 ($t = 33.28$, $df = 1000$, P .005). No such drop in speed was experienced in the comparison city. The presence of the truck also caused a significant speed drop in the block "entry" and "exit" zones.

At the truck, the criterion for a "safe" speed was either a complete stop, or between one and five miles per hour. A marginal condition was thought to be between six and fifteen miles per hour and sixteen and above was "unsafe". Just about all (99 percent) of the speeds measured before the field test were in the unsafe range. During the first three measurement waves (1976), 25 percent of the speeds were in the safe category (six percent of the cars actually stopped), between 23 and 27 percent were marginal and 48 to 52 percent were unsafe. The comparison city sites yielded relatively stable speeds with more than 95 percent of the readings in the unsafe category throughout.

No significant differences were found in speeds near the truck during week and weekend days. However it appeared that there was a trend toward lower speeds in outer city areas when compared to inner city neighborhoods.

Vendor accidents averaged 48 per year during the three years before the field test year. Although the test started halfway through the vending season, 33 vendor accidents were recorded during 1976 (32.18% reduction; $\chi^2 = 5.05$, $df = 1$, $p < .05$). The following year only 11 vendor accidents (77% reduction) were recorded ($\chi^2 = 29.16$, $df = 1$, $p < .001$).

3.3 Evaluation Issues Relative to the Case Studies

There is no doubt that both cases were undertaken by competent and motivated researchers who approached their work with plans that reflected the meticulous scientific products expected of them. They managed to conduct their studies within practical and political constraints and, one certainly hopes, provided sound information to the process of decision-making by public officials.

While accident statistics were sufficient in the Ice Cream Truck Ordiance case, they were numerically small. The Detroit area with a population of 1.5 million is more likely to yield enough such data than is a city of 150,000.

Several aspects do emerge that deserve noting:

- The interpretation of speed reduction, as an intermediate measure in terms of a safety improvement.
- Definition and categorization of observations on the presence, behavior and configuration of entities in motion (pedestrians, cars).

- Use of public awareness, public education, and expected public feelings relating to their sense of safety.
- Transferability of results.

3.3.1 Speed Reduction Criteria - Use of Intermediate Measures

In the school crossing case, the 85th percentile speed, at the crossing within a speed zone (25 mph) and where enforcement was provided, stayed above the limit. It was reduced to under 30 mph (normal, posted speed was 35 mph) when pedestrians were present. Such a reduction (about seven mph) was considered to be sufficient to avoid receiving a speeding citation. The ice cream vendor truck field test yielded reductions of over 12 miles per hour, at the truck. The "area" size (population, density) offered the opportunity to compare vendor accidents, even though these data were numerically few, the reduction was large enough to be statistically significant. The school crossing case whose test "area" was much smaller - in population terms - did not have this kind of possibility and relied on a speed reduction criterion based on the "tolerance" level of the local police department.

We return to the question of how much of a speed reduction "causes" how much of an accident reduction? And in the absence of significant accident data, what effect - in these cases - must an intermediate measure have in order to make judgements about safety stragegies? Both cases, it should be pointed out, exceeded the typical expectation of a three to four mile per hour speed reduction.

Perhaps we should not be pedantic when trying to relate speed reduction to accident reduction and simply go along with the common wisdom and experience and accept the concept. In so doing, however, one should not overlook the cost of such a safety countermeasure. It often requires police services and devices which mean budget decisions by local officials, and which brings us back to their possible concern about the validity of speed reduction as an intermediate measure.

In the school crossing case, it was noted that the driver was motivated to comply with the reduced speed limit only when he perceived the need for caution - by seeing pedestrians. Local authorities may prefer to work on ways to reinforce such motivations by more signs, road markings and education and one could well end up trying to measure some form of driver reaction - other than speed change - by observation.

3.3.2 Defining and Categorizing Observations

Both cases used observational data. The presence of pedestrians was noted in the school crossing study and an observer looked for those instances where the stopping requirement at the ice cream vendor truck might yield rear end collisions or traffic back-ups (neither problem materialized).

The difficulty of observing and categorizing even simple events like presence or absence in a dynamic situation is well known. Near misses of aircraft are regularly recorded and though not familiar with judgement criteria for such situations one assumes they must exist. As has already been mentioned, contributing factors leading to or present during the closing of two or more moving entities should be identified and classified as part of an observation. The number of pedestrians, whether they are standing quietly waiting to cross, or whether there is pushing and yelling, can be observed. But how are such factors categorized when observing potential conflicts? Are we to observe the chain of events on the chance that a "near miss" or other defined conflict type will occur?

To capture this kind of information, we cannot proceed along the lines of in-depth accident investigation nor overwhelm a locality with monitoring and recording paraphernalia whose presence alone may have a greater effect than the factors to be observed. And how unobtrusive really is a radar speed gun operation?

Many study proposals deal with the subject of recording methods and criteria. There are suggestions that car drivers use voice recording machines while driving to document maneuvers, speed, traffic and road conditions, and so forth. Elaborate schemes for instrumenting cars are common. We can probably expect ways to record physiological impulses from the driver. All of these schemes could yield a large body of data in short order, but at a steep cost. The proposals, however, invariably come down to using human observers, after exhaustive discussion.

The observation schemes are usually accompanied by statements that promise thorough training, and development of recording protocols which give the impression that little will be left to chance. The subsequent reality turns out very differently. We have found data sets which include a large number of incomplete cells (unknowns), not to mention instances where training was sparse, and observers both underpaid and unsuitable.

3.3.3 Evaluating the "Sense of the Public"

Publicity was employed in both of our cases and as was noted, a planned survey of public awareness could not be conducted in the ice cream vendor ordinance field test. Neither evaluation, however, relied on this type of proxy measure to establish effectiveness. There is nevertheless a continuing urge by safety program managers - and evaluators - that somehow or other a measurement of "awareness" or "attitude change" can, if nothing else, at least "fill out the picture". Before proceeding, a statement by Griffin, et al. [2] serves as a basis for further discussion:

> "Some would argue that using 'public awareness and attitude change' as proxy measures may be the best indicators presently available with which to evaluate certain programs. Accordingly, they would argue that even though the correlation between these variables and the legitimate aims of highway safety is negligible, in the absence of other, more appropriate proxy measures, these measures should be used. This is not necessarily true. Bu using proxy measures which are inappropriate, a false sense of security is created."[3]

3/Ibid., p.32

With the focus on short-term, area-wide evaluations, the use of awareness and attitude measures is certainly tempting. Low cost, quick and subject to interpretation, such evaluative designs are often proposed.

A public's awareness, mood, and attitude is at times quite volatile and dynamic and when measured often yields "socially acceptable" answers rather than accurate behavioral measures. One perceives such measurement as not much more than instantaneous opinion polls, given the attention span of the subject and the personal priorities of individuals in most of our societies. Even if a publicity campaign has registered attention, such as frequent local drunk driving media news segments, we are dealing with an acceptance of the situation or problem - but one which involves "the other guy" or depicts a situation - an accident - which is "not going to happen to me". In fact, a significant registration of "awareness" may only reinforce the notion that a problem is under control, and one can therefore expect a safer environment - the false sense of security.

3.3.4 Transferability of Results

The Ice Cream Truck Ordinance was a field test of a relatively novel safety measure. At the time, a number of cities could have been likely sites for the test and the one chosen probably offered the preferred conditions for a successful project. The local government's aspirations paralleled those of the researchers. Although not all project design requirements were met, such as the attitude survey mentioned earlier, and police enforcement (there were city budgetary problems which resulted in layoffs during the first phase of the test), a respectable amount of cooperation was evident.

This, of course is not always the case - the relative freedom of test area choice. As we have seen, evaluative work must often contend with area-specific safety applications and/or where funding incentives draw somewhat less than desirable, but willing, localities.

While there are many situational and design differences in the two cases and a simple comparison of their respective safety measure effects is not appropriate, they do raise some issues about conducting evaluations area-wide. Would it, for example, follow that a successful countermeasure in one area can be expected to have similar effects in another area? In the Ice Cream Vending Truck case the effects may well be achieved in other places. Children's behavior near ice cream trucks would appear independent of city size. Yet one potential application transfer will not constitute a general law. It is this very issue which has been a nagging problem for national safety agencies who, under the banner of national leadership, are either charged with or take it upon themselves to be distributors of proven "high payoff" safety countermeasures, on the tenuous assumption that what works in place A will work everywhere.

What is even more unfortunate are the generaltiies with which safety measures are recommended. Recognizing the practical difficulties under which even the well designed evaluations must be performed, much of the recommended safety practice still rests on perceived effectiveness, rather than field tests done by competent researchers. We should, however, not discard the transfer "theory", until we have further explored the conditions under which intermediate measures - such as speed - truly serve as surrogates to infer safety measure effects on accidents.

4.D Multiple Countermeasures

The coexistence of safety, environmental and land use programs, and countermeasures is probably more widespread than is commonly realized. The advent of the catalytic converter to reduce vehicle emissions, smoke stack exhaust controls, aircraft and plant noise abatement, special routing of hazardous cargo shipments, leaf burning restrictions, together with various road safety measures are present simultaneously. One can expect that at any given time changes in zoning ordinances, shopping center plans, expansion or discontinuance of public transport, not to speak of revised police patrol tactics and coverage will affect the quality of life over time - and the level of traffic hazards.

While in overall urban and suburban planning the analytic tools of cost effectiveness and environmental impact analysis have become popular, the actual results of the various schemes, after implementation, have usually not been evaluated until problems or protests have emerged.

At the very beginning of this paper, the example of an evaluation of a selective enforcement project, gone astray, was mentioned. With all the potential concurrent traffic safety and transit countermeasures present, it would have made for an interesting case study. This was not to be. There are indeed no apparent evaluative analyses that would serve as appropriate examples.

4.1 A Multiple Safety Countermeasure Program

One demonstration program employing several safety countermeasures is underway in Dade County, Florida (this includes the City of Miami) [7], and while it is not within our short-term criterion (it is a three-year project funded by the Federal Government) it could be if such a restriction were necessary.

The county with a population of 1.27 million includes the City of Miami (population 335,000). There are several other cities in the county. The usual procedure for federally-funded demonstration projects is to contract with the local government to carry out and manage the operation on the basis of a plan which includes certain reporting procedures and financial accountability. The evaluation is normally done by the locality, often on a contractual basis with a local university or consulting firm.

By definition a demonstration project is less rigorous than a research field test though appropriate evaluation designs, data collection, controls, and analysis techniques are required so that a project's effectiveness in terms of accident reduction and behavioral change can be assessed.

The pedestrian countermeasure project in Dade County, Florida, was designed so that each participating governmental unit would have to develop cooperative operating procedures to carry out the various countermeasures. One important objective is that an evaluation of the countermeasures be adequate. Among the participating agencies are: the county traffic and transportation department, attorney's office, teachers' union and the city police force.

So much for the introduction. Many of the difficulties and subsequent

compromises inherent in placing a project into the real world have already been covered. The main purpose here is to give a current illustrative example of a multicountermeasure evaluation attempt, one for which no results are available, and which is limited to pedestrian safety countermeasures. The following is a list of what is taking place at the project site:

- o A curriculum to teach safe midblock street crossing behavior to schoolchildren. (K-3)
- o A bus stop location ordinance which allows for moving the stop from the near to the far side of an intersection to cause pedestrians to cross behind the bus.
- o An intersection parking ordinance which prohibits parking or standing within 50 feet of the intersection on the approach side of marked crosswalks, and 60 feet for all other intersections.
- o An ice cream vendor ordinance - with which we are now familiar, but which was not used since the local statistics had shown declines for that type of accident in prior years, and during the initial phase of the demonstration project.
- o Police enforcement for compliance with ordinances.
- o A public information and education campaign stressing the need for pedestrian safety, using
    - * general news coverage, speeches, brochures, etc.
    - * TV film clips, posters and games to highlight and reinforce the school curriculum
    - * Specialized TV and radio announcements to publicize:
        - The ice cream vendor ordinance (this was dropped since the ordinance was not used)
        - The threat to pedestrians when crossing in front of a stopped car(s) and being hidden from the view of drivers in the next lane
        - The danger to a pedestrian when a car makes a turn or is merging into traffic and its driver fails to notice a crossing pedestrian
        - The risks of crossing in front of a bus

Each of the safety measures is directed toward reducing the implied failures, assumed to cause the specific types of accidents. For example, the typical dart-out and mid-block dash accidents involving children under ten years of age are addressed by both the school curriculum and TV film. The curriculum incorporates the "stop at curb" and "look left, right and left again" procedures.

Accident data for this multiyear program given an area of considerable size and population, is expected to be sufficient for statistical analysis. Observations, phone surveys and interviews are used to obtain behavioral and awareness data. It is a classical "before and after" design with a comparison site, Hillsborough County, which includes the City of Tampa, Florida, some 230 miles away.

Given the mix and overlap of some of the countermeasures it may well be difficult to isolate their effects. The school curriculum for "look out" training may well synergize with parking set-backs. Both children and adults may respond to TV and radio messages.

While this project has a multiple safety measure feature, the evaluation will probably fall short if one expects it to be as rigorous as one for a field test. It is, however, too early to make judgements on what single measure, or synergistic effects can be documented.

5.0 Causal Factors

At a symposium conducted in late 1975 [8], several papers turned to the topic of methods to determine the causes of accidents. Causal factors structured in various ways to develop models which in turn would describe the sequence of events leading to accidents have been attempted many times in the past. The process is largely based on a clinical approach such as in-depth accident investigations whereby detailed findings of fact are strung together in hierarchical chains or networks.

One approach that might illustrate an initial step in formulating intermediate measures and that conceptually is part of a causal structure is the work done to identify and define "unsafe driving actions" (UDA's).

5.1 Unsafe Driving Actions

On the assumption that an unsafe driving act, such as speeding or failing to stop at a stop sign, contribute to the risk of having an accident, a study was commissioned by the National Highway Traffic Safety Administration [9] to identify such acts (UDA's). The study further determined their frequency on the basis of:

- o Police accident reports
- o Citations issued for committing UDA's
- o Observation of UDA's by the driving public

Each data set produced a frequency ranking, and by studying the relationships of the ranked frequencies, it was possible to ascertain relative risks. For example, if "following too closely" was reported by police as a factor in 20 percent of accidents, and "speeding" in 40 percent, yet from observations of traffic, the incidence was one and 50 percent, respectively, it appears that "following too closely" is particularly hazardous when compared to "speeding".

The citation frequency ranking of UDA's was compared to the accident

risk rankings to find out whether there is a relationship between the most "popular" citations and UDA's having the highest accident risk.

While this is a very simplified description of the work done in the study, it may be of interest to look at some results.[4/]

Type of UDA	No. of Accidents	No. of Observed UDA's	Relative Accident Risk	No. of Citations
Following too closely	4193	479	21	307
Pulling in front	2361	51	101	215
Turning in front	1226	9	320	363
Stop sign/signal violation	1151	225	12	11877
Speeding	980	3312	7	31250
Driving left of center	748	187	9	643
No UDA's		28591	1.0*	

*Assumed to be 1.0

To the researchers it seemed apparent that enforcement is concentrated on what may be those unsafe driving acts involving lesser risk. While there are relatively few citations for the first three UDA's on the list, these are difficult to observe and enforce, and are not necessarily illegal. While this is but one study and not necessarily conclusive, one might wonder about the value of countermeasures targetted against speeding, and evaluation designs using speed change as a surrogate measure.

Additional research is underway to confirm some of the findings about accident risks on the basis of unsafe driving acts, better ways to conduct roadside observations, and to define certain predisposing factors in more detail.

6.0 Measures of Exposure

Improvements in safety are usually measured by the change in accident - particularly fatality - rates using vehicle miles travelled (VMT), population, registered vehicles or licensed drivers, as measures of exposure or population at risk. It is done on a national or State basis in the United States. These are, however, measures which could neither be readily obtained, nor uniformly applied in many area-wide evaluations.

6.1 The Use of Exposure Measures

Normal practice for area-wide studies seems to favor standardizing factors relating to exposure, either through control sites and/or traffic flow rates

4/L. S. de Savornin Lohman, E. C. Leggett, and B. J. Campbell. Identification of Unsafe Driving Actions and Related Countermeasures, (Springfield, Virginia: National Technical Information Service, 1976, DOT HS-803 064), p.78.

at the sites. Exposure like so many other factors has to be defined to suit specific cases. The number of trips within, to or from an area, in mileage or time classes, may be a useful exposure measure, given area size restrictions. On the assumption that unsafe driving acts could be used as intermediate measures, the number of these per average trip time (or mileage) could be explored. This, however, leads to the need for information about the type of trip. For example, changes in gasoline supplies and/or prices affect segments of the population in different ways - the most likely effect is on discretionary travel. These are the kind of trips thought to involve more risk - potential failures - and therefore more likely to lead to accidents than commuting trips. While the concept may be interesting, applying this approach to an area may well be an insurmountable problem since trips originating outside the area and either ending or continuing through the area could not easily be counted. Unless one stations observers at main artery boundaries, even simple cordon surveys cannot be conducted.

Accidents at intersections serve as an example for a potential exposure measure. Here exposure might be expressed as the number of vehicles negotiating an intersection. While this exposure measure may not serve as a surrogate safety rating, it is surely one which can be obtained by count and used in conjunction with an "unsafe driving act" such as a stop sign violation.

Exposure measures for pedestrians present a more complex problem since being a pedestrian is not a discrete status during a "trip". Car occupants after having driven to their general destination, park and walk to their specific destination, in the course of which they became pedestrians. The familiarity with certain walking routes is a factor to consider when contemplating exposure as a surrogate measure. The activities of children and the elderly are different not only from one another but do not necessarily constitute specific trips.

It should be noted that a British study [10] defined and surveyed five pedestrian exposure measures: walking time, distance, number of roads crossed, number of pedestrian islands and pavements ("safe points") involved, and the number of paces an interviewer used to rewalk routes indicated by the subjects surveyed.

6.2 Value and Burden

Although the preceding discussion merely highlights the potential use of exposure measures, this type of data may offer a basis of evaluative analyses provided research effort and resources are thoughtfully planned. Since there is no prescriptive definition of the "correct" measure of exposure, there is room for a good deal of creative work.

There is, however, a burden which applies to measures of exposure and to their collection. While active or passive instrumentation has found widespread use in research, it is obviously cumbersome, expensive and usually limited. We always fall back to the observational method. Given good sampling procedure, rotation and proper recording protocols, it can be successfully employed. Much needs to be done, however, since the effects of weather, pay scale, conspicuity of observers, their training, and replacement can variously affect data quality - particularly where subjective judgement is required. With the constraints of "short-term and area-wide", it is all the more important

that great care must be exercised to ensure adequacy and accuracy. We also need to address automated, remotely directed devices for measurements whose feasibility, given the micro electronics explosion, might supplement or supplant observers, thus providing efficiencies and economies.

7.0 In Conclusion

There probably is a wide range of opinion in what is meant by area-wide and short-term evaluation. The roadway safety view may focus on specific localities where a change in traffic signals or traffic diversion has taken place to enhance safety. An area might be all city and suburban sections where safe street crossing countermeasures are instituted. The evaluation possibility is directly related to what and how much can be counted (measured) to satisfy the methods of statistical analysis.

One has heard ever so often that the evaluation design must be simultaneous with the safety plan, that the choice and placement of countermeasures are contingent on the possibility for evaluation and that the manner of research be practical and scientific. Not all of these conditions will prevail, but that need not dampen the effort. Perhaps the most important contribution an evaluator can make is the clarity with which both the significant results and the limitations of the analyses are presented to the public. Without inherent evaluative credibility, myth and folklore about safety get an even break.

Evaluation must be marketable. It's the only chance we've got!

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SOME EXPERIENCE IN CANADA WITH PROBLEMS OF SHORT-TERM EVALUATION OF SAFETY MEASURES

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Abstract

Facing the problems of lack of sufficient accident experience under controlled circumstances to identify the impacts of safety measures, researchers in Canada have turned to assessments of impacts on "intermediate" variables in the chain of accident causation. These include road user attitudes, knowledge, physical condition, self-reported and observed behaviour, and (in some initial experiments) perceived risks. Alternatively, assessments have attempted to use traffic "conflicts" as proxy measures of safety.

The paper briefly examines some of these efforts, considering the questions:

(1) can the evaluation techniques be improved so that conclusive results can be obtained; and

(2) if not, are partial answers useful?

INTRODUCTION

The need for evaluation of the effectiveness of safety measures is well-recognised, as are the overall methods of effectiveness research (see for example the recent OECD report on Methods for Evaluating Road Safety Measures (1)). These prescribe that effectiveness be measured against the ultimate criteria of accidents, casualties and other accident losses. In general the measurement should be through experimental research, in which groups of sites or subjects are administered the treatment and their performance compared to that of untreated control groups with similar characteristics, or compared to their own performance prior to the treatment.

Unfortunately, such experimental evaluations are expensive and time-consuming, and constraints on their size or duration often in practice mean that it is difficult or impossible to obtain enough accident data to be able to recognise important changes. Moreover, there are fundamental problems imposed by imperfections of accident data and related data for evaluations: the appropriate accident methodology may be specified by the researchers, but cannot be implemented if the required data are not collected.

With each of these constraints, there are two consequent questions:

(1) can the evaluation techniques be improved so that conclusive results can be obtained?

(2) if not, are partial answers useful?

These are questions which we hope the Seminar will address, and which we shall try to cast a little light on from Canadian experience.

EXAMPLES OF PROBLEMS IN SHORT-TERM EVALUATIONS

Evaluations in our experience have been short-term either because: (1) resources for experimentation have been limited, or (2) the safety measures to be evaluated have themselves been short-term.

Into the first group of cases fall many examples of very localised safety measures, particularly installations of road design changes or traffic control devices. Accident occurrence at any installation is so infrequent that installations would have to be combined in large numbers or monitored over long periods of time before reliable estimates of accident risks could be made. The necessary expense or delay required by the researchers may be considered unacceptable for a number of reasons, including an understandable aversion to a high ratio of evaluation expense to installation costs, as well as short-term budget restrictions. Then the nature of the evaluation has to change. The Department of Transport has participated in evaluations under such circumstances, when recognition that accident data would be insufficient has led to the evaluations being designed to concentrate on 'intermediate' criteria of effectiveness. These have included variables presumed to be part of the causal chain leading to accidents or variables presumed to correlate well with accidents (such as conflicts or perceived risks).

Example 1

A first example concerns the attempt to evaluate the effectiveness of certain designs of special pedestrian crossings, undertaken in 1978-79(2). The study examined 42 intersections in seven cities, comparing three different types of pedestrian crossings: unprotected, protected by full traffic signals and protected by the special pedestrian signals (generally with flashing amber lights facing traffic). Average annual accident frequencies were obtained for each location from accident records in recent years (generally three years), but could not provide very reliable estimates of risks. The numbers of accidents were very low indeed: virtually all sites averaged less than one pedestrian accident per year, and many had no accidents at all during the previous three years. Comparisons of average accident frequencies (or of accident risks per pedestrian or vehicle exposed) among the three types of crossing could not reasonably be made.

Instead, the evaluation attempted to assess the relative safety of each crossing from the behaviour of vehicles and pedestrians. A number of aspects of behaviour were observed, and the assessment focussed on the delays experienced by pedestrians and vehicles, on distances separating pedestrians from vehicles, and on compliance with the crossing controls by the two types of traffic. Some very tentative conclusions were drawn that the special crossings are likely to improve safety relative to unprotected crossings, as they tend to further separate pedestrians from vehicles without creating sufficient pedestrian frustration as to cause compliance to be eroded. In addition, the assessment included interviews with users of the various crossings, obtaining subjective impressions of their safety, which tended to confirm the assessment based on observed behaviour. Of course, it was conceded readily that the relative safety of the different types of crossings was not proven, in the absence of reliable estimates of the risks of accidents and casualties.

Finally, this example also illustrates another of the problems of evaluating local improvements: that of combining information on sites with differing traffic conditions. An examination of the characteristics of the sites in this study, chosen essentially at random from the subgroups of sites with each type of pedestrian crossing in the study cites, shows very wide variation in both vehicle and pedestrian traffic. As it is entirely possible that the safety of each location depends on these traffic flows, this further confounds the assessment made. A confident evaluation could only be made between groups of sites which were well-matched in their traffic characteristics, and such matching would be more and more difficult to achieve as the number of sites needed in the evaluation expanded.

Example 2

The second example is of an experiment in police enforcement, also confined by lack of research resources to a small number of sites (3). The study selected seven intersections, similar in traffic volumes, adjacent land use and traffic control. Six were subjected to treatments of increased police surveillance during peak traffic hours over a period of 20 days, while another acted as an untreated control. Accidents reported at these sites during the previous three years varied from 37 to 62, or annual averages of between about 12 and 20. During the study period only about 12 to 15 accidents could be expected to occur in the absence of treatment at all the sites combined; while only 2 or 3 could be expected at the control site. Obviously the accident data would not allow a precise estimate of the effectiveness of the countermeasure.

Instead the evaluation was designed to obtain observations of traffic violations and 'conflicts' during a 10-day 'before' period, 20-day study period and 10-day 'after' period at all seven sites. Statistical analysis of the violation records showed significant reductions associated with police presence at three of the sites, though with less marked reductions in the more hazardous types of violations (i.e. those more frequently associated with accidents in police records).

The observations of conflicts proved of little use to the evaluation. Conflicts were defined here as any abnormal deceleration, lane-changing or stopping to avoid collision. Major problems in their observation were encountered, the observers apparently taking longer to learn to record conflicts consistently than was expected. This confounded recordings during the study period, leading the researchers to conclude it was "meaningless to attempt to quantify the possible effects of enforcement on this variable".

This example study also demonstrates another of the problems of evaluations mentioned above: the quality of accident data recording. Records of accidents were of course obtained for the study period, and showed the perverse result of increasing over the treatment sites combined. This was interpreted to be because the increased police presence led to more conscientious reporting of accidents by drivers involved!

A brief note on 'conflicts'

Conflicts have long been thought to hold promise as substitute evaluation criteria to accidents and casualties, being more readily accumulated in large enough numbers to allow changes to be recognised by conventional statistical means. Unfortunately, Canadian experience with definition and observations of conflicts to date have not fulfilled that promise. The attempt in Example 2 above to define and measure conflicts suffered from problems of achieving measurement consistency found commonly in conflict studies. More recently, a more objective definition of conflicts has been tested, using 'post-encroachment time' (defined as the time between a vehicle without right-of-way leaving a point in a traffic lane and a vehicle with right-of-way reaching it), which has been shown to be easier to apply with consistency (4,5). But the two limited attempts made to date to validate the use of such conflicts as substitutes for accidents at urban signalised (5) and unsignallised (6) intersections have not been encouraging.

Evaluation of short-term measures

The second group of short-term evaluations are those which are forced to be so because the countermeasures are short-term. Familiar examples of such measures are the short-lived campaigns or 'crackdowns' of law enforcement or public education. They may be confined to single cities or small regions, or may be national in scope, but have the distinguishing features of lasting only a few weeks and costing relatively little compared to many permanent countermeasures. The problems for the researchers are similar to those in the above examples, in that it is not expected that changes in accidents or casualties can be recognised with the necessary precision. This may be because it is impossible to establish well enough the expected level of risk for a single city or a small area over a period as short as a few weeks. Or it may be for the rather more fundamental reason that the hypothesised safety improvement, while it would be cost-effective, would be so small that it is beyond the researchers' ability with conventional statistical analysis to recognise. Thus for example the Department's national public education campaigns typically cost less than $1 million. These would be cost-effective, we expect, if they reduced casualties by about 5 fatalities or 250 injured, or various combinations thereof. With national totals of over 5,000 fatalities and 250,000 injured annually, and considerable unexplained fluctuations in these totals, we could never expect to recognise such changes. Accepting this, and noting that evaluation research is expensive relative to the total costs of such short-term measures, it is tempting for programme administrators to ignore evaluation altogether.

Alternatively, it can be argued that at least some of the effects of the measures can be determined, by research once again into effects on intermediate variables. This has been the usual recent response of researchers at the Department of Transport, as the examples below will briefly illustrate.

Example 3

At the beginning of 1976 the Department undertook a 13-week national public education campaign to promote seat belt use. Anticipating that the effects would not be distinguishable in accident statistics (which proved correct) an evaluation was designed to assess the effects on intermediate variables (7). It had been decided that the expense of surveys of road user behaviour was unwarranted given the size of the campaign, and the evaluation instead assessed effects on road user attitudes and self-reported belt use behaviour, through telephone surveys before, during and after the campaign.

Statistical analysis of the survey responses showed that the campaign messages had been received by much of the target population. Attitudes towards some aspects of seat-belt performance were judged to have changed significantly (though slightly), while others showed no change. A minor increase in reported seat belt use was found, but was not statistically-significant.

Example 4

Later in 1976 Canada's law relating to driving while impaired by alcohol was amended, easing enforcement by allowing police to conduct road-side breath tests of drivers. The Department undertook a public education campaign early in 1977 to promote awareness of the new legislation. Fortunately, the new law was not proclaimed simultaneously by all Provinces, so part of the country still had the old law. The researchers were also successful in arguing for the campaign to be withheld from some regions where the new law did exist. It was therefore possible for an evaluation to be designed to assess the effects both of the introduction of the law alone and of the introduction of the law together with the campaign by comparing geographic regions subject to the differing conditions (8).

The evaluation used telephone surveys before and after the campaign period, to obtain information on drivers' drinking habits, driving habits, and awareness of the new legislation. In addition an attempt was made to elicit from respondents their estimates of the probabilities of impaired drivers being (a) stopped by police and (b) charged with the offence if stopped. It was hypothesised that increases in these perceived probabilities were necessary prior to reductions in impaired driving and ultimately in accidents.

Analysis of the survey responses showed that awareness of the legislation increased significantly (and substantially) where the campaign accompanied its introduction. Changes in the perceived probabilities of drivers being apprehended and charged were less clear. It was concluded that there was a statistically-significant increase in one of the probability measures used, when comparing regions exposed to the campaign to those not exposed, but other measures showed no increase. And the importance of the observed increase can only be guessed, without validation of the relation between the measured variable and accidents.

Example 5

The final example is of the slightly different case of a localised short-term measure, that of a single city's campaign of publicity and enforcement of a seat belt use law, for one month in late 1979. It was hoped that the campaign would have a substantial and lasting effect on seat belt use (averaging about 60% prior to the campaign) and therefore on casualties. However, estimates of the efficacy of seat belt use in accidents suggested that an optimistic 'substantial' effect would reduce total fatalities in the city by only about 5-10%, and total injured by about half that proportion. Given the historical fluctuations observed in the city's casualties, it was reasoned that such effects would probably not be detectable using conventional statistical testing (as turned out to be correct). An evaluation (9) was therefore designed to examine the effects on intermediate variables, though in this case with the emphasis on road user behaviour, as the expense of behavioural observations was acceptable when limited geographically. A series of belt use observations together with attitude surveys before, during and after the campaign was designed, with an untreated nearby city studied as a control.

The study showed that seat belt use in the treatment city rose substantially (to about 80%) during the campaign, declining over the next six months, but remaining significantly above the pre-campaign level (at about 70%). Seat belt use in the control city was observed to decline marginally over the same period. An examination of survey respondents' estimates of the probability of being charges with an offence if not wearing a seat belt proved inconclusive (rising apparently significantly in both cities). And attitudes towards seat belts, as measures on ordinal scales, changed slightly perversely in the treatment city (suggesting to the investigators that attitudes and behaviour might change in opposite directions under enforcement).

DISCUSSION

The above examples illustrate the Department's practice of evaluating the effects of supposed countermeasures against intermediate criteria, which have been adopted once it has been accepted by the researchers that evaluations against accidents/casualties are not possible. Of course, it remains indisputable that until we successfully link the intermediate variables to the final criteria variables we cannot prove the effectiveness of the countermeasures, nor their cost-effectiveness relative to alternative countermeasures.

In defence of studying the intermediate variables, it can be argued that they can teach us a great deal about the linkages between variables, which is valuable in itself for our understanding of the safety system. In recent years our research designs and statistical analysis methods used have improved, so our assessments of the linkages, and the effects on them of the supposed measures, have become more confident. We have also learnt much about the reliability of our methods for estimating the variables. For example, our experience gained from evaluations such as those outlined above warns us that considerable caution should be exercised in using attitudinal variables of the sort used there. The inconsistencies in their changes and the lack of correlations with behaviour suggest that the measurement systems are inadequate, or the phenomena being measured are too transitory to be useful. Similar comments apply to measurements of perceived probabilities of enforcement activity, on our evidence to date.

Of course, for certain of the intermediate variables, notably observed seat belt use or measured blood alcohol content, the justification is much clearer, as the links to accidents and casualties are quite well established from in-depth accident investigations and laboratory simulations. And a number of other variables can provide important evidence of the probable lack of effectiveness of an experimental countermeasure, when they can be argued (if not proven) to be necessary to effectiveness. For example, in the cases of our public education campaigns if we fail to get people to see the message we can be relatively sure of failure, even though we could not claim success just because people did see them. Similarly, in Example 3 we obtained a good indication that we would have no significant impact on casualties from the evidence that reported seat belt use did not increase; even though an increase would not have enabled us to estimate how effective the campaign was on casualties. Intermediate variables may therefore be guides to some aspects of the efficiency of the proposed countermeasures, if not to their ultimate effectiveness.

In the light of the current practice described above, the Introduction suggested two questions to be posed. Some observations on possible answers are provided below.

1. Can evaluation techniques be improved so that conclusive results can be obtained?

In some cases such as described above, the answer must be an unqualified 'yes'. It is clear that some evaluations are inadequate because the necessary time and resources to obtain conclusive answers are not allowed. There are still advances to be made through convincing decision-makers and programme administrators both of the need for evaluations and of the possibilities for definitive evaluations to be made, if experiments can be widespread enough and can last long enough.

The research expense must naturally be a concern, and it is inevitable that the more substantial countermeasure programmes, absorbing greater resources, will tend to claim evaluation resources sooner than localised or short-term measures. However, it is observable that initially limited measures (such as the campaigns in examples 3-5) are sometimes repeated at intervals or in other locations, and the resources devoted to them over the long term may be substantial - substantial enough to justify a major evaluation if foreseen. This suggests that foresight of all possible future applications should be encouraged.

It is alternatively possible that evaluations against intermediate variables will become much more conclusive, if the relationships between these variables and the ultimate criterion variables, accidents and casualties, can be revealed. It seems probable that specific research into the relationships, particularly between behaviour and accidents/casualties, will clarify the linkages. And research might possibly be more fruitful pursuing in-depth accident investigations, laboratory experimentation or simulation, rather than field implementation of behavioural programmes, with all the difficulties of controlling extraneous factors in the field.

Another rather less conventional possibility of improvement exists in the proposal by Ezra Hauer to substitute an alternative decision analysis method to that provided by conventional statistical testing. Emphasising that the latter systematically biases against recognising effective countermeasures as being so, Professor Hauer suggests that Bayesian decision analysis techniques might be more appropriate (10). The suggestion is very stimulating, and appears to hold great promise.

2. Are partial answers useful?

To expand the question: is it likely that evaluations such as the examples given above will improve the allocation of resources in this field or hinder it (by condoning ineffective measures)? The question is probably unanswerable, capable of resolution only when our record of success can be assessed over the long run (and even then we cannot know how nearly optimal our choices were).

An easier question to answer is: are we aiding decision-making with such evaluations? It seems very likely that the reply of programme administrators and politicians would be strongly affirmative. Faced with short-term decisions over alternative uses of established safety budgets, any information on the likely effects is better than none. We are often able to provide quite well-established estimates of effects on some of the intermediate variables. Researchers are reluctant to make logical leaps along the chain of causal factors to infer how accidents will change as intermediate factors change, but decision-making often requires much larger leaps, when much poorer information exists.

This must not excuse us from continually seeking to improve our understanding of the relationships among intermediate factors and accidents (or conflicts and accidents): decision-makers would no doubt prefer to receive recommendations which are better-established and more confidently made. But it does give us some justification for applying our best efforts to estimating the effects of countermesures on intermediate variables, if that is all we can do. Furthermore, it might be more and more reasonable, after all of the recent experience with research, to conclude that the clear guidance to effectiveness expected from conventional statistical testing of hypotheses in safety experiments will remain unattainable in practice. If so, alternative methods of decision-analysis, explicity recognising the extent of uncertainty, should be explored.

Summary of possible improvements

1. Encourage further acceptance of sound evaluation methods, promoting more extensive experimentation; encourage foresight of likely future applications of short-term measures and recognition of long-term costs, justifying more extensive evaluation.

2. Investigate relationships between intermediate variables and final criteria of accidents and casualties, to validate the use of intermediate variables as criteria of effectiveness.

3. Similarly investigate relationships between conflicts and accidents.

4. Investigate alternative decision analysis techniques to conventional statistical hypothesis testing.

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"Short-Term Evaluation and Decisionmaking"

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ABSTRACT

Research budgets too often are among the first to be reduced in times of fiscal restraint. Public research organizations must remain aware of their public character, since they function in politically competitve frameworks. They must be able to respond in a timely manner to top-level officials when the opportunity arises, or risk losing and alienating an important clientele.

The objective of road safety research is to contribute to the content and direction of public decisions in the field by providing scientific and technical support. Yet, decisions often must be made on questions on which little or no definitive research exits, while moderate levels of controversy may require relatively quick responses. Valid short-term methodologies can help fill this void and can enhance the ability of the research community to secure from the political-budgetary process the level of resources required to carry on a broad range of quality research by increasing the visibility of its expertise.

Short-term methodologies, though, must be kept in perspective. Most decisions in road administrations are rather routine and are undertaken in a "stable" environment. This is conducive to applying the results of long-term research, which must remain the primary activity of research organizations.

However, "open" decisions, i.e., not routine and not foreclosed to staff input by highly charged controversies or by firmly established governmental positions, offer the research community the opportunity to apply short-term methodologies in a useful and timely manner. If applied to appropriate questions, short-term methodologies can help research organizations to reach two important objectives:

1. contribute to a broader range of public questions; and
2. secure the necessary resources in the future.

INTRODUCTION

Research budgets too often are among the first to be reduced by ministries during periods of fiscal restraint. The current experience among many Member countries is no exception. Budgets for a broad range of research activities, including road and transport safety research have been reduced substantially in some Member countries, either in current or in real terms.

Because road and transport research, for the most part, is funded directly or indirectly by the public, the research community must secure its resources within a political-budgetary process. Yet, the nature of reseach often places the community at a distinct disadvantage in that process.

That is, to retain its integrity, research must be detached from the day-to-day conflicts and competition that are a fundamental element of democratic government. Consequently, top-level officials very often are not properly exposed to the activities of research organizations and they often remain unconvinced of the valuable contributions that research has made, and can continue to make, to a ministry's overall mission. Further, few public research organizations in any discipline have the luxury of broadly-based constituencies that can provide effective support to counteract the above disadvantage during the budgetary process. As a result, unlike most public activities, research organizations, to a great degree, must secure their own clientele.

This paper hopes to establish, by examining the nature of decisionmakers and decision environments, that valid short-term methodologies are in the best interests of the research community, as they can fill part of the void that exists on questions that must be addressed quickly, but on which appropriately definitive research is lacking. Though these cases are relatively few, they tend to be highly visible to top-level officials. Therefore, the value of short-term methodologies can be two-fold: (1) the research community will enhance its capability to fulfill its primary mission of providing scientific and technical support to decisions made in the field; and (2) the relatively high visibility of their applications will help strengthen the position of research organizations in the budgetary process by increasing access to and providing more support for an important clientele -- top-level officials.

DECISIONMAKERS AND DECISIONS

The fields of Public Administration and Political Science offer considerable literature on the nature of decisionmakers and decision environments. Of course neither the nature of decisions nor their environments are always the same. Decisionmakers, or top-level officials, bring with them a wide variety of values and intellectual frames of reference, plus varying degrees of familiarity with the substance of a field. Similarly, the environment in which a decision is made can range from routine and stable to one that is made nearly chaotic by a high level of controversy.

Decisionmakers

Erwin Hargrove succinctly summarizes the theme of much of the literature in this field when he states that public "executives deal in ideas and images, not programs." This is indicative of the literature as it suggests that top-level officials have little to no background with which to understand either the substantive field or the organizations in which they work. Though this characterization may be accurate at times, it badly underestimates the skills and intellectual capacity of top-level officials, many of whom bring to their posts considerable backgrounds in their substantive fields. Further, if a serious shortcoming exists in an official's background, someone usually will fill the void to one degree or another. That "someone" will be either a career official who seeks to increase his own access, or an appointed official with an appropriate field of expertise.

John D. Steinbruner offers a more useful tool with which to understand top-level decisionmakers. He identifies two opposite points on a spectrum and, presumably, every decisionmaker falls someplace within this range. Steinbruner characterizes decisionmakers as "uncommitted thinkers" and "theoretical thinkers." Though his labels are unimportant, his observations can be useful here.

Uncommitted Thinkers

The uncommitted thinker is characterized by a broad familiarity with a field. Though his information may be highly aggregated, as he must cope with a wide range of questions, he may compliment this aggregation with detailed knowledge of a number of subjects in the field.

Most importantly, the uncommitted thinker does not restrict himself to a narrow range of ideas. He is not committed to a particular course of action in advance. He is willing to be convinced of the merits of another's ideas.

The more firmly a decisionmaker falls on this side of the spectrum, the more realistic is the chance that short-term methodologies can contribute to a decision.

Theoretical Thinkers

Steinbruner characterizes the theoretical thinker as having "very abstract and extensive belief patterns," which are based on a rather narrow set of firmly held personal values. They are much more doctrinaire and less likely to allow themselves to be convinced of the merits of others' ideas. Rather, they are strongly commited to their own abstracted values and they aggressively attempt to affect public policies and decisions according to these values. Whenever research (or any other support function) fails to confirm these beliefs and values, it is dismissed as irrelevant or as not being open to "new thinking."

The more firmly a decisionmaker falls at this end of the spectrum, the less realistic is the chance that short-term methodologies can contribute in a meaningful way.

In reality, of course, few (if any) decisionmakers fulfill either extreme of the spectrum as outlined here. While a decisionmaker may be somewhat more or somewhat less doctrinaire or open than others, most rely on varying mixes of abstracted values and aggregated information as a matter of necessity, depending on the range of questions with which they must contend. In any event, most top-level decisionmakers must deal with such a broad range of questions that they should not be expected to bring an in-depth substantive knowledge with them for every question.

Decisionmaking Environments

The literature generally classifies decisions as Rational, Political or Organizational (see Graham Allison). Rational decisions are the ideal. They are based on an identification of goals and objectives, analyses of alternatives and the selection of the best alternatives. Political decisions are the outcomes of competition among various interests. Organizational decisions are the results, or sums, of separate units acting independently, in which standard operating procedures (SOP's), formal and informal organizational structures are perceived to be the dominating factors. As the literature suggests, most decisions, to one degree or another, reflect some characteristics of all three of these decisionmaking models.

A variation of this framework (somewhat suggested by Jerel A. Rosati) may be useful for the purpose of identifying when short-term methodologies can be productive. We can classify the environment in which decisions are made as stable, open and foreclosed, with the degree of controversy increasing in the open and foreclosed environments. Again, labels are not important, but the ideas may be useful.

Stable Environments: The Majority of Road Decisions

A stable environment combines aspects of Allison's Rational and Organizational models. Controversy is completely or nearly absent, and the question at hand clearly falls into an organization's field of expertise. These decisions are not highly visible and, therefore, do not invite the personal involvement of an administration's top leadership, nor that of competing interest groups.

Rather, the decision is routine. An organization can apply a Rational model and its SOP's. A stable environment, in fact, characterizes the overwhelming majority of decisions made in road administrations. For example, relatively few decisions are as highly visible or controversial as a "build/no-build" decision. Rather, most decisions are concerned with proper bridge or pavement design, proper barriers, repavement of an existing road, etc. Even after a controversial "build" decision, most subsequent decisions on a project will be rather routine.

The following table illustrates the dominance of stable environments in the decisionmaking of the Federal Highway Administration of the U.S. Department of Transportation. The table classifies Federal-aid highway projects for 1979 according to costs. Though cost certainly is not the only factor that determines stability or controversy, it at least provides a sense of scale.

The table shows that only one in ten projects cost over $3 million (FHWA's definition of a "major" project). If projects on the nearly completed Interstate System are excluded, only 5.8% of all projects in 1979 exceeded $3 million, with the median cost being slightly over $250,000. Further, this table is limited to Federal-aid roads, which generally are the more costly and higher design roads in the U.S. This would suggest that State and local road programs are even more heavily dominated by smaller projects and, by implication, stable decisionmaking environments.

TABLE

SUMMARY OF ALL FEDERAL-AID HIGHWAY CONSTRUCTION CONTRACTS
CALENDAR YEAR 1979
(BY COST OF PROJECT)

CONTRACT SIZE (x $1,000)	NON-INTERSTATE PROJECTS		NON-INTERSTATE COSTS	INTERSTATE PROJECTS		INTERSTATE COSTS	ALL PROJECTS PROJECTS		ALL PROJECTS COSTS
	#	%	%	#	%	%	#	%	%
0-50	620	11.8	0.4	109	6.8	0.1	729	10.6	0.2
50-100	662	12.6	1.1	179	11.2	0.3	841	12.3	0.7
100-250	1,289	24.5	4.9	242	15.2	1.0	1,531	22.3	3.0
250-500	967	18.4	7.8	222	13.9	2.0	1,189	17.3	5.0
500-1,000	780	14.8	12.4	197	12.3	3.5	977	14.2	8.2
1,000-3,000	635	12.1	23.7	329	20.6	14.6	964	14.1	19.4
3,000-5,000	143	2.7	12.4	102	6.4	9.8	245	3.6	11.2
OVER 5,000	166	3.1	37.3	217	13.6	68.7	383	5.6	52.3
TOTAL	5,262	100.0	100.0	1,597	100.0	100.0	6,859	100.0	100.0
AVERAGE COST OF CONTRACT (X $1,000)		849.0			2,566.7			1,249.0	

Source: Bid Opening Report; Federal Highway Administration, U.S. Department of Transportation

The sense of scale provided by the table indicates that research in the field of road transport has the reward of seeing its work applied in practice. Like all research, road research must rest on two inherent assumptions: (1) causes and effects can be known and identified; and (2) scientific knowledge is the proper basis on which to make decisions. The table suggests that these two assumptions are valid in the great majority of decisions made in road administrations.

However, almost by definition, the opportunity for short-term methodologies to make important contributions is limited in a stable environment. Its very stability means there is little need for quick results.

Foreclosed Decisions

At the opposite end of the spectrum from the stable environment are foreclosed decisions. They preclude the opportunity for research or any other staff function to provide meaningful scientific and technical support to a decision, and are characterized by one of two environments:

a. a decision is highly controversial and requires a political decision, with high personal involvement from top officials;

b. a question that may not have been controversial inherently is made controversial by a Government's policy or by a strong sense of commitment from a top official.

In the first case (a), decisionmakers must practice the art of their trade. In doing so, they also provide an important service to research organizations, as a highly charged controversy hardly provides an atmosphere that is conducive to productive research. Even the very best work that can be produced is, under these circumstances, too easily misrepresented by the advocates of various positions.

In the second case (b), no career professional need waste his own career nor the resources of his organization to produce work that can be actively identified as opposing a clearly established position of the Government or of a top-level official. In a foreclosed environment, decisions often are symbolic or the result of personal resolve -- again, not the type of atmosphere that is conducive to productive research, short-term or not.

Open Decisions: The Opportunity for Short-term Methodologies

Open decisions are neither routine nor foreclosed. They are important enough to attract the personal involvement of top-level officials and may include manageable levels of controversy. They are open to influence as they lack both clearly established positions by the leadership and definitive research findings.
Unlike the other two classes of decisions identified here, top-level officials are seeking some guidance in these cases. Secondly, their uncertainty and manageable controversy require some type of useful short-term response.

If measured by the volume of an agency's activities, these decisions are relatively few. However, they consume a disproportionate share of an administration's resources precisely because they are neither routine nor foreclosed. They are highly visible to top-level officials and, consequently, the behaviour of organizations during these decisions is also highly visible. The last thing a top-level officials needs to hear in these cases is "we will need two years." Such a response will immediately, and perhaps permanently, alienate an important clientele and will restrict future access to top-level officials. Conversely, a productive short-term methodology can visibly remind this clientele of the wealth of expertise that is housed in research organizations, or the career staff in general, and can improve the opportunity for reseach to contribute to a broader range of decisions in the future.

When such an opportunity does arise, an informed sympathy for the decisionmaker is necessary. This includes a recognition that the high-level official is the point at which numero s lines of communication meet. He is subject to a broader range of questions, concerns and pressures than decisionmakers at lower levels in the hierarchy. Therefore, one should not expect even the best short-term methodology to provide the definitive "answer" to a question, as the varying levels of controversy may require that other considerations form part of the response.

However, one can expect at least to help define the range of reasonable decisions. If this is done, the short-term methodology will have contributed a considerable degree of information and rationality to the decision. This is a rather limited goal, i.e., to help define a range of reasonable responses, but, if accomplished regularly, short-term methodologies will have two important effects:

1. the research community will improve its capacity to contribute to the substance and direction of public decisions in the field; and

2. the relative position of the research community will be strengthened, thereby improving the chances that adequate resources can continue to be secured within the political-budgetary process of a ministry.

CONCLUSIONS

Because road and transport safety research relies directly or indirectly on public funding, research is required to consider its position vis-a-vis other organizations in the budgetary process. Short-term methodologies, all their limitations notwithstanding, can be an important tool for maintaining or even strengthening that position.

However, because the overwhelming majority of decisions in road administrations will be made in stable environments on relatively routine questions, research organizations cannot emphasize short-

term methodologies to the detriment of more traditional research. The strength of road safety research is, and will remain, the more traditional, applied long-term research.

Nevertheless, "open decisions" offer the research community a means by which to contribute directly to non-routine decisions that are visible and complex enough to consume a disproportionate share of an administration's energies and resources. Because these decisions require relatively quick action and because they are highly visible to top-level officials, useful and timely contributions can enhance the position of one's organization within a large ministry.

Though short-term methodologies should not be expected to provide "the answer" in such decisions, they can make an important contribution to the rationality of a decision by helping to define a range of reasonable responses. This can increase the capability of the research community to fulfill its essential task of providing scientific and technical support to the substance and direction of public decisions in the field. Of comparable importance, it will improve the ability of the research community to secure the resources it requires from the budgetary process in order to sustain a broad range of quality and useful research.

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WHY AN EVALUATION OF TRAFFIC SAFETY MEASURES ?

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Summary

Traffic safety is a major preoccupation in most countries, and the high cost of road accidents justifies that large sums of money should be spent on safety research and safety countermeasures. Now, how to use the money as efficiently as possible ? How to reach the best results in terms of numbers of lives saved and accidents avoided ? How to assess these results ? How to improve future safety policies ? It is clear that there is a need for evaluation studies and definition of evaluation processes, adequately designed to answer the various preoccupations of researchers and policy-makers.

The purpose of this paper is to list some of these preoccupations, find out which forms of evaluation are best suited to bring an answer to them, and state (briefly) which kind of data is required to perform the task.

We hope that it will contribute to promoting a better evaluation of safety work, which will be a help for research and increase the general efficiency of safety action.

I. RECOMMENDING STANDARD SAFETY MEASURES

In most countries, it is considered a task of State agencies to draw guidelines for use by local authorities. These guidelines may include descriptions of standard road facilities as well as principles and examples for area-wide safety measures or educational programs and so on ; they may be used only as an aid for decision-taking at a local level, but it is often also required that the guidelines be followed in order to get state funds for the implementation of the safety measures considered.

In any case, all the recommendations included in State guidelines have a common features : they must have been shown to play a positive part in improving safety in a general way, even though individual implementation results may vary according to the location, the population of road-users concerned, or the implementation process itself.

Researchers working at a national level are therefore in charge with evaluating new forms of safety measures. When a particular measure is expected to prove very "efficient", it would be nice of course to be able to check that through a fast evaluation study, in order to accelerate the implementation process. However, when figures of "efficiency" are required to get financial help from the State, the only efficiency recognized so far has been defined in terms of probable reduction of road fatalities ; as a consequence, evaluation has to be carried out on the basis of actual road accidents, whatever length of time is needed for data collection.

To yield results of a general value, such evaluation studies must deal with large accident figures and a variety of examples of implementation ; if a local facility is being experimented (for instance, a new pedestrian crossing), it will be necessary to take into account several spots where it has been fitted ; if it is an area-wide measure (for instance, improvement schemes for résidential areas, or plans for traffic limitations in city centers), several areas will have to be included in the evaluation ; if an educationnal program is being tested, it should be applied to different groups of population. The size of samples to retain is linked to the variety of possible implementation conditions (the following recommendations should apply to most situations), but also to the amount of accident data required and the maximum time allowed to collect it : the greatest the number of locations or population groups, the shortest the waiting-time.

Once the length of the data-collecting period and the size of the sample have been decided upon, a before-and-after study is undertaken : total accident and fatality figures are compared for the same number of months or years before and after implementations of the safety measure. When the evaluation process spreads over several years, possible changes in the general accident situation must be taken into account, and control samples have to be selected (though this is not always easy...). Most evaluation studies of this kind are generally carried out over 3 to 6 years : they may be area-wide, but they certainly are long-term !

This kind of evaluation has been widely spread and the corresponding process, shortly described here is well known and much used. But it is to be remembered that the results obtained this way have only an administrative importance and an indicative value (a safety measure which generally works efficiently may still have reverse effects on particular locations or under particular implementation circumstances). It must also be noted that, even though it is most often researchers that must perform the evaluation task, this kind of results is virtually of no use to them as it won't give any information as to how the safety measure works or in which way it could be made more efficient.

II. CHECKING WHAT HAS JUST BEEN DONE

Once the implementation of a safety measure, a-priori assumed to be efficient, has been decided upon and carried out locally, the body responsible for it, most often a local authority, could be considered as having achieved its end. However, things are not so simple and a number of questions arise that justify a new form of evaluation :

- local authorities may have to justify the results of their safety policies, in view of coming elections or in order to obtain further funds for future safety action.

- it has been seen that a local measure, even when proved efficient at a national level, may not have the expected effect on all implementation locations. Real effects must therefore be checked, in order to be able to counterbalance them rapidly by taking complementary measures, should the first results appear negative (or not as positive as hoped).

- some safety measures may induce unwanted side-effects, unforeseen when the general evaluation was carried out. In some cases, these side-effects appear very important and can be felt very negatively by the road-users, even if they do not in fact cancel completely the safety effect of the measure concerned. It is a task for the local authorities to detect them as quickly as possible and take the necessary course of action to reduce them, before the benefit of their safety policies is destroyed, in real terms or in the mind of the local road-users.

The kind of assessment that is needed here has been termed in this seminar "product evaluation". Again it should answer the question of whether a particular safety measure works or not, but this time at a local level, which means that only one or a small number of implementations is to be considered, and in the short-term, a local authority being allowed a period of months rather than years to render as positive an account as possible to its constituents. When the safety measure under examination is a physical one, evaluation should be carried out, not only on the spot or the area where is applies directly, but also on as wide a neighbourhood as necessary to take into account all the possible side-effects : it appears therefore, that even measures corresponding to pin-point locations (such as a particular crossing facility, a traffic light, a forbidden left-turn, ans so on) may well justify an area-wide evaluation.

It is now clear that the form of evaluation study required here must be based on short before and after periods, of the order of one year for instance, and that the limited application field of the local measures under examination makes it (hopefully) unlikely to collect a large amount of accident data : comparisons between numbers of accidents or fatalities will prove, in most cases, without any statistical meaning, even when area-wide evaluation is undertaken.

Some substitution data is therefore needed ; it must be in some way linked to injury-producing accidents (both sets of data must at least show parallel variations in numbers) and collected over short periods of time. Researchers have so far considered two types of new safety indicators :

- traffic conflicts, counted over a period of a few days, according to techniques developped in several countries.

- items of road-users'behaviour, defined in relation with the particular safety problem at hand as likely accident factors (for instance, going through a red traffic-light, refusing priority to a pedestrian...). Observation of those items of behaviour can also be carried out in a matter of days.

Evaluation studies on the basis of conflicts counts or behavioural observation can, of course, be performed by researchers ; but the task at hand is not so complex, once proper definitions are agreed upon, and teams of observers can be trained locally, to be rapidly available as soon as a safety measure has been accepted for implementation. Indeed, the training of local people to use the new evaluation tools may prove absolutely necessary in view of the short-term requirements.

This type of evaluation may, however, be of some use to the researcher himself, especially as experimental studies now tend to develop, involving the collaboration of both field engineers or technicians and people from research institutes interested in testing their findings through monitored implementations. A study of the side-effects arising under some circumstances is, for instance, of general value.

III. UNDERSTANDING HOW A MEASURE WORKS

Short-term "product evaluation" is necessary, but not sufficient in many cases. Discovering whether a measure works or not leads immediately to the question : "WHY ?". Trying to find out what a measure actually does once implemented, which has been termed as "process evaluation", is very important for several reasons :

- when local action has proved inefficient (or, at least, not efficient enough) through short-term "product evaluation", the conclusion is only that something has got to be done about it ; but what ? There is not much immediate information as to what went wrong, and unless the fault is an obvious one previously overlooked, more investigation work will be needed prior to defining improvements.

- when a local application of a generally considered efficient measure yields unsatisfactory results, it is logical to try and find out which local factors reduced its efficiency, in order to restrict the conditions under which this measure is recommended, or to suggest adaptations.

- a safety measure is always designed with underlying assumptions as to how it should work : for instance physically restraining some dangerous action of the road-users, or influencing behaviour to make it safer, or eliminating accident-prone physical features of the road or the environment. Unfortunately, a measure might not work the way it was intended to... It is important for the engineer, the planner or the researcher to check their assumptions, not only to improve matters locally, but also to improve future safety action and research.

In short, most progress in safety policies and safety research depends upon "process evaluation". This will even become more important as experimental studies develop, with safety measures being implemented in a more flexible way than has been the case in the past.

Given the questions it is meant to answer, it is clear that "process evaluation" should be carried out mostly in the short term and should have a descriptive value rather than a quantitative one. Accidents, if they occur, can be of use only if the way they happened is thoroughly analysed. Traffic conflicts are a possible indicator, if conflict-data is collected in a detailed way. Behavioural observation is the most flexible tool available and should be taken here in a broader sense than where "product evaluation" was concerned : the items of behaviour to investigate may be defined in relation with the local accident problem, but also with the assumptions on which the safety measure is based, or, more generally, behaviour can be monitored to detect any significant change. How to influence behaviour is a research subject in itself !

Obviously, this particular form of evaluation is best suited for researchers and local people who have a special interest in traffic safety. An evaluation study of this kind has to be designed in view of each particular problem, including the area to which it applies, the necessary technical tools and indicators, and the methods of data collection. There is no possible recipe on guidelines as to how to proceed, and a certain amount of methodological training is therefore necessary for the people in charge of the study. Short-term "process evaluation" is difficult (and actually still experimental), but the amount of information to be expected makes it worth the effort.

CONCLUSION

We have tried to show how necessary a task evaluation was, for policy-makers, for planners, engineers or technicians dealing with traffic safety in local authorities, and for researchers. Unfortunately, this task has been performed so far only in a very restricted way. Long term evaluation based on accident data raises no problems, but as soon as new safety indicators are needed (short term studies) and whole physical areas have to be considered, evaluation tends to be forgotten, and examples of proper follow-up studies are very rare indeed.

We hope that this paper will contribute to promoting a better evaluation of safety work, which will be a help for research and increase the general efficiency of safety action. Tools and methods are available and people can be trained !

PRINCIPLES IN SHORT-TERM EVALUATION OF SAFETY MEASURES

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SUMMARY

The last development in the field of technics has solved many problems in applying theory to the practise. This is how short-term evaluation of safety measures has become more and more important and at the same time very much has happened in the theoretical development.

With short-term evaluation there is a better possibility to get an insight of the real process of the traffic. We are able to measure the basic changes in the variables that connect behaviour for instance to the improvements of safety. At the same time we anyway meet new challenges like questions of generalizing of results, controlling factors and planning of test arrangements.

The experiences we have show that short-term evaluation can be a very useful tool in producing information for decisions. Methods have been used often in giving quick answers for restricted and practical questions. Relevant hypothesis should be tested and also the exact control of the possible affecting variables is an prerequisite for using the results in safety-work.

We cannot give up the use of statistics. They have their role at least in everydays´ safetywork. Short-term evaluation of safetywork has its advantages in the possibilities of quick analysies and in the tight contacts to the explaining variables.

INTRODUCTION

Road Administration is in Finland responsible for improving safety on public roads. In this work the road authorities carry out annually numeral measures. Part of this work consists of research and developing of safety measures.

When the state of safety on the roads has improved significantly as in Finland during the last ten years, marginal output of new safety measures decreases. Resources are scarce but still those making decisions wait for quicker and more accurate answers. This is where short-term evaluation can be useful if scientifical and practical questions are overcome.

On the other hand better safety is possible to reach only by safety-work with clear objectives. Because the problems today also in Finland are in densely populated areas as in cities and their neighbourhood there is more need for area-wide plans and programs for the improvement of safety. In these plans we handle simultaneously higher level safety measures and traditional improving methods. Effect on the safety is a very important matter but difficult to answer when bearing in mind that there is a lack of information even with separate minor safety measures.

In the following short-term evaluation measures are studied mainly from the practical view. Stress is in the role of these evaluations and the suitability in giving information for the decision-makers.

BACKGROUND

For a long time short-term evaluations using behavioural measurements have been dependent on equipment and suitable methods. Now when we have small and handy microprocessors this problem is mainly solved and does not harm studies.It is now important to develope theory and test arrangements which can measure the relations and connect behaviour in traffic to safety. Road Administration has been developing conflict method for its own purposes. At the same time several studies have been made to resolve efficiency of certain safety measures. For this same reason also behavioural studies have been done. Behaviour, especially speed of the traffic will be followed continiously because this variable is related to the general development of safety in many ways.

Role of short-term and area-wide evaluations

These evaluation methods are very popular today in the field of safety. We have seen that the safety is not only traffic and accidents but a lot more. Safety is a part of the standard of living and it affects possibilities to take part into activities of society. Area-wide evaluation of safety measures is also an important part in the developing of new evaluation methods. Many times we may succeed in lowering the risk in a certain part of the area but transfers of traffic cause more accidents elsewhere and often also other nuisances as noise and pollution. What the result is depends on the whole group of traffic objectives and their priorities.

General views

We are not giving up using accident-statistics in the safety evaluations but we have been able to see that these studies have many restrictions. When there is a need of quick decisions - as it is nowadays - studies based on statistics might take years and are not always possible. With short-term evaluations data is gathered at least during some months. Also the systematical errors in statistics are avoided.

In Finland many of the short-term evaluations are used in giving answers to quite specialized problems that are accura-

tely defined. A measure should cause some kind of change in the traffic. This change is connected with the changes in accidents /1/. These two aspects reflect the background of short-term evaluations. Reduction of accidents has its causes and these causes are normally measureable. When the changes happen in real traffic modern technology is often easy to apply. When the change is concentrated for instance in vigilance there is a need of profound testing methods. Theoretically we are able to make causal conclusions when the both changes mentioned above are measured. However, these conclusions cannot always be generalized.

For the background of the evaluations we might think that traffic consists of a great amount of incidents. Accidents are a rare incident among these all. The normal way is to group these incidents in traffic-incidents, conflicts and accidents /2/. With accidents we have difficulties such as representativity of statistics and the long time needed for the analysies. The effect of safety measures is difficult to proof without taking also account of exposure. This is the other main factor of which we often lack data. In short-term evaluations these difficulties can be avoided.

We should be able to measure also safety from the point of view of feelings of unsafety. The methods based on accidents have defects when we are dealing with unactive population as pedestrians-children and old people. Certain activities will be left out and acting in the surrounding might be restricted. When there are no accidents we might think that there are no safety problems. There is a possibility to measure this feeling of unsafety through measuring behaviour. This can be done for instance so that we measure those activities people have to do because of great risk. They have to see their children off to school or they have to watch them in the yard and parks/1/.

Findings

In the positive safetywork we try to find out measures without

accident-statistics. Effective measures should be applied as quickly as possible but they should be economical and those using them should also know the degree of effectiveness.
When we are working with measures that are mainly carried out because of safety, short-term evaluations are practical. Often there is a situation where entirely new approaches are applied and no historical data is available.

Even though short-term evaluations have very many good sides there are also limitations. Testing and measurements must have exact hypothesis which are based on reliable relations to safety. It is also sometimes difficult to achieve measurable variables even though we have microprocessors. When measuring behaviour there are often very many control factors which need to be registered. In many cases even when dealing with about the same questions the arrangements have to be changed because of testing places etc. This causes troubles in transferability and comparison of results. Changing conditions might cause the same problems as we have with accidents - insufficient data.

Behaviour of the traffic is changing with time. Results based merely on behaviour might loose there usefulness in the course of time. Short-term evaluations should be dated as other studies. Then there is the question of money. For instance conflict sudies are often expensive because the data is complicated to analyze and many measurements are needed.

With short-term evaluations we have to plan the collection of data and the relevant variables very carefully. There has to be right hypothesis of the relations, better understanding of the traffic and the process.

APPLICATIONS

In the following there are presented some results of short-term evaluation. The first part consists of three behaviour

oriented cases and the second of two typical conflict studies. These cases are dealt briefly and the practical value of the results is discussed.

Short-term evaluation - behaviour

Road Administration needed information about flashing beacons and pedestrian safety in school zones. A decision should be made whether to use this measure or not, there was no information of the effects on safety. Because this was a new measure there were many things to find out. There were 9 studies in this project /3/:

- effects of the flasher on spot roads
- effects on changes in cars´speed and lateral displacement
- effects of the location of the flasher
- immediate responses of drivers
- effects on steering and breaking responses
- slowing down and giving way
- timing of flashing periods
- long-term effects, local and other drivers
- correct understanding

The results were that the new flasher reduces speeds, but the effect changes after some time so that the flasher mainly increases drivers attention. Anyway the flasher has no effect on slowing down and giving way on pedestrian crossings. With a warning sign the effects are better. The study showed that flashers could be used to enhance safety in cases where children are going to and from school along the road. Installation of it with a warning sign should be useful.

In this study controls are made very carefully. The main effecting variables are studied. The only argument against it is that the measurements of which the result are based are made in the same region. There might be some differences between regions with different conditions. Because of this some further experiments are made but the main questions have got answers.

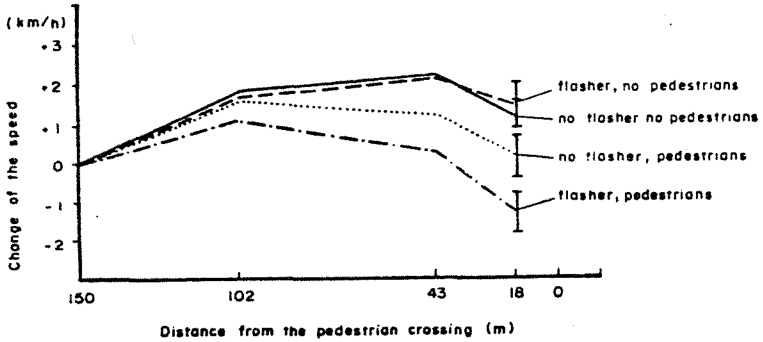

Figure 1. The change of speeds of the vehicles in autumn in one of the places

Recently there has been much discussion of the rumble stripes. Road Administration made an experiment with the rumble stripes in junctions on the country side. Main question was does this measure improve safety and is it economical. In this study the speeds of the traffic were measured before and after installation of stripes. After that there was an interview of road users, maintenance-study and a study of other effects especially on noise-level /6/.

Speeds went down after installation of the stripes. The effect lasted and did not vanish in time. Drivers appreciated this solution but it increased noise-level in the surrounding. There was also a tendency that accidents decreased even though the data was restricted. Especially single-accidents seemed to decrease. Most of the important variables were controlled. This measure seems to be useful in the countryside and especially when the road with high speed-limit ends in a T-junction.

The third study /4/ consisted of studying behaviour of pedestrians and drivers on the pedestrian crossings. This study was based on observations of the road users. Observation method was tested and it was reliable and valid. From

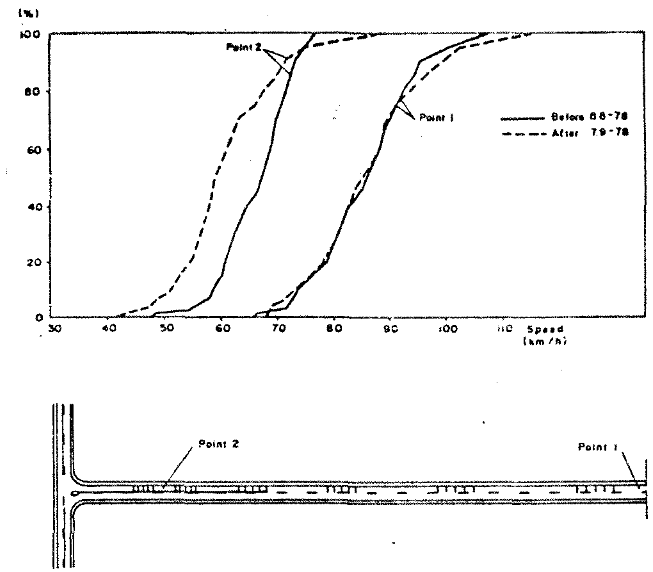

Figure 2. Distribution of the speeds in a testing place

the reactions and the behaviour of the road users in different places there was a possibility to study crossings of male and female persons, crossings of persons of different ages, crossing in different weather and lightness-conditions and the relation between the behaviour of car-drivers and pedestrians. The study pointed out that the speed limit should not be more than 60 km/h and that pedestrian crossings do not have a high stimulating effect on the behaviour of the drivers.

This study gave some critic to the use of the pedestrian crossings. These results tell us also something about why there happen so many accidents in the pedestrian crossings.

Short-term evaluation - conflicts

Road Administration has in the end of the 1970´s studied the usefulness of conflict method /5/. In these studies conflict method has been used in 50 junctions by observers. When comparing results with the accidents we could see that conflicts did not always give the same information of the safety as accidents. There were also many differences between junctions The better conditions in the junction were the better was the correlation between accidents and conflicts. We could also see that in junctions with quite low traffic volume we should observe conflicts quite a long time to get reliable results. This study concludes that conflict method gives information about the general safety of the junction but cannot give very reliable results of types of the accidents.

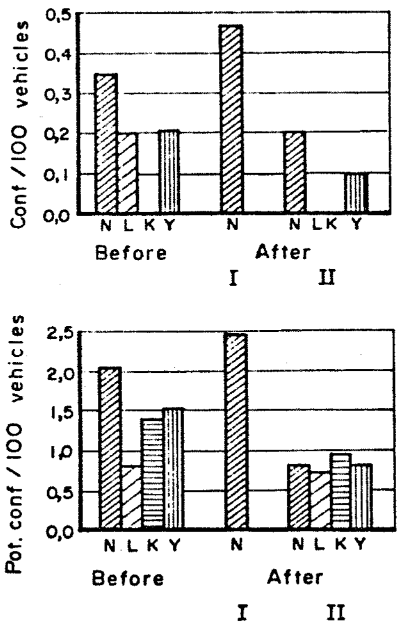

Figure 3. Conflicts and the conflict-risk before and after implementing the measure (N, L, K, Y are different places and I = just after, II = three months after)

Road Administration decided in 1980 to replace crawling lanes (right hand lane for slow vehicles) by overtaking lanes and immediately study the effect of the change in safety with conflict method/11/. Observations were made in three locations with before - after-system using video equipment.

The study done by Technical Research Centre of Finland showed that under the new regulation where the left lane is overtaking and the right lane a driving lane, traffic runs smoothly and safely. There was some confusion in lane behaviour and right-of-way situations two weeks after the change, but hardly any confusion three months after the change. The change did not seem to have any significant effect on the speed of the vehicles.

After the study road authorities became sure that this change had not any bad effects on safety. When observing the traffic one could see that this measure is a very good improvement and it obeys the right hand rule that we are used to.

TOOLS IN EVALUATION

Statistics in safetywork

Safetywork nowadays is a great deal dependent on accident statistics even though we try to find other effective ways to evaluate the need of countermeasures. There are anyway many difficulties in using statistics especially in the practical phase when the places where measures are applied should be defined. Restricted resources and paradoxically the lack of accidents forces us to pay more attention on research and development work.

In Finland there are accident statistics from three different sources: Central Statistical Office, Road Administration and the Finnish Motor Insurers'Bureau. Research projects are carried out by which we try to find out what differences there are between these statistics, how many accidents there actually happen annually, why all the accidents don´t come to the statistics and how the statistics should be improved so that they could better be used in safetywork.

In practical safetywork when there is a need of countermeasure in a certain place only the statistics of Road Administration has direct contacts to other variables needed. Because of the fact that effective countermeasures also in Finland should be more and more concentrated to the built-up-areas we need also this kind of statistical register in towns. There is a project going on where this system is planned.

Using damage-only accidents

When thinking of the usefulness of using damage-only accidents we have to know how the general situation looks like.

According to the new research reports /7,8,9,10/ accidents occur on an average to 3,5 % of the population in Finland annually.

The police will be informed of about 30 % of all the accidents and insurance-organizations of about 70 %. Only about 25 % of the damage-only accidents will be informed to the police and the road authorities. The insurance companies will be informed in more than 70 % of the cases.

Road authorities in Finland collect and localize annually also all the damage-only accidents that are informed by the police. They are used mainly when trying to get a general view where the accidents happen and concentrate.

It is not a new idea that one should try to use those statistics that have also a lot of damage-only accidents as statistics of insurance companies. In Finland the central difficulty is that it is a hard task to try to localize accidents because

they are informed by the insurance taker with no exact control of the actual place. A recent study /9/ done by Road Administration shows that different types of accidents are represented in different ways in statistics (table 1).

Table 1. Correcting factors for types of accidents in one county when comparing the amount of accidents in the statistics of Road Administration (RA) and insurance companies (IC)

Type of accident	Correcting factor from RA statistics to IC
Driving into rear	1.86
Head-on accident	1.45
Crossing accident	1.54
Single accident	1.10
Pedestrian accident	1.15
Animal accident	1.01
Others	1.66

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THE POTENTIAL FOR AREA-WIDE APPLICATION OF ACCIDENT COUNTER-MEASURES IN RESIDENTIAL AREAS

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ABSTRACT

The research reported in this paper involved an evaluation of the potential for wide-spread application of low-cost accident counter-measures in residential areas where, typically, vehicular and pedestrian volumes are relatively low. It presents a summary of the procedure by which the counter-measures were evaluated against certain criteria and then compared one with another, in order that the most promising could be identified.

Fifty three counter-measures were identified, within six strategies. Most have been applied in the UK, although not necessarily in residential areas or as a single measure. Evidence of the effectiveness of individual counter-measures is rare as most are commonly used as components of an overall traffic or environmental management scheme. Furthermore, despite the relatively widespread use of some of the devices, in general little examination of their effectiveness appears to have been undertaken.

As a result this evaluation, in some respects, is subjective. The framework however, has been designed with this in mind and allows the adoption of alternative value-judgements and the consideration of their implications on the results of the evaluation. The results presented, where firm evidence does not exist are based on a range of plausible judgements and are relatively stable with respect to them.

The research was carried out under contract to the Transport and Road Research Laboratory.

1. INTRODUCTION

Three-quarters of the national total of injury accidents on British roads occur in urban areas; of these, about one-third takes place in residential areas where traffic flows are relatively low. Although the number of accidents is large in total, they are diffusely scattered, rarely occurring in sufficient numbers at any one location to be amenable to site-specific treatment. Previous research (see, for example, Dalby, 1979 and Dalby and Ward, 1981) has shown that inexpensive environmental improvement schemes, aimed at reducing traffic volumes and/or speeds, often have resulted in a reduction in accidents. This suggests that an area-wide approach to safety in residential areas, using low-cost measures as components of a comprehensive management stragegy, could be fruitful. The Transport and Road Research Laboratory has argued the case for a comprehensive approach to road safety in urban areas (TRRL Leaflets LF656/1977 and LF772/1979).

In order to explore the potential of such an approach, research is being undertaken to establish the extent to which low-cost measures, applied on an area-wide basis, can contribute to accident-reduction in those parts of an urban area where site-specific measures alone are unlikely to make any appreciable impact on the overall accident toll. As part of this research, The Transport Operations Research Group of the University of Newcastle upon Tyne was commissioned to evaluate the potential effects of the widespread use of accident counter-measures in residential areas. One of the objectives was to identify those counter-measures that seem to be most generally applicable to the area-wide safety approach, using criteria that take account of different aspects of social and engineering practicability and cost-effectiveness. This report describes the method used in this part of the study.

As the investigation was concerned only with the use of counter-measures in residential areas, no consideration was given to any possible use on rural roads, major inter-urban routes, urban arterial routes or roads in central areas, and the results given should not be taken as relevant to these. As used here, a residential area should be taken to mean an area in which the primary and predominant land-use is housing, although some commercial and industrial land-use may also be found. It should be bounded by, rather than contain, sections of the arterial (primary or district distributor) road network; internal circulation should be by local distributor and residential access roads. Access roads should have the single traffic function of providing vehicular access to fronting properties, whilst the principal traffic use of local distributor roads should be to connect the access roads to the arterial road network. In recently-developed areas these two functions are kept separate, but in the older areas the distinctions are blurred; local distributors may also have to serve access functions for fronting housing, whilst through-traffic may make convenient use of residential access roads, so that it is not always a straightforward task to label a particular road within an area as "local distributor" or "residential access". Especially difficult in this respect are the "spine roads", of intermediate function, that connect a group of access roads to a local distributor, and wholly combine the functions of both. However, in view of other objectives in the study the distinction between "access" and "local distributor" has been maintained throughout.

2. CLASSIFICATION OF COUNTER-MEASURES

Six broad strategies have been adopted to embrace the range of possible approaches to road safety when treated at an area-wide scale; these reflect the common objectives of traffic management, and thus provide the basis of a classification system for the counter-measures used to implement them. The strategies are:

(1) Control of vehicle routes and volumes
(2) Control of vehicle speeds
(3) Modification of road user behaviour
(4) Restrictions on stationary vehicles
(5) Segregation of pedestrians and vehicles
(6) Warning devices

The counter-measures have been classified according to what is considered to be their main function, although in many cases they can be seen to contribute to more than one strategy. Moreover some sub-division of the strategies seemed appropriate. Table 1 shows the counter-measures that were identified, classified by strategy and, where appropriate, by subdivisions of this.

The list of 53 techniques and devices was identified from the literature and from essential discussions with British local authorities. Essential to their choice was that they should be low in cost, and be capable of use within the existing boundaries of public rights-of-way. They were to be free-standing and not involve only minor modification to other counter-measures. Although the information was gathered from the literature of several countries, there has been, necessarily, a bias towards British sources, given the greater access to information collected in, and relating to this country.

3. FRAMEWORK FOR THE EVALUATION

3.1 The construction of the evaluation framework

Although the terms of reference for the research required that appraisals be made of the effectiveness of each counter-measure, as a consequence of which some form of comparative evaluation should be conducted, it was clear that neither the evaluation nor the appraisal could be wholly objective. Even if comprehensive and compatible data for each counter-measure had been available, and this was far from the case, the process would require the comparison of different aspects and consequences of the various techniques and devices, and thus be akin to comparing apples and pears. Having accepted the need for subjective value-judgements, the first important aim was to devise a basis whereby they could be made in the most consistent possible manner. In recognition of this an evaluation framework was designed to fulfill two requirements:

(1) to present information about each counter-measure as clearly and consistently as possible; and

(2) to establish and explore the implications of different subjective value judgements, with a view to discovering the degree of sensitivity associated with them.

Providing a base to the framework were the seven criteria used to judge the effect of applying each counter-measure; they are described in Section 3.2 following. The results from these judgements were entered on the Basic Evaluation Matrices, shown in Tables 2-7, where the rows describe each counter-measure and the columns relate to the criteria used. Thus an entry in a cell

represents an aspect of an individual counter-measure's performance; where there are two such entries in a cell, the first concerns its performance when applied on a residential access road, and the second when it is used on a local distributor road. Single entries always imply that there is no discernable difference in effect between the two uses.

For the first six criteria, A-F, the evaluation of performance used a five-point scale, with the symbols ++, +, o, -, --. The double-positive (++) implies a strongly beneficial effect, whilst the double-negative (--) implies the reverse. An entry of o indicates little or no apparent effect. In cases where the application of a counter-measure appeared to lead to both positive and negative effects with regard to a particular criterion the symbol ± is used.

Criterion G, which relates to the expected reduction in accidents, uses a shorter range of value ratings, as it is clearly a fundamental requirement that any counter-measure included should be expected to enhance traffic safety. Although closer inspection showed that some accepted measures have had little real effect, only those that were thought likely to bring an increase in accidents were excluded from the evaluation. Thus there are the three value-ratings, ++, +, o.

3.2 Criteria for the basic evaluation

Seven criteria were used to represent different aspects of the practicability and cost-effectiveness of the counter-measures.

A. Compatibility with other traffic and social objectives

The assumed traffic and social objectives were defined at the outset. They were:

(a) for access roads - the broad social objectives are to create a street environment where social and household activities are paramount, ease of movement for vehicles is secondary and the only traffic functions of relevance are access to buildings and parking for those vehicles requiring such access.

(b) for local distributor roads - the traffic-distribution function is given a greater importance than the access function, but where the access requirement is significant ways have to be found to reduce conflicts between vehicles fulfilling different traffic functions, as well as those between pedestrians, vehicles and the environment.

With these objectives assumed,

(a) for access roads counter-measures which reinforce the dominance of traffic and vehicular movement (eg traffic signals) receive negative scores, whilst those that tend to enhance the ambience of the street as a place for people rather than traffic (eg road narrowing and speed control humps) earn positive scores.

(b) for local distributor roads the balance is weighted less toward people and their environment, but totally unrestricted traffic flow is still held to be less important than provision for pedestrian activity, residents' amenity, parking and access for commercial vehicles and the loading and unloading of public service vehicles.

B. Ease of implementation and maintenance

This criterion is concerned with the physical problems of installing and operating the counter-measure. Some,eg road markings, present no design or implementation difficulties, and thus attract positive scores. Others involve the departments undertaking them in considerable effort and relatively difficult engineering problems, whilst people living in the area might be subject to a period of disruption, such as may occur where a subway is being constructed.

Some more common factors that have to be taken into account are indicated in the columns of the matrix:

(1) some form of authorization procedure is necessary before implementation can legally take place,eg a Traffic Order must be required;

(2) the counter-measure is not legally sanctioned for use on public roads in the United Kingdom;

(3) the counter-measure is regulatory, in that it has a statutory meaning, and penalties are prescribed for any failure by individuals to comply with it. This implies that some degree of enforcement will be required calling for additional effort by the enforcing agency.

(4) to be effective the counter-measure has to be applied on an area-wide basis, rather than at a particular site. Thus "School Routes" would embrace the whole of a given school catchment area, rather than the use of a single length of road.

D. Capital and maintenance costs

Judgements as to what measures may be described as "low cost" should take into account the size of the area and the budget which may be available to improve it. For the purpose of this evaluation "high cost" has arbitrarily been assumed to apply to any measure costing more than £5000 (mid 1981 prices). The value rating is, therefore,

++ (very low cost)	up to say £500
+ (low cost)	£500-£1000
o (medium cost, low end of range)	£1000-£3000
- (medium cost, high end of range)	£3000-£5000
++ (high cost)	more than, say £5000

Some counter-measures, eg Pelican Crossing, can readily be defined in terms of a single installation to which a firm cost can be applied. Others are less discrete entities; thus Speed Control humps are rarely installed singly, but comprise several Humps placed at intervals along a road. Most difficult of all to define are those measures, eg Pedestrian Guardrail, for which there is no standard unit of installation, but which can be used in a very wide range of quantities.

The cost-ranges given in the matrix have assumed a typical installation, eg one Pelican Crossing, a set of eight Speed Control Humps, or an effective

use of Pedestrian Guardrail, with 20 m on each side of the road on the approach to a potential hazard. Counter-measures that can be applied effectively to an area-wide scale eg a Safety Campaign, generally are shown as high cost.

Maintenance costs are assumed to reflect capital costs except where evidence to the contrary is available.

D. Effect on user behaviour and learning

This criterion is concerned with the effectiveness of the counter-measure in performing the primary function implied by the strategy. Thus a speed-control device will attract positive marks in its effect on behaviour if experience shows that it controls (reduces) speed, zero if it is seen to have little or no effect, and negative if it appears to encourage drivers to go faster. The ± indication is used where the effect is variable or contradictory, eg with some devices it has been found that vehicle speeds in the faster part of the range have decreased, whilst those in the slower part of the range have increased.

The application of a particular counter-measure within an area is assumed to be (a) potentially widespread throughout the area, and (b) well within any budgetary constraint. Additionally, it is assumed to have been designed in a proper manner (the "best design" assumption), with any supplementary work being carried out to a similar standard. One implication of this is that the effects experienced at single sites will be repeated where ever a device is used, ie there will be no loss of efficiency resulting from the over-exposure of road users to the device. It has also been generally assumed that the effects of a measure on local distributors and access roads will be similar, except for some of those calssified under Segregation of Pedestrians and Vehicles, where the higher traffic flows on the local distributor routes may be expected to produce a significant difference in pedestrian behaviour.

E. Secondary effects

In most cases the application of a counter-measure will bring effects additional to those directly sought, often relating to other strategies. Under such circumstances the beneficial or detrimental effects may be expected to result mainly from, respectively, a decrease or an increase in one or more of the following: traffic volumes, vehicle speeds, conflict between vehicles and pedestrians, and accessibility. Further detrimental effects include:

(a) non-compliance with regulatory counter-measures, in places such as minor residential streets, where they are unlikely to be enforced, and

(b) adverse effects on the residential environment,eg the possible visual intrusion of roadside warning posters.

F. Level of support and political acceptance

Entries in this column represent judgements of the extent to which each counter-measure would be supported by those likely to be concerned or affected by it, namely the public authorities, the affected population, conservationist lobbies, the emergency services, public transport operators and the police. Discounting the obvious tendency for any change always to be resented by a few people, the general interpretation of the ratings used is as follows:

++ unsolicited demand for installation of the counter-measure;
+ acceptance when installation of the counter-measure is proposed;
o the neutral position, ie tacit acceptance or no objection;
- rejection when installation of the counter-measure is proposed;
-- strong and continued opposition even after installation; and
± a mixture of acceptance and rejection.

G. Expected reduction in accidents

As all listed counter-measures have valid claims to change accident patterns for the better, the meaning of the entries used is as follows:

++ either statistically valid evidence of accident-reduction in practice exists, or the changes that the measure would bring are absolute (eg with pedestrianisation), so that opportunities for traffic conflicts are eliminated and accidents can no longer occur;
+ there is little, or no statistical evidence regarding effects on accident patterns, but judgement suggests that a real potential for accident-saving exists; and
o no evidence is available regarding effects on accident patterns, and little other than neutral evidence exists regarding behavioural change. Judgement suggests that no worthwhile long-term benefits can be expected in the majority of situations.

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In only 9 of the 53 counter-measures listed was it possible to give a double positive rating. A wide variety of evidence had to be brought together in order to arrive at one of the other two decisions, the main external sources being:

(a) recorded evidence concerning the use of the counter-measure in non-residential, or other parallel situations;
(b) evidence regarding improvements to road user behaviour where this was clearly related to accident occurrence; and
(c) the potential effectiveness of measures designed to deal particularly with known high-risk types of accident or casualty group (eg school children).

To these had to be added the combined experience of all those who were involved in the study.
The value ratings awarded relate only to accident decreases in the lengths of road or areas in which the counter-measures are expected to exercise a direct effect, and no account has been taken of any changes outside these. It was reasoned that any possibility of an increase in accidents resulting as a secondary effect could be discounted because of the good design assumption, as any such potential increase would have been predicted in advance, and measures taken to offset it. Indeed, the whole approach to the area-wide application of counter-measures stems from the philosophy of using an interacting assemblage that concentrates the residual potential conflict-situations at places where there are opportunities to use relatively cheap and well-tried engineering techniques to eradicate them.

3.3 Evaluation procedure

Although each counter-measure was evaluated in accordance with the defined

criteria, and in as consistent a manner as possible, the data available varied widely in nature and extent, so many of the decisions taken were qualitative rather than quantitative. The rest of the evaluation process was concerned with simplifying the large amount of information obtained, whilst limiting the effect of the qualitative decisions that had been taken. The end-point of this process was the reduction of the seven criteria assessment to two factors, namely "performance", which may be equated to an overall traffic engineering-social-economic acceptability, and "expected accident reduction". The performance factor was obtained by operational evaluation, where the relative importances of the criteria A-F, and of the six strategies into which the counter-measures were classified, were examined by means of a weighting system. When this was set against the accident reduction factor it became possible to identify those measures that seemed to offer the best opportunity for application in the defined conditions.

4. EVALUATING OVERALL EFFECTIVENESS

4.1 The development of an evaluation index

The starting point for the construction of the quantitative rating system for the data was the attachment of integer values to the five-point scale used in the Basic Evaluation Matrix. Separately, and in combination, weights could then be given to each of the various strategies, and to each criterion used. A simple computer program allowed the calculation of a total score-value for each counter-measure, for any given set of weights, separate totals being given for access roads and local distributor locations.

There is, of course, no "correct" set of scores or weights, nor do any of the resulting total score-values have any absolute meaning in a cardinal sense. However, when these are ranked ordinally, it is possible to explore the relative importance of the different counter-measures in the light of any assumptions made concerning the strength of the criteria used to evaluate them, and of the strategies used to classify them. Furthermore, by varying all the numerical values involved, namely:

(a) the integers attached to the scoring system;
(b) the weightings given to the strategies; and
(c) the weightings given to the criteria,

it is possible to explore the robustness of the resulting ordinal rankings through a range of input values. Finally, in common with all such analyses of sensitivity, it enables the often complex effects of changes in policy to be followed through, since, for any alterations in this, an appropriate set of weightings can be applied and their effects revealed.

Preliminary tests indicated that, whilst variations in the numerical values produced changes in the total score-values for any counter-measure, a significant number of them consistently gained relatively high or low scores. It was recognised that the consideration of small differences in totals would not be appropriate, because the judgements on which these were based were imprecise. To overcome this a coarser ranking system was developed, based on ranges of score-values defined by reference to two bench-marks. Again this was incorporated in the computer program. The resulting 'evaluation indices' are referred to as follows:

α very good β good γ neutral δ poor

At each use of the system, and in advance of the application of any form of weighting, the bench-marks used to define the evaluation indices were themselves defined, by reference to the performance of two hypothetical counter-measures:

- the first, regarded as neutral in its performance, had an assumed entry of "o" in each cell of the basic evaluation matrix. Performances better than this were regarded as "good"; those worse were regarded as "poor". The few counter-measures having overall neutral performances were placed in the "neutral" category. As the objective was to give scale to the good counter-measures, poor performance was not further subidivided.

- the second, used to separate "very good" and "good" had an assumed score value of one-half of that of the highest-scoring counter-measure under the particular scoring system being used.

4.2 Scoring system

In the development of the scoring system used to give scale to the decision taken in the basic evaluation there were three problems to which attention had to be paid:

(1) Should both positive and negative scores be used? There was a natural preference for this, as it reflected the double-sided scale used in the basic matrices. More important, however, the use of only positive scores could lead to anomalous results, as where counter-measures with negative entries in some columns might receive high total score-values (rather than the intuitively correct lower scores) whenever the strategy within which they were classified was weighted.

(2) How should the '±' entry be dealt with? In view of the double-sided scoring system it was decided that the positive and negative effects could be regarded as cancelling each other out. Thus '±' was considered as being equivalent to 'o'.

(3) Should the scale be one of equal, or unequal intervals? Recognising that the coarse nature of the five-point scale could not reflect small differences, and that different interpretations of the basic matrix were possible, this problem was resolved by examining the effects of using a range of scoring systems. In these the ratio of the interval between neutral (o) and a single entry (+ or -) and between a single entry (+ or -) and the corresponding double entry (++ or --) ranged from 3:1 to 1:3. The five systems were

Scale mark	(++)	(+)	(o) (±)	(-)	(--)	Ratio of intervals, neutral-single and single -double entries
Scoring systems	4	3	0	-3	-4	3:1
	3	2	0	-2	-3	2:1
	2	1	0	-1	-2	1:1
	3	1	0	-1	-3	1:2
	4	1	0	-1	-4	1:3

For each scoring system the total score-value for each counter-measure was first calculated unweighted, ie assuming that each criterion and each strategy was equally important. Score values for the bench marks were then calculated

and the evaluation indices for the counter-measures were determined. Applications to access roads and local distributor routes were considered separately.

The results given in Table 8 show that in the majority of cases variations in the scoring system had little effect on the evaluation indices. This has been taken to imply a reasonable stability for the procedure used. More specific conclusions are:

(a) the counter-measures evaluated are generally better suited to access roads (12 δ values) than to local distributor routes (27 δ values);

(b) some counter-measures are equally applicable to access roads and local distributor routes; and

(c) 'control of vehicle routes and volumes' and 'control of vehicle speeds' are strategies more suitable for use on access roads than local distributors whilst 'warning devices' involves a strategy giving similar results on both road types.

4.3 Criteria weighting

To investigate the sensitivity of the results to changes in the relative importance of the different evaluation criteria (defined in Section 3.2) each in turn was differentially weighted by factors of 2 and 3, all others remaining unweighted. This produced 12 different combinations of weight, to be compared with the basic ie unweighted, case for each road type and for each of the five scoring systems. Thus at this stage a total of 65 sets of evaluation indices were generated for both access roads and local distributor routes.

The effect of weighting a particular criterion, where a counter-measure has a positive entry, is to increase the total score value; where the entry is negative the total is decreased. In some cases there is a resulting change in the evaluation index, this change being more marked at the higher weight. Tables 9 and 10, show, for access roads and local distributor routes respectively, the ranges of evaluation indices produced by the five scoring systems and with different degrees of weighting.

A detailed examination of the full results showed that criterion C - capital and maintenance costs - exercised the strongest effect, by reducing the performance of several counter-measures entered as "high-cost" - in the basic matrix. In particular the following counter-measures, considered only to be capable of application on an area-wide basis, only showed a δ evaluation index in some of the cases when this criterion was weighted.

Advisory Route signing) Cycle Routes) Local Safety Campaign)	application on access roads and local distributor routes
Area-wide Speed Limit	application only on access roads

4.4 Strategy weighting

The relative merits of the different strategies (defined in Section 2) were examined in a similar way to that used to test the sensitivity to criteria weighting, each strategy in turn being weighted by factors of 2 and 3 to give the same number of evaluation indices. The general effect of weighting strategies is to increase positive, and to decrease negative total score-values , which produces a change in the evaluation index from β to α for any counter-measure where the value crosses the second bench-mark. Counter-measures with an index of α , γ or δ cannot show any change.

The detailed results showed that the only strategy where counter-measures did not show variations in the evaluation indices was "Warning Devices"; for the other strategies, on access roads 11 counter-measures showed an improvement with a weighting of two, increasing to 17 when a weighting of three was introduced. The respective totals for local distributors were 11 and 12.

4.5 Multiple weightings

Although in the foregoing calculations weighting has been applied to a single criterion or strategy, in practice it is probable that any individual's subjective judgement would have to be expressed as a mix of criteria and strategy weightings. Without attempting to define any "best" set of weightings, tests were made to explore the effects resulting from a variety of mixes, using an equal interval scale. The weightings used were

Test no.	Criteria weighting						Strategy weighting
	A	B	C	D	E	F	
(a)	2	1	3	3	1	2	All equal to 1
(b)	3	2	1	2	2	3	All equal to 1
(c)	1	1	2	2	1	1	'Route and Volume' and 'Speed'. Others equal to 1
(d)	2	1	1	3	2	1	All equal to 1
(c)	1	1	1	3	2	1	All equal to 1

A detailed comparison of the results from this test with those given in Tables 9 and 10 showed that there was a close similarity.

The results obtained here, taken together with those described previously, suggest that the scoring system is reasonably robust, and that it can be used to convert the assessments in the basic evaluation matrices into a means of comparing the relative performance of the counter-measures. The method adopted provides a framework into which alternative scoring systems and weightings for both strategies and criteria can be applied, so that any particular set of circumstances can be reflected.

4.6 Overall performance rating

Before these results can be set against the expected effectiveness in reducing traffic accidents it is desirable that they be drawn together into a single scale. This has been done in the overall performance rating, the four levels of which express not just the relative performance rating per se, but also the extent to which to which the evaluation indices varied with separate or combined changes in the scoring systems, the criteria weightings and the strategy weightings. The four levels are

Performance rating	Consistency	Evaluation indices
I (first rate)	stable	α
II (second rate)	variable	β to α
	stable	β
	variable	γ to α
	variable	γ to β
III (third rate)	stable	γ
	variable	δ to α
	variable	δ to β
IV (fourth rate)	variable	δ to γ
	stable	δ

A number of minor adjustments were made to the performance ratings of particular counter-measures, generally in cases where variations due to a single factor appeared to lead to an unreasonable representation of overall performance.

5. RESULTS OF THE EVALUATION

In the final stage of the process criterion G, the expected effectiveness in reducing accidents, was introduced into the assessment. In Tables 11 and 12, for use on access roads and local distributor routes respectively, this criterion is related to the overall performance ratings. Counter-measures are listed in declining order of both characteristics, from the most desirable at the top left of each table to the least desirable at the bottom right. In Table 11 it can be seen that 23 of the 33 counter-measures considered to be likely to achieve accident reductions when used on access roads also have a first or second rate performance rating. In Table 12 the situation is similar, except that those counter-measures considered likely to achieve accident reductions, but having third or fourth rate performances, are generally incompatible with the traffic function of local distributor routes. Thus, in general terms, there appears to be a strong relationship between a counter-measure's potential for accident-saving and its performance rating as established in this analysis.

It may be concluded from this evaluation that, under current conditions of road user education and vehicle design, the most promising strategies for accident reduction away from town centres and main arterial routes are likely to lie in the area of conventional traffic management, ie the control of vehicle-routes and volumes on both access roads and local distributors. On access roads the control of vehicle speeds is clearly important; on the other hand no other obvious strategies apart from the segregation of pedestrians and vehicles, appear to have emerged for application on local distributor routes.

In general the conclusions of this evaluation confirm the initial premise, that a combination of conventional low-cost traffic engineering techniques, applied on an area-wide basis, can offer improved road safety in residential areas.

6. REFERENCES

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TABLE 1 CLASSIFICATION OF COUNTER-MEASURES ACCORDING TO STRATEGY

CONTROL OF VEHICLE ROUTES AND VOLUMES			
Passive Control			ADVISORY ROUTE SIGNING CYCLE ROUTE
Active Control	Capacity reduction		ROAD CLOSURE SINGLE LANE CARRIAGEWAY TRAFFIC SIGNAL THROTTLE
	Restricted entry		ACCESS ONLY PROHIBITION WIDTH RESTRICTION
	Movement control at junctions	Signs	PROHIBITED TURN MANDATORY MOVEMENT NO ENTRY ONE-WAY OPERATION
		Islands	MEDIAN TRAFFIC ISLAND STAR DIVERTER DIAGONAL DIVERTER TRIANGULAR DIVERTER
CONTROL OF VEHICLE SPEEDS			
Speed Limits			AREA-WIDE SPEED LIMIT LOCALISED SPEED LIMIT
Control at Junctions			STOP CONTROL GIVE WAY CONTROL ROUNDABOUT CONTROL
Horizontal Alignment Modification			HORIZONTAL CURVATURE ROAD NARROWING SHARED SURFACE
Road Surface Modification			BAR MARKINGS RUMBLE AREA RUMBLE STRIPS JIGGLE BARS SPEED BUMPS SPEED CONTROL HUMPS
MODIFICATION OF ROAD USER BEHAVIOUR			ROADSIDE POSTERS LOCAL SAFETY CAMPAIGN RESIDENTIAL AREA WARNING SIGN SCHOOL ROUTES
RESTRICTIONS ON STATIONARY VEHICLES			WAITING RESTRICTIONS LOADING RESTRICTIONS CONTROLLED PARKING
Stopping Restrictions			MANDATORY SCHOOL ENTRANCE MARKINGS
SEGREGATION OF PEDESTRIANS AND VEHICLES			
Restricting Traffic Movement			PEDESTRIANISATION PLAYSTREET
Pedestrian Crossing Facilities			FOOTBRIDGE OR SUBWAY ZEBRA CROSSING PELICAN CROSSING PEDESTRIAN PHASE SIGNALS REFUGE RAMPED VEHICLE CROSSING
Restricting Pedestrian Movement			SCHOOL CROSSING PATROL PEDESTRIAN GUARDRAIL
WARNING DEVICES			LOCAL FLOODLIGHTING ROAD MARKINGS SURFACE COLOUR CHANGE WARNING SIGNS
Flashing Lights			FLASHING LIGHTS AT SCHOOLS FLASHING LIGHTS AT JUNCTIONS

TABLE 2 BASIC EVALUATION MATRIX : CONTROL OF VEHICLE-ROUTES AND VOLUMES

CRITERIA / COUNTERMEASURES	A Compatibility with other traffic social objectives	B Ease of implementation and maintenance	C Capital and maintenance cost	D Effect on users' behaviour and learning	E Secondary effects	F Level of support and political acceptance	G Expected reduction in accidents
ADVISORY ROUTE SIGNING (4)	++	+	--	o	o	±	o
CYCLE ROUTES (4)	++	+	--	+	o	+	+
ROAD CLOSURE (1) (3)	++ (--)	+	o	++	± (--)	++ (--)	++
SINGLE LANE CARRIAGEWAY	+ (--)	- (--)	- (--)	+	± (--)	± (--)	o
TRAFFIC SIGNAL THROTTLE (1)(3)	- (--)	o	--	+	- (--)	± (--)	+
ACCESS ONLY PROHIBITION (1)(3)	++ (--)	++	+	+	- (-)	+ (--)	+
WIDTH RESTRICTION (1) (3)	++ (--)	+	o	++	± (--)	++ (--)	o
PROHIBITED TURN (1) (3)	+	++	++	+	±	+	++
MANDATORY MOVEMENT (1) (3)	+	++	++	+	±	+	++
NO ENTRY (1) (3)	+ (--)	++	++	++	± (--)	+ (--)	+
ONE WAY OPERATION (1) (3)	+ (--)	++	+	++	± (--)	+ (--)	+
MEDIAN TRAFFIC ISLAND (1)(3)	± (+)	o	o	++	±	± (+)	+
STAR DIVERTER (1) (3)	± (--)	-	-	++	± (--)	± (--)	+
DIAGONAL DIVERTER (1) (3)	± (--)	o	o	++	± (--)	± (--)	+
TRIANGULAR DIVERTER (1)(3)	± (--)	-	-	++	± (--)	± (--)	+
5 POINT SCALE FOR CRITERIA A to F, - with values ranging from strongly positive (++) effects through neutral (o) to strongly negative (--) effects	+ Compatible - Incompatible	+ Easy - Difficult	+ Low Cost - High Cost	+ Desirable - Undesirable	+ Beneficial - Detrimental	+ Acceptable - Unacceptable	3 POINT SCALE ++ Significant + Likely o Unlikely

( ) - Entries in brackets contain the values for DISTRIBUTOR ROADS where these differ from ACCESS ROADS. Otherwise entries are common to both.

(1) - Some form of statutory procedure is necessary for implementation
(2) - Not sanctioned for use in the UK at the present time
(3) - A regulatory measure
(4) - Application assumed to be area-wide rather than site-specific

TABLE 3 BASIC EVALUATION MATRIX : CONTROL OF VEHICLE-SPEEDS

CRITERIA / COUNTERMEASURES	A Compatibility with other traffic social objectives	B Ease of implementation and maintenance	C Capital and maintenance cost	D Effect on users' behaviour and learning	E Secondary effects	F Level of support and political acceptance	G Expected reduction in accidents
AREAWIDE SPEED LIMIT (1)(3)(4)	++ (±)	+	--	+	±	++ (±)	++
LOCALISED SPEED LIMIT (2) (3)	++ (+)	++	+	+	-	++	o
STOP CONTROL (1) (3)	- (--)	+	+	+	- (--)	± (--)	o
GIVE WAY CONTROL (3)	- (--)	+	+	+	- (--)	± (--)	o
ROUNDABOUT CONTROL (3)	++ (+)	o	o (-)	++	±	+ (±)	+
HORIZONTAL CURVATURE	+ (--)	-	-	+	- (--)	± (--)	+
ROAD NARROWING	++ (+)	-	- (--)	+	± (-)	+ (-)	+
SHARED SURFACE	++ (--)	--	--	±	± (--)	+ (--)	o
BAR MARKINGS (1) (3)	- (+)	+	+	+	-	± (+)	o (+)
RUMBLE AREA	+	o	--	o	±	±	+
RUMBLE STRIPS	+ (++)	o	-	++	±	±	++
JIGGLE BARS	+ (++)	-	-	++	±	±	++
SPEED BUMPS (2)	± (--)	+	o	±	-	± (--)	o
SPEED CONTROL HUMPS (1)	++ (--)	o	-	++	±	++ (--)	++
5 POINT SCALE FOR CRITERIA A to F, - with values ranging from strongly positive (++) effects through neutral (o) to strongly negative (--) effects	+ Compatible - Incompatible	+ Easy - Difficult	+ Low Cost - High Cost	+ Desirable - Undesirable	+ Beneficial - Detrimental	+ Acceptable - Unacceptable	3 POINT SCALE ++ Significant + Likely o Unlikely

( ) - Entries in brackets contain the values for DISTRIBUTOR ROADS where these differ from ACCESS ROADS. Otherwise entries are common to both.

(1) - Some form of statutory procedure is necessary for implementation
(2) - Not sanctioned for use in the UK at the present time
(3) - A regulatory measure
(4) - Application assumed to be area-wide rather than site specific

TABLE 4 BASIC EVALUATION MATRIX : MODIFICATION OF ROAD-USER BEHAVIOUR

CRITERIA / COUNTERMEASURES	A Compatibility with other traffic social objectives	B Ease of implementation and maintenance	C Capital and maintenance cost	D Effect on users' behaviour and learning	E Secondary effects	F Level of support and political acceptance	G Expected reduction in accidents
ROADSIDE POSTERS*	+	++	++	+	-	+	+
LOCAL SAFETY CAMPAIGN * (4)	++	+	--	+	o	++	+
RESIDENTIAL AREA WARNING SIGN (2) (4)	++ (--)	++	--	o	-	++	o
SCHOOL ROUTES (4)	o (++)	+	o	+ (++)	o	++	+
5 POINT SCALE FOR CRITERIA A to F, - with values ranging from strongly positive (++) effects through neutral (o) to strongly negative (--) effects	+ Compatible - Incompatible	+ Easy - Difficult	+ Low Cost - High Cost	+ Desirable - Undesirable	+ Beneficial - Detrimental	+ Acceptable - Unacceptable	3 POINT SCALE ++ Significant + Likely o Unlikely

( ) Entries in brackets contain the values for DISTRIBUTOR ROADS where these differ from ACCESS ROADS. Otherwise entries are common to both.

(1) - Some form of statutory procedure is necessary for implementation
(2) - Not sanctioned for use in the UK at the present time
(3) - A regulatory measure
(4) - Application assumed to be area-wide rather than site specific
(*) - These are usually considered to be short term measures

TABLE 5 BASIC EVALUATION MATRIX : RESTRICTIONS ON STATIONARY VEHICLES

CRITERIA / COUNTERMEASURES	A Compatibility with other traffic social objectives	B Ease of implementation and maintenance	C Capital and maintenance cost	D Effect on users' behaviour and learning	E Secondary effects	F Level of support and political acceptance	G Expected reduction in accidents
WAITING RESTRICTIONS (1) (3)	- (+)	++	++	+	±	- (+)	+
LOADING RESTRICTIONS (1) (3)	-- (±)	++	++	o	±	-- (-)	o
CONTROLLED PARKING (1) (3) (4)	- (+)	o	--	+	-	±	+
MANDATORY SCHOOL MARKINGS (1) (3)	o	++	++	o	o	++	o
5 POINT SCALE FOR CRITERIA A to F, - with values ranging from strongly positive (++) effects through neutral (o) to strongly negative (--) effects	+ Compatible - Incompatible	+ Easy - Difficult	+ Low Cost - High Cost	+ Desirable - Undesirable	+ Beneficial - Detrimental	+ Acceptable - Unacceptable	3 POINT SCALE ++ Significant + Likely - Unlikely

( ) - Entries in brackets contain the values for DISTRIBUTOR ROADS where these differ from ACCESS ROADS. Otherwise entries are common to both.

(1) - Some form of statutory procedure is necessary for implementation
(2) - Not sanctioned for use in the UK at the present time
(3) - A regulatory measure
(4) - Application assumed to be area-wide rather than site specific

TABLE 6 BASIC EVALUATION MATRIX : SEGREGATION OF PEDESTRIANS AND VEHICLES

CRITERIA / COUNTERMEASURES	A Compatibility with other traffic social objectives	B Ease of implementation and mainten-ance	C Capital and maintenance cost	D Effect on users' behaviour and learning	E Secondary effects	F Level of support and political acceptance	G Expected reduction in acciden'
PEDESTRIANISATION (1) (3)	++ (--)	-	-	++	± (--)	± (--)	++
PLAYSTREET (1) (3)	++ (--)	++	++	±	- (--)	+ (--)	+
FOOTBRIDGE/SUBWAY	-- (+)	--	--	o (+)	-- (-)	-- (±)	o (+)
ZEBRA CROSSING (1) (3)	± (++)	+	o	o (+)	-	++	o (++)
PELICAN CROSSING (1) (3)	- (+)	+	-	- (+)	-	+ (++)	o (+)
PEDESTRIAN-PHASE SIGNALS (1) (3)	- (+)	o	--	- (+)	-	± (+)	o (+)
REFUGE	+ (++)	+	o	o (+)	±	+	o (+)
RAMPED VEHICLE CROSSING	++ (--)	+	o	+	± (--)	+ (--)	+ (o)
SCHOOL CROSSING PATROL	++	+	o	++	+	++	+
PEDESTRIAN GUARDRAIL	±	+	o	+	-	+	o (+)
5 POINT SCALE FOR CRITERIA A to F, - with values ranging from strongly positive (++) effects through neutral(o) to strongly negative (--) effects	+ Compatible - Incompatible	+ Easy - Difficult	+ Low Cost - High Cost	+ Desirable - Undesirable	+ Beneficial - Detrimental	+ Acceptable - Unacceptable	3 POINT SCALE ++ Significant + Likely - Unlikely

( ) - Entries in brackets contain the values for DISTRIBUTOR ROADS where these differ from ACCESS ROADS. Otherwise entries are common to both.

(1) - Some form of statutory procedure is necessary for implementation
(2) - Not sanctioned for use in the UK at the present time
(3) - A regulatory measure
(4) - Application assumed to be area-wide rather than site specific

TABLE 7 BASIC EVALUATION MATRIX : WARNING DEVICES

CRITERIA / COUNTERMEASURES	A Compatibility with other traffic social objectives	B Ease of implementation and mainten-ance	C Capital and maintenance cost	D Effect on users' behaviour and learning	E Secondary effects	F Level of support and political acceptance	G Expected reduction in accidents
LOCAL FLOODLIGHTING	±	+	o	o	-	±	o (+)
ROAD MARKINGS (3)	+ (++)	++	++	++	o	++	+
SURFACE COLOUR CHANGE	+	-	--	o	o	-	o
WARNING SIGNS	+ (++)	++	++	++	o	+	+
FLASHING LIGHTS AT SCHOOLS	++	++	++	+	o	++	o
FLASHING LIGHTS AT JUNCTIONS (2)	- (+)	o	o	+	- (--)	- (±)	o (+)
5 POINT SCALE FOR CRITERIA A to F, - with values ranging from strongly positive (++) effects through neutral (o) to strongly negative (--) effects	+ Compatible - Incompatible	+ Easy - Difficult	+ Low Cost - High Cost	+ Desirable - Undesirable	+ Beneficial - Detrimental	+ Acceptable - Unacceptable	3 POINT SCALE ++ Significant + Likely - Unlikely

( ) - Entries in brackets contain the values for DISTRIBUTOR ROADS where these differ from ACCESS ROADS. Otherwise entries are common to both.

(1) - Some form of statutory procedure is necessary for implementation
(2) - Not sanctioned for use in the Uk at the present time
(3) - A regulatory measure
(4) - Application assumed to be area-wide rather than site specific

TABLE 8 EVALUATION INDICES UNDER SCORING SYSTEMS 1 TO 5 : CRITERIA AND STRATEGIES UNWEIGHTED

STRATEGY	COUNTER-MEASURE	ACCESS ROADS	LOCAL DISTRIBUTORS
CONTROL OF VEHICLE-ROUTES AND VOLUMES	ADVISORY ROUTE SIGNING	β	β
	CYCLE ROUTE	β	β
	ROAD CLOSURE	α	δ
	SINGLE LANE CARRIAGEWAY	γ	δ
	TRAFFIC SIGNAL THROTTLE	δ	δ
	ACCESS ONLY PROHIBITION	α	δ
	WIDTH RESTRICTION	α	δ
	PROHIBITED TURN	α	α
	MANDATORY MOVEMENT	α	α
	NO ENTRY	α	γ
	ONE-WAY OPERATION	α	δ
	MEDIAN TRAFFIC ISLAND	β	variable β to α
	STAR DIVERTER	variable δ to β	δ
	DIAGONAL DIVERTER	β	δ
	TRIANGULAR DIVERTER	variable δ to β	δ
CONTROL OF VEHICLE-SPEEDS	AREAWIDE SPEED LIMIT	variable β to α	variable δ to β
	LOCALISED SPEED LIMIT	α	α
	STOP CONTROL	β	δ
	GIVE WAY CONTROL	β	δ
	ROUNDABOUT CONTROL	α	β
	HORIZONTAL CURVATURE	δ	δ
	ROAD NARROWING	β	δ
	SHARED SURFACE	δ	δ
	BAR MARKINGS	β	variable β to α
	RUMBLE AREA	δ	δ
	RUMBLE STRIPS	β	β
	JIGGLE BARS	β	β
	SPEED HUMPS	γ	δ
	SPEED CONTROL HUMPS	variable β to α	δ
MODIFICATION OF ROAD-USER BEHAVIOUR	ROADSIDE POSTERS	α	α
	LOCAL SAFETY CAMPAIGN	β	β
	RESIDENTIAL AREA WARNING SIGN	β	δ
	SCHOOL ROUTES	variable β to α	α
RESTRICTION ON STATIONARY VEHICLES	WAITING RESTRICTIONS	β	α
	LOADING RESTRICTIONS	γ	β
	CONTROLLED PARKING	δ	δ
	MANDATORY SCHOOL ENTRANCE MARKINGS	α	α
SEGREGATION OF PEDESTRIANS AND VEHICLES	PEDESTRIANISATION	β	δ
	PLAYSTREET	α	δ
	FOOTBRIDGE AND SUBWAY	δ	δ
	ZEBRA CROSSING	β	variable β to α
	PELICAN CROSSING	δ	β
	PEDESTRIAN PHASE SIGNALS	δ	variable δ to β
	REFUGE	β	variable β to α
	RAMPED VEHICLE CROSSING	variable β to α	δ
	SCHOOL CROSSING PATROL	α	α
	PEDESTRIAN GUARDRAIL	β	β
WARNING DEVICES	LOCAL FLOODLIGHTING	γ	γ
	ROAD MARKINGS	α	α
	SURFACE COLOUR CHANGE	δ	δ
	WARNING SIGNS	α	α
	FLASHING LIGHTS AT SCHOOLS	α	α
	FLASHING LIGHTS AT JUNCTIONS	δ	variable δ to β

KEY : α very good β good γ neutral δ poor

TABLE 9 EVALUATION INDICES FOR ACCESS ROADS WITH EACH CRITERION WEIGHTED IN TURN

STRATEGY	COUNTER-MEASURE	CRITERIA WEIGHTING		
		None	2:1 in turn	3:1 in turn
CONTROL OF VEHICLE-ROUTES AND VOLUMES	ADVISORY ROUTE SIGNING	β	δ to β	δ to α
	CYCLE ROUTE	β	δ to α	δ to α
	ROAD CLOSURE	α	α	α
	SINGLE LANE CARRIAGEWAY	γ	δ to β	δ to α
	TRAFFIC SIGNAL THROTTLE	δ	δ	δ
	ACCESS ONLY PROHIBITION	α	α	β to α
	WIDTH RESTRICTION	α	α	α
	PROHIBITED TURN	α	α	α
	MANDATORY MOVEMENT	α	α	α
	NO ENTRY	α	α	α
	ONE-WAY OPERATION	α	α	α
	MEDIAN TRAFFIC ISLAND	β	β	β to α
	STAR DIVERTER	δ to β	δ to β	δ to α
	DIAGONAL DIVERTER	β	β	β to α
	TRIANGULAR DIVERTER	δ to β	δ to β	δ to α
CONTROL OF VEHICLE-SPEEDS	AREAWIDE SPEED LIMIT	β to α	β to α	δ to α
	LOCALISED SPEED LIMIT	α	α	β to α
	STOP CONTROL	β	γ to β	δ to β
	GIVE WAY CONTROL	β	γ to β	δ to β
	ROUNDABOUT CONTROL	α	α	α
	HORIZONTAL CURVATURE	δ	δ to γ	δ to β
	ROAD NARROWING	β	β	δ to α
	SHARED SURFACE	δ	δ to β	δ to β
	BAR MARKINGS	β	γ to β	δ to β
	RUMBLE AREA	δ	δ to β	δ to β
	RUMBLE STRIPS	β	β	δ to α
	JIGGLE BARS	β	δ to β	δ to α
	SPEED HUMPS	γ	δ to β	δ to β
	SPEED CONTROL HUMPS	β to α	β to α	β to α
MODIFICATION OF ROAD-USER BEHAVIOUR	ROADSIDE POSTERS	α	α	β to α
	LOCAL SAFETY CAMPAIGN	β	β to α	δ to α
	RESIDENTIAL AREA WARNING SIGN	β	β to α	δ to α
	SCHOOL ROUTES	β to α	β to α	β to α
RESTRICTION ON STATIONARY VEHICLES	WAITING RESTRICTIONS	β	β to α	δ to α
	LOADING RESTRICTIONS	γ	δ to α	δ to β
	CONTROLLED PARKING	δ	δ	δ
	MANDATORY SCHOOL ENTRANCE MARKINGS	α	α	α
SEGREGATION OF PEDESTRIANS AND VEHICLES	PEDESTRIANISATION	β	δ to α	δ to α
	PLAYSTREET	α	β to α	β to α
	FOOTBRIDGE AND SUBWAY	δ	δ	δ
	ZEBRA CROSSING	β	β	δ to α
	PELICAN CROSSING	δ	δ	δ to γ
	PEDESTRIAN PHASE SIGNALS	δ	δ	δ
	REFUGE	β	β to α	β to α
	RAMPED VEHICLE CROSSING	β to α	β to α	β to α
	SCHOOL CROSSING PATROL	α	α	α
	PEDESTRIAN GUARDRAIL	β	β	γ to α
WARNING DEVICES	LOCAL FLOODLIGHTING	γ	δ to β	δ to β
	ROAD MARKINGS	α	α	α
	SURFACE COLOUR CHANGE	δ	δ	δ
	WARNING SIGNS	α	α	α
	FLASHING LIGHTS AT SCHOOLS	α	α	α
	FLASHING LIGHTS AT JUNCTIONS	δ	δ	δ to γ

KEY : α very good β good γ neutral δ poor

TABLE 10 EVALUATION INDICES FOR LOCAL DISTRIBUTORS WITH EACH CRITERION WEIGHTED IN TURN

STRATEGY	COUNTER-MEASURE	CRITERIA WEIGHTING None	2:1 in turn	3:1 in turn
CONTROL OF VEHICLE-ROUTES AND VOLUMES	ADVISORY ROUTE SIGNING	β	δ to β	δ to α
	CYCLE ROUTE	β	δ to α	δ to α
	ROAD CLOSURE	δ	δ	δ to β
	SINGLE LANE CARRIAGEWAY	δ	δ	δ
	TRAFFIC SIGNAL THROTTLE	δ	δ	δ
	ACCESS ONLY PROHIBITION	δ	δ to β	δ to β
	WIDTH RESTRICTION	δ	δ	δ to β
	PROHIBITED TURN	α	α	α
	MANDATORY MOVEMENT	α	α	α
	NO ENTRY	γ	δ to β	δ to β
	ONE-WAY OPERATION	δ	δ to β	δ to β
	MEDIAN TRAFFIC ISLAND	β to α	β to α	β to α
	STAR DIVERTER	δ	δ	δ
	DIAGONAL DIVERTER	δ	δ	δ to γ
	TRIANGULAR DIVERTER	δ	δ	δ
CONTROL OF VEHICLE-SPEEDS	AREAWIDE SPEED LIMIT	δ to β	δ to β	δ to β
	LOCALISED SPEED LIMIT	α	β to α	β to α
	STOP CONTROL	δ	δ to γ	δ to β
	GIVE WAY CONTROL	δ	δ to γ	δ to β
	ROUNDABOUT CONTROL	β	β	δ to α
	HORIZONTAL CURVATURE	δ	δ	δ
	ROAD NARROWING	δ	δ	δ
	SHARED SURFACE	δ	δ	δ
	BAR MARKINGS	β to α	β to α	β to α
	RUMBLE AREA	δ	δ to β	δ to β
	RUMBLE STRIPS	β	β to α	δ to α
	JIGGLE BARS	β	δ to α	δ to α
	SPEED HUMPS	δ	δ	δ
	SPEED CONTROL HUMPS	δ	δ	δ to β
MODIFICATION OF ROAD-USER BEHAVIOUR	ROADSIDE POSTERS	α	β to α	β to α
	LOCAL SAFETY CAMPAIGN	β	β to α	δ to α
	RESIDENTIAL AREA WARNING SIGN	δ	δ to β	δ to β
	SCHOOL ROUTES	α	α	α
RESTRICTIONS ON STATIONARY VEHICLES	WAITING RESTRICTIONS	α	α	α
	LOADING RESTRICTIONS	β	β to α	γ to α
	CONTROLLED PARKING	δ	δ to β	δ to β
	MANDATORY SCHOOL ENTRANCE MARKINGS	α	α	α
SEGREGATION OF PEDESTRIANS AND VEHICLES	PEDESTRIANISATION	δ	δ	δ
	PLAYSTREET	δ	δ to γ	δ to β
	FOOTBRIDGE AND SUBWAY	δ	δ	δ to β
	ZEBRA CROSSING	β to α	β to α	β to α
	PELICAN CROSSING	β	β to α	β to α
	PEDESTRIAN PHASE SIGNALS	γ to β	γ to β	γ to β
	REFUGE	β to α	β to α	β to α
	RAMPED VEHICLE CROSSING	δ	δ	δ to γ
	SCHOOL CROSSING PATROL	α	α	α
	PEDESTRIAN GUARDRAIL	β	β	γ to α
WARNING DEVICES	LOCAL FLOODLIGHTING	γ	δ to β	δ to β
	ROAD MARKINGS	α	α	α
	SURFACE COLOUR CHANGE	δ	δ	δ
	WARNING SIGNS	α	α	α
	FLASHING LIGHTS AT SCHOOLS	α	α	α
	FLASHING LIGHTS AT JUNCTIONS	δ to β	δ to β	δ to β

KEY : α very good β good γ neutral δ poor

TABLE 11 OVERALL EFFECTIVENESS : ACCESS ROADS

Expected Reduction in Accidents	PERFORMANCE RATING I (First Rate)	II (Second Rate)	III (Third Rate)	IV (Fourth Rate)
Significant	Road Closure Prohibited Turn Mandatory Movement	Speed Control Humps Area-Wide Speed Limit Rumble Strips	Jiggle Bars Pedestrian-isation	
Likely	No Entry One Way Operation Roundabout Control Road Markings Warning Signs Width Restriction School Entrance Marks School Crossing Patrol Flashing Lights at Schools	Cycle Routes Access Only Prohibition Diagonal Diverter Roadside Posters School Routes Local Safety Campaign Playstreet Ramped Vehicle Crossing	Star Diverter Triangular Diverter Horizontal Curvature Road Narrowing Rumble Area Waiting Restrictions	Traffic Signal Throttle Controlled Parking
Unlikely		Advisory Route Signing Local Part-Time Speed Limit Residential Area Warning Sign Zebra Crossing Refuge Pedestrian Guardrail	Single Lane Carriageway Stop Control Give Way Control Shared Surface Bar Markings Speed Bumps Loading Restrictions	Footbridge/Subway Pelican Crossing Pedestrian Phase Signals Local Flood-lighting Surface Colour Change Flashing Lights at Junctions

TABLE 12 OVERALL EFFECTIVENESS : LOCAL DISTRIBUTORS

Expected Reduction in Accidents	PERFORMANCE RATING			
	I (First Rate)	II (Second Rate)	III (Third Rate)	IV (Fourth Rate)
Significant	Prohibited Turn Mandatory Movement	Zebra Crossing Area-Wide Speed Limit Rumble Strips	Jiggle Bars	Road Closure Pedestrianisation
Likely	School Routes Waiting Restrictions Road Markings Warning Signs School Crossing Patrol	Median Traffic Island Roadside Posters Pelican Crossing Refuge Pedestrian Guardrail Cycle Routes Roundabout Control Local Safety Campaign	Access Only Prohibition No Entry One Way Operation Controlled Parking Footbridge/Subway Pedestrian Phase Signals Local Flood-lighting	Speed Control Humps Rumble Area Playstreet Traffic Signal Throttle Star Diverter Diagonal Diverter Triangular Diverter Horizontal Curvature Road Narrowing
Unlikely	School Entrance Markings	Advisory Route Signing Local Part-Time Speed Limit Bar Markings Loading Restrictions	Stop Control Give Way Control Flashing Lights at Junctions	Residential Area Warning Sign Width Restriction Single Lane Carriageway Shared Surface Speed Bumps Ramped Vehicle Crossing Surface Colour Change

SESSIONS 2+3:
Methodology and analysis

SESSION 2 AND SESSION 3

Chairman: Mr. M. Koornstra (the Netherlands)

Theme: Methodology and analysis

U. Brüde and J. Larsson (Sweden)	: The "regression-to-mean" effect
S.O. Gunnarsson and: S. Lillienberg (Sweden)	An interactive computer system for traffic accident analysis
E. Hauer (Canada)	: A learning disability and its cure
D.F. Jarett, C. Abbess and C.C. Wright (U.K.)	: Bayesian methods applied to road accident blackspot studies: some recent progress
S. Oppe (the Netherlands)	: Detection and analysis of accident-black-spots with even small accident figures
J.P. Roos, R. Hamerslag and M. Kwakernaak (the Netherlands)	: The application of weighted multiproportional poisson models in safety improvement measures
L.K. Thomsen (Denmark)	: Short-term and area wide evaluation of safety measures implemented in a residential area named Osterbro. The statistical tools
H. Ward and R. Allsop (U.K.)	: Evaluation of area wide safety schemes by monitoring traffic and accidents

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THE "REGRESSION-TO-MEAN" EFFECT

Some empirical examples concerning accidents at road junctions

by Ulf Brüde and Jörgen Larsson

ABSTRACT

A randomly large number of accidents during a "before-period" is normally followed by a reduced number of accidents during a corresponding "after-period" even if no countermeasures have been implemented. This statistical phenomenon is termed the <u>"regression-to-mean" effect</u> (or shorter the <u>regression effect</u>).

Road junctions constitute points in the road network with particularly high accident rates although the average number of accidents per junction is low. The latter means that the regression effect can be expected to appear even in very modest accident numbers.

The examples described in this report are based on accidents at <u>unaltered</u> rural junctions in the national major road network. The years 1972-1975 have been regarded as the before-period and 1976-1978 as the after-period.

The examples show that the regression effect (accident reduction) in accidents reported to the police often can be about 30-40 %. For accidents involving personal-injury the regression effect is often about 50-60 %. In the case of junctions with a significantly large number of accidents (in relation to the amount of traffic) during the before-period the regression effect is usually even greater.

1. INTRODUCTION

A randomly large number of accidents during a before-period is normally followed by a reduced number of accidents during a corresponding after-period even if no countermeasures have been implemented (and a randomly small number of accidents is normally followed by an increased number of accidents). This statistical phenomenon is termed the <u>"regression-to-mean effect*</u> (or shorter the <u>regression effect</u>).

An earlier article (1) describes examples which show that:

- the regression effect can be very large
- the regression effect can have an entirely decisive influence on the results of before-and-after studies.

The objective of this report is to describe some examples of the regression effect in more detail.

The project was financed by the National Road Administration.

* The phenomenon is also called "bias-by-selection".

2. SOME EXAMPLES OF "REGRESSION-TO-MEAN" EFFECT OF ACCIDENTS AT UNALTERED ROAD JUNCTIONS

Comments relating to Tables 1-5:

- The tables are based on 2637 rural road junctions* in the national major road network which were unaltered from 1972 to 1978**.

- The 4-year period 1972-1975 has been regarded as the before-period and the 3-year period 1976-1978 as the after-period.

- Tables 1, 2 and 5 relate to police-reported accidents including both personal-injury and property-damage accidents.

- Tables 3 and 4 relate only to personal-injury accidents.

- The annual amount of traffic was on average 13.6 % greater during 1976-1978 than during 1972-1975. However, the annual number of police-reported accidents was on average about 15.5 % greater during 1976-1978 than during 1972-1975 (Table 1***). The annual number of personal-injury accidents was on average about 16 % greater during 1976-1978 than during 1972-1975 (Table 3****).

  In these calculations the number of accidents for 1972-1975 has been multiplied by $\frac{3}{4} \cdot 1.136$ in order to obtain a comparison between the number of accidents for 1972-1975 and 1976-1978.

* A speed limit of ⩾ 70 km/h in force on every national connecting road. Straight primary road, stop sign. No pedestrian or cycle path and no traffic signals.

** According to information from the 1977-1978 inventory of junctions, updated to 31st of December 1978.

*** $1896/\frac{2189 \cdot 3}{4} = 1.155$

**** $704/\frac{809 \cdot 3}{4} = 1.160$

- The average number of police-reported accidents per junction and year for 1972-1975 was 0.21 (Table 1*). This means that junctions with 1 police-reported accident during this 4-year period had a greater accident number than average.

- The average number of personal-injury accidents per junction and year during 1972-1975 was 0.08 (Table 3**). This means that junctions with 1 personal-injury accident during this 4-year period had an accident number about 3 times greater than average.

- According to Table 1 there were, for example, 4 police-reported accidents per junction at 53 junctions (a total of 212 accidents) during 1972-1975. A total of 103 police-reported accidents occured at the same junctions during 1976-1978. The accident reduction between the before-period and after-period (the estimated regression effect) was therefore

$$(1 - 103/\frac{212 \cdot 3 \cdot 1.136}{4}) \cdot 100 \% = 43 \%$$

- For police-reported accidents (Table 1) the estimated regression effect is on average just over 35 % provided that at least 2 accidents occurred during the before-period. Where there occurred 1 police-reported accident during 1972-1975 the estimated regression effect is on average about 10 % (Table 1).

- For personal-injury accidents (Table 3) the estimated regression effect is on average just over 55 % provided that there occurred at least 2 personal-injury accidents during the before-period. It is notable that the estimated regression effect is on average about 50 % even in the case where there occurred only 1 personal-injury accident during 1972-1975 (Table 3).

* $\frac{2189}{2637 \cdot 4} = 0.21$

** $\frac{809}{2637 \cdot 4} = 0.08$

- The fact that the regression effect becomes greater for personal-injury accidents than for all police-reported accidents is theoretically to be expected, since the personal-injury accidents are on a lower numeric level and thus have a relatively greater standard deviation in relation to the mean (assuming that the accidents follow the Poisson distribution).

- In Tables 1 and 3 it should also be noted that the junctions with 0 accidents during the before-period account for a very large proportion (about one third and one half respectively) of the total number of accidents during the after-period. In this case there is a regression effect from the opposite direction, i.e. an accident increase.

- If a study is made of only those junctions which, according to the Institute's models*(2), had a significantly higher number of police-reported accidents than expected (level of significance 2.5 %) during the before-period the estimated regression effect increases to an average of about 65 % (Table 5). For personal-injury accidents the estimated regression effect in corresponding cases can be seen to increase to an average of about 75 %.

- It must be remembered that the examples mentioned here apply to the case where the before-period covers 4 years. If a shorter before-period had been chosen, the estimated regression effects would have been even greater.

- For junctions with significantly more police-reported accidents than expected during 1972-1975 Table 5 allows a comparison to be made between the number of accidents actually reported to the police for 1972-1975 and for 1976-1978 respectively, with the predicted (expected) number of accidents according to the Institute's models.

  It can be seen that even during the after-period (i.e. after the number of accidents has regressed towards its true means) the

* The models relate to type (3- or 4-way junction), number of entering vehicles (pair of axles) from primary and secondary roads and proportion of secondary road traffic.

recorded number of accidents is on average considerably larger than predicted. It would therefore not have been an incorrect decision, seen as an average, to attempt to modify these junctions on the basis of the significantly high accident numbers recorded during 1972-1975. In this case, however, it would have been impossible to estimate correctly the possible accident reduction effects of individual countermeasures.

- If those junctions in a specific road network having $\geq k$ accidents during a before-period are selected, it may be expected, assuming that no countermeasures are taken, that during a corresponding after-period the number of accidents at these junctions will equal the total number of accidents at those junctions which had $\geq (k+1)$ accidents during the before-period. This ingenious yet simple method has been introduced by Hauer (3,4).

  It can be seen that the recorded number of accidents for 1976-1978 agrees very well with the number which may be expected according to Hauer's method* (Tables 2 and 4).

* When calculating the expected number of accidents according to Hauer's method correction has been made by multiplying with the factor $\frac{3}{4} \cdot 1.136$.

Table 1. Police-reported accidents. Rural junctions in the major road network which were unaltered during 1972-1978.

Junctions which, during 1972-1975, had:	a Pred. no. of accidents 1972-1975 according to model	b Recorded no. of accidents 1972-1975	c Recorded no. of accidents 1972-1975 adjusted[1] to be comparable against the recorded no. of accidents 1976-1978	d Predicted no. of accidents 1976-1978 according to model[2]	e Recorded no. of accidents 1976-1978	f $\frac{e}{c}$	g Estimate of the regression effect	h $\frac{e}{d}$
≥7 accidents (26 junctions)	76.1	232	197.7	64.8	142	0.72	28%	2.19
6 accidents (17 junctions)	44.8	102	86.9	38.2	52	0.60	40%	1.36
5 accidents (39 junctions)	93.4	195	166.1	79.6	105	0.63	37%	1.32
4 accidents (53 junctions)	97.5	212	180.6	83.1	103	0.57	43%	1.24
3 accidents (101 junctions)	159.1	303	258.2	135.6	181	0.70	30%	1.33
2 accidents (244 junctions)	301.0	488	415.8	256.5	253	0.61	39%	0.99
1 accident (657 junctions)	567.4	657	559.8	483.4	509	0.91	9%	1.05
0 accidents (1500 junctions)	761.2	0	0	648.5	551	-	-	0.85
Total (2637 junctions)	2100.5	2189	1865.1	1789.6	1896	1.02	-	-

1) Multiplied by $\frac{3}{4} \cdot 1.136$ (an average of 13.6% more traffic per year during 1976-1978 than during 1972-1975)

2) Predicted number of accidents during 1972-1975 according to the model multiplied by $\frac{3}{4} \cdot 1.136$

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Table 2. Police-reported accidents. Rural junctions in the major road network which were unaltered during 1972-1978.

Junctions which, during 1972-1975, had:	a Recorded no. of accidents 1972-1975	b Recorded no. of accidents 1972-1975 adjusted[1] to be comparable against the recorded no. of accidents 1976-1978	c Recorded no. of accidents 1976-1978	d $\frac{c}{b}$	e Estimate of the regression effect	f No. of accidents 1976-1978 predicted by "Hauer's method"
≥ 7 accidents (26 junctions)	232	197.7	142	0.72	28%	108.2
≥ 6 accidents (43 junctions)	334	284.6	194	0.68	32%	197.7
≥ 5 accidents (82 junctions)	529	450.7	299	0.66	34%	284.6
≥ 4 accidents (135 junctions)	741	631.3	402	0.64	36%	450.7
≥ 3 accidents (236 junctions)	1044	889.5	583	0.66	34%	631.3
≥ 2 accidents (480 junctions)	1532	1305.3	836	0.64	36%	889.5
≥ 1 accident (1137 junctions)	2189	1865.0	1345	0.72	28%	1305.3
≥ 0 accidents (2637 junctions)	2189	1865.0	1896	-	-	1865.0

1) Muliplied by $\frac{3}{4} \cdot 1.136$ (an average of 13.6% more traffic per year during 1976-1978 than during 1972-1975)

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Table 3. Personal-injury accidents. Rural junctions in the major road network which were unaltered during 1972-1978.

Junctions which, during 1972-1975,had:	a Recorded no. of accidents 1972-1975	b Recorded no. of accidents 1972-1975 adjusted[1)] to be comparable against the recorded no. of accidents 1976-1978	c Recorded no. of accidents 1976-1978	d $\frac{c}{b}$	e Estimate of the regression effect
≥ 4 accidents (14 junctions)	58	49.4	21	0.43	57%
3 accidents (24 junctions)	72	61.3	32	0.52	48%
2 accidents (119 junctions)	238	202.8	84	0.41	59%
1 accident (441 junctions)	441	375.7	184	0.49	51%
0 accidents (2039 junctions)	0	0	383	-	-
Total (2637 junctions)	809	689.3	704	1.02	-

1) Multiplied by $\frac{3}{4} \cdot 1.136$ (an average of 13.6% more traffic per year during 1976-1978 than during 1972-1975)

Table 4. Personal-injury accidents. Rural junctions in the major road network which were unaltered during 1972-1978.

Junctions which, during 1972-1975, had:	a Recorded no. of accidents 1972-1975	b Recorded no. of accidents 1972-1975 adjusted[1)] to be comparable against the recorded no. of accidents 1976-1978	c Recorded no. of accidents 1976-1978	d $\frac{c}{b}$	e Estimate of the regression effect	f No. of accidents 1976-1978 predicted by "Hauer's method"
≥ 4 accidents (14 junctions)	58	49.4	21	0.43	57%	-
≥ 3 accidents (38 junctions)	130	110.8	53	0.48	52%	49.4
≥ 2 accidents (157 junctions)	368	313.5	137	0.44	56%	110.8
≥ 1 accident (598 junctions)	809	689.3	321	0.47	53%	313.5
≥ 0 accidents (2637 junctions)	809	689.3	704	-	-	689.3

1) Multiplied by $\frac{3}{4} \cdot 1.136$ (an average of 13.6% more traffic per year during 1976-1978 than during 1972-1975)

Table 5. Police-reported accidents. Rural junctions in the major road network which were unaltered during 1972-1978 and which, according to the Institute's models, had a significantly higher number of police-reported accidents than expected during 1972-1975.

Junctions which, during 1972-1975, had:	a Predicted no. of accidents 1972-1975 according to model	b Recorded no. of accidents 1972-1975	c Recorded no. of accidents 1972-1975 adjusted1) to be comparable against the recorded no. of accidents 1976-1978	d Predicted no. of accidents 1976-1978 according to model2)	e Recorded no. of accidents 1976-1978	f $\frac{e}{c}$	g Estimate of the regression effect	h $\frac{e}{d}$
≥7 accidents (21 junctions)	52.2	189	161.0	44.5	104	0.65	35%	2.34
6 accidents (8 junctions	13.4	48	40.9	11.4	19	0.46	54%	1.67
5 accidents (17 junctions)	25.6	85	72.4	21.8	31	0.43	57%	1.42
4 accidents (26 junctions)	28.7	104	88.6	24.5	25	0.28	72%	1.02
3 accidents (35 junctions	23.9	105	89.5	20.4	25	0.28	72%	1.23
2 accidents (40 junctions)	15.7	80	68.2	13.4	23	0.34	66%	1.72
1 accident (31 junctions)	4.6	31	26.4	3.9	5	0.19	81%	1.28
Total (178 junctions)	164.1	642	547.0	139.8	232	0.42	58%	1.66

1) Multiplied by $\frac{3}{4} \cdot 1.136$ (an average of 13.6% more traffic per year during 1976-1978 than during 1972-1975)

2) Predicted number of accidents during 1972-1975 according to the model multiplied by $\frac{3}{4} \cdot 1.136$

3. HOW CAN THE "REGRESSION-TO-MEAN" EFFECT BE ADJUSTED IN NON-EXPERIMENTAL BEFORE-AND-AFTER STUDIES?

On the basis of the results described in Chapter 2 information is obtained on the average magnitude of the regression effect at road junctions in the Swedish major road network for different accident numbers during a before-period covering 4 years. Hauer's method provides in more general terms a possibility for estimating the average regression effect for groups of selected objects.

From the practical aspect it is especially desirable to be able to estimate the regression effect for investigated objects (e.g. junctions) either individually or in small groups.

For the 2637 unaltered junctions already studied subsequent processing has shown that

- it may be appropriate to have the before-period to cover 5 years
- it may also be appropriate to omit a certain number of the worst accident years (the year/years with the greatest number of accidents) and instead to allocate these years the average number of accidents per year for the other years.

With this procedure it should be possible to make a rough but individual correction for the regression effect.

The following table shows that, for junctions which had significantly more police-reported accidents in 1972-1976 than expected (level of significance 2.5 %) according to the Institute's models and at the same time at least 5 police-reported accidents during this period, it would be necessary on average to omit the 2 worst years during the before-period in order to obtain approximately the same number of accidents per junctions and year as for the after-period 1977-1978*.

* Attention has been paid to the fact that the average annual amount of traffic was about 12.6 % greater during 1977-1978 than during 1972-1976.

For those junctions which, according to the Institute's models, had significantly more police-reported accidents during 1972-1976 than expected but fewer than 5 police-reported accidents it would seem more appropriate to omit only the worst accident year.

Junctions (unaltered during 1972-1978) with significantly more police-reported accidents than expected for 1972-1976:

Junctions which, during 1972-1976, had	a 1972-1976, no. of accidents per junction and year*	b 1972-1976 excl. the worst accident year, no. of accidents per junction and year*	c 1972-1976 excl. the 2 worst accident years, no. of accidents per junction and year*	d 1977-1978, no. of accidents per junction and year
≥ 10 accidents (12 junctions)	3.15	2.51	1.94	1.88
9 accidents (5 junctions)	2.03	1.58	1.35	1.10
8 accidents (8 junctions)	1.80	1.44	1.08	1.00
7 accidents (7 junctions)	1.58	1.09	0.70	1.07
6 accidents (11 junctions)	1.35	0.92	0.68	0.64
5 accidents (19 junctions)	1.13	0.74	0.57	0.39
4 accidents (26 junctions)	0.90	0.50	0.27	0.56
3 accidents (29 junctions)	0.68	0.35	0.13	0.26
2 accidents (37 junctions)	0.45	0.23	0.00	0.19
1 accident (18 junctions)	0.23	0.00	0.00	0.03

* Multiplied by 1.126 since the average annual amount of traffic was 12.6 % greater during 1977-1978 than during 1972-1976.

For those junctions which, according to the Institute's models, had more, but not significantly more, police-reported accidents than expected it would be too drastic to omit the worst accident year. Instead, it would be better to take the "mean" of not omitting any accident year and omitting the worst accident year.

Junctions (unaltered during 1972-1978) with more, but not significantly more, police-reported accidents than expected for 1972-1976:

Junctions which, during 1972-1976, had	a 1972-1976, no. of accidents per junction and year*	b 1972-1976 excl. the worst accident year, no. of accidents per junction and year*	c $\frac{a+b}{2}$	d 1977-1978, no. of accidents per junction and year
17 accidents (1 junction)	3.82	3.10	3.46	5.50
8 accidents (4 junctions)	1.80	1.48	1.64	1.50
7 accidents (11 junctions)	1.58	1.00	1.29	1.23
6 accidents (12 junctions)	1.35	0.89	1.12	1.13
5 accidents (24 junctions)	1.13	0.73	0.93	0.75
4 accidents (42 junctions)	0.90	0.52	0.71	0.71
3 accidents (81 junctions)	0.68	0.36	0.52	0.41
2 accidents (205 junctions)	0.45	0.21	0.33	0.28
1 accident (391 junctions)	0.23	0.00	0.12	0.12

* Multiplied by 1.126 since the average annual amount of traffic was 12.6 % greater during 1977-1978 than during 1972-1976.

For junctions with more (not necessarily significantly more) personal-injury accidents than expected* it would seem appropriate to take the "mean" of omitting the worst accident year and omitting the two worst accident years. For personal-injury accidents the pattern in a procedure of this nature will however not be as clear as that described for police-reported accidents on pages 12 and 13.

A procedure following that described above is conceivable at least for road junctions in the Swedish major road network. The advantages of this method are that it is both very simple and that the regression effect is treated individually for each junction. The disadvantage is that the method is rough and especially that it is not in any way supported by theory.

* Calculated with a standard method using the Institute's models

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AN INTERACTIVE COMPUTER SYSTEM FOR TRAFFIC ACCIDENT ANALYSIS

By

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Introduction

Traffic accidents are a serious consequence of the road traffic system and should be carefully monitored. This creates a need for a computer system which provides continuing information on traffic accidents within a particular area (e.g. a county, a metropolitan area, a city or a town).

This paper describes the design and the use of an interactive computer system for analysis of traffic accident data, called TRAFO, developed by Nordisk Planeringskonsult AB, Göteborg, Sweden, in cooperation with the SCAFT Traffic Safety Group at Chalmers University of Technology.

Objectives

A computer system should have the following objectives:

- study trends in accident statistics;
- analyze factors contributing to accidents, particularly the "traffic environment";
- make priority lists for improvements;
- provide a base for the design of improvements;
- carry out follow-up studies.

The system should be easy to handle and produce understandable results in a flexible but reliable way.

The solution will be an interactive system, using terminals and displays for a dialogue communication between the user and the computer. A set of programs will be necessary for input, control, data analysis and visual presentations.

Design of the TRAFO system

The TRAFO system has been designed to achieve:

- Interactive input of accident reports and corresponding data;
- Control of consistency simultaneous with the input of data;
- Automatic classification of types of accidents;
- Display of results on tables and maps which can be easily read and understood;
- Easy modification of the system in order to accomodate special studies;
- Possibility to coordinate the computer system with other accident registers (e.g. from hospitals), as well as with other information (e.g. from traffic counts and prognoses); and
- Reasonable processing costs.

The TRAFO system consists of sub-programs for:

(1) Input of accident reports;

(2) Control and testing of accident data, as well as clear printout text;

(3) Automatic classification of type of accident with storage on tape or discs;

(4) Updating of accident reports and background data (i.e. traffic volumes, street characteristics);

(5) Determination of simple distributions and relations (crosstabulation);

(6) Analysis of trends, costs and black-spots for accidents;

(7) Making of maps and diagrams of accidents with an automatic drawing machine, or presentation on a display; and

(8) Models for accident prediction.

Geographical presentation of accident spots

A well-known problem in data processing of accidents is to set up a principle for the location of accidents. The following methods can be applied:

- The address of the streets/places;
- A code for the streets;
- A code for the junctions;
- Coordinates for the spots;

The TRAFO system can allow all these types of location principles. However, it has been found practical to only locate in detail accidents which have occurred on the main network. This means that 80-90 percent of the accidents directly can be placed on the network scheme. The other rest will be referred to small areas (districts) between the main streets. In some cases a code for junctions can be useful to describe accidents as about 50 percent of the accidents is located to junctions. Accidents on street sections can be presented as a place between two junctions.

Input

Input consists of:

- Accident data, such as information on location, time, traffic elements involved, and special environmental factors. Data are collected from police reports or similar information.
- Network data, such as information on general characteristics of the traffic network (e.g. geometrical design, traffic regulation, traffic volume). Data are collected from maps, traffic counts, or through studies on location.
- Data in clear text, such as name of coded locations, accident types, and environment characteristics. Data are collected from street registers and code keys.

Output

The results of the processing can be displayed as:

- Cross-tables, indicating relations between variables, e.g. most severe consequences and type of accident.
- Ranking lists, showing locations in order of total number of accidents, percentage accidents during darkness, accident quotient (black-spots), etc.
- Accident maps, showing geographical distribution of accidents.
- Collision diagrams, showing type of road user, type of conflict, type of injury etc.

The tables are designed so they can easily be duplicated and published. The Figure 1 shows an example of a collision diagram, automatically produced on a graphic display.

Applications and experiences

The TRAFO system is used by Scandinavian cities and towns of different sizes in their continuous analysis of accidents. Gothenburg among others in Sweden and Oslo in Norway.

The reason for chosing a computer system has been the difficulties in using accident pin maps and other manual made summaries to explain the accident situation.

The main disadvantages with the manual methods are:

- Accident overview maps can only show the accident location and one or two additional variables for a fixed period.
- Manual analysis are expensive and time consuming.
- Unplanned summaries cannot be done fast enough which means that current safety problems cannot be regarded.

Manual methods therefore give poor information to the decision maker about the risk level and the explanation of an accident pattern.

When questions could not be answered from the standard routines, it will be necessary to make a new complete investigation of the accident records, which can be very time consuming.

A computerized system gives the user a possibility to make standard analysis as well as unplanned summaries when new questions arise. The decreasing cost for cumputer time and user-ackomodated dialogue routines make computers more and more attractive for traffic accident analysis.

The advantages of computer based analysis which have been found by the TRAFO-users are as follow:

- Interactive input of accident data combined with coding support results in simple handling of data.
- Errors in input data can be corrected immediately.
- Automatic classification of the accident type eliminates classification errors which cannot easily be identified.
- Analysis can be made for any period and for any conditions, e.g. for trend analysis and black-spot analysis.
- Accident data can easily be related to background data, i.e. traffic volumes, demographic and environmental datas.

  An example of a ranking list is given in Fig. 1. Studies have also been made for special type of accidents, e.g. in darkness conditions, red light violence driving.
- A bank of knowledge and experiences is available, e.g. for before-after-studies.
- Hypothesis can be immediately tested by a man-computer dialogue.
- Automatic presentation of results in form of collision diagrams and overview maps can easily be done.

A computer system is therefore a useful tool for analysis of short-term measures.

Further development

The TRAFO system is continuously developed together with the users. Efforts will be done to increase the possibilities to work interactively. Efforts are also made to link traffic accident data with external data bases, e.g. background data such as weather conditions, traffic counts, social and demographic datas.

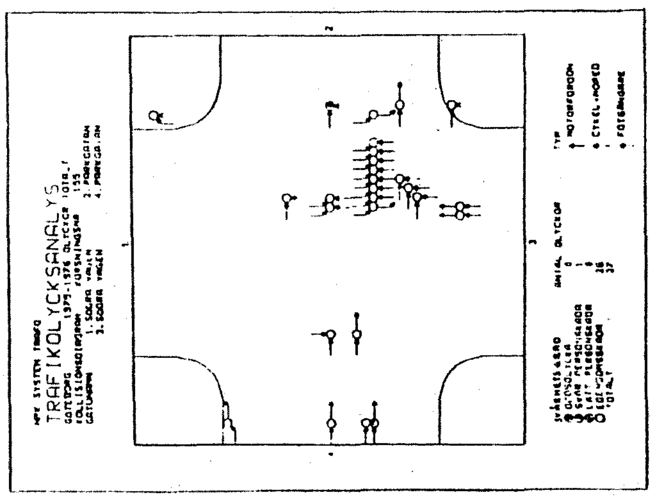

Fig. 1. Example of a collision diagram, drawn by the computer for an intersection in Gothenburg.

INTERSECTIONS OF ARTERIALS

NO.	STREET NAMES		TOTAL NUMBER OF ACCIDENTS	ACCIDENT QUOTIENT %	ACCIDENTS DURING DARKNESS	TYPE OF ACCIDENT: UNKNOWN	FATAL	SEVERE	LIGHT	PROPERTY DAMAGE ONLY
623	NYGARDSVAGEN	V M SKAGGETORP	2	100	2	0	0	0	1	1
531	TULLBRON	NORRKÖPINGSVÄG	3	66	2	0	0	0	0	2
344	HAMNGATAN	VALHALLAGATAN	3	66	2	0	0	0	0	2
401	VISTVAGEN	SÖDERLEDEN	3	66	2	0	0	0	0	2
81	DJURGARDSGATAN	DROTTNINGGATAN	4	50	2	0	0	0	1	1
422	SODERLEDEN	BROKINDSLEDEN	7	42	3	0	0	0	1	2
61	OSTGOTAGATAN	STORGATAN	10	40	4	0	0	0	0	4
641	GRENADJARGATAN	INDUSTRIGATAN	5	40	2	0	0	0	2	0
93	S:T LARSGATAN	DROTTNINGGATAN	7	28	2	0	0	0	1	1
192	MAJGATAN	MALMSLÄTTSVÄGEN	8	25	2	0	0	0	1	1
161	BERGSVAGEN	INDUSTRIGATAN	10	20	2	0	0	0	0	2
			62	40	25	0	0	0	7	18

Fig. 2. Example of a ranking list from the city of Linköping, Sweden.

A LEARNING DISABILITY AND ITS CURE*

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ABSTRACT

Sensible management of traffic safety is predicated on having reasonable expectations about the effect of various safety programmes and countermeasures. Unfortunately, in spite of decades of research and experience, the safety effect of many countermeasures is largely unknown. This sorry state of affairs is mainly due to the fact that it is difficult to conduct conclusive experiments about the effect of safety countermeasures.

Recognition of this objective difficulty should lead one to question the usefulness of classical statistical tests of significance as a device for scientific progress in this field. The unquestioning and all-pervasive use of significance testing in evaluative research on safety amounts to a self-inflicted learning disability. The first part of the paper explains why.

The fundamental problem of evaluative research is how to build knowledge from experimental results. Recognizing that in transport safety knowledge is gradually accumulated from the results of many studies, alternative approaches are explored. The application of a Bayesian approach in a specific case is described.

1. Transport Safety Management

The management of transport safety is a multifaceted and amorphous public activity. So many are the players in this game and so loosely coordinated appear their game plans to be, that the common aspects of "transport safety delivery" may escape recognition. Yet when one thinks of, say, the air traffic control system, the provision of school crossing guards, the licensing of drivers and highway geometry design as a few selected components of a transport safety management system, one comes to recognize how all-pervasive this public activity is and how large are the resources devoted to it. Legend has it that some 80% of the Transport Canada budget is linked to management of safety. It is therefore both natural and necessary to be concerned about the effectiveness with which resources are allocated and spent in this domain of public expenditure.

Resources are allocated to a variety of safety related tasks, programmes standards, etc. It is best to lump these under the term: countermeasures. One can accept without qualms the statement, that improved knowledge about the safety effect of countermeasures is likely to enhance the rationality of transport safety management. Conversely, no matter how well the outfit responsible for safety management is run and how sophisticated its officials are, if the safety effect of countermeasures is not known, one can not expect efficiency in resource allocation. These dicta are the motivation for engaging in research on the effect of countermeasures on transport safety.

This trite introduction is needed to set the stage for the arguments to come. It is best to state at the outset that evaluative research in transport safety is viewed here not as an element in the quest for the understanding of

* The support of Transport Canada in the conduct of this inquiry is gratefully acknowledged.

nature nor as an activity satisfying a primeval human thirst for knowledge. It is viewed within a utilitarian perspective as the kingpin of rational decision-making in the management of safety.

2. A Learning Disability

Progress in research on the effect of safety countermeasures has been uneven and in many cases, sluggish. It is hardly unfair to maintain that in spite of many decades of experience with many countermeasures (such as driver education, illumination, speed limit enforcement, traffic signals, vehicle inspection, demerit point systems, etc.) there is no concensus about their safety effect. This is an unusual and perplexing fact which should give pause for thought. There must be reasons which explain why after half a century a century of doing something as costly and unpopular as, e.g., enforcing speed limits, society has been unable to use such extensive experience in order to learn whether the enforcement activity has some effect on safety.

Some of the formidable objective obstacles to progress in research on safety are well known. Foremost among those is the practical difficulty of conducting controlled experiments. Yet, there is a nagging doubt whether these objective difficulties are sufficient to explain the persistence of ignorance. After all, reality does offer opportunities for study. To study, e.g., the effect of speed enforcement, one can find speed limit enforcement programs introduced and abandoned, police strikes, differences in levels of enforcement, etc. Researchers are skillful to recognize many such opportunities. Thus, there exists a multitude of research studies, small or extensive, properly conducted as well as deficient in design and execution. Yet, in spite of laborious and costly research efforts spanning several decades, concensus about the effect of many a countermeasure is slow to emerge. Is it not possible, therefore, that in addition to the objective difficulties, there is also some "learning disability" at work? Is there not something in the manner in which we learn from experience and extract information from experimental evidence which acts as an obstacle to the emergence of knowledge about the effect of safety countermeasures?

It seems prudent to admit the possibility that not all fault lies with an adverse "state of nature"; that other factors contribute to slow progress in evaluative research on safety; that some of the impediments to progress are self-inflicted.

One of the important traits of observations on system safety is their random nature. This is why safety is explored using the theory of probability and the tools of statistics. The whipping-boy in this paper will be some methods of classical statistics. It will be argued in the sequel that the machinery of classical hypothesis testing is largely irrelevant for the task at hand and is often the reason for conservatism and slow learning. Alternative methods for extracting information from data will be explored later.

3. A Brief Critique of the Classical Testing of Hypotheses

A typical study about the safety effect of some countermeasure begins by designing an experiment and proceeds by collecting the data leading to the analysis thereof. The punch line in most cases is the testing of statistical hypotheses about the safety effect of the countermeasure studied. The conclusion therefore is usually a statement on whether a hypothesis can or can not be rejected at a chosen level of significance when confronted with some alternative hypotheses.

There is considerable attraction in the apparent rigour of this process. It evokes the image of an idealized "scientific method" in which hypotheses are postulated and supported (or falsified) by experiments. This image of rigour seems to be particularly dear to disciplines not endowed by the facility for purposeful experimentation and deductive reasoning so characteristic of the natural sciences.

Be it as it may, the discourse on the method of science is best left to its philosophers. Here we will merely try to substantiate the claim that the persistent practice of interpreting data through classical tests of hypotheses may exert a thwarting influence on progress in research about safety countermeasure effectiveness. This is so, because the "decision" to reject or not to reject a hypothesis is largely arbitrary and can not be interpreted in any meaningful manner. Moreover, the real life setting in which research on the effectiveness of safety countermeasures has to be conducted is characterized by relatively small samples and deals with countermeasures the effect of which is typically small. The conventional test of a hypothesis in these circumstances will usually return the answer: the hypothesis "no effect" can not be rejected. The net results of this built-in conservatism is that most real life countermeasures are branded as "not shown effective". This in turn leads to perpetuation of the status quo and to stagnation. Thus, it appears important to argue the case against the use of classical tests of hypotheses in research on the effect of safety countermeasures.

The "knocking" of statistics is a popular pastime. It is usually done on the basis of some improper use of the statistical method. To any such charge, the statistician would respond by claiming that misuse is not the fault of the method but of those using it incorrectly. (Even the validity of this response can be questioned. It is not common to find statistical methods used properly. Nor is there a good prospect that this will change. Thus, if a method cannot be used properly be well meaning mortals, it may not be fit for general human consumption.) However, this critique is aimed at the case when the classical method is applied as intended - without flaw. I will claim, that in the context of research on countermeasure effectiveness in transport safety, methods of classical hypothesis testing are largely irrelevant and often harmful. This claim will rest on two groups of arguments.

a) The outcome of a classical test of hypothesis is arbitrary. Whether a hypothesis is "rejected" or "not rejected" depends on considerations that cannot be related in any meaningful fashion to the real circumstances of the issue under scrutiny. Thus, one can "decide" either to reject or to accept any of the hypotheses under consideration.

b) The "decision" (to reject or not) which is the result of the "test" is difficult to interpret in some straightforward manner. Yet, the obscure concept of "decision" is the fulcrum on which everything hinges. Moreover, the criteria used to make this "decision" can not be used to weigh the importance of the consequences in a real decision-making context.

These two groups of arguments are explored in some detail below.

The first group of arguments leads to the conclusion that the result of a test of hypothesis is arbitrary. The arbitrariness of the procedure stems from three major difficulties.

Firstly, whether the null hypothesis is rejected or not depends entirely on the chosen level of significance. Given the results of an experiment, for some levels of significance you reject the null hypothesis, for others you don't. If the results of a test depends so immediately on the chosen level of significance, one would like to be shown that the custom and convention in this matter have a rational justification. For, if such a basis can not be found, one is justified in thinking the test to be arbitrary.

Both elementary and advanced texts on statistics either leave it to the discretion of the analyst to choose the appropriate "critical levels" (as if it was evident how to do so) or recommend to follow custom and use the 0.01 or 0.05 levels of significance. But how is one to judge what is "appropriate"? Does adherence to custom make the outcome "arbitrary-by-custom"?

A down-to-earth justification of the conventional critical levels is given by Bross (1971). His argument is rooted in the practice of biostatistics and consists of two elements. Firstly, progress would be impeded if too many erroneous claims (say, of drug effectiveness) were published. Thus, it is necessary to set some level of significance to keep "false positives" out of the pages of journals. Secondly, "the 5% level ... is a feasible level at which to do research work" - in biostatistics.

In research on the effect of safety countermeasures, the 5% level is rarely a feasible one. To illustrate, Berg (1980) concludes that in order to examine the safety effect of an advance warning sign for railroad-highway crossing at the 5% level of significance, one would require 15000 "treatment" and 15000 "control" sites. This exceeds the total number of level crossings in the USA. Thus, if there is to be a conventional level of significance in safety research, it is not necessarily that which is suitable for biostatistics or agriculture.

The damage done to scientific progress by the publication of an erroneous account of effectiveness must be weighed against the damage done by branding "not proven effective" many-a-promising countermeasure. Which is the more serious damage is surely a matter of opinion. Thus, even the level-headed argument by Bross leads back to the exercise of judgement. This judgement is far removed from the specific research question at hand or a set of experimental data to be interpreted. It is difficult to think of a test as not arbitrary if its result depends on some metaphysical aspects of scientific progress.

Secondly, the answer returned by a statistical test of hypothesis depends crucially on yet another custom - the convention by which one selects the "null hypothesis". The outcome of the test is often determined by the decision which of the contending hypotheses to cast in the role of the "null hypothesis".

Consider two simple hypotheses:

X - countermeasure has no effect.
Y - countermeasure is 10% effective.

Given is a small set of experimental results and an appropriate level of significance is agreed upon - somehow. When X is selected to serve as the null hypothesis, it can not be rejected. One concludes:

(1) The hypothesis that the countermeasure has no effect can not be rejected.

If Y were selected to serve as the null hypothesis it also can not be rejected (at the same level of significance and using the same experimental data). In this case one states:

(2) The hypothesis that the countermeasure is 10% effective can not be rejected.

Ordinarily, statements (1) would be interpreted as being different in meaning from statement (2). If so, one obtains different answers from a test as a result of a choice about which of the contending hypotheses is to serve in the role of the "null hypothesis". This choice is dictated by arbitrary convention.

One can maintain that statements (1) and (2) should not convey different impressions about the effectiveness of the countermeasure; that they are complementary and illumine the same facts from two slightly different angles. In fact, that there is a whole range of parameter values, hypotheses about which can not be rejected. This interpretation runs counter to the concept of a "test" which culminates in a "decision". It runs counter to the manner in which the machinery of hypothesis testing is used. Finally, even if one swallows convention in both cases and agrees on a level of significance and null hypothesis, the outcome of the test remains arbitrary. For, no matter how small the difference between the "null" and the "alternative" hypotheses, the null hypothesis can be almost always rejected when the experiment is large enough. Thus, not only does the outcome of a "test" depend on two inexplicable conventions, it also depends on the budget available for experimentation. It is difficult to see what meaning to assign to a "test" if its outcome is determined by vague conventions and other extraneous influences.

The second set of objections to the process of classical hypothesis testing centers on the lack of clarity as to what a "decision" is to mean. At the end of a test of a hypothesis, one has to "decide" whether "to reject" or "not to reject" the null hypothesis. What precisely are the consequences or guidance for subsequent action implied by such a decision? One interpretation of what "deciding" means may be, that until such time as the null hypothesis can be rejected, it remains the accepted doctrine. I do not know whether this is a workable scheme in the natural sciences. In safety, it is seldom easy to determine what is meant by "accepted doctrine". In any case, this interpretation seems to run counter the convention of using "no effect" as the hypothesis we are trying to reject. It is difficult to believe that the acepted doctrine about most countermeasures we test is, that they have no effect. The contrary may be closer to the truth. We test them because there is some ground to believe they might be effective.

This leads to another possible interpretation of what "deciding" might mean. The null hypothesis we select (no effect) is really only a strawman; it is placed on the altar only to be destroyed by experimental evidence ("it is

merely something set up like a coconut to stand until it is hit" Jeffreys, 1961). When so rejecting the "no-effect" hypothesis we imply that the "yes-effect" hypothesis replaces it. But if we do not manage to unseat the no-effect" hypothesis (as happens with discouraging but persistent regularity) we are saddled with a reigning hypothesis which we did not believe in from the outset and which was selected, so to speak, out of spite. In this case the most that can be said is that while we do not necessarily believe in the "no effect" hypothesis, we have no sufficient proof to reject it. In, say, the biological sciences, it might be possible to buy more guinea pigs and experiment till the null hypothesis can be rejected. Such an option does not ordinarily exist in research on safety.

This same sentiment is expressed delightfully by Edwards (1972, pp. 179, 180): "unfortunately any method which invites the contemplation of a 'null' hypothesis is open to grave misuse, or even abuse, and this seems particularly so in the social sciences, where high standards of objectivity are especially difficult to attain, and data often of dubious quality. The argument runs as follows: 'I am interested in the effect of A on B (for example, the influence of hereditary factors in the determination of human intelligence, or the effect of increased family allowances on population growth) and I propose to use approved statistical techniques so that no one can question my methodology. These require me to state a null hypothesis, namely, that A has no effect on B. I now test this null hypothesis against my data. Unfortunately my data are not very extensive, but I have done the Angler-Plumfather two-headed test and found $0.20 \leq P \leq 0.10$. I therefore accept the null hypothesis.' Further sets of data - none of them very extensive - continue to 'miss the coconut', and after a time the null hypothesis joins that corpus of hypotheses referred to as 'knowledge', on no positive grounds whatever.

The dangers are obvious. In the first place, the problem is usually one of estimation (to use the conventional word) rather than hypothesis-testing; in the second place, the chosen null hypothesis is often such that no rational man could seriously entertain it: who doubts that hereditary factors have some influence on human intelligence, or that increased family allowances have some influence on population growth? And in the third place, not only is each test itself devoid of justification, but sequential rather than concentrated assaults on the null hypothesis are practically powerless in difficult cases: it is like trying to sink a battleship by firing lead shot at it for a long time. What used to be called judgement is now called prejudice, and what used to be called prejudice is now called a null hypothesis. In the social sciences, particularly, it is dangerous nonsense (dressed up as 'the scientific method'), and will cause much trouble before it is widely appreciated as such"

Edwards' diagnosis is near prophetic in view of the following comment by Meehl (1978):

"I believe that the almost universal reliance on merely refuting the null hypothesis as the standard method for corroborating substantive theories in the soft areas is a terrible mistake, is basically unsound, poor scientific strategy, and one of the worst things that ever happened in the history of psychology."

The last escape from this morass I can think of is, that the consequences of deciding to reject or not to reject vary from case to case and therefore each situation requires separate analysis. This might be a sensible escape route. Unfortunately it is blocked. To weigh the importance of "rejection" or "non-rejection" in a specific case, we need probabilities of erring. The classical test of a hypothesis does not yield estimates of the probability of making an error one way or another. It returns conditional probabilities. That is, the probability of erring if one (or the other) hypothesis is true. But, since it remains unknown whether one or the other hypothesis is true, WE ARE NOT IN A POSITION TO WEIGH THE IMPORTANCE OF DECIDING TO REJECT OR NOT TO REJECT.

In summary, the classical test leads to a "decision" in some contorted sense of the word and uses for that purpose conditional probabilities which cannot be related to the importance of the consequences of error, the costs and benefits associated with any real decision-making.

One cannot fault classical hypothesis testing for being entirely devoid of any consideration based on cost or benefits. The method has not been conceived to be used as a decision making tool. (Perhaps the terminology which uses the word "decision" in the context of testing hypotheses has been an unfortunate choice.) It is possible that when experimentation is cheap, the classical method is a good safeguard against unproven hypotheses and its consistent use promises to keep the body of knowledge unpolluted and the ship of progress on even keel.

However, research on the effect of safety countermeasures is in support of deliberations about costs and benefits. It is therefore incongrous to think that "decisions" can be made without reference to resource implications. By this reason alone, classical hypothesis testing should be rejected as a legitimate tool for summarizing experimental results in research on safety countermeasure effectiveness.

As used, classical hypothesis testing is a one shot affair. It is the punch line of a study. An experiment is conducted, outcomes are tabulated and then subjected to a test. When, as often happens, the null hypothesis is not rejected, the information contained in the outcome loses much of its value. It is not used in the next study of the same issue. This is possibly the most unfortunate feature of the classical significance testing - as used. We operate in an environment in which knowledge accumulates through many experiences. Failure to use all accumulated information in a purposeful learning process virtually assures stagnation.

4. How to Learn From Data

The central question before us is: "how to extract information from results of experiments and how to learn from it".

In discussing this question here, the primacy of two aspects of the prevailing situation has to be recognized. Firstly, that the purpose of research on the effect of safety countermeasures is to facilitate sensible decisions about the allocation of resources in safety management. Secondly, that a single experiment by itself is likely to be too small and noisy to yield authoritative knowledge. Therefore, in most cases, one cannot settle a question once and for all.

Thus, research on countermeasure effectiveness is a process. The need to engage in it arises when one suspects that the present state of knowledge on

some countermeasures is insufficient to make good decisions about its implementation. That, in fact, if we knew more, we might make better use of resources. It follows, that the purpose of research is to improve, update and revise present knowledge. This revised knowledge will serve for any decisions that need to be made here and now. But if one still has ground to believe that better knowledge might save resources, there is room for more research and yet another revision of present knowledge, and so on ad infinitum.

To elucidate the role played by research on the effect of safety countermeasures we start by describing a simple minded but general framework for making decision. This will be followed by an illustrative example.

4.1 A Naive Framework for Decision Analysis

Implementation of a countermeasure is considered. Two of its attributes are of interest: the cost of the countermeasure and its ability to improve safety. Let then C denote the annual cost of the countermeasure and θ be an index measuring the effectiveness of the device. When the device is implemented on a system on which the expected annual number of accidents is M, the expected annual accident after implementation* will be $M\theta$. If $\theta=0$, the device is totally effective. If $\theta=1$, the countermeasure does not reduce expected annual number of accidents. The magnitude of θ is never known exactly. Informative statements about θ must always be couched in terms of odds and probabilities. The aim of research on the effectiveness of safety countermeasures is to obtain a good estimate of θ.

The decision to implement the countermeasure has positive and negative repercussions. On the credit side of the ledger is the reduction in the expected annual number of accidents $M(1-\theta)$. On the debit side is the expenditure of resources C.

Whether implementation of the countermeasure is a worthwhile investment can be judged only if it is known whether the same resources can not result in a larger safety improvement if invested in a different countermeasure**. Let then A denote the reduction in the annual number of accidents obtainable by investing one unit of money per annum in the best alternative countermeasure. With this meagre notational arsenal, a sensible decision rule might be:

Implement device if:

$$M\,(1-\theta) > CA \qquad \ldots 1$$

---

* For sake of simplicity, it is assumed that the effect of the countermeasure is to change the expected number of accidents. Safety is not measured only in terms of quantity of accidents but also their severity. This simplication has no effect on the essence of the argument to follow.

** The problem of project divisibility is neglected here. It is assumed the investment in countermeasures is finely divisible. Nor do we propose to deal with uses of money in fields other than the management of transport safety.

The rule incorporated in the inequality urges one to implement the accident reducing device if (with equal expenditure of money) it is expected to save more accidents than the best alternative countermeasure*.

Estimation of three out of the four variables in inequality 1 is relatively straightforward. It makes common sense that when considering the investment of some money, one should know what the cost of the project (C) is, what the magnitude of the problem (M) is and what could be done with the money elsewhere (A). Normally, however, the index of countermeasure effectiveness (θ) is known with little certainty and decisions must be made on the basis of the best available evidence.

So far, θ was assumed to have some unique value estimates of which are obtainable from experimental data. However, the same countermeasure when applied to different systems is likely to be different in effectiveness. Thus, it is legitimate to think of θ as a random variable with a probability distribution function and an expected value. It will be argued in the sequel that the decision-analytic framework is well served by a Bayesian approach to extracting information from data. This approach is based on a recurring revision of the probability distribution function of θ. Thus, to keep all options open, we will replace θ in inequality 1 by $\hat{E}\{\theta\}$.

Within this framework, the role of research on the effect of safety countermeasures is to revise current estimates of $\hat{E}\{\theta\}$ on the basis of new empirical evidence. The value of evaluative research is then measurable from the (expected) increase in the effectiveness with which resources are allocated.

4.2 Illustrative Example

The principal issues can be illustrated by a hypothetical numerical example. Wide implementation of a novel pedestrian crossing device (PCD) is contemplated. Naturally, little is known about its safety performance. In this state of ignorance, the decision makers might wish to ask for expert opinion. Of the 100 experts polled, three opinion groups can be identified:

10 think the PCD will increase accidents by 10% (Group I)
60 think it will have no effect (Group II) and
30 think it will bring about a 10% reduction in accidents (Group III).

Installing the device at sites which have (jointly) some 100 fatal pedestrian accidents per annum would cost $200,000 per annum.

Depending on which group of experts is right, the following are the repercussions of implementing the PCD.

* This decision rule is unrealistically stringent. Even if the new device only exceeds the cost-effectiveness of the worst presently financed countermeasure it should be implemented, provided that resources can be diverted from one to the other.

TABLE 1.

	Expected Savings (fat./year)	Costs ($/year)
Group I is right	-10	200,000
Group II is right	0	200,000
Group III is right	10	200,000

If the decision makers value equally the opinion of every expert, and no other information about the effectiveness of the new PCD is available, the best presently available estimate of $(1-\hat{E}\{\theta\}) = 0.02$ $[0.1 \times (-0.10) + 0.6 \times (0.00) + 0.3 \times (0.10) = 0.02]$. Accordingly, the best estimate of $M(1-\hat{E}\{\theta\})$ is $100 \times 0.02 = 2$ fatalities/year. This is the estimate of the expected reduction in pedestrian fatalities obtained by the investment of $200,000 per year.

Assuming that one could hire for the same amount of money some 10 crossing guards and expect to save thereby 3 fatalities per year, it would be wise to decide against implementing the novel PCD.

If, however, the experts in Group III happen to be right, an incorrect decision has been made (to save 3 lives instead of 10). It may therefore be worthwhile to do some research about the effectiveness of the PCD so as to improve our ability to make good decisions and thereby to enhance the efficiency with which money is used in safety management. Assume then that for research purposes the new PCD has been implemented at some representative sites. During the year prior to implementation these sites recorded 10 fatal pedestrian accidents. During the year following implementation, 5 fatalities occurred. Now the task is to make use of this new experimental evidence.

Were one to subject this result to a classical test of hypothesis, the inescapable conclusion is that the hypothesis "PCD is not effective" can not be rejected. What effect such a conclusion would (or should) have on the decision about the future of the PCD is unclear. Thus, having conducted a test of hypothesis, one is hardly further ahead. It appears to be a singularly unproductive way in which to learn from evidence. It is therefore important to try and suggest better ways for squeezing information out of data. Three important options present themselves:

(1) Classical "point estimation".

(2) The "Likelihood" method, and

(3) "Bayesian" estimation.

The three methods are intertwined. Thus, one of the more popular techniques for obtaining a point estimate is to search for the maximum of the likelihood function. Also, the likelihood function plays a central role in Bayesian estimation.

All three options are viable devices for the accumulation of empirical evidence, as will be shown below.

Were one to adopt classical "point estimation", the data indicates $\hat{\theta}$ = 5/10 = 0.50. Following Cox and Lewis (1966, pp. 223-225), the 95% confidence interval for $\hat{\theta}$ is 0.14-1.70. Should results of another study on the PCD be, say, 4 accidents "without" and 3 accidents "with", it is easy to revise the earlier estimate. Now, $\hat{\theta} = (5+3)/(10+4) = 0.57$ and the 95% confidence interval is 0.21 - 1.44.

Thus, it is not only possible, but in some cases very simple, to ensure that the estimate of θ is revised when new data becomes available; the current estimate is to reflect all evidence accumulated till then.

As the body of experimental evidence grows, the confidence interval becomes narrower. In this sense, the confidence interval is a useful index of the degree of uncertainty in $\hat{\theta}$. A word of caution is in order. It is a common misconception to think that the true value θ is contained with a probability of 0.95 in the 95% confidence interval calculated from some data. This is nonsense. The value θ either is or is not within a specified range and to speak of probability in this context has no meaning. However, this misconception seems to be much less damaging than the acceptance-rejection malaise. Therefore, no more will be said about it.

The second of the aforementioned three options for extracting knowledge from data is to make use of the notion of "likelihood". If an experimental result has a greater probability of occurring if θ_1 is true than if θ_2 prevails, θ_1 is said to be more "likely" than θ_2. Thus, likelihood measures the strength of support which data lend to alternative values of an unknown parameter. The concept has first been introduced by Fisher (1925); its logical foundations are explored by Hacking (1965) and one of its convincing proponents is Edwards (1972).

In Figure 1, two likelihood functions are shown. The ordinate of the dashed curve is the likelihood of θ when only information about 10 "before" accidents and 5 "after" accidents is available. In this case, best supported (most likely) value of θ is 0.5, in accord with common sense and the "point estimate" obtained earlier. When new evidence in the form of 4 accidents "without" and 3 accidents "with" becomes available, the dashed curve is modified and the solid likelihood function obtains. Now the best supported value of θ = 0.57. An increase in information will, in general, result in a narrower likelihood function. This merely indicates that some values of θ become less supported by the data in comparison with the most likely value.

There are many attractions to the likelihood method. It presents the empirical evidence in a manner which is closely tied to common sense and without the obfuscation which goes with levels of significance. The method invites consecutive revisions as new data is acquired. It extracts all relevant information from the data (i.e. is a "sufficient" statistic).

Neither "point estimation" nor the "likelihood method" take cognizance of what knowledgeable people believe the PCD can do to enhance safety. It may be inappropriate to disregard their experience in reaching a decision - particularly in view of the paucity of data. Nor are any of the aforementioned methods capable of answering questions such as: "what are the odds that the PCD is harmful?" In contrast, the Bayesian approach is ideally suited for the task of making decisions.

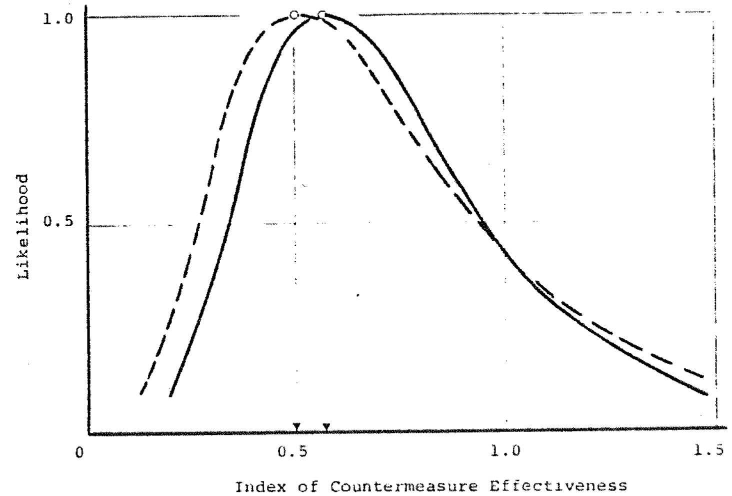

Figure 1.

Thus, relying on expert opinion only, the probability (as degree of belief) that the PCD will increase accidents by 10% (θ=1.10) is 0.10 (column 3 in Table 2). When results of research show 10 accidents "before" and 5 accidents "after", this probability is revised to 0.05 using the machinery of the Bayesian method.

TABLE 2.

1	2	3	4
Group	Index of Effectiveness θ	Probability estimate based on expert opinion P(θ)	Revised probability estimate based on expert opinion and result of experiment* P(θ)
I	1.10	0.10	0.05
II	1.00	0.60	0.53
III	0.90	0.30	0.42

The revised estimate of the P(θ) in column 4 are consistent with what the experts knew about such and similar devices through their experience and with what has been learned from the limited research.

* Assuming that pedestrian fatalities at the selected sites obey the Poisson probability law with a mean of 10 fatalities per year.

Using the new values of $P(\theta)$, the current estimate of expected effectiveness ($E\{\theta\}$) is 0.963. Accordingly, the current estimate of the expected reduction in pedestrian fatalities obtainable by implementing the PCD is $100 \times 0.037 = 3.7$ fatalities per year. This appears now to be more attractive than the hiring of crossing guards. In fact, by spending $200,00 per annum on crossing guards, we expected to save 3 fatalities; however, one needs to spend only $160,000 per annum on the PCD's to expect to save 3 fatalities. The expected cost reduction of $40,000 per annum is attributable to the information obtained through research which led to a better decision. It is possible that more research on this countermeasure could be justified. Results of any such research would be used to revise estimates of $P(\theta)$ in the rightmost column of Table 2.

No illustrative example can be convincing in all detail. Nevertheless, the overall impression is, I hope, of common sense and rationality. The meaning and context of decision making is clear and fits the task of managing safety; new information created by research contributes to better decisions by revising previously held views. There is no need for obscurantism about imaginary decisions, pseudo-scientific hypotheses, arbitrary levels of significance and convoluted definitions of "errors".

The Bayesian frame of thought seems to solve several problems: even small experiments contribute to knowledge; the method ensures that results of all previous experiments influence present knowledge; the output is in a form which can be directly related to cost effectiveness exercises; it is possible to assess the importance of research beforehand and to identify research designs which will not yield information.

4.3 Discussion

Three options for learning from experimental evidence have been outlined. Each can be used to update and revise estimates of countermeasure effectiveness in an accumulative manner. Thus, each option is a promising cure to the learning disability brought about by the affliction of hypothesis testing.

Our preference is for a combination of the likelihood and the Bayesian method. The likelihood function is to retain and accumulate all "objective" evidence. Decisions are to be taken using probabilities provided by the Bayesian machine.

The starting point of the Bayesian procedure in the illustrative example is subjective "expert" opinion. This fact is commonly viewed as a weakness which renders the method "unscientific". After all, arguments are convincing when based on facts, not opinion. Also, as is well known, people are poor assessors of probability and expertise is no insurance against bias.

Proper exploration of this issue leads to the realm of the modern philosophy of probability which is beyond the scope of this paper and the competence of its author. However, for a realistic perspective and balanced view, few points deserve mention. For one, the role of expert opinion in the process of revising the estimates of $P(\theta)$ is limited. It is only the first step, setting into motion a self-rectifying process which, in principle, goes on indefinitely. The set of probabilities which is based on expert opinion is, as it were, the initial guess in a convergent iterative solution algorithm. A poor initial

guess implies many iterations till a sufficiently accurate solution is obtained whereas a successful starting guess will converge in a few cycles. However, nobody will brand the result of an iterative solution as unscientific because it began from a subjective guess. In the same manner, it is hardly just to stigmatize the Bayesian procedure because its starting point is expert opinion.

For two, it has been argued earlier that the rigor of classical statistical methods begins only after some arbitrary specification of, say, the level of significance. This, in some sense, is worse than expert opinion since any honest attempt of such specification is unaided by intuition and does not derive from any human experience. Thus, one ordinarily resorts to the illusory comfort of convention.

The "Bayesian Controversy" has raged for decades. Numerous books and articles by eminent scholars have been devoted to this subject. It is not the aim of this paper to add new insights into the argument. Its purpose is to introduce the Bayesian controversy into the realm of evaluative research on transport safety. Since the proof of the pudding is in the eating, results of an application to a specific countermeasure are described in detail below.

5. Application of the Bayesian Method to an Impaired Driver Rehabilitation Program

Persons convicted of impaired driving are often ordered to attend a rehabilitation programme. The question is, to what extent participation in such a programme affects the driver's inclination to drive while impaired. Due to recent, large and carefully designed studies there appears to an emerging concensus about the classes of persons which can be affected by such programs and how large the effect might be (Nichols, 1980). Thus, it is not the purpose of this case study to bring about authoritative information on the effectiveness of such rehabilitation programmes. Rather, the purpose is to explore the manner in which Bayesian techniques would cause such authoritative consensus to emerge. In the application, the following setting is assumed:

> *Introduction of a rehabilitation programme for persons convicted for driving while under the influence of alcohol seems to be a promising countermeasure. Accordingly, several such programmes are established. The effect of two programmes is subsequently examined. When classical methods are applied to data from both studies, the hypothesis that "the rehabilitation programme does not affect recidivism" can not be rejected. This weak claim does not advance either knowledge or concensus. Those who swear by the programme can justly attribute this result to the small sample size in both cases and the virtual impossibility to detect realistic levels of programme effectiveness. Those who do not believe in the effectiveness of the programme will be reassured in their scepticism.*
>
> *To illustrate the workings and use of the Bayesian method, results of the same two studies will be used. It will be shown how initial opinions about the effectiveness of such programmes are molded and modified by modest experimental results and how the procedure supports the building of a rational concensus.*

The application of the Bayesian method within this setting entails two steps. In the first, the prevailing views about the effectiveness of an

Impaired Driver Rehabilitation Programme have to be converted into estimates of subjective probabilities. This is described in Section 5.1. In the second step, these subjective probabilities are successively revised on the basis of experimental evidence from two studies. This is the subject matter of Section 5.2.

5.1 The Starting Point

To set the Bayesian machine in motion, one has to provide an initial guess about the probability of effectiveness for the countermeasure under investigation.

In this study we have elected to do so by compiling the opinion of many individuals into a composite guess.

The main vehicle of data collection was a letter mailed to some 500 persons. The letter contained a one-page description of a typical rehabilitation programme consisting of four two-hour sessions and a question about the reconviction rate expected by the respondents. Detailed description is provided elsewhere (Hauer [1981]). Some 200 usable answers were received. From these an empirical probability distribution function of θ was constructed for each of five groups of professionals. Means and standard deviations are given in Table 3.

TABLE 3

Sample Sizes, Means and Standard Deviations

Group	Sample Size (n)	Sample Mean ($\bar{\theta}$)	Sample Standard Deviation (s)
I. Transportation Engineers	69	0.75	0.22
II. DWI* Coordinators	19	0.59	0.25
III. Judges	55	0.70	0.27
IV. Psychologists	7	0.93	0.13
V. Safety Researchers	50	0.91	0.14

* Driving Without Impairment programme in Saskatchewan.

Two phenomena deserve mention.

Firstly, one's occupation is closely linked to one's opinion. It is apparent that DWI Coordinators and Judges believe the treatment to be much more effective (30-41% reduction in recidivism) than Psychologists and Researchers do (7-9% reduction). It is possible that this difference is due to the fact that groups II and III base their opinion on personal contact with drivers sent for treatment, whereas members of groups IV and V form their view on the basis of experimental findings published in the literature and a generalization of related, relevant facts. Alternatively, it is plausible to attribute the difference in opinion to the fact that for a person whose

professional life is tied to the administration of similar treatments, it would be difficult to live with and admit to scepticism about the merit of his work. In any case, it may be idle to aim for sophistication in eliciting subjective opinions. The answer one gets depends very strongly on who has been asked.

Secondly, there is a noticeable difference in the diversity of opinion within the groups. The optimists (DWI Coordinators and Judges) vary widely in the opinions they hold ($s \cong 0.25$). In contrast, the range of opinion within the sceptical groups (Psychologists and Safety Researchers) is much narrower ($s \cong 0.13$). When members of a group are good probability assessors, their judgements will be close to each other and the standard deviation of the distribution of their opinions small. Thus, a narrow distribution is a good omen. However, members of a group may be homogeneous in holding incorrect views. Accordingly, one can not make valid inferences about the quality of the empirical probability distribution function of a group of assessors on the basis of the standard deviation only. A Gamma distribution has been fitted to each of the five empirical probability distribution functions. The choice of this functional form is, of course, arbitrary. Its merits are that θ is allowed to vary in its proper domain $(0,\infty)$; it is parsimonious in parameters; and fits the data well. The distribution for the most optimistic and most pessimistic groups are shown in Figure 2.

Having dwelt on the description of how subjective "expert" opinion has been elicited, there is a danger that the reader may associate this approach with some variant of the Delphi technique. This is not a correct perception. We are attempting to devise a scheme by which objective evidence from experiments is systematically used to improve knowledge about the effect of safety countermeasures. Expert opinion serves as a sensible starting point. Thereafter, all successive revisions are the work of objective data.

To adequately describe the product of the Bayesian machine, it may be best to imagine some anonymous decision maker who in the absence of useful objective evidence forms an opinion about the effect of some countermeasure by asking for the informed opinion of experts. When empirical evidence becomes available, the decision maker must reconcile his views with the data. This is accomplished using the only coherent device - the Bayesian machine. The revised opinion is what a rational decision maker should adopt in view of his prior opinion and the available empirical evidence. Thus, the product is a revised probability distribution of countermeasure effectiveness. The probability is still a subjective one; it is akin to "odds" or "degree of belief". It is, however, a degree of belief entirely in tune with the available facts.

5.2 The Bayesian Machine

According to Bayes' theorem,

The probability that an unknown parameter has a specific value when prior knowledge as well as data from an experiment are both considered

is proportional to

the probability of obtaining the experimental result when the parameter has this specific value

multiplied by

the probability that the unknown parameter has the specific value based on "prior knowledge" alone.

This can be stated equivalently by

$$\pi(\theta|\underline{x},H) \propto P(\underline{x}|\theta)\,\pi(\theta|H) \qquad \ldots 2$$

where

π denotes probability as "degree of belief",
P denotes probability in the "frequency" sense,
θ is the value of the unknown parameter,
$\underline{x}$ the vector of data from the experiment, and
H the state of knowledge about θ prior to obtaining $\underline{x}$.

The three terms in equation 2 have acquired standard names:
Posterior Probability $\propto$ Likelihood x Prior Probability.

The coefficient of proportionality is determined so as to make the sum of the posterior probabilities for all possible values of the unknown parameter equal unity.

At this point, the "prior probability" is the Gamma distribution fitted to the responses provided by one of the groups of professionals. The "likelihood" component of the product reflects the contribution of data from experiments.

The first data to be used comes from the evaluation of the Alberta Impaired Drivers' Programme (Zelhart, 1975). Some drivers convicted for driving while impaired were assigned to partake in the A.I.D.P. sessions, others were not. The assignment was approximately random. The subsequent reconviction record was noted and the results are summarized below.

TABLE 4

Summary of A.I.D.P. Data

	Total	Number reconvicted within 3 years
1. Drivers Not Treated	652	93
2. Drivers Treated	611	79

Thinking of the "number of reconvictions" as "failures" and the "total" as "number of experiments", the Binomial probability law can be used to write the likelihood function. For the data in Table 4, the likelihood function is shown in Figure 2.

Using the likelihood function alone, the best supported value of θ is 0.91 [=(79/611)/(93/652]. Also values of θ outside the range (0.7, 1.2) are very unlikely. Thus, due to the structure of equation 2, bulk of the posterior PDF of θ will also be in this range irrespective of the prior PDF of θ. That this is the case is easy to see in Figure 3 which shows the posterior PDF of θ which combines the likelihood function based on the A.I.D.P. data and the opinions of DWI Coordinators shown as the "prior" PDF.

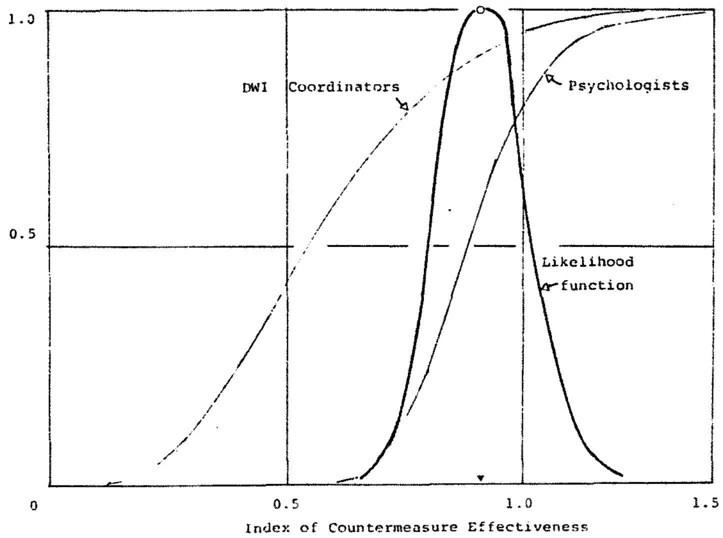

FIGURE 2

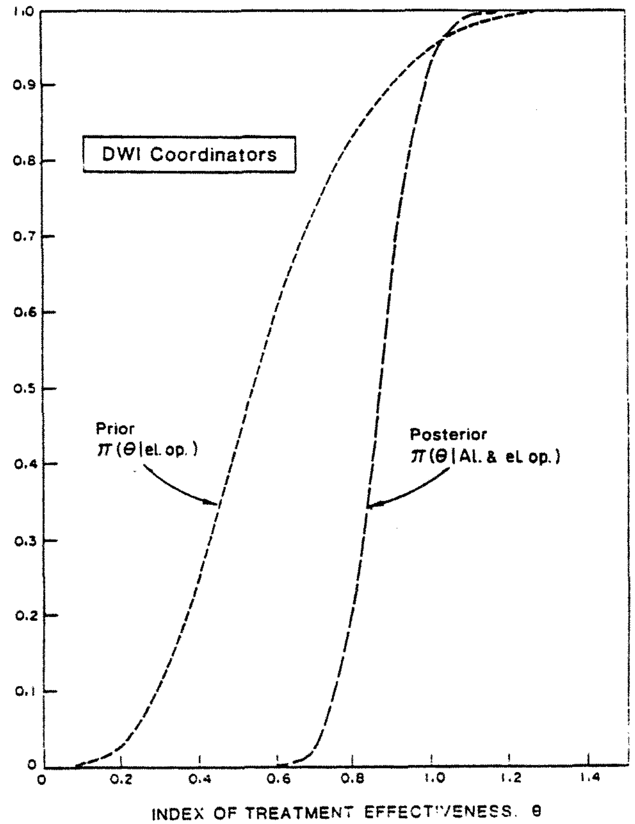

FIGURE 3

Posterior PDF's for θ have been obtained for all five groups of professionals. Some summary statistics are given in Table 5 below. Comparison with the "prior" statistics in Table 3 is self-explanatory and illuminating.

TABLE 5

Means and Standard Deviations of the Posterior PDF.

Group	Average Effectiveness E{θ}	Standard Deviation of θ
Engineers	0.88	0.09
DWI Coordinators	0.88	0.09
Judges	0.89	0.09
Psychologists	0.91	0.08
Safety Researchers	0.91	0.08

In the present case, the Bayesian revision process seems to have succeeded in accomplishing two missions. Firstly, efficient use has been made of modest data to describe the effectiveness of the A.I.D.P. and similar programs in reducing the rate of recidivism. The description is in a form directly usable for both qualitative and quantitative decision making. Secondly, the Bayesian revision process virtually eliminated differences of opinion which can legitimately be held in view of the experimental results.

One can hardly fail to be impressed by the increase in "knowledge" from the diverse and diffuse views in Table 3 to the consistent and compact distributions in Table 5. All this due to sensible use of the data in Table 4. To belabour a point made earlier, consider the contrasting statement made on the basis of the same data in an earlier study: "...While there were fewer recidivists among the Subjects attending A.I.D.P., the differences were not statistically reliable; $\chi^2 = 1.49$, df = 2, 0.5 >p> 0.3."

In spite of the diversity in "prior" opinions, the five posterior distributions are all very similar to the likelihood function. It is natural therefore to ask: why not use the likelihood function directly? Two important reasons should be considered. Firstly, it is the PDF of θ which is needed for decision making. However, it is not legitimate to confer a probability interpretation upon the concept of "likelihood". Equation 2 is the only known device for obtaining a statement about probabilities from the likelihood function. Secondly, when the experimental data is small, the likelihood function is "wide" and the effect of the prior distribution on the posterior will be considerable. The same will obtain if the prior distribution reflects marked unanimity. This is as should be when one thinks about the making of resource-allocation decisions.

It is legitimate, however, to be concerned about the mixing of "opinions" with "objective" data. The decision maker may not wish to rely on opinions not applicable to his country or condition; the researcher may wish to keep objective fact and subjective opinion separate. This concern is easy to accommodate. All that is needed is to keep the expressions of likelihood and

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initial prior probability separate. Thus, the issue is merely a matter of report writing style not of principle.

We will carry the revision process one step further. Vingilis et al (1981) reported the following results.

TABLE 6

Summary of Oshawa Data

	Total	Number Reconvicted within 3½ years
1. Drivers Not Treated	58	9
2. Drivers Treated	62	12

It should be noted that the Oshawa Impaired Drivers Programme differs from the Alberta Impaired Drivers Program in duration (nine instead of four sessions) type of subjects (second offenders after imprisonment rather than "persons convicted of impaired driving") and of course in all the intangible but real differences between East and West (Oshawa is in Ontario).

The question whether data from Oshawa can be combined with data from Alberta is of central importance. It is one which transcends statistical reasoning. If one believes that by and large Ontarians respond to such treatment as Albertans do and that once subjected to a driver improvement course, it matters little whether it is four or eight sessions in duration, the two data sets should be combined and a common likelihood function written.

Returning to the imagery in Section 5.1, consider a decision maker in Ontario contemplating an Oshawa-type driver improvement programme. Before the institution of such a programme in Ontario and its evaluation, the "posterior " PDF in Figure 3 might be considered by the decision maker to be the best description of the effectiveness to expect. This is the basis on which to make decisions in spite of the aforementioned differences between the two Provinces. Once the Oshawa data is in, the PDF is revised again. The "posterior" from Figure 3 becomes the "prior" in Figure 4. The solid curve in Figure 4 represents best current knowledge based on data from Oshawa, Alberta and the initial opinions of DWI Coordinators. The expected value of θ is now 0.91 if one starts with the optimists (DWI Coordinators) and 0.93 starting from the opinions provided by what can now be called realists (researchers or psychologists).

6. Brief Summary

A message which runs counter to much of present practice is bound to raise discussion. To keep discussion on the central issues, it may be useful to restate the main points made.

Experimental data about the effect of many safety countermeasures comes often in small doses. Accordingly, the process of learning about the safety effect of countermeasures must allow for gradual accumulation of evidence. The classical hypothesis testing frame of thought is ill-suited for this task. In

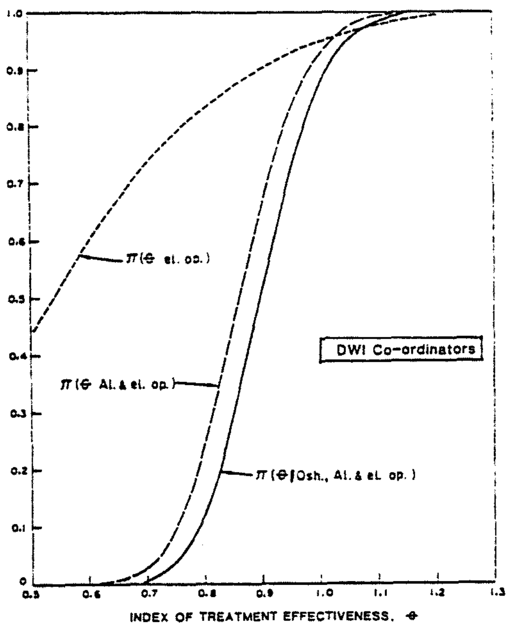

FIGURE 4

contrast, point estimation, the method of likelihood and the Bayesian probability revision machine are promising candidates. The decision making frame of reference is well served by the Bayesian machine. To keep data and opinion separate, it is useful to adhere to a reporting practice explicitly identifying the likelihood function and the original "prior".

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BAYESIAN METHODS APPLIED TO ROAD ACCIDENT BLACKSPOT STUDIES : SOME RECENT PROGRESS

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1. Introduction

Statistical methods for evaluating the effectiveness of treatment applied to a group of road accident blackspots are important for two reasons. First, they enable the engineer to see how successful the treatment has been, and to guide him towards the most effective deployment of alternative treatments at different types of site. Second, they enable the researcher to test and compare new forms of treatment objectively. However, the statistical methods commonly used in this field are not very well suited to the job. Their output tends to be expressed in the form

"the effect of this treatment is significant at the $\alpha\%$ level"

In other words, the treatment has probably brought about a reduction in the frequency of accidents at the treated sites. Conventional tests do not say a great deal about how large the reduction might have been, and whether it might be worth risking capital by investing in a particular form of treatment applied on a wide scale. Decision-making in a situation where the outcome is uncertain is a process which calls for a different type of analysis. (Hauer, 1981). Furthermore, because sites selected for treatment tend to be sites which have much higher observed accident rates than the main body of sites on the road network, there is a built-in bias or "regression-to-mean" effect which on average will result in a fall in accidents after treatment whether or not the treatment itself is successful (Gipps, 1980; Hauer 1980). Conventional methods of analysis do not take this into account.

Bayesian methods appear to offer a very useful alternative. The (unknown) annual accident rate at a blackspot is regarded as the value of a random variable having a probability distribution. Given the observed accident frequency over a recent period, Bayes' theorem is used to convert this 'prior' distribution into a 'posterior' distribution. Gipps (1980) and Abbess, Jarrett and Wright (1981) have shown that if the prior distribution is of gamma form, and if the number of accidents at the site has a Poisson distribution, then the posterior distribution is again a gamma distribution. The parameters of this posterior distribution can be derived very simply from the prior parameters and the observed data. Moreover, the mean of the posterior distribution is a prediction of the accident frequency in a future year, assuming that the true accident rate remains constant. (Note that this prediction takes account of the regression-to-mean effect.) This result provides a promising basis for a number of applications in accident analysis, assuming that the prior distribution is in fact gamma, or approximately so.

Abbess et al proposed that the observed distribution of accident rates at similar sites to the one under consideration would provide useful information on which to base the prior distribution, and some preliminary

tests with data from a rural county (Hertfordshire) revealed that the gamma distribution provided a reasonable fit. (Note that if the true accident rates follow a gamma distribution, the observed frequencies, which individually follow Poisson distributions about the various true means, will collectively appear to follow a negative binomial distribution. In actuality, it was a negative binomial distribution which was fitted to the observed frequencies, and the parameters of the gamma distribution of true rates were deduced from it.) However, the data showed a higher proportion of sites with low accident frequencies than would have been expected, and the parameters fluctuated somewhat from year to year.

In this paper, the results of some further tests are given. The data relate to 'accident nodes' in the City of Westminster, London, which are defined somewhat arbitrarily as junctions with appreciable numbers of accidents. In addition, the regression-to-mean effect is re-examined and given a slightly different interpretation from those put forward previously, and some developments aimed at constructing more realistic 'models' of accident variation, which take into account fluctuations in overall accident rates from year to year, are outlined.

2. Bayesian estimation of the regression effect

We suppose that in a time period of given duration the number of accidents at a given site has a Poisson distribution with mean m, so that the probability that x accidents will occur at this site in the period is

$$p\,(x|m) \;=\; \frac{e^{-m}\,m^{x}}{x!} \qquad (x = 0,\,1,\,2,\,\ldots) \qquad \ldots\ldots(1)$$

In addition, we suppose that the value of the true accident rate m varies amongst the population of sites according to a gamma distribution with parameters c and k, with probability density function

$$f\,(m) \;=\; \frac{c^{k}}{\Gamma\,(k)}\, m^{k-1}\, e^{-cm} \qquad (m > 0) \qquad \ldots\ldots(2)$$

This distribution [(1)] has mean k/c and variance k/c^2. The value of m at a particular site is regarded as being randomly selected from this distribution; $f(m)$ is the prior distribution of the true accident rate m.

Now suppose that, at a particular site, x accidents occur in the period. It follows from Bayes' theorem (see the references given in Abbess et al.) that the posterior distribution of m, i.e. the probability distribution of m given that x accidents have occurred, is again a gamma distribution but with parameters

$$c' = c + 1 \quad \text{and} \quad k' = k + x$$

(1) Notation

This paper	Abbess et al	Gipps
k	s_0	α
c	n_0	$1/\beta$

Its probability density function is therefore

$$f\,(m|x) \;=\; \frac{(c+1)^{k+x}}{\Gamma\,(k+x)}\; m^{k+x-1}\; e^{-(c+1)m} \qquad (m>o)$$

This posterior distribution reflects our uncertainty about the value of m after taking into account the fact that x accidents have occurred at the site. It can be regarded as describing the variation in m amongst those sites in the population at which x accidents occurred. The conversion of the prior into the posterior distribution is illustrated in Fig. 1 of Abbess et al.

The mean of this distribution is

$$E\,(m|x) \;=\; \frac{k'}{c'} \;=\; \frac{k+x}{c+1}$$

This is our estimate of the true accident rate m at a site at which x accidents occurred. Regarded as a function of x, E (m|x) is the <u>regression function</u>: it is the optimal predictor (in the least-squares sense) of the number of accidents which will occur at the site in a future time period - assuming, of course, that the value of m remains unchanged. The magnitude of the <u>regression effect</u> is the difference between E(m|x) and x. Notice that E (m|x) is a linear function of x, with slope 1/(c + 1). The parameter c is necessarily positive, so this slope is always less than unity. The regression line intersects the 45^{o} line where x = k/c (the mean of the prior distribution, i.e. the population mean of m). For values of x greater than k/c the regression effect is <u>negative</u>, indicating an expected <u>reduction</u> in the number of accidents. If x is less than k/c we expect an <u>increase</u> in the number of accidents. (See Fig.1.)

The expected percentage change in the number of accidents is

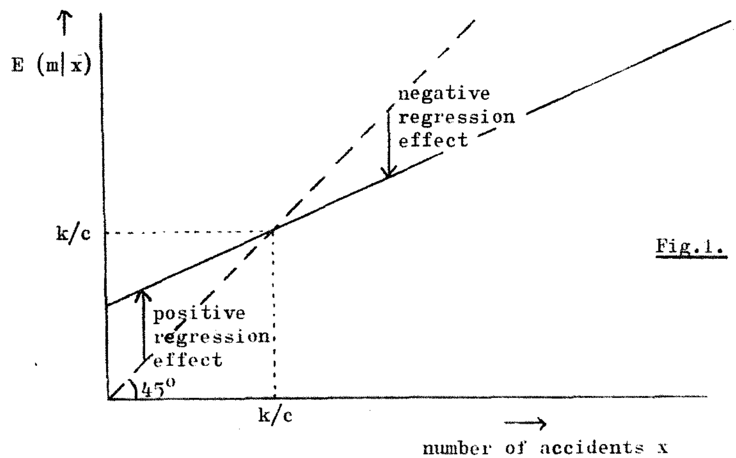

Fig.1.

$$R \;=\; \left[\frac{E(m|x)\;-\;x}{x}\right] \times 100\%$$

$$\;=\; \left[\frac{k+x}{c+1}\,\frac{1}{x} - 1\right] \times 100\%$$

The graph of R against x is a rectangular hyperbola and is illustrated in Fig. 4 of Abbess et al., which also shows the corresponding graphs where x is the <u>average</u> number of accidents over two and three time periods respectively.

Actual calculation of the regression effect requires knowledge of the values of c and k. As indicated in Abbess et al, although it is possible to adopt a <u>subjective</u> Bayesian approach, regarding the prior distribution as representing the investigator's prior beliefs about the value of m, and choosing the values of c and k so that f(m) accurately reflects these beliefs, it is more appropriate here to use an <u>empirical</u> Bayes method, and estimate the values of c and k from available accident data. Under the assumption that x has a Poisson distribution with mean m, while m itself has the prior gamma distribution f(m), the variability of x over all sites in the population is described by the probability distribution obtained by 'integrating out' m:

$$q(x) \;=\; \int_{o}^{\infty} p\;(x|m)\; f\;(m)\; dm$$

Under the assumptions made, it is easily shown that

$$q(x) \;=\; \frac{\Gamma\;(k+x)}{x!\;\Gamma\;(k)}\left(\frac{1}{1+c}\right)^{x}\left(\frac{c}{1+c}\right)^{k} \quad (x = 0,\,1,\,2,\,\ldots), \quad \ldots.(3)$$

a negative binomial distribution. (See Gipps, Abbess et al.) c and k can then be estimated by fitting this distribution to the observed accident distribution for a group of sites. If the numbers of accidents at different sites are independent random variables, and if the group of sites can be regarded as a random sample from the population of sites described by the prior distribution f(m), then the values of c and k can be estimated by the method of maximum likelihood.

Results using accident data for the County of Hertfordshire were given in Abbess et al, where it was found that the negative binomial distribution provided a reasonable fit for each of the years 1975 to 1978 and a slightly worse fit for 1979; however, different values of the parameters were needed for each year, possibly indicating that the true accident rates were <u>not</u> constant in time. Table 1 of this paper shows the result of fitting a negative binomial distribution to accident data for the City of Westminster in 1976. As suggested by Abbess et al, a truncated distribution has been fitted: effectively, the zero class has been ignored, in order to overcome the problem of the large number of sites at which no accidents occurred. The fit of the truncated negative binomial distribution to the data is illustrated in Fig. 2.

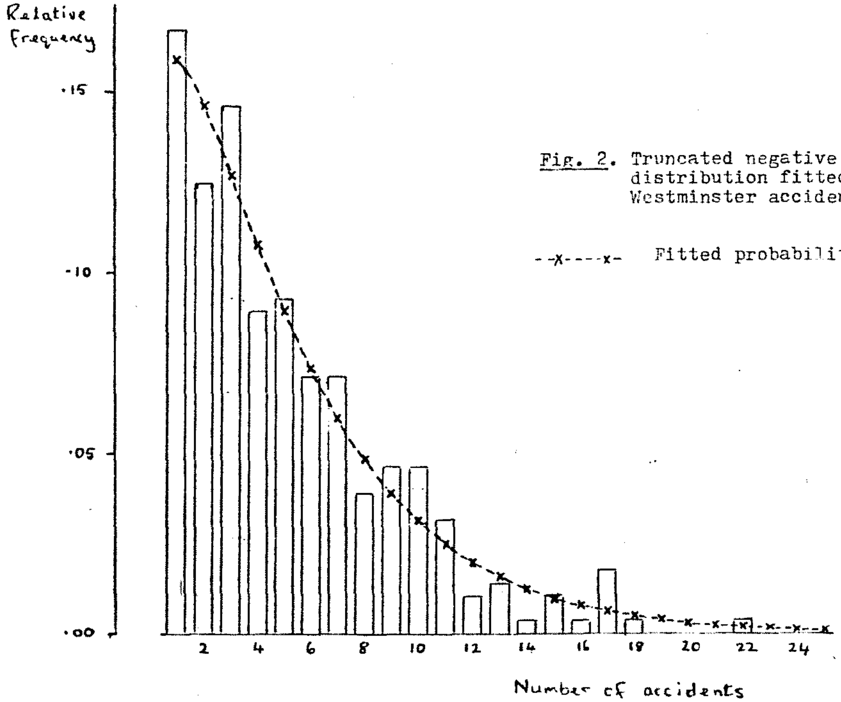

Fig. 2. Truncated negative binomial distribution fitted to Westminster accident data, 1976

Replacing c and k by their estimates gives the estimated regression function

$$\hat{m} = \frac{\hat{k} + x}{\hat{c} + 1} = \frac{\hat{k}}{\hat{c} + 1} + \frac{1}{\hat{c} + 1}\, x$$

For the Westminster data this gives

$$\hat{m} = 1.0696 + 0.7723\, x$$

This is plotted in Fig. 3.

3. A predictive test of the model

The regression function $E(m|x)$ gives the expected number of accidents at a site at which x accidents have occurred. If data for two time periods are available, we can test the predictive ability of our model by comparing $E(m|x)$ with the actual mean number of accidents in the second period for those sites at which x accidents occurred in the first period. We have in fact done this using data for Westminster for the years 1976 and 1977. For instance, at the 47 sites which had one accident each in 1976, there was a total of 102 accidents in 1977, giving an average of

Table 1. Fitting a truncated negative binomial distribution to Westminster accident data, 1976.

Number of accidents	Number of nodes[1]	Fitted frequency[2]
1	47	44.45
2	35	40.94
3	41	35.66
4	25	30.21
5	26	25.12
6	20	20.65
7	20	16.80
8	11	13.60
9	13	10.96
10	13	8.80
11	9	7.03
12	3	5.59
13	4	4.44
14	1	3.54
15	3	2.81
16	1	2.22
17	5	1.74
18	1	1.38
19	0	1.10
20	0	0.84
21	0	0.67
22	1	0.53
23	0	0.42
24	0	0.34
25	0	0.25
> 25	2(28,35)	0.90
Total	281	280.99

Notes: (1) There were in addition 189 nodes at which no accidents occurred.

(2) Fitted truncated negative binomial distribution with parameters $\hat{c} = 0.2949$, $\hat{k} = 1.3849$.

Table 2. Comparison of predicted and actual mean number of accidents, Westminster, 1977.

1976		1977		
Number of accidents	Number of sites	Mean number of accidents		Standard error of mean(3)
		Predicted(1)	Actual(2)	
x	f	$\hat{m}$	$\bar{y}_x$	$SE(\bar{y}_x)$
1	47	1.84	2.17	0.26
2	35	2.61	2.60	0.36
3	41	3.39	3.29	0.38
4	25	4.16	4.12	0.54
5	26	4.93	4.73	0.58
6	20	5.70	5.00	0.71
7	20	6.48	7.20	0.76
8	11	7.25	4.45	1.08
9	13	8.02	9.69	1.05
10	13	8.79	9.92	1.09
11	9	9.56	13.33	1.37
12	3	10.34	11.00	2.47
13	4	11.11	12.25	2.22
14	1	11.88	11.00	4.59
15	3	12.65	17.33	2.73
16	1	13.43	17.00	4.88
17	5	14.20	16.00	2.24
18	1	14.97	12.00	5.15
22	1	18.06	41.00	5.66
28	1	22.69	22.00	6.34
35	1	28.10	27.00	7.06

Notes: (1) $\hat{m} = \dfrac{\hat{k} + x}{\hat{c} + 1} = 1.0696 + 0.7723\,x$

(2) $\bar{y}_x$ = mean number of accidents 1977 at nodes with x accidents in 1976

(3) $SE(\bar{y}_x) = \sqrt{\dfrac{\text{var}\,(y|x)}{f}}$ where $\text{var}\,(y|x) = \dfrac{(\hat{c} + 2)\,(\hat{k} + x)}{(\hat{c} + 1)^2}$

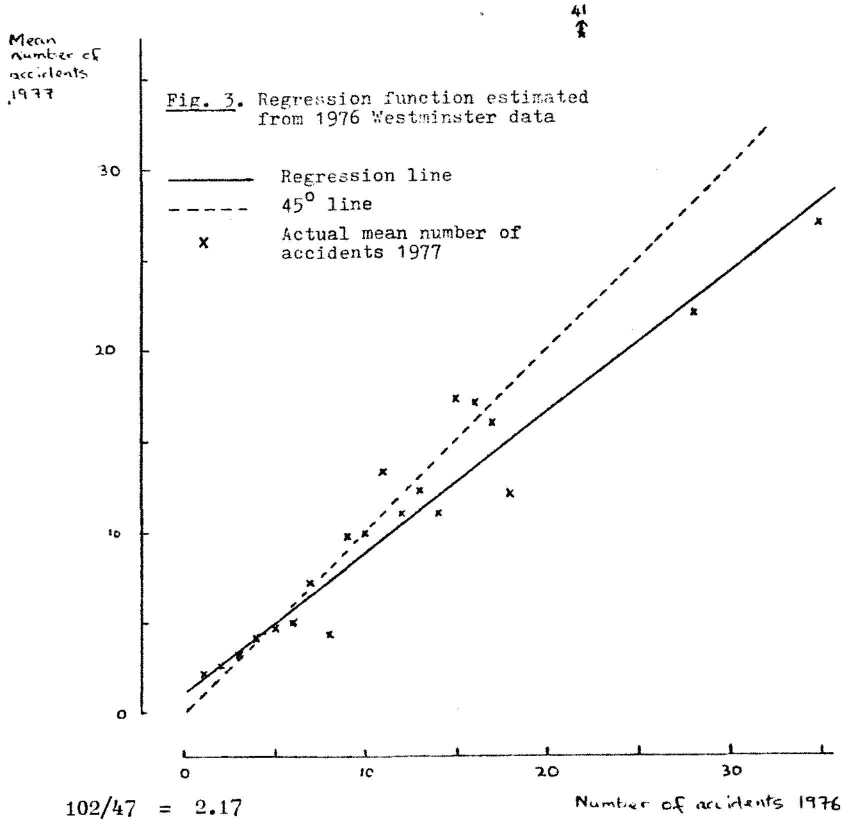

Fig. 3. Regression function estimated from 1976 Westminster data

$102/47 = 2.17$

accidents per site. Similar calculations were made for sites with 2, 3, 4, ... accidents in 1976, giving the results shown in Table 2 and plotted in Fig. 3. (Note that those sites at which no accidents occurred in 1976 have again been excluded; however it is important to include in the average those sites at which no accidents occurred in 1977). It will be seen that the first few points are extremely close to the predicted values, but that some of the points for larger values of x appear to be a long way off the predicted line.

We must be careful in interpreting these results, however, for two reasons. Firstly, the averages are based on samples of widely differing sizes (e.g. the mean for sites with 1 accident in 1976 is based on 47 observations, whereas the means for sites with 22, 28 and 35 accidents are based on one observation each). Secondly, as we show below, the natural variability of the number of accidents about the predicted mean increases with x. We need to find the standard errors of the sample averages before evaluating our predictions.

These standard errors can be found as follows. The distribution of the number y of accidents in the second period, given that x accidents occurred at that site in the first period, is obtained by 'integrating out' m as before - but now using the posterior distribution of m. Thus

$$p\ (y|x) \;=\; \int_0^\infty p\ (y|m)\ f\ (m|x\ )\ dm$$

Assuming that y has a Poisson distribution with mean m, and using the fact that f (m|x) is a gamma distribution with parameters $c' = c + 1$ and $k' = k + x$, we find that the predictive distribution p (y|x) is the negative binomial distribution

$$p\ (y|x) \;=\; \frac{\Gamma\ (k' + y)}{y!\ \ \Gamma\ (k')}\ \left(\frac{1}{1 + c'}\right)^{y} \left(\frac{c'}{1 + c'}\right)^{k'} \quad (y = 0,1,2,..) \qquad ...(4)$$

(C.f. Equation (4) of Abbess et al.) This has mean

$$E\ (y|x) \;=\; \frac{k'}{c'} \;=\; \frac{k + x}{c + 1} \;=\; E\ (m|x)$$

and variance

$$\text{var}\ (y|x) \;=\; \frac{k'\ (c' + 1)}{c'^2} \;=\; \frac{(k + x)\ (c + 2)}{(c + 1)^2}$$

Now suppose that there are f sites at which x accidents occurred in 1976. Then we have f observations on y in 1977, so the standard error of the mean $\bar{y}$ is

$$\sqrt{\frac{\text{var}\ (y|x)}{f}}$$

This is calculated in column 5 of Table 2.

Examination of the predicted and actual means shows that very few differ by more than would be expected on the basis of these standard errors. In fact, for only three values of x (8, 11 and 22) does the difference exceed two standard errors. Three out of a total of 21 values is perhaps more than we would like, but the following points should be borne in mind before rejecting the model on whose basis the predictions were made:

(1) The standard errors given here actually underestimate the true standard errors, since sampling error in the estimates of c and k has not been taken into account.

(2) The distribution of the sample means $\bar{y}$ will not be exactly Gaussian (normal), especially for small sample sizes f.

A more exact test of the adequacy of the predictions E (m|x) could perhaps be made using the negative binomial form of the predictive distributions. (See the remarks in section 4 of Abbess et al.) However, rather than considering this possibility here we will go on to consider the use of the bivariate frequency distribution of x and y as a means of testing the model.

4. A bivariate regression model

The term 'regression' is normally used in the context of a two-variable

model, and the reader may be wondering whether our use of the term 'regression function' for E (m|x) is justified. In fact we will see that E (m|x) is the same as the regression function obtained from the bivariate probability distribution of x and y.

To derive this distribution, suppose that the numbers of accidents x, y in successive time periods are independent Poisson variables with mean m. Then the joint probability distribution of x and y is p (x|m) p (y|m), where p (x|m) is given by Equation (1). To obtain the joint distribution of x and y over the whole population of sites, m is integrated out according to the prior f (m) to give

$$p\ (x,\ y) \;=\; \int_0^\infty p\ (x|m)\ p\ (y|m)\ f\ (m)\ dm\ .$$

When p has the assumed Poisson form, and f (m) is the gamma distribution (2), this can be shown to equal

$$p\ (x,\ y) \;=\; \frac{\Gamma\ (k + x + y)}{x\,!\ y\ !\ \Gamma\ (k)}\ \left(\frac{1}{2 + c}\right)^{x} \left(\frac{1}{2 + c}\right)^{y} \left(\frac{c}{2 + c}\right)^{k} \qquad ...(5)$$

$$(x,\ y \;=\; 0,1,2,\ ...).$$

This is (a special case of) a bivariate negative binomial distribution (see Rogers (1974), Johnson & Kotz (1969)). The marginal distributions of both x and y are ordinary negative binomial distributions (given by (3)), and the conditional distribution of y given x is

$$p\ (y|x) \;=\; \frac{p\ (x,\ y)}{q\ (x)}$$

$$= \frac{\left[\dfrac{\Gamma\ (k + x + y)}{x\ !\ y\ !\ \Gamma\ (k)}\ \left(\dfrac{1}{2 + c}\right)^{x} \left(\dfrac{1}{2 + c}\right)^{y} \left(\dfrac{c}{2 + c}\right)^{k}\right]}{\left[\dfrac{\Gamma\ (k + x)}{x\,!\ \Gamma\ (k)}\ \left(\dfrac{1}{1 + c}\right)^{x} \left(\dfrac{c}{1 + c}\right)^{k}\right]}$$

$$= \frac{\Gamma\ (k + x + y)}{y\,!\ \Gamma\ (k + x)}\ \left(\frac{1}{2 + c}\right)^{y} \left(\frac{1 + c}{2 + c}\right)^{k + x}\ .$$

Recalling that $c' = c + 1$, $k' = k + x$, this is seen to be equal to the predictive distribution (4). (Indeed, it follows from Bayes' theorem that this result holds whatever forms are assumed for the distributions p (x|m) and f (m).) Conversely, if x has the negative binomial distribution (3) and if the conditional distribution of y given x is given by (4), then the joint distribution of x and y is the bivariate negative binomial (5).

The regression function of y on x is the conditional expectation E (y|x) regarded as a function of x. But E (y|x) is the mean of the conditional (or predictive) distribution p (y|x) and we have already seen that this is equal to E (m|x). (Again this result holds for any distributions p (x|m) and f (m).) Thus our two uses of the term 'regression function' are equivalent.

The method we have used to estimate c and k provides an estimate of this regression function from one period's data only. Substitution of the estimates in Equation (5) gives estimates of bivariate negative binomial probabilities, again on the basis of one period's data. Comparison of this fitted bivariate distribution with actual frequencies would provide an overall test of the predictive ability of the model for a group of sites.

Alternatively, if two periods' data are available, we could fit the distribution using the bivariate frequency distribution. If the assumptions of the model are correct, this should give improved estimates of c and k and hence of the regression effect. It can be shown that the maximum likelihood estimates of c and k can be obtained from consideration of the distribution of the total number of accidents x + y at each site; this will again be a negative binomial distribution, with the parameter c replaced by c/2 (see Maritz (1970)). Preliminary results indicate that for the Westminster data the distribution of x + y may not be well-fitted by the negative binomial, so this simple model would appear to be inadequate. However, further work needs to be done before any definite conclusion can be reached.

A more complex model would allow the true accident rates m to vary with time. The simplest assumption would be that the ratio of the accident rates in the second period to those in the first period was a constant b, the same for all sites. The distribution of x and y will then be a more general bivariate negative binomial distribution. Two periods' data can be used to estimate the parameters of this distribution (which include b) and to test the hypothesis that b equals 1 (i.e. that the true accident rates are unchanged), or that b takes some other specified value; such a test would be particularly appropriate if applied to a group of treated sites, especially if a comparative group of control sites was available. However, it can be shown that such a test reduces to a standard test for the comparison of Poisson means (see Tanner (1958) or Cox and Lewis (1966) for this test): the introduction of the prior f (m) makes no difference to the analysis. However, the model should provide additional insight, and we hope to give more details of this model, and of its multivariate generalisation (for three or more time periods), at a later stage.

5. Conclusions

Four main conclusions can be drawn from this paper:

(i) Since our application of the Bayesian model generally to accident analysis depends for its simplicity on the assumption of a gamma prior, it is clearly important that the gamma prior should in fact be appropriate. Results obtained with the Westminster data confirm earlier results obtained with Hertfordshire data, insofar that the gamma distribution turns out to be a reasonable fit.

(ii) The regression-to-mean effect with the Westminster data is smaller than the corresponding effect with the Hertfordshire data, although it is far from negligible. It seems possible that for dense urban areas where the variance of the accident rates from site to site tends to be smaller, the regression-to-mean effect will generally be less pronounced than it is for rural areas.

(iii) The 'regression-to-mean' effect can be interpreted as a result of trying to predict accident rates in a future year by fitting a linear regression line to data from the past year: the 'best' prediction does not in general lie on the 45^{o} line, ie., it is not usually equal to the observed value in the past, for any individual site. This effect arises from the variability in the data itself, and its existence can be demonstrated by plotting observed accident rates for two consecutive years for a sample of sites (Fig. 3).

(iv) Although further tests still need to be carried out, in cases where it is desired to estimate the regression-to-mean effect for sites in any particular area, the formula given by Abbess, Jarrett and Wright (1981) will probably give a good enough estimate if the parameters c and k of the prior distribution are obtained by fitting a negative binomial distribution to the observed accident frequencies for comparable sites using the method of moments (see eq. 8, 10 and 11 in that paper).

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DETECTION AND ANALYSIS OF BLACK SPOTS WITH EVEN SMALL ACCIDENT FIGURES

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1. Accident black-spot techniques

Accident black spots are usually defined as road locations with (relatively) high accident potentials.
In order to detect such a hazardous location, we have to know the probability of an accident for a traffic situation of some kind (e.g. the crossing of a pedestrian or the encounter between two cars), or the mean number of accidents for some unit of time.
The comparison of the probability or the mean with some norm (absolute black spots) or with the probability or mean of other locations (relative black spots) may result in the detection of a black spot.
There are a lot of problems related to this definition. In order to define our sample space, we have to know what is and what is not an accident. Furthermore there are weighting problems if one is interested in loss resulting from accidents instead of accidents themselves (e.g. weighting with respect to severity). Although these problems are in general underestimated, we will not go into detail on this subject and concentrate on the general structure of black spot analysis.
In almost all known procedures, road locations are treated as isolated spots.
One tries to detect the black spots by estimating the expected number of future accidents at a specific location from the number of accidents that already have occurred at that location. For many locations, especially in built-up areas, the number of observed accidents is too small to give an accurate estimation of the accident potential. This leaves us with a very inaccurate ordering of locations with regard to accident risk. We know that the black spots on the average are placed higher on the list, but we cannot distinguish them sufficiently from the grey, or even white spots.

If one still uses this detection method, then the next problem is to find the causes of the supposed danger. Little information is given in the

small accident numbers and one is almost completely dependent on an ad-hoc analysis of the location, based on rather general theories only. This approach, in which locations are investigated as isolated spots, does not seem promising to us, especially not if the accident numbers are small.
An alternative procedure starts from the comparison between the road locations. The central question is: "what do accident black spots have in common and in which respects do they differ from safe locations?"
If we cannot relate accident figures to characteristics of the locations then treatment of black spots from general theories does not seem possible at all. Therefore we think that the analysis of black spots should start with the investigation of the relations between the characteristics of road locations and accidents for a group of locations that can be compared with each other.
Multiple linear regression analysis and canonical correlation analysis are often used to detect such relations.
In this case, however, there are a number of problems to be solved before these techniques can be applied. Several characteristics (such as the kind of road surface etc.) do not seem metric and some of the metric characteristics do not need to be linearly related to the probability of an accident. It seems not unreasonable to expect e.g. a curvilinear relation between the probability of an accident and the width of a road.
Furthermore, reflection on the combined effect of characteristics suggests to use multiplicative models instead of models that are additive in the independent variables the probability of an accident at a location with characteristic A and B will be equal to the product of the probabilities for A and for B if both are independent. Experimental evidence supports these multiplicative models (see: Rasch, 1973; Oppe, 1979).
However, new techniques are developed that account for all these problems. The solution of the problem is related to the canonical analysis of contingency tables approach as described e.g. by Kendall & Stuart, 1969 Vol II, pp 568 vv.
Recently Goodman (1981) compares this model with the log-linear models. The difference between both methods is that in the canonical analysis approach, one is interested in the scaling of variables in order to maximize the correlation or dependency, where as in log-lineair analysis

one rescales the variables under the assumption of independency. Interaction, or association as Goodman calls it, can be investiated within the loglinear model if one adds further restrictions on the residuals with regard to the row and column position of these residuals. Under special restrictions of this kind, both models result in identical solutions.
The fundamental idea behind the canonical-analysis approach is, that the computation of the correlation coëfficient between the "non-linear" row and column variable makes sense after the proper rescaling of these variables. The analysis results in that scaling of both variables that maximizes this correlation coëfficient.
If we generalize this procedure to multiway tables, then we arrive at some kind of non-linear principal-components analysis: variables are rescaled in such a way that they are as "homogeneous" as possible (which means that there mean intercorrelation is maximal).
A second generalization is found if we add new rows from different row variables to the table and eventually new columns from other new column variables. We then have some kind of super canonical-analysis problem, that reduces, after rescaling, to multiple linear regression (if there is only one column variable) or to the classical canonical correlation analysis (if there are more than one column variables).
These analysis techniques and the related computer programmes (Homals for the generalized homogeneity analysis and Canals for the generalized Canonical analysis) are developed at the Department of Data theory of the Leyden State University. A full description is given in Gifi (1981).

We will describe how we used these techniques for the description of the relations between accident figures and the characteristics of road locations.

2. Blackspot data

SWOV started an extensive research project in one of the Dutch provencies, called Noord-Brabant. This research was financed by the Ministry of Transport and the Noord-Brabant Provincial Council. One of the investigations within the project was concerned with a description of the relations between many accident-, road- and traffic characteristics of almost all public roads outside built-up areas in that province. Data collection is done by the Provincial Public Works Department and the

regional department of "Rijkswaterstaat". The engineering office D.H.V. took care of all data handling necessary before starting the analyses of this data.
The roads were classified in single-lane and dual-lane roads and each class consisted of three sub-categories. Each road was divided in parts of 100 meters. Intersections were deleted in the first analysis. New studies, concerning the intersections and larger units (routes) take place at the moment. A full report of this study is found in SWOV (1981). We use only some of the results, in order to demonstrate the usefulness of the relational techniques for black-spot analysis.
In Table 1 one will find the marginals, with regard to the total number of injury accidents for each group of road locations. Black-spot detection and analysis based on the accident figures of these locations as such do not seem practical at all.

We see that motorways have on the average the lowest number of accidents. The highest mean number of accidents (M) is found with dual-lane roads closed for slow traffic. If we correct for traffic flow then the single-lane roads will most likely turn out to be more dangerous.
As to the variance (V) we see that this measure exceeds the mean, except for the dual-lane roads closed for slow traffic. The z-values, standard normal values derived from the Poisson index of dispersion which is defined as

$$X^2 = \sum_{i=1}^{T} (X_i - M)^2/M)$$

are significant, except for the one road category mentioned. This suggests that all other sets of roads are heterogeneous and an investigation with regard to differences in accident potential does make sense.
In a mixed Poisson distribution, an estimate of the variance in Poisson parameters is given by the difference between the variance and the mean of X (see last column in Table 1).
If we delete the locations without accidents and fit a truncated Poisson distribution to this data, then we find that not only the number of locations without accidents, but also the number of locations with 1, 4 and 5 accidents are systematicly underestimated, while the numbers for 2

and 3 accidents are overestimated. Therefore it is [illegible] the difference between locations with and without accidents that accounts for the variance in the Poisson parameters. Estimates with corresponding χ^2-values and df (ignoring the zero class) are given in Table 2. The estimates for the negative binomial distribution and the corresponding χ^2-values are also given in Table 2. Here the zeroclass has been included. These values show a reasonable fit. The χ^2-value is significant only for the category of roads with mixed traffic. This suggests that the distribution of X is indeed a mixed Poisson distribution of a type as found by Greenwood & Yule (1920). The distribution of Poisson parameters for the category of roads with mixed traffic is perhaps more complicated then that of the other road types.

3. Application of relational techniques for the analysis of road sections with mixed traffic

The major aim of the analyses that we have done first was to find relations between 26 road and traffic characteristics of the 3833 single-lane roads with mixed traffic and their observed number of accidents.
A list of these characteristics is found in the legenda of Figure 2. As can be seen from table 1, most of the locations do not have injury accidents within the 5-year period. We have accomplished a second analysis using only the 685 accident locations. Both Canals analyses are in fact "non-linear" multiple-regression analyses, because there was only one dependent variable: the total number of injury accidents. From Figure 1 we can see that both in the first and in the second analysis the scaling of the dependent variable is logarithmic. This is in agreement with the assumption of a multiplicative (log-linear) model: the model is linear in the independent variables with regard to the log-value of the accident numbers. Also the conclusion, drawn from the fit of the truncated Poisson distribution, that the difference in Poisson parameters is more complicated than between locations with and without accidents, is confirmed with this scaling. If there had been a clear distinction, then we should have found a dichotomous scale. The scale found here suggests a more continuous distribution of accident probabilities.
Here we will not discuss the solutions with respect to the independent variables. The main difference in both solutions was due to the influence

	Number of accidents (X)										
dual lane roads:	0	1	2	3	4	5^+	T	M	V	Z	V-M
1. motorways	873	139	21	8	1	-	1042	.201	.258	6.17	.057
2. other road for motor vehicles	207	49	15	5	8	-	284	.444	.776	8.15	.332
3. roads closed for slow traffic	68	40	12	1	-	-	121	.554	.495	-.75	-
single lane roads:											
1. roads for motor vehicles	345	50	23	4	9	-	431	.334	.636	11.18	.302
2. roads closed for slow traffic	1867	329	113	41	22	8	2380	.339	.600	22.89	.260
3. roads with mixed traffic	3148	424	167	56	27	11	3833	.284	.520	30.93	.236

Table 1. Accident figures for almost all non-reconstructed 100 meter sections (intersections excluded) of primary and secundary roads outside built-up areas in Noord-Brabant. Data are collected over the five year-period from 1971 through 1975.

	Truncated Poisson							Negative Binomial						
	0	1	2	3	4	5^+	χ^2 /df	0	1	2	3	4	5^+	χ^2 /df
D1	304.9	134.5	29.6	4.4	.5	-	6.08/2	873.5	136.1	25.8	5.2	1.4	-	1.83/2
D2	39.6	42.8	23.1	8.3	2.2	.5	15.45/3	204.9	50.7	17.5	6.6	2.6	1.7	4.01/3
D3	84.0	41.1	10.0	1.6	.2	-	.78/2	67.4	41.7	10.5	1.3	.1	-	.40/2
S1	40.6	46.2	26.3	10.0	2.8	.6	13.55/3	339.7	59.7	19.4	7.3	2.9	2.0	7.25/3
S2	306.2	301.3	148.3	48.6	12.0	2.4	30.13/4	1851.8	353.8	110.9	39.3	14.7	9.5	5.84/4
S3	391.2	395.9	200.3	67.6	17.1	3.5	26.86/4	3116.9	483.7	147.3	52.2	19.8	13.1	13.54/4

Table 2. Estimated values and the corresponding χ^2-values and df's for the truncated Poisson distribution and the negative binomial distribution for the data of table 1.

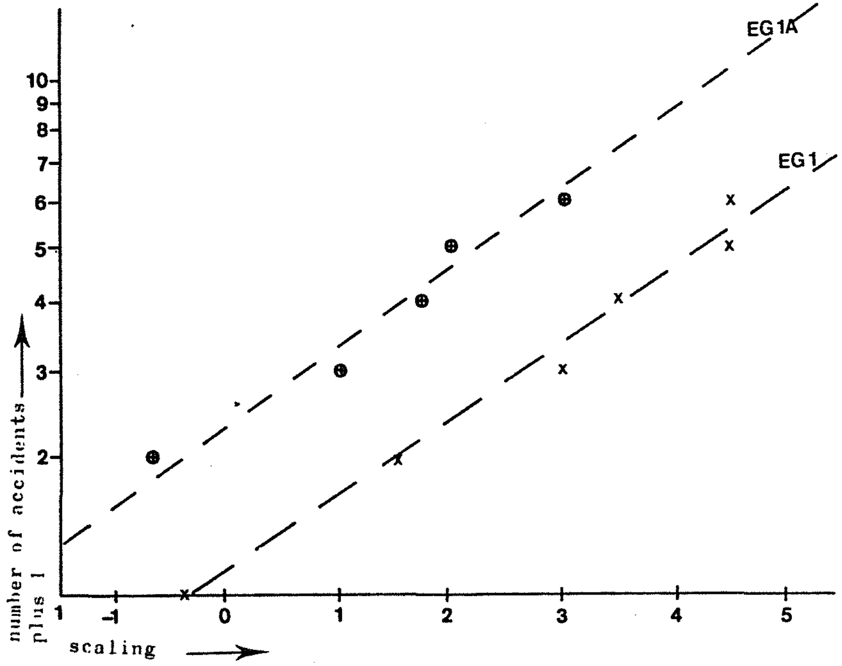


Fig 1. scale value versus number of accidents (on a log-scale) , For the total set of locations with mixed traffic (EG 1) and for the set of accident locations with mixed traffic (EG 1A).

of traffic volume on accident numbers. Traffic volume is an important variable in the analysis of all locations but not in the analysis of accident locations only.
Succeeding analyses were concerned with more than one dependent variable. In these analyses various types of accidents were investigated together with the total number of accidents. The total number of accidents was included in each analysis in order to find an explanation for the specific accident types in addition to the explanation of the total number of accidents. For these analyses we used only the 685 locations with accidents. Some analyses had more than two dependent variables. We will describe one of these non-linear canonical analyses here in order to explain the black spot method. We choose the analysis with the total number of accidents and the number of fatal accidents as dependent variables. This analysis has been done in order to investigate to what

extend the explanation of the most severe accidents differs from that of less severe accidents.
The first canonical axis corresponds almost completely to the total number of accidents. The canonical correlation after rescaling is $r_{c1} = .41$.
The second canonical axis corresponds primarily to the number of fatal accidents. The canonical correlation for this axis is $r_{c2} = .27$. In order to visualize relations between variables, we may represent variables graphicly by vectors in a space spanned by the locations (a space with 685 dimensions). The correlation between two variables is then represented by the cosine of the angle between the corresponding vectors. A correlation of 1 means a cosine of 1 and an angle of 0 degrees. A correlation of 0 means an angle of 90 degrees.
In figure 2 the projection of the independent variables on the plane through the dependent variables (in the space spanned by the locations) is given for the scaled variables.
Figure 3 shows us the scaling of the dependent variables and the most important independent variables for the explanation i.e. the variables with the largest projections. If we look at the canonical correlations, then at first glance these values seem to be low. Especially for a situation where 26 independent variables are used which are rescaled such that the canonical correlation is maximal. We did a bootstrap analysis to investigate the stability of the solution. This bootstrap analysis was done by taking samples (with replacement) from the 685 locations. In order to make comparisons with the original analysis, each sample existed again of 685 locations. We concluded that the results were more stable than expected. A plot of the mean bootstrap-analysis is given in figure 4. From this bootstrap study we estimated the canonical correlations for the population to be $r_{c1} = .35$ and $r_{c2} = .20$ for the first and second dimension.

Reflection on these figures learned that the the correlations may be that low primarily due to the low accident figures for each location and not because of the non-existence of relations between the accident probabilities and the characteristics of the locations. We cannot predict such small accident figures for locations accurately even if we know the real accident probabilities. This was in fact our initial problem. In

order to investigate to what extend this effect might influence our results, we did a Monte-Carlo study as follows.
The canonical scores for the locations that resulted from the analysis may be regarded as proportional to the logarithm of the probability of an accident at that location, because of the fact that the first canonical axis almost completely coincides with rescaled number of accidents. Therefore we transformed these values into real accident probabilities

for the 685 locations and regarded these values as real population values. We then used these values as multinomial probabilities in an experiment in which we distributed 404 accidents over the 685 locations, according to the multinomial probabilities. We have chosen this number of accidents, because there are 1089 - 685 = 404 accidents that are freely distributed over the total set of accident locations.
Then we computed the correlation between the accident probabilities and the number of allocated accidents that resulted from the multinomial experiment. The mean correlation for 100 of these Monte-Carlo runs was r = .45. Using samples of 10 times as much accidents (4040 accidents), we found r = .84, this to give an indication of the increase of r with sample size. From the Monte-Carlo study we conclude that the maximum value to be expected for the canonical correlation of the first dimension is .45. The estimated population-value of r_{c1} = .35, resulting from the bootstrap study, seems rather high if we compare this value with the maximum of .45.
Therefore our conclusion is that, because we used the information of all locations together in our canonical analysis, we were able to predict the accident probability for each location a lot better from the road and traffic characteristics of the locations than it should have been possible using their individual accident number only.
Furthermore, this analysis gives us the relation between the danger and the road and traffic characteristics. This information can be used in order to take countermeasures.

4. Black-spot investigation based on non-metric canonical analysis

In the previous paragraphs, we found that the accident probabilites of locations differ especially for roads with mixed traffic. Furthermore we found that relational techniques for categorical data seem to be useful

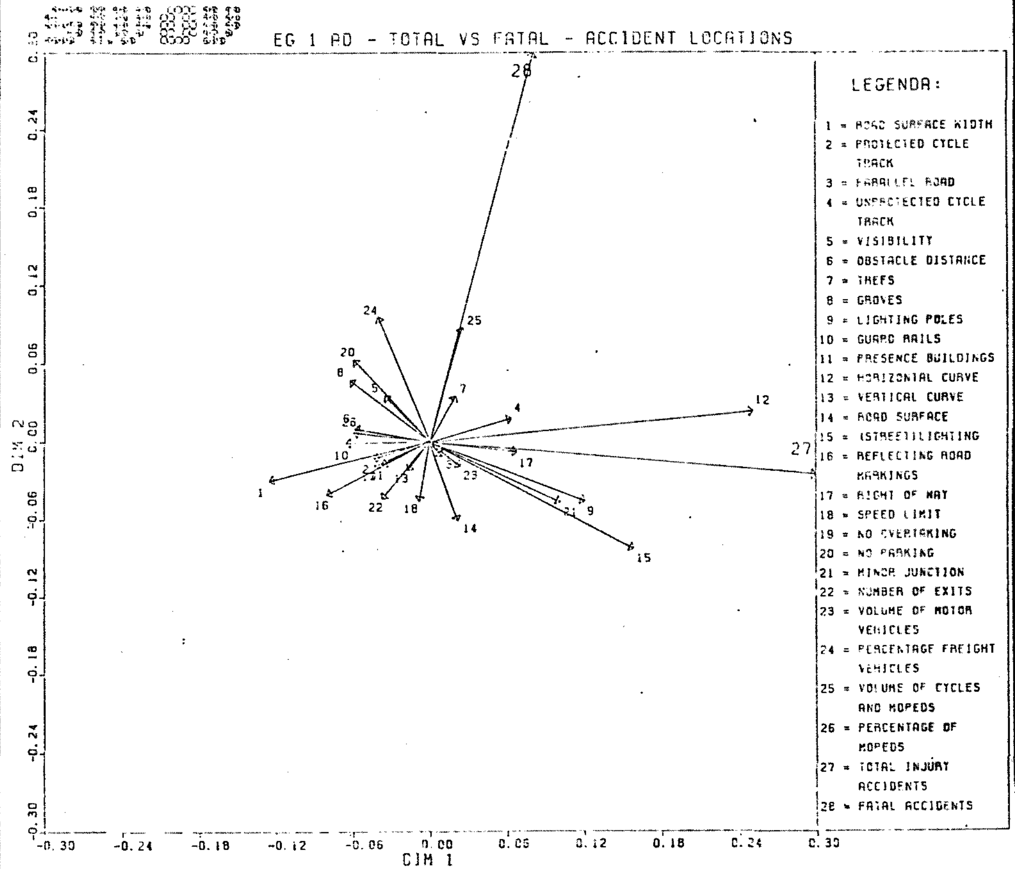


Figure 2

techniques to predict accident potential. We will give here a more explicite description of how these techniques can be used for black spot analysis.
In order to accomplish an analysis as described, we have to collect the relevant data for the investigation. The object of investigation may be

an intersection, a road section of some specific length as we used in the example, a pedestrian crossing in a small residential area, although the detailed comparison of complete areas will become increasingly difficult. For each object we have to measure the criterion value(s), e.g. the total number of injury accidents, accidents at daytime and nighttime, accidents with pedestrians involved etc.

Furthermore we must select the relevant characteristics of the units with regard to the explanation of our criterion. For black spot analysis, this will be primarily variables that are related to road characteristics or road conditions and controlling variables such as traffic volume, percentage of freight vehicles etc. This results in a "data matrix" consisting of n rows, corresponding to the n objects and m columns corresponding to the m characteristics. After the Canals analysis we get a new data matrix of rescaled variables. This rescaling is part of the solution that describes the relation between the criterion and the road and traffic characteristics. In addition, the solution results in an ordering of the characteristics with regard to the contribution of the independent variables to the explanation of safety. Finally we get an ordering of the locations with regard to unsafety.

In the example that has been described, we find a rescaling for each characteristic, and an ordering of objects and variables for each dimension. Table 3 shows this ordering for the first dimension. Only the five most important explaining variables are represented for the 25 most dangerous and 25 least dangerous locations. Table 4 shows us the same data for the second dimension. Figure 3 gave us the scaling of the five major independent variables for each dimension and the scaling of the dependent variables.

If we look e.g. at location 3 and 4 of Table 3, we see that these are two adjacent locations that are curved and have two and three minor crossings respectively. Furthermore the road is rather small at these points (< 6 m) and has orientation lighting. One location has one accident, the other has three accidents, including one fatal accident. Figure 5 gives us an idea of these locations.

A plot of the most dangerous locations on a map may suggest structural countermeasures. An analysis of and comparison with the least dangerous spots may also suggest countermeasures.

From Table 4 we see that if we want to concentrate on fatal accidents, countermeasures with regard to a high percentage of freight vehicles,

Table 3

location code	canonical score for set of road and traffic variables	canonical score for set of accident variables	total number of accidents + 1	number of lethal accidents + 1	horizontal curve	lighting	road surface width	lamppoles	number of minor junctions
10210716	3.699	1.735	4	1	-0.547	1.062	-0.806	11.180	3.486
10210405	3.197	0.845	3	1	1.929	1.062	0.146	5.336	-0.280
10208437	3.052	-0.756	2	1	1.929	1.062	-0.806	0.517	3.486
10208436	2.945	1.810	4	2	1.929	1.062	-0.806	0.517	4.203
10205126	2.859	0.920	3	2	1.929	1.062	0.146	-0.223	-0.280
10205117	2.720	0.845	3	1	1.929	1.062	-0.806	-0.223	-0.280
10201623	2.590	-0.756	2	1	1.929	1.062	0.146	5.336	3.486
10208404	2.572	1.735	4	1	1.929	1.062	-0.806	0.517	-0.280
10210418	2.493	1.810	5	2	1.929	1.062	-0.806	0.517	-0.280
10205672	2.420	0.845	3	1	1.929	1.062	-0.806	-0.223	-0.280
10210854	2.414	1.735	4	1	1.929	1.062	1.563	0.517	-0.280
10200417	2.296	1.735	4	1	-0.547	1.062	0.146	11.180	-0.280
10210415	2.250	0.845	3	1	1.929	1.062	-0.806	0.517	-0.280
10204427	2.236	0.845	3	1	1.929	1.062	-0.806	-0.223	-0.280
10205664	2.188	-0.756	2	1	1.929	1.062	-0.806	-0.223	-0.280
10204420	2.185	0.920	3	2	1.929	1.062	-0.806	-0.223	3.486
10210403	2.181	0.845	3	1	1.929	1.062	-0.806	0.517	-0.280
10201868	2.174	0.845	3	1	1.929	-0.942	0.146	-0.223	-0.280
10202556	2.139	0.845	3	1	1.929	1.062	-0.806	0.517	-0.280
10201019	2.090	0.920	3	2	-0.547	1.062	-0.806	5.336	-0.280
10200419	2.057	0.845	3	1	1.929	1.062	1.563	5.336	-0.280
10206377	2.041	2.922	6	3	1.929	-0.942	1.563	0.517	-0.280
10210428	2.032	0.920	3	2	1.929	1.062	-0.806	0.517	-0.280
10202010	2.011	-0.756	2	1	1.929	1.062	-0.806	-0.223	-0.280
10211227	2.008	1.735	4	1	1.929	1.062	-0.806	0.517	-0.280

25 locations with highest canonical scores on first dimension

10202430	-1.689	-0.756	2	1	1.929	1.062	1.563	-0.223	-0.280
10202418	-1.691	-0.756	2	1	-0.547	-0.942	1.563	-0.223	-0.280
10206117	-1.770	-0.756	2	1	-0.547	-0.942	1.563	-0.223	-0.280
10202428	-1.791	-0.756	2	1	1.005	-0.942	1.563	-0.223	-0.280
10210388	-1.804	-0.756	2	1	-0.547	-0.942	1.563	-0.223	-0.280
10210692	-1.816	-0.756	2	1	-0.547	-0.942	1.563	-0.223	-0.280
10130352	-1.827	-0.756	2	1	-0.547	-0.942	1.563	-0.223	-0.280
10210335	-1.858	-0.681	2	2	-0.547	1.062	1.563	0.517	-0.280
10209612	-1.876	-0.756	2	1	-0.547	1.062	1.563	0.517	-0.280
10208991	-1.927	-0.756	2	1	-0.547	1.062	-0.806	-0.223	-0.280
10209650	-1.955	0.845	3	1	-0.547	-0.942	0.146	-0.223	-0.280
10204492	-1.957	-0.756	2	1	-0.547	-0.942	-0.806	-0.223	-0.280
10202411	-2.116	-0.756	2	1	-0.547	-0.942	1.563	-0.223	-0.280
10202395	-2.124	-0.756	2	1	-0.547	-0.942	1.563	-0.223	-0.280
10211478	-2.223	-0.756	2	1	-0.547	1.062	1.563	0.517	-0.280
10130379	-2.227	-0.756	2	1	-0.547	-0.942	1.563	-0.223	-0.280
10208990	-2.230	-0.756	2	1	-0.547	1.062	-0.806	-0.223	-0.280
10208963	-2.230	-0.756	2	1	-0.547	1.062	-0.806	-0.223	-0.280
10208966	-2.230	-0.756	2	1	-0.547	1.062	-0.806	-0.223	-0.280
10209610	-2.264	-0.756	2	1	-0.547	1.062	1.563	-0.223	-0.280
10206253	-2.299	-0.756	2	1	-0.547	-0.942	1.563	-0.223	-0.280
10202406	-2.334	-0.756	2	1	-0.547	-0.942	1.563	-0.223	-0.280
10209641	-2.437	-0.756	2	1	-0.547	-0.942	0.146	0.517	-0.280
10209646	-2.606	-0.756	2	1	-0.547	-0.942	0.146	-0.223	-0.280
10202126	-2.667	-0.756	2	1	-0.547	1.062	1.563	-0.223	-0.280

25 locations with lowest canonical scores on first dimension

order of the locations with regard to the predicted accident potential
(first canonical dimension) together with information about the most relevant characteristics

Table 4

location code					percentage of freight-vehicles	moped and bicycle volume	lighting	par king prohibited	road surface
10204992	4.957	-0.014	2	1	2.693	0.816	-0.942	2.699	-0.056
10204994	4.957	-0.443	3	1	2.693	0.816	-0.942	2.699	-0.056
10204987	4.094	9.066	4	3	2.693	0.816	1.062	2.699	-0.056
10204985	4.063	9.304	3	3	2.693	0.816	1.062	2.699	-0.056
10204984	3.794	-0.014	2	1	2.693	0.816	1.062	2.699	-0.056
10208951	3.488	-0.014	2	1	2.693	0.816	1.062	-0.346	2.183
10204792	3.328	-0.014	2	1	2.693	0.816	-0.942	-0.346	-0.056
10201603	3.286	0.867	2	2	0.128	0.816	-0.942	-0.346	-0.056
10204788	3.195	0.438	3	2	2.693	0.816	-0.942	-0.346	-0.056
10204790	3.128	-0.443	3	1	2.693	0.816	1.062	-0.346	-0.056
10206395	2.961	-0.443	3	1	2.693	0.816	-0.942	-0.346	-2.055
10210925	2.911	-0.778	6	1	2.693	-1.134	-0.942	2.699	-0.056
10210930	2.844	-0.014	2	1	2.693	-1.134	-0.942	2.699	-0.056
10201606	2.733	9.304	3	3	0.128	0.816	-0.942	-0.346	-0.056
10210921	2.534	-0.014	2	1	2.693	-1.134	-0.942	2.699	-0.056
10210920	2.534	-0.014	2	1	2.693	-1.134	-0.942	2.699	-0.056
10211647	2.441	-0.443	3	1	0.128	1.314	1.062	2.699	-0.056
10206402	2.394	-0.014	2	1	2.693	0.816	1.062	-0.346	-2.055
10204942	2.332	0.867	2	2	0.128	0.816	-0.942	2.699	-0.056
10206387	2.256	-0.443	3	1	0.128	0.816	-0.942	-0.346	-2.055
10204934	2.245	0.867	2	2	0.128	0.816	-0.942	2.699	-0.056
10208004	2.199	-0.014	2	1	0.128	-1.134	-0.942	-0.346	-0.056
10204492	2.196	-0.014	2	1	0.128	-1.134	-0.942	-0.346	-0.056
10206380	2.157	-0.014	2	1	0.128	0.816	-0.942	-0.346	-2.055
10206385	2.157	-0.014	2	1	0.128	0.816	-0.942	-0.346	-2.055

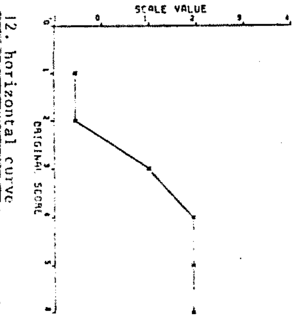
25 locations with highest canonical scores on second dimension

10202097	-1.623	-0.014	2	1	-0.416	-1.134	-0.942	-0.346	-0.056
10202556	-1.690	-0.443	3	1	-0.416	-1.134	1.062	-0.346	-0.055
10201651	-1.691	-0.014	2	1	0.128	-1.134	1.062	-0.346	-0.056
10208399	-1.692	-0.682	4	1	0.128	-1.134	1.062	-0.346	-0.056
10206174	-1.694	-0.682	4	1	-0.416	-1.134	1.062	-0.346	-0.056
10200417	-1.715	-0.682	4	1	0.128	0.816	1.062	-0.346	-0.055
10203438	-1.731	-0.443	3	1	0.128	0.816	1.062	-0.346	2.183
10202416	-1.760	-0.014	2	1	-0.416	-1.134	1.062	-0.346	2.183
10202363	-1.787	-0.443	3	1	-0.416	-1.134	1.062	-0.346	2.183
10201626	-1.805	-0.443	3	1	0.128	-1.134	1.062	-0.346	-0.056
10206167	-1.806	-0.443	3	1	-0.416	-1.134	-0.942	-0.346	-0.056
10206172	-1.806	-0.014	2	1	-0.416	-1.134	-0.942	-0.346	-0.056
10202096	-1.813	-0.443	3	1	-0.416	-1.134	-0.942	-0.346	-0.056
10211055	-1.843	-0.014	2	1	-0.416	-1.134	1.062	2.699	2.183
10206081	-1.868	-0.014	2	1	0.128	1.314	1.062	-0.346	-0.056
10203272	-1.887	-0.443	3	1	0.128	0.816	-0.942	-0.346	-2.055
10201583	-1.921	-0.014	2	1	0.128	-1.134	1.062	-0.346	-0.056
10202391	-1.924	-0.014	2	1	-0.416	-1.134	1.062	-0.346	2.183
10205111	-1.930	-0.014	2	1	-5.556	-2.129	1.062	-0.346	2.183
10202401	-2.009	-0.014	2	1	-0.416	-1.134	1.062	-0.346	2.183
10203441	-2.210	-0.014	2	1	0.128	0.816	1.062	-0.346	2.183
10206554	-2.269	-0.014	2	1	0.128	-1.134	1.062	-0.346	-0.056
10205106	-2.625	-0.443	3	1	-5.556	-2.129	1.062	-0.346	2.183
10201623	-2.845	-0.014	2	1	0.128	-1.134	1.062	-0.345	-0.056
10200221	-3.443	-0.014	2	1	-0.416	0.816	1.062	-0.346	-0.056

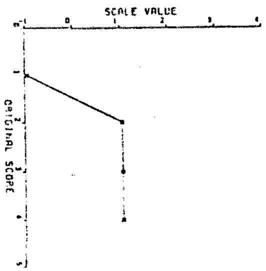
25 locations with lowest canonical scores on second dimension

order of the locations with regard to the predicted number of lethal accidents (second canonical dimension) with information about the most relevant characteristics

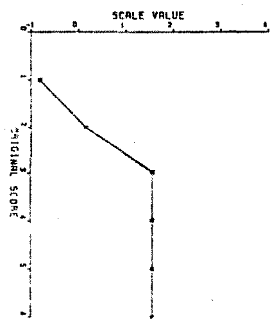
Figure 3a



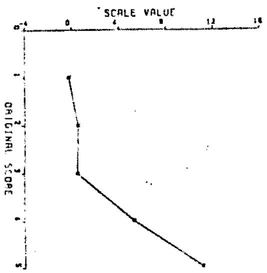
12. horizontal curve
cat. 1 (-0.547): no (C ≥ 1000 m)
cat. 2 (-0.547): 700 ≤ C < 1000 m
cat. 3 (1.005): 500 ≤ C < 700 m
cat. 4 (1.929): 400 ≤ C < 500 m
cat. 5 (1.929): 200 ≤ C < 400 m
cat. 6 (1.929): C < 200 m



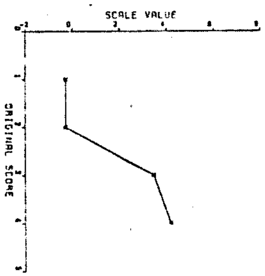
15. lighting
cat. 1 (-0.942): not present
cat. 2 (1.602): partially
cat. 3 (1.062): orientation lighting
cat. 4 (1.062): full lighting



1. road surface width
cat. 1 (-0.806): W ≤ 6.0 m
cat. 2 (0.146): 6.0 < W ≤ 6.5 m
cat. 3 (1.563): 6.5 < W ≤ 7.0 m
cat. 4 (1.563): 7.0 < W ≤ 7.5m
cat. 5 (1.563): 7.5 < W ≤ 8.0 m
cat. 6 (1.563): W > 8.0 m

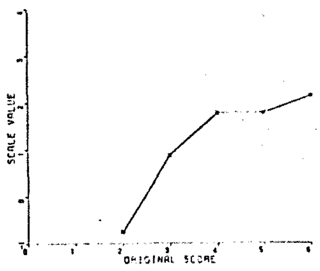


9. lamppoles
number of section parts of lamppoles
cat. 1 (-0.223): 0
cat. 2 (0.517): 1
cat. 3 (0.517): 2
cat. 4 (5.336): 3
cat. 5 (11.180): 4

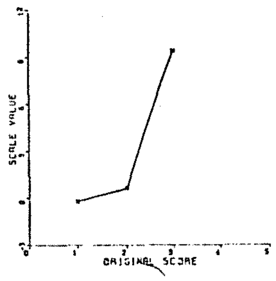


21. number of minor junctions
cat. 1 (-0.280): 0
cat. 2 (-0.280): 1
cat. 3 (3.486): 2
cat. 4 (4.203): 3

Figure 3c

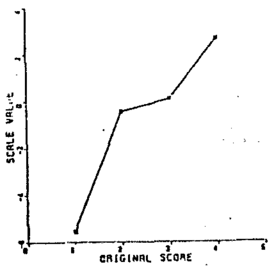


27. total number of accidents
cat. x: number of accidents plus 1

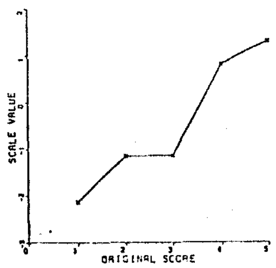


28. lethal accidents
cat. x: number of lethal accidents plus 1

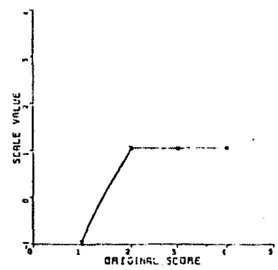
Figure 3b



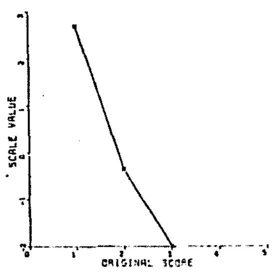
24. percentage of freight vehicles
cat. 1 (-5.556): null
cat. 2 (-0.416): 0 < P ≤ 10
cat. 3 (0.127): 10 < P ≤ 20
cat. 4 (2.693): P > 20



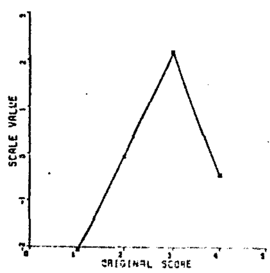
25. volume of cycles and mopeds
cat. 1 (-2.129): V = 0
cat. 2 (-1.134): 0 < V ≤ 117
cat. 3 (-1.134): 118 ≤ V ≤ 351
cat. 4 (0.816): 352 ≤ V ≤ 1053
cat. 5 (1.314): > 1054



15. lighting
cat. 1 (-0.942): not present
cat. 2 (1.062): partially
cat. 3 (1.062): oriëntation lighting
cat. 4 (1.062): full lighting

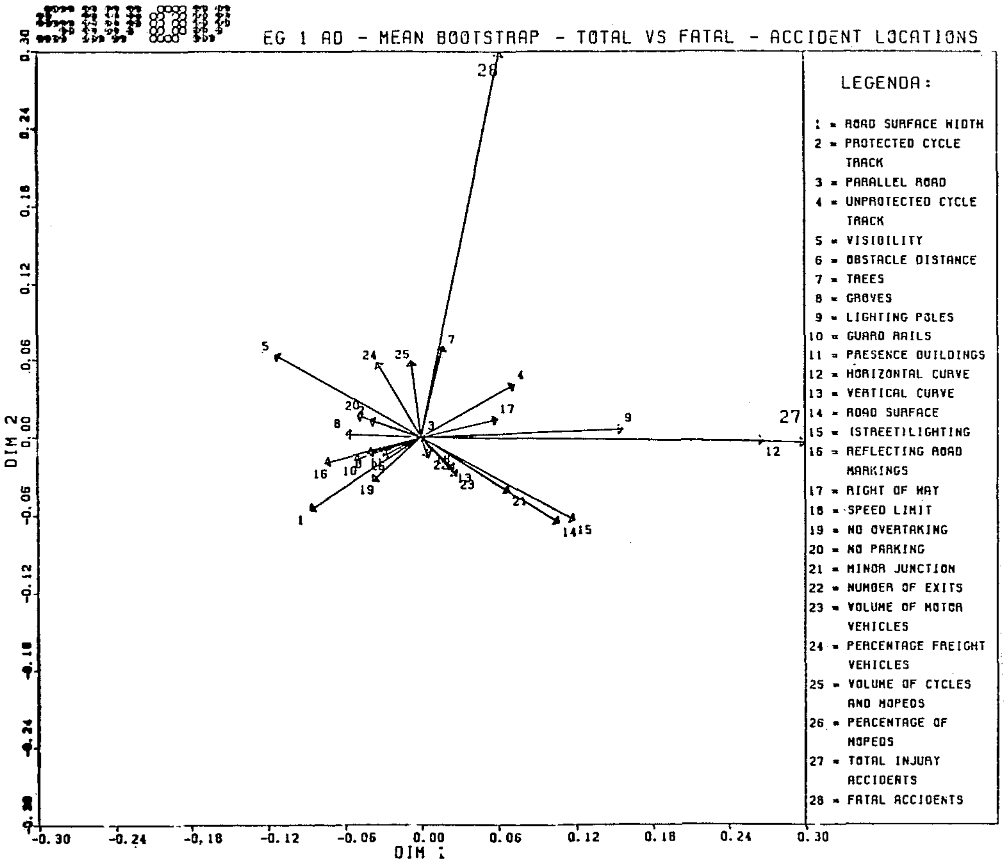


20. no parking
cat. 1 (2.699): parking allowed
cat. 2 (-0.346): no parking because of road type
cat. 3 (-1.984): no parking because of shield



14. road surface
cat. 1 (-2.055): concrete
cat. 2 (-0.056): asphalt
cat. 3 (2.183): pavingbricks
cat. 4 (-0.453): setts

Figure 4



together with high bicycle volumes seem to be urgent. The first five locations are almost adjacent. Two of the locations have two fatal accidents. Figure 6 gives us an idea of these locations. Structural measures instead of measures on the locations itself seem to be indicated here.

Fig. 5. Hazardous location of first dimension

This is just an example to show that this technique works and how it works.

Finally we will mention the advantage of this procedure for the evaluation of safety measures. A general problem in the evaluation of safety measures is the effect of the "regression-to-the-mean". This effect is due to the fact that if we divide the locations into two groups, one with high numbers of accidents in the past and the other with low accident numbers, then there will be a tendency for the mean accident number of the first group to decrease in time and for the mean accident number of the second group to increase, even if we do not change any location. This results from the fact that several locations in the first group have high accident numbers and several locations in the second group low accident numbers by chance. These effects can be very substantial and suggest accident reductions that are far too optimistic.

We may want to solve the problem by incorporating the accidents of all locations (including the locations that have not been treated) in the evaluation study or even estimate the regression-to-the-mean effect using

Fig. 6. Hazardous location of second dimension

the non-treated locations only. Here we do not have to deal with this problem, because we can estimate the expected number of accidents for a given location if there will be no treatment. Furthermore we can compute the accident reduction as a result of the countermeasures that have been taken, without referring directly to the number of accidents that occurred in the past on that location.

<u>LITERATURE</u>

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THE APPLICATION OF WEIGHTED MULTIPROPORTIONAL POISSON MODELS IN SAFETY IMPROVEMENT MEASURES

Presented to the Seminar on Short-term and Area-wide Evaluation of Safety Measures (April 1982)

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ABSTRACT

Accidents are caused by faulty decisions of traffic participants, often partially influenced by the traffic situation itself. There are specific situations in which numerous accidents occur; these accidents can be studied and the circumstances improved accordingly. However, the majority of accidents occur outside these so-called black spots. Other traffic situations are characterized by the fact that pratically no accidents occur

in a period of a year. Nevertheless, because there is a countless number of such situations, the total number of accidents is high.

It is virtually impossible to make a study of accidents in such isolated situations. For example, the number of severe accidents on secondary and tertiary roads outside the built-up area is about 0.3 per km per year.
To analyse the accidents occurring in such situations, data would have to be collected for a long period, say 30 years. Apart from other considerations, traffic and road characteristics would alter so greatly in this period of time that the analysis would be valueless.

Regression model techniques do provide a feasible approach to this type of traffic situations.
Such a model that describes the effects of the traffic and road characteristics can be used to determine the accident rate. Instead of waiting for until accidents occur which can then be analysed, a forecast is made of the accidents that can be anticipated. Systematic and area-wide reconstruction regulations can then be enforced to reduce the probability of such accidents occurring.
This contribution deals with a regression model technique that is suitable for use in such cases. This technique, which has been successfully applied in studies on interurban bicycle and car traffic, is based on the weighted multiproportional Poisson model.

The relevant bicycle traffic study showed car volume, bicycle volume, bicycle lane width, median width and the presence of trees along the road to be of major importance; the relevant car traffic study showed car volume, shoulder width, type of obstacle, obstacle distance, sight distance and horizontal curvature to be of the major importance.

1. INTRODUCTION

Traffic accidents are caused by faulty decisions of traffic participants or by defects in vehicles. The occurrence of accidents is related to the psychological characteristics of the traffic participants as well as to the physical characteristics under which they take part in traffic. These physical characteristics are for instance the weather conditions (fog, slipperiness), the light or dark period of the day and the road characteristics. There are specific situations in which numerous accidents occur; these accidents can be studied and the circumstances improved accordingly. However, the majority of accidents occur outside these so-called black spots. Other traffic situations are characterized by the fact that practically no accidents occur in a period of a year. Nevertheless, because there is a countless number of such situations, the total number of accidents is high. It is one of the tasks of the traffic-engineer to examine whether the accident rate can be lowered by improving the traffic situation.

The occurrence of accidents can be analysed by means of mathematical models. Regression analysis is often used; sometimes analysis of variance and factor analysis are also used to ascertain the effect of road and traffic characteristics. E.g. (1), (2) and (3) used linear regression. Often a multiplicative model is made linear, see for instance (4), (5).

In the use of multiple linear regression it is implicitly assumed that the observation results are normally distributed. This assumption is not very realistic since the analysis is specifically concerned with traffic situations in which few accidents occur. The probability that

the number of accidents would become negative is not negligible in that case.

The drawback of an erroneous assumption with respect to the sampling distribution is even greater when using the multiplicative model linearized by a logarithmic transformation. The logarithm of zero is not defined and a zero observation can therefore not be included in the investigation.

The zero observations are sometimes omitted from the analysis. This seems undesirable since traffic situations without accidents are of a very real importance.

Other devices are sometimes used too; for instance, a small number (e.g. ½) may be added to all observations, (6), (7) and (8). Such a pretreatment of observations can greatly affect the estimate and is therefore undesirable.

For the method being proposed it is not required either. This contribution deals with the weighted multiproportional Poisson model and illustrates this method with some applications. The number of accidents is used as the dependent variable, whereas the accident rate is not; in fact, the rate depends on the dimensions used. The lengths of road segments where accidents have been observed lead to the introduction of weighted models. Accidents are related to road and traffic characteristics by means of a multiplicative or multiproportional model. The accidents are assumed to be Poisson distributed.

Section 2 motivates and specifies the model used. The estimation of the coefficients is discussed in section 3, while section 4 deals with the statistical testing of the coefficients and with a strategy for the selection of important influencing factors from a large number of possible factors.

The advantages of using this model over simple cross-classifications of survey data are shown in section 5. Section 6 shows how the estimated model can be used in constructing a safety index; this is illustrated in one example . Results of two safety studies are shown in section 7.

2. THE WEIGHTED MULTIPROPORTIONAL POISSON MODEL

The weighted multiproportional Poisson model is based upon two assumptions. First, it is assumed that accidents are Poisson distributed with some expected value. Subsequent accidents are not correlated and the time interval between two subsequent accidents has a negative-exponential distribution. Secondly, the expected number of accidents μ is multiplicative, i.e. the product of the effects of independent variables.

This model is based on the analysis of higher order cross-classifications to test whether the factors (roadway and traffic characteristics) of influence are independent. In using the accident model it is important to include many roadway and traffic characteristics simultaneously in the analysis. The multiplicative model introduced here is a logical continuation of the analysis of cross-classifications containing one or two roadway features, thus allowing all detailed information available to be analysed. Oppe (9) gives some theoretical and experimental justification for the use of a multiplicative model.

In addition it should be taken into account that some road segments (with a certain combination of factors) may differ considerably in length (L) from other segments (with a different combination of factors). The experimental design is not balanced. As a consequence

of the governmental road design policy these are combinations of road and traffic characteristics which do not exist, e.g. roads with a small lane width but a high car volume. Moreover, observations from long road segments are more reliable than those from short segments. In the literature on this subject little attention is paid to the analysis of such weighted cross-classifications, e.g. (6), (10). A computer package like BMDP does not contain software for the analysis of weighted cross-classifications.

The presence of weight factors is a vital difference between the method being proposed and the standard log-linear analysis of cross-classifications. Note that the ratio between the number of accidents and the weighting factor is not suitable for analysis since in that case the analysis will depend on the dimensions used, (11).

The form of the model is:

$$\mu_{klmn} = a_k \cdot b_l \cdot c_m \cdot d_n \ldots\ldots\ldots\ldots L_{klmn} \qquad (2.1)$$

In this formula:

μ_{klmn} = the expected number of accidents in case the explanatory variables belong to the categories k, l, m and n

L_{klmn} = the length of the segment belonging to the categories k, l, m and n (if necessary, weighted by period of observation)

a_k, b_l, c_m, d_n, etc. are the coefficients (estimate is indicated by ^)

a, b, c, d are the factors (characteristics of the road and traffic situation)

k, l, m and n are the classes with $k = 1, 2, 3, 4, \ldots\ldots$

$l = 1, 2, 3, 4, \ldots\ldots$

$m = 1, 2, 3, 4, \ldots\ldots$

$n = 1, 2, 3, 4, \ldots\ldots$

Interactions can also be taken into account. This means that the influence of several independent variables together differs from that of each separate independent variable.

As it is possible to multiply the coefficients a_k by 100 and to divide the b_l coefficients by 100 etc. without affecting the number of accidents, a normalization is used. So, the coefficients are not unique, but the ratios between the coefficients of any factor are unique. In performing the computations this complication is taken into account.

The influence of the traffic volume can be estimated by means of one of the traffic coefficients. It is also possible to include the traffic volume directly as an independent explanatory variable, if so required. In the latter case L_{klmn} becomes equal to the product of volume, length and observation period.

3. ESTIMATION EQUATIONS

The coefficients in the accident model are estimated on the basis of the maximum likelihood method. Maximization of the likelihood gives the estimation equations. As indicated above, the nature of the occurrence of an accident is a Poisson process. Consequently, the probability of y_{klmn} accidents at an expected value μ_{klmn} is given by the equation:

$$\Pr[y_{klmn}] = \{\exp(-\mu_{klmn}) \cdot \mu_{klmn}^{\;y_{klmn}}\}/y_{klmn}! \qquad (3.1)$$

The numbers of accidents y_{klmn} are assumed to be independent for all combinations of k, l, m, n, ... As a result the value of the

log-likelihood function (λ) becomes:

$$\lambda = \sum_k \sum_l \sum_m \sum_n \ln \Pr[y_{klmn}] \qquad (3.2)$$

In the formula 2.1 the coefficients should be chosen in such a way that the log-likelihood has a maximum value, i.e. that the predicted number of accidents is in optimum agreement with the observed number. Details of the further derivations are omitted here, see (12).
A set of non-linear equations is developed, with which the coefficients are determined.

$$\hat{a}_k = \frac{y_{k...}}{\sum_l \sum_m \sum_n \hat{b}_l\, \hat{c}_m\, \hat{d}_n \,.....\, L_{klmn}} \;; \quad \forall\, k \qquad (3.3a)$$

$$\hat{b}_l = \frac{y_{.l..}}{\sum_k \sum_m \sum_n \hat{a}_k\, \hat{c}_m\, \hat{d}_n \,.....\, L_{klmn}} \;; \quad \forall\, l \qquad (3.3b)$$

$$\hat{c}_m = \frac{y_{..m.}}{\sum_k \sum_l \sum_n \hat{a}_k\, \hat{b}_l\, \hat{d}_n \,.....\, L_{klmn}} \;; \quad \forall\, m \qquad (3.3c)$$

$$\hat{d}_n = \frac{y_{...n}}{\sum_k \sum_l \sum_m \hat{a}_k\, \hat{b}_l\, \hat{c}_m \,.....\, L_{klmn}} \;; \quad \forall\, n \qquad (3.3d)$$

In these formulas:

$$\sum_l \sum_m \sum_n y_{klmn} = y_{k...}; \quad \forall\, k \qquad (3.4a)$$

$$\sum_k \sum_m \sum_n y_{klmn} = y_{.l..}; \quad \forall\, l \qquad (3.4b)$$

$$\sum_k \sum_l \sum_n y_{klmn} = y_{..m.}; \quad \forall\, m \qquad (3.4c)$$

$$\sum_k \sum_l \sum_m y_{klmn} = y_{...n}; \quad \forall\, n \qquad (3.4d)$$

$y_{k...}$, $y_{.l..}$, $y_{..m.}$ and $y_{...n}$ are the observed marginal frequency distributions of accidents.

The coefficients are determined by an iterative method in accordance with the Gauss-Seidel principle.

The method being proposed can be modified, if necessary; e.g., the Poisson distribution of the accidents could be replaced with some other distribution (gamma, Erlang) if the empirical data would indicate so.

4. STATISTICAL TESTING AND SELECTION OF FACTORS

The estimators of the coefficients are stochastic variables. Each of these stochastic variables has a probability distribution, a mean and a standard deviation. The smaller the standard deviation of the estimator is, the more reliable a coefficient is considered to be.
It is examined by testing whether certain assumptions concerning the parameters of a distribution (comprised in the null hypothesis) can be rejected in favour of the alternative hypothesis. Since a multi-proportional model is being used here, it should be examined whether the ratio between the coefficients of each set of classes per factor (a_k/a_1, c_m/c_1, d_n/d_1, etc.) differs significantly from one. The standard errors of the coefficients can be estimated, (12), (13).

Figure 1 shows the effect of the average daily traffic volume and the estimated standard errors (shaded) for the data mentioned in table 7.2. The influence of traffic volume is significant.
In some studies we estimated the effects of a large number of roadway characteristics. The results of the simultaneous estimation can then be supported by some simple strategies.

Depending on the problem a distinction can be made between the various roadway characteristics. These have been selected on the basis of the hypotheses that are to be analysed. As a tool in selecting roadway

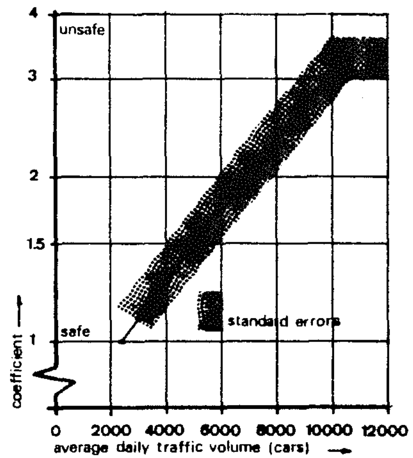

Figure 1. Coefficients and standard errors car traffic volume (from table 7.2)

features the likelihood-ratio test statistic (G^2) is used, see for instance (6).

$$G^2 \overset{\text{def}}{=\!=\!=} 2\ [\ \lambda^* - \lambda(\mu)\ ] = 2\ \Sigma\ y_{klmn}\ \ln \frac{y_{klmn}}{\mu_{klmn}} \quad \text{(sum over all the observations)}$$

with:

- $\lambda(\mu)$ is the value of the log-likelihood function with estimated coefficients ($\hat{a}$, $\hat{b}$, $\hat{c}$, $\hat{d}$, etc.);
- λ^* is the highest attainable value of the log-likelihood. This value of the log-likelihood function is attained if the model results become equal to the observation results;
- G^2 is chi-square distributed if the number of observations is sufficiently large (i.e. asymptotic).

When the value of G^2 is calculated for each separate roadway characteristic priorities can be assigned to them according to their explanatory power (12).

Table 4.1

Roadway characteristic	G^2	Degree of freedom	Significance level
average daily traffic volume	266.90	6	> .999
points of conflict	94.32	3	> .999
type of obstacle	102.00	6	> .999
horizontal curve	63.81	2	> .999
obstacle distance	75.33	4	> .999
parallel facility	54.64	4	> .999
environment features	40.41	3	> .999
median width	49.33	4	> .999
sight distance	49.30	5	> .999
profile narrowings	9.93	1	.997
truck percentage	12.74	3	.995
shoulder width	15.96	5	.994
pavement width	10.27	7	~ .80
pavement	18.50	7	.99
lane width	10.13	6	.90
permitted speed	0.67	1	~ .60
gradient	0.29	1	~ .40
discontinuities	0.26	2	~ .20

It would be incorrect to regard these (simple) analyses as definitive, since the effects of all other factors are ignored and the observations are classified solely on the basis of the one factor considered. Though these simple analyses do indicate the relative importance of the various factors, the weighted multiproportional Poisson model, which takes account of many factors simultaneously, must be considered decisive.

5. COMPARISON OF OBSERVED AND ESTIMATED RESULTS

The value of the application of the model is illustrated by comparing the observation results with the estimation results, for the bicycle traffic study (one-sided bicycle lanes). The estimation results have been taken from table 7.1.

In practice two-dimensional tables are often used to search for

independent variables. In table 5.1 the relation between the accident rate per km per year and the volumes of car traffic and (motorized) bicycle-traffic is shown. To allow comparison with the model results all observation results were divided by the number of accidents in the upper left cell.

Table 5.1 Observation results; normalized accident rate per km per year

Volume (motorized) bicycles	Volume cars (or motor vehicles) < 2000	2000 - 4000	4000 - 6000	> 6000
< 250	1.00	0.91	0.77	0.94
250 - 700	0.78	1.50	1.23	1.47
700 - 1000	0.00	2.63	3.33	4.88
> 1000	0.52	0.45	5.83	6.27

The number of accidents is expected to increase with the increasing volumes of the motor vehicles and of cycles. In table 5.1 however, the first line and the first column might suggest that the accident rate decreases with an increase of the traffic volume.

The second column and last line also present a rather illogical picture. The reason is that other roadway characteristics also affect the occurrence of accidents. This effect cannot be demonstrated in a two-dimensional table.

In table 5.2 the model results are shown. The table is the result of multiplying the estimated coefficients for motor vehicle volume by those for (motorized) bicycle volume, see table 7.1. The effect of other roadway features was incorporated in the other estimated coefficients, but is omitted from this table. The model results are well in line with the expectations. An increase in traffic volume results in more accidents.

Table 5.2 Model results; normalized accident rate per km per year

Volume (motorized) bicycles	Volume cars (or motor vehicles)			
	< 2000	2000 - 4000	4000 - 6000	> 6000
< 250	1.00	1.23	1.56	1.74
250 - 700	1.27	1.56	1.98	2.21
700 - 1000	2.99	3.68	4.66	5.20
> 1000	3.92	4.82	6.12	6.82

In table 5.3 to illustrate the use of interaction coefficients another example is presented. In this table the width of the bicycle lane and the width of the median between bicycle lane and roadway are included:

Table 5.3 Observation results

median width	bicycle lane width	
	< 2.7 m	> 2.7 m
< 2.3 m	1.00	1.68
> 2.3 m	0.81	0.73

The wider a bicycle lane with a narrow width the more dangerous. This table has led to the hypothesis of interaction. Consequently, coefficients were estimated for each cell of the matrix. These were included in table 5.4.

Table 5.4 Model results

median width	bicycle lane width	
	< 2.7 m	> 2.7 m
< 2.3 m	1.00	0.85
> 2.3 m	0.65	0.54

If the cells outside the diagonal are multiplied, a value of 0.55 results which differs little from the estimated value of 0.54. So the

G^2 does not differ significantly. Consequently, the assumed interaction apparently does not exist.
In the final estimation (presented in table 7.1), therefore, interaction is not present.
The estimation results show that wide bicycle lanes are safer than narrow ones and that a wide median is safer than a narrow one, which is entirely in line with the expectations. The difference between model results and observation results must be attributed to the fact that apparently in table 5.3 other independent variables (e.g. volumes) come into play as well.

6. SAFETY FORECASTING

The estimated coefficients can be used in a number of applications. One possible application is discussed here. Two specific roads with a one-sided bicycle lane are compared with respect to their safety. The figures 2 and 3 show two roads with a one-sided bicycle lane; these roads differ with respect to four important roadway characteristics, viz. access points, median width, width of bicycle lane and type of obstacles. Table 6.1 shows that the road shown in figure 2 is about 3.5 times less safe than the one shown in figure 3.

Figure 2. Road with one-sided bicycle lane; unsafe situation

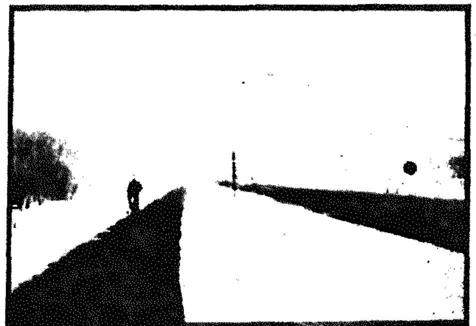

Figure 3. Road with one-sided bicycle lane; safe situation

Table 6.1 Calculation of road safety

Roadway characteristics	Coefficients* for the road shown in	
	figure 2	figure 3
access points	1.00	0.89
median width	1.00	0.65
width of bicycle lane	1.00	0.85
obstacle	1.66	1.00
safety index	1.66	0.49

* from table 7.1.

In this way systematic and area-wide (re)construction regulations can be suggested to reduce the probability of accidents.

7. APPLICATION IN SPECIFIC SITUATIONS

Introduction

In the Netherlands the weighted multiproportional Poisson model was used:

- for polder roads (1974), (14)
- for interurban bicycle traffic (1978), (15)
- for interurban car traffic (1979), (16).

Some results of the latter two studies are discussed in this section; for more details references is made to (12), (13).

7.1. Interurban bicycle traffic

The study was concerned with 1774 accidents to (motorized) cyclists resulting in severe injuries, which were or were not fatal. The

accidents have been taken from the national accidents survey with accidents per road segment. The roadway characteristics have been determined by a direct survey. The role of secondary and tertiary roads outside the built-up area (with a total length of 2439 km) in these accidents was studied. There are roads with bicycle lanes on both sides, roads with bicycle lanes on one side and roads without lanes (figures 2 and 3).
The inventory unit used was a road segment. A segment is a part of the road between intersections and/or junctions with public roads, within which there are no changes in the most important characteristics of the road and which has a maximum length of 200 m.

In this paper results are shown for the roads with a separate bicycle lane on one side (i.e. with a reservation between the car and bicycle lanes).

Some of the most important results (so far) are:

- The probability of accidents is greatly influenced by the motor vehicle volume. Average daily traffic volumes were used; the volume at the time of the accident could not be used, because data were lacking. The influence of the volume on accidents is considerably greater for roads without bicycle facilities, factor 1 in table 7.1.
- It can be concluded that an increase in the bicycle volume greatly increases the probability of accidents (table 7.1).
- An other conclusion for the construction of bicycle lanes is that the probability of accidents is greater on roads with a wide bicycle lane and a narrow median than on roads with a less wide bicycle lane and a wider median (see table 5.4). This is

particularly true for roads with a bicycle lane on one side.

- Roads with many access points generate significantly more accidents than roads with few or no access points (factor 3, table 7.1).
- The influence of parking bays, bus stops, etc. is not significant on roads with bicycle facilities on one side or on both sides as could be expected because there are no conflicts. On roads without bicycle facilities the probability of accidents is increased by more than 20%.
- No significant effect could be demonstrated for other influencing factors.

7.2. Interurban car traffic

The following data are cited from Jager and Gijsbers (16). The study was concerned with 1545 accidents causing severe injuries, which were or were not fatal on two-lane or equivalent roads maintained by the National or Provincial Governments (1300 km). To obtain a unit of analysis inventory, the road net was subdivided into lengths of approximately 100 m. The analysis was carried out on segments of roads, most of which were 200 m in length. The used road characteristics in a cross-section are given in figure 4. Table 7.2 presents the estimation results.

The results of the analysis are as follows:

- As may be expected, the average daily traffic volume (factor 1 in table 7.2) is by far the most important explanatory variable. The accident density is approximately a factor 3 higher on roads with an average daily traffic volume of more than 9,000 motor vehicles, than on roads with a volume lower than 3,000 motor

Table 7.1 Example of estimation results. Roads with a bicycle lane on one side

Factor	Class		L	Y	C	t-value between classes			
1		Motor vehicle volume					1	2	3
	1	< 2000	147	66	1.00				
	2	2000 - 4000	150	98	1.23	2	1.29		
	3	4000 - 6000	123	102	1.56	3	3.02	1.68	
	4	> 6000	129	255	1.74	4	3.02	2.31	0.85
2		Bicycle volume					1	2	3
	1	< 250	230	105	1.00				
	2	250 - 700	192	120	1.27	2	1.83		
	3	700 - 1000	48	83	2.99	3	8.66	5.35	
	4	> 1000	78	213	3.92	4	9.69	9.35	1.94
3		Access points bicycle lane side					1		
	1	< 225 m	135	199	1.00				
	2	≧ 225 m	414	232	0.89	2	0.64		
4		Access points other side					1		
	1	< 225 m	130	211	1.00				
	2	≧ 225 m	419	310	0.97	2	0.17		
5		Median bicycle lane					1		
	1	< 2.3 m	215	281	1.00				
	2	≧ 2.3 m	334	240	0.65	2	3.13		
6		Width bicycle lane					1		
	1	< 2.7 m	235	230	1.00				
	2	≧ 2.7 m	314	291	0.85	2	0.96		
7		Pavement bicycle lane					1		
	1	asphalt + concrete	318	307	1.00				
	2	brick pavement	231	214	1.21	2	2.03		
8		Sight distance					1		
	1	100%	338	308	1.00				
	2	< 100%	211	213	1.15	2	1.23		
9		Obstacle					1	2	3
	1	no obstacle	411	290	1.00				
	2	others	61	73	1.15	2	0.85		
	3	trees (continuous)	55	120	1.57	3	3.84	1.87	
	4	trees (discrete) + lights	22	38	1.66	4	2.85	1.51	0.33

L = total segment length in km, weighted by the analysis period
Y = the number of accident per class
C = the coefficients estimated

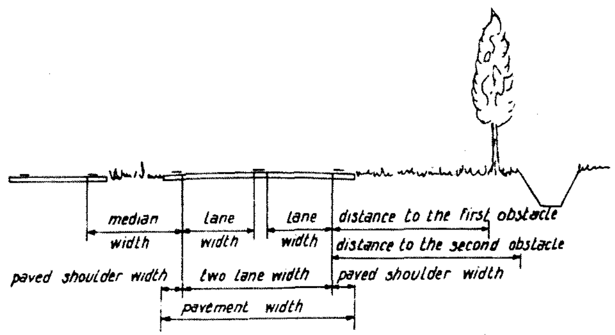

Figure 4 Road characteristics of a cross section

vehicles per 24 hours (provided all other roadway features are equal). The accident density hardly increases with an increase of the intensity over 10,000 motor vehicles per 24 hours. These analysis results scarcely differ from the conclusions that can be drawn from, in particular, West German and Danish studies, (5), (17), (18) en (19).

If the regression coefficients are normalized by traffic performance (roughly speaking this means dividing by volume), it appears that in comparing roads, of which the other features are the same, a road with a high volume is safer than a road with a relatively low volume.

- The two-lane width does not significantly influence the accident density, whereas the pavement width and shoulder width do (factor 3), although the pavement width less than the shoulder width. The two-lane width therefore seems to influence the accident density much less than the paved shoulder width. The effects found for the shoulder width are significant in all cases. A paved shoulder width smaller than 0.85 m produces a greater probability of accidents than a wider paved shoulder. The accident density is not significantly changed by increasing the width of shoulders of 1.8 to 2.0 m wide. The accident density is as much for roads with a shoulder width of 1.8 to 2.0 m as for roads with considerably wider shoulders. Within the classes smaller than 0.9 m the widths of 0.4 to 0.5 m appear to be significantly safer than the slightly wider (0.6 to 0.8 m) or the slightly narrower (≦ 0.3 m) widths. The results found for the lane width are not in line with the conclusion drawn from other studies, i.e. that the traffic safety increases with an increase of the lane width.

Table 7.2 Example of estimation results. Lane width study

Factor	Class		L	Y	C	t-value between classes					
1		Motor vehicle volume					1	2	3	4	5
	1	< 3000	256	172	1.00						
	2	3000 - 3999	177	156	1.23	2	1.83				
	3	4000 - 5999	282	329	1.55	3	4.48	2.37			
	4	6000 - 7999	238	329	2.07	4	7.59	5.30	3.56		
	5	8000 - 9499	123	236	2.72	5	9.83	7.56	6.32	3.18	
	6	≥ 9500	130	323	3.11	6	11.57	9.29	8.48	5.05	0.52
2		Truck percentage					1				
	1	< 20%	1003	1253	1.00						
	2	≥ 20%	204	292	1.14	2	1.89				
3		Paved shoulder width					1				
	1	≥ 0.85 m	131	136	1.00						
	2	< 0.85 m	1077	1409	1.22	2	2.15				
4		Obstacle distance					1	2			
	1	absent	39	37	1.00						
	2	2.5 - 3.5 m	1012	1197	1.21	2	1.13				
	3	< 2.5 m	156	311	1.43	3	1.96	2.20			
5		Median width					1	2			
	1	absent	653	703	1.00						
	2	≥ 4.0 m	412	612	1.15	2	2.29				
	3	< 4.0 m	143	230	0.98	3	0.25	1.93			
6		Type of obstacle					1	2	3		
	1	absent	764	829	1.00						
	2	other	312	453	1.03	2	0.44				
	3	open row of trees	87	145	1.26	3	2.41	2.04			
	4	row of lighting columns	47	118	1.35	4	2.62	2.41	0.52		
7		Sight-distance					1				
	1	≥ 900 m (both directions)	263	258	1.00						
	2	other	945	1287	1.14	2	1.91				
8		Pavement					1				
	1	concrete	121	195	1.00						
	2	asphalt	1086	1350	0.85	2	1.99				
9		Horizontal curvature					1	2			
	1	≥ 1500 m	982	1141	1.00						
	2	750 - 1499 m	128	198	1.25	2	2.29				
	3	≤ 749 m	96	206	1.64	3	6.29	2.70			
10		Points of conflict					1	2			
	1	absent + crossings	1073	1261	1.00						
	2	access points	111	206	1.32	2	3.45				
	3	intersections	24	78	2.65	3	8.25	5.15			
11		Profile narrowings					1				
	1	absent	1178	1487	1.00						
	2	present	29	58	1.48	2	2.90				

Source: "Rijkswaterstaat" (Department of Public Works)/DHV Consulting Engineers

L = total segment length in km, weighted by the analysis period
Y = the number of accident per class
C = the coefficients estimated

The various research workers, however, do not come to the same conclusion concerning the relation between lane width and accident density: (20) have found a linear relation; (3), (21), a parabolic relation, and (22) has concluded a hyperbolic relation. On the whole the results for shoulder width and pavement width, however, are in keeping with the conclusions drawn from the study of literature (17), (18), (20), (22).

- The type of obstacle (factor 6 in table 7.2) significantly influences the accident density. Open rows of trees and rows of lighting columns significantly increase the probability of accidents with 26%. With regard to the effects of the rows of lighting columns a reservation should be made. In general, lighting is used along motorways only if the traffic volume in conjunction with the road situation calls for such a provision.
- The obstacle distance (factor 4) significantly influences the accident density. The distance from the inner side of the edge marking of the lane to the first obstacle in the shoulder is used as a measure for the obstacle distance. From the analysis it becomes obvious that the accident density decreases with an increase of the obstacle distance. The accident density for obstacle distances smaller than 2.5 m was found to differ significantly from that for obstacle distances greater than 2.5 m. Significant differences in accident density could be found neither for obstacle distances between 0 and 2.5 m nor for those greater than 2.5 m.
- The presence of most types of conflict points (factor 10) significantly increases the accident density. After traffic volume, this road feature influences the accident density most. A distinction was made between the following points of conflict:
  - pedestrian crossings and bicycle crossings, both with or without traffic lights; crossings for mixed traffic;
  - residential and agrarian access points and minor intersections;

  - type B intersections (intersections without road signs and without changes in their cross sections).

  Access points and B-type intersections significantly influence the accident density. The presence of type B intersections increases the accident density considerably more than that of access points.
- Horizontal curves (factor 9) with a radius greater than 1500 m do not affect the accident density. With a decrease in the horizontal radius the accident density significantly increases.
- The sight-distance (factor 7) significantly affects the accident density. A sight-distance greater than 900 m is significantly safer than a more restricted one. With a further decrease of sight-distances smaller than 900 m, the increase of the probability of accidents was found to be insignificant. From other studies (5) it appeared that sight-distances smaller than 400 m result in a higher accident density than sight-distances greater than this. From the literature study it was found that sight-distances greater than 400 m hardly affect the accident density at all.
- Besides the roadway features mentioned, the median width (factor 5), the type of pavement (factor 8), the truck percentage (factor 2) and the profile narrowings also affect the probability of accidents, though to a less extent.
- For some features no relation to the probability of accidents can be demonstrated. This applies to the (legally permitted maximum) speed and the presence of grades.

8. EVALUATION

Up to this moment the weighted multiproportional Poisson model presented here has yielded practical results when used in traffic situations with few accidents.
Road and traffic characteristics affect the occurrence of accidents substantially. The estimated results enable the traffic engineer to design and evaluate safety measures.

This has been shown by one example : two specific roads have been compared on the basis of the safety index computed from the model coefficients.
The results suggest construction and reconstruction regulations to be enforced.
If the finances are limited it is possible to set up a list of priorities in order to minimize the number of accidents.

It has been the usual practice to improve traffic situations after a lot of accidents have happened. The weighted multiproportional Poisson model forecasts accidents and enables us to improve dangerous situations before accidents happen.
The use of this technique helps us to reduce the number of accidents.
This technique is offered as an important tool in improving safety efficiently.

Acknowledgement

Besides the authors, M.C. Huisman was closely connected with the development of the method. Tables and results were taken from the

studies by Jager, Van der Wal and Gijsbers, which were made for "Rijkswaterstaat" (Department of Public Works).
The authors are grateful for having been allowed the use of these data.

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Short Term and Area-wide Evaluation of Safety Measures Implemented in a Residential Area Named Østerbro. The Statistical Tools.

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ABSTRACT.

With emphasis on a newly finished traffic restraint programme carried out in Østerbro, Copenhagen (cfr. Engels abstract) the mathematical statistical tools for evaluation are exposed.

The exposition will fall in two parts. The first will deal with the statistical procedures related to the actual accident analysis. The second will be the analysis of different behavioural studies of the street-users with emphasis on speed-measurements of motorized vehicles.

The statistical tools for the accident analysis have two main-purposes. The first is: "Has the accident rate actually changed?" while the second is "in case of a change, what size has this change and which are its limits?".

The first question is answered by means of statistical tests using multiple-dimensional log-linear-Poisson-models. A special case of control-area (Placebo)-philosophy is used here. The second question about the size of the effect is answered by more conventional statistical theory but carried out as well with as without a control-area.

Supporting the accident-analysis behavioural studies have been carried out. The speed-measurements are dealt with in mathematical statistical terms using analysis of variance, investigating the assumptions of these analysis and dealing with general behaviour of street-users in terms of log-linear Poisson-models.

Finally some conflict-and accident-studies by Zimolong (1980) are reanalyzed by means of log-linear Poisson models.

Conclusion.

In order to make a satisfactory accident-frequency-study of the before/after-effect of a traffic-replanning-program two periods of three years and a densely populated area of half a square-km is needed.

1 Introduction.

This paper is closely related to that by Engel as it reveals the statistical methods used in the traffic restraint program treated by Engel.

2 Accident frequency related methods.

In the before/after study extensive traffic censuses are collected. These have been used for the calculation of accident frequencies according to several categorizations.

We thus have variables formally given by

$$A_{ijk} \in \text{Poisson}(T_{ijk} \cdot \lambda_{ijk})$$

where A_{ijk} is the number of accidents for a given street, a given street-user-group and a given period. T_{ijk} designates the number of kilometres travelled by the given group at the given location in the given period. T is deterministic. Finally λ_{ijk} is the accident frequency.

Any comparison of accident (and casualty) frequencies is treated as a weighted cross-table using the theory of weighted log-linear Poisson models.

The literature on this subject is very sparse. The original paper in this context is that of Andersen (1977). In the paper of Andersen only the two-dimensional case is treated and it is expanded for any dimension in Thomsen and Thyregod (1981).

The estimation and testing in these tables become laborious. De Leeuw and Oppe (1976) describe a computer-program using minimum chi-square estimation. The maximum likelihood-approach of Alvey (1977) is used in the project described here.

Testing in statistical terms only answers the in fact very academic question of "Has the accident frequencies changed?" Answering yes, one wants to know the actual size of the change and its confidence limits. In the more than one-dimensional case this becomes complicated, but is a very important result. It is not treated in detail here, but will in Engel (1983), that is under preparation.

3 Accident frequencies and the general accident trend.

Looking at accidents and their multi-dimensional structure one realizes that the patterns are very different according to geographical location. For this reason we have in the Østerbro-project (cfr. the paper of Engel) rejected the idea of an external control-area.

As described by Engel it has in the experimental area been possible to divide accidents into two groups, the experiment accidents and the control accidents.

Analyzing the control accidents by the weighted log-linear Poisson model it is possoble to obtain an estimate of the general accident trend, i.e.

$$\rho_{gen} = \frac{\lambda_{after}}{\lambda_{before}}$$

where ${}_{gen}$ designates the general accident trend λ_{after} the accident frequency after the restraint-

program and λ_{before} the frequency before.

This result enables us to estimate and divide a given accident number into three components, one from the general accident frequency trend, one from the amount of traffic and finally one component obtained from the traffic replanning-program.

These calculations become very technical and will be reported in Engel (1983).

4 Behavioural Studies.

Several behavioural studies have been carried out before and after the countermeasures have been introduced.

Several different types of speed-measurements have been carried out. Very often the analysis of variance turns out to be a very appropiate method.

Its assumptions are

1. normal distribution
2. identical means
3. identical variances and
4. independence between observations.

In these measurements non-normality is very often the case as the speed distribution is skewed to the right with with heavy tails. Transformations are used but rather often the assumptions are not satisfied anyway.
It is not possible in the collection of behavioural data to obtain groups that are balanced, i.e. the number observations differs from group to group. This means that the analysis of variance has to be performed unbalanced and makes the ana-

lysis of the group-counts necessary and for this purpose the unweighted log-linear model is well suited.

These studies are related to the normal behaviour of the street-users and are not conflict studies. Some critical remarks related to the conflict-technique are launched in the following working paper.

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Working Paper no. 1
In addition exists an appendix of tables.

A Reanalysis of Some Data from "Traffic Conflicts at Urban Junctions".

1 Introduction.

This working paper is a translated and slightly modified version of a working paper in Danish. The idea is to present one of the few studies of the possible relation between accidents and conflicts. Coming across "Traffic Conflicts at Urban Junctions - Reliability and Validity Studies" by Bernhard Zimolong (cfr. list of references). I found it interesting to reexamine these data using the theory of log-linear Poisson models. Some good books on this topic are Bishop (1975) and Haberman (1974).

2 Data and Analysis.

Data are from Zimolong (1980), p. 19 and are shown in table 1.

Junction	Types of	Right Angle	Parallel	Pedestrian	Sum
1	Accidents	20	0	0	20
	Conflicts	10	0	2	12
2		6	0	0	6
		3	0	0	3
3		0	0	0	0
		2	0	0	2
4		5	0	1	6
		8	0	0	8
5		6	0	0	6
		8	0	5	13
6		15	11	1	27
		8	8	3	19
7		39	8	4	51
		35	5	11	51
8		19	16	0	35
		25	11	0	36
9		31	9	0	40
		31	9	3	43
10		24	16	0	40
		19	2	4	25
Sum	Accidents	165	60	6	231
	Conflicts	149	35	28	212

Table 1. The analyzed accidents and conflicts (incidents) grouped according to junction and type. (Zimolong, 1980, p. 19).

The same table produced by the computer program BMDP3F, Dixon (1979), is shown in the appendix, table t.1.

The corresponding accidents and conflicts are distributed according to 10 junctions and three traffic-types. It is seen that this three-dimensional structure consists of several zero counts. In the following it will be shown how one analyzes such "thin" structures.

It is seen from table t.2 that the computer program reacts on the zeros. For the partial tests given at the bottom of the table, it is ssen that amongst the two-factor-interactions only TI (type*incidents) and TJ (type*junction) are significant on a 5% level. This holds for the marginal tests as well. These facts are important to bear in mind when looking at table t.3, where 17 of the 19 possible models are shown.

It is seen from table t.3 that several models have estimated (fitted) values, which are zero. The number of degrees of freedom is thus calculated from the following formula

$$f_{act} = f_{BMDP} - (f_{fit} - f_o) \qquad \{1\}$$

where f_{act} is the actual degrees of freedom, f_{BMDP} those given by the computer, f_{fit} the number of fitted zero-values while f_o is the number of marginal zeroes. The method given by {1} is described in detail by Fienberg (1980) and Bishop (1975). For the best fitting models the goodness-of-fit-probability is added by hand in table t.3.

In the marginal total TJ is seen eight zeros, which

means that for models including this interaction we have $f_{o,TJ} = 8$. The marginal total IJ has one zero and gives $f_{o,IJ} = 1$. For the most interesting models the actual number of degrees of freedom are added and the goodness-of-fit shown.

As an example one can examine the model JT, JI. It consists of two interactions with zero counts. Using {1} we obtain

$$\begin{aligned} f_{act} &= f_{BMDP} - (f_{fit} - f_{o,TJ} - f_{o,IJ}) \\ &= 20 - (17 - 8 - 1) \\ &= 12 \end{aligned}$$

The correct number of degrees of freedom is thus 12.

Three models in table t.3 are of special interest. They are 1. TJ,I;   2. TJ,JI and 3. TI,TJ,IJ.

The model TJ,I corresponds to that type depends on junction. If the model described data well this interaction would be the same for accidents and conflicts. This would mean that the number of conflicts was a good accident-indicator.

The goodness-of-fit-level of 0.0007 using the likelihood-ratio-test and 0.0066 using Pearson tell that *the model TJ,I does not describe the data in a good way.*

A better fit can be obtained by using either TJ,TI or TI,TJ,IJ. Both models are above the 0.05-level and thus seem satisfactory. As the interaction IJ tested partially gives a very small test-statistic one must conclude that a good fit is obtained by TJ,TI. It must be concluded that there exists interaction between type and junction and interaction between type and incident.

One could interpret the model as for a given type there exists homogeneity between junction and incident. In ordinary terms this means that for a given type it might be possible to use conflicts as an indicator of accidents in different junctions.

The interaction between type and incident does not seem surprising as the type category is very crude. The interaction makes the use of conflict data complicated.

3 Summary and conclusion.

A collection of German data from Zimolong (1980) is analyzed using the log-linear Poisson models. It can on the existing data be rejected, that there exists homogeneity between accidents and conflicts. This means that the conflicts in a poor manner describes the number and the structure of the accidents. The structure is in this case made up of only two categories, junction and traffictype.

Concluding on the data shown here one might say that with a modest categorization of accidents and conflicts, one gets a poor description of the accidents using conflicts as an indicator.

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Conflict Techniques
Working Paper no. 1.
Appendix of tables.

Tables to

A Re-analysis of Some Data from

"Traffic Conflicts at Urban Junctions".

11

THE FOLLOWING TABLE IS ANALYZED.

JUNCTION J	INCIDENT I	TYPE (T) RIGHT	A. PARALLEL	PEDESTR.
JUNCT. 1	ACCIDENT	20	0	0
	CONFLICT	10	0	2
JUNCT. 2	ACCIDENT	6	0	0
	CONFLICT	3	.0	0
JUNCT. 3	ACCIDENT	0	0	0
	CONFLICT	2	0	0
JUNCT. 4	ACCIDENT	5	0	1
	CONFLICT	8	0	0
JUNCT. 5	ACCIDENT	6	0	0
	CONFLICT	8	0	3
JUNCT. 6	ACCIDENT	15	11	1
	CONFLICT	8	8	3
JUNCT. 7	ACCIDENT	39	8	4
	CONFLICT	35	5	11
JUNCT. 8	ACCIDENT	19	16	0
	CONFLICT	25	11	0
JUNCT. 9	ACCIDENT	31	9	0
	CONFLICT	31	9	3
JUNCT.10	ACCIDENT	24	16	0
	CONFLICT	19	2	4

THE TOTAL FREQUENCY IS 441

MARGINAL TOTALS

TYPE (T) RIGHT	A. PARALLEL	PEDESTR.
314	95	32

MARGINAL TOTALS

INCIDENT(I) ACCIDENT	CONFLICT
231	210

MARGINAL TOTALS

JUNCTION(J) JUNCT. 1	JUNCT. 2	JUNCT. 3	JUNCT. 4	JUNCT. 5	JUNCT. 6	JUNCT. 7	JUNCT. 8	JUNCT. 9	JUNCT.10
32	9	2	14	17	46	102	71	83	65

MARGINAL TOTALS

INCIDENT I	TYPE (T) RIGHT	A. PARALLEL	PEDESTR.
ACCIDENT	165	60	6
CONFLICT	149	35	26

MARGINAL TOTALS

JUNCTION J	TYPE (T) RIGHT	A. PARALLEL	PEDESTR.
JUNCT. 1	30	0	2
JUNCT. 2	9	0	0
JUNCT. 3	2	0	0
JUNCT. 4	13	0	1
JUNCT. 5	14	0	3
JUNCT. 6	23	19	4
JUNCT. 7	74	13	15
JUNCT. 8	44	27	0
JUNCT. 9	62	18	3
JUNCT.10	43	18	4

MARGINAL TOTALS

JUNCTION J	INCIDENT(I) ACCIDENT	CONFLICT
JUNCT. 1	20	12
JUNCT. 2	6	3
JUNCT. 3	0	2
JUNCT. 4	6	8
JUNCT. 5	6	11
JUNCT. 6	27	19
JUNCT. 7	51	51
JUNCT. 8	35	36
JUNCT. 9	40	43
JUNCT.10	40	25

Table t.1. Table corresponding to table 1 added with marginal totals.

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THE RESULTS OF FITTING ALL K-FACTOR MARGINALS.
THIS IS A SIMULTANEOUS TEST THAT ALL K+1 AND HIGHER FACTOR INTERACTIONS ARE ZERO

K-FACTOR	D.F.	LR CHISQ	PROB.	PEARSON CHISQ	PROB.	ITERATIONS
0(MEAN)	59	698.73	0.0	766.75	0.0	
1	47	129.70	0.0000	116.74	0.0000	2
***IN THE MODEL BELOW	17	FITTED VALUES ARE ZERO. THE D.F. ARE NOT COMPUTED CORRECTLY. SEE NOTE				
2	18	16.17	0.5807	15.82	0.6053	4

A SIMULTANEOUS TEST THAT ALL K-FACTOR INTERACTIONS ARE ZERO.
THE ENTRIES ARE DIFFERENCES IN THE ABOVE TABLE.

K-FACTOR	D.F.	LR CHISQ	PROB.	PEARSON CHISQ	PROB.
1	12	569.02	0.0	650.02	0.0
2	29	113.53	0.0000	100.92	0.0000

**THE REMAINING MODELS HAVE ZEROS AS FITTED VALUES, THEREFORE DIFFERENCES ARE NOT COMPUTED.

A TEST OF PARTIAL ASSOCIATION OF THE FACTORS.
IT IS CALCULATED AS THE DIFFERENCE BETWEEN THE FULL K-TH ORDER MODEL AND THAT WHICH EXCLUDES ONLY THE SPECIFIED EFFECT. K IS THE NUMBER OF FACTORS IN THE EFFECT.

A TEST OF MARGINAL ASSOCIATION OF THE
THE TABLE IS SUMMED OVER THE UNSPECIFI
AND THEN THE EFFECT IS TESTED TO BE ZE

EFFECT	D.F.	LR CHISQ	PROB.	ITERATIONS	LR CHISQ	PROB.	ITERATIONS
T	2	296.10	0.0				
I	1	1.00	0.3173				
J	9	271.92	0.0				
TI	2	20.15	0.0000	2	19.95	0.0000	2
TJ	18	81.98	0.0000	2	81.78	0.0000	2
IJ	9	11.81	0.2245	2	11.61	0.2364	2
TIJ	18	16.17	0.5807	4			

Table t.2. Partial and marginal tests of association. It is seen that the only two-factor-effects are type*junction and type*incident. There is homogeneity between incident and junction.

ALL MODELS ARE REQUESTED—

MODEL	DF	LIKELIHOOD-RATIO CHISQ	PROB.	PEARSON CHISQ	PROB.
T	57	402.63	0.0	886.36	0.0
I	58	697.73	0.0	363.02	0.0
J	50	426.81	0.0	388.95	0.0
T.I	56	401.63	0.0	885.85	0.0
T.J	48	130.70	0.0000	117.53	0.0000
I.J	49	425.81	0.0	385.91	0.0
T.I.J	47	129.70	0.0000	116.74	0.0000
TI	54	381.68	0.0	351.89	0.0
***IN THE MODEL BELOW 16 FITTED VALUES ARE ZERO. THE D.F. ARE NOT COMPUTED CORRECTLY. SEE NOTE					
TJ	30	48.93	0.0160	41.30	0.0820
***IN THE MODEL BELOW 3 FITTED VALUES ARE ZERO. THE D.F. ARE NOT COMPUTED CORRECTLY. SEE NOTE					
IJ	40	414.20	0.0	862.57	0.0
TI.J	45	109.76	0.0000	94.57	0.0000
***IN THE MODEL BELOW 16 FITTED VALUES ARE ZERO. THE D.F. ARE NOT COMPUTED CORRECTLY. SEE NOTE					
TJ.I	29 / f = 21	47.92	0.0150 / 0.0007	40.40	0.0777 / 0.0066
***IN THE MODEL BELOW 3 FITTED VALUES ARE ZERO. THE D.F. ARE NOT COMPUTED CORRECTLY. SEE NOTE					
IJ.T	38	118.10	0.0000	101.11	0.0008
***IN THE MODEL BELOW 16 FITTED VALUES ARE ZERO. THE D.F. ARE NOT COMPUTED CORRECTLY. SEE NOTE					
TI.TJ	27 / f = 19	27.98	0.4122 / 0.0838	24.97	0.5762 / 0.1615
***IN THE MODEL BELOW 3 FITTED VALUES ARE ZERO. THE D.F. ARE NOT COMPUTED CORRECTLY. SEE NOTE					
IT.IJ	36	98.15	0.0000	81.81	0.0008
***IN THE MODEL BELOW 17 FITTED VALUES ARE ZERO. THE D.F. ARE NOT COMPUTED CORRECTLY. SEE NOTE					
JT.JI	20 / f = 12	36.32	0.0141 / 0.0003	30.75	0.0586 / 0.0072
***IN THE MODEL BELOW 17 FITTED VALUES ARE ZERO. THE D.F. ARE NOT COMPUTED CORRECTLY. SEE NOTE					
TI.TJ.IJ	18 / f = 10	16.17	0.5807 / 0.0949	15.82	0.6053 / 0.1049

Table t.3. 17 of the possible 19 models. To the most interesting models the calculated number of degrees of freedom is added.

EVALUATION OF AREA-WIDE SAFETY SCHEMES BY MONITORING TRAFFIC AND ACCIDENTS

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ABSTRACT

Area-wide application of low-cost engineering measures for accident reduction aims to prevent many accidents which occur at diffusely scattered points in urban areas. It is designed to affect road user behaviour and the usage of roads of different types. Because the possible effects of introducing measures over whole areas may be widespread it is important to carry out efficient monitoring which can be used to evaluate a scheme both in terms of effectiveness in reducing accidents and in terms of ease of movement by car, bus, bicycle and walking. The resulting information is relevant not only to technical and economic assessment but also to any public debate which may arise.

Efficient monitoring should provide both short-term and medium-term information. In the short-term it should give indication not only of success in reducing accidents but also of any undue inconvenience or additional accidents which might be occurring as a result of unforeseen features of the operation of any component of the scheme. In the medium-term effects can be estimated more precisely and trends in the pattern of traffic and accidents can be detected by continued monitoring.

This paper describes various methods that have been developed for monitoring occurrence of accidents and distribution of traffic in residential areas and on main traffic routes outside town centres. The techniques described deal with analysis of accident frequencies and with measurement and sample sizes for traffic flows, turning movements, pedestrian crossing behaviour, journey times, journey lengths and speed of movement along main roads and through residential areas.

1. BACKGROUND

Over the last decade the annual number of fatal and serious injuries on the roads of Great Britain has fallen by 13 per cent and the injury accident rate per 100 million vehicle-kilometres by 30 per cent, but the problem of road accidents remains large, with just over 1/4 million injury accidents occurring in 1980, of which nearly 72000 involved fatal or serious injury (Department of Transport, 1981). The problem is being tackled in terms of the road, the vehicle and the road user (Sabey, 1980), and this paper relates to the first of these: it is concerned with important current developments in the application and assessment of certain kinds of safety measures in the field of highway and traffic engineering.

Outside built-up areas, substantial reductions in accidents are being achieved by building new or greatly improved roads which are safer than the ones they replace (Department of Transport, 1980), and by the identification and treatment of hazardous road locations (OECD, 1976). Whilst the former involves heavy investment, the latter can achieve large reductions in accidents at low cost (see, for example, Hertfordshire County Council, 1981). Both of these methods have a part to play also in built-up areas, where about three-quarters of injury accidents on British roads occur, but their role in built-up areas is limited. On the one hand, new road construction in towns is expensive and often causes disruption which is unpopular with the public, and, on the other hand, a relatively small proportion of accidents in built-up areas occur at hazardous locations that can be identified by the repeated occurrence of accidents at a disproportionate rate.

Systematic study of the occurrence of injury accidents in typical free-standing towns in Britain (Faulkner, 1975; Chapman, 1978) has shown that up to one-third occur in town centres, and the remainder are roughly equally divided between residential areas and main traffic routes. The same research also shows that very few of the accidents in residential areas and at most about one-third of those on the main traffic routes occur at identifiable hazardous locations. The majority of accidents in built-up areas therefore occur at locations that are scattered diffusely through the road network, which means that they are not susceptible to reduction by engineering measures taken to remedy hazardous locations. This is one of two main reasons for adopting an area-wide approach to the application of highway and traffic engineering safety measures in towns (Dalby, 1979). The other main reason is the wide availability of alternative routes for traffic in urban road networks, which means that measures taken to reduce accidents in one part of the network may cause traffic to use other parts of the network with consequent increases in accidents there.

Many British town centres are the subject of comprehensive traffic management schemes with a range of objectives including safety, and in successful cases these have achieved substantial reductions in accidents in the town centre without increasing accidents elsewhere in the town (see, for example, Nottinghamshire County Council, 1976). Town centres are therefore not considered further in this paper.

In other parts of British towns it has for well over a decade been standard practice in new development and extensive redevelopment to provide a hierarchical road system with the minimum of frontage access on main traffic routes and few if any through routes and crossroads in residential areas (Ministry of Transport, 1966; Department of the Environment, 1977). Large parts of most towns are, however, of earlier layouts in which many main traffic routes are two-way single-carriageway roads with frontage access and frequent junctions, and residential areas contain crossroads and streets which provide attractive routes for through traffic. These parts of our towns are the main target for the area-wide application of low-cost highway and traffic engineering safety measures intended to

(a) improve conditions on the main traffic routes both to make them safer and to make it practicable to discourage through traffic in residential areas, and

(b) create conditions in which traffic requiring access to residential areas uses their roads and streets safely and can enter and leave the adjacent main traffic routes safely,

thus strengthening the degree of hierarchy in the existing network without major reconstruction. Many relevant safety measures have been discussed in an earlier OECD report (1979). This paper is concerned with methods of monitoring the effects of such schemes, and is based on work carried out in the Transport Studies Group at University College London under contract to the Transport and Road Research Laboratory (TRRL) including the monitoring of a pilot study in the town of Swindon, in southern England (Dalby and Ward, 1981).

2. EFFECTS OF AREA-WIDE SCHEMES AND SCOPE OF MONITORING

Schemes of the kind being considered here, and having safety as the primary objective, can be expected to affect, in various degrees

(a) the number of road accidents,

(b) severity of accidents,

(c) distribution of accidents over the road network,

(d) distribution of accidents among groups of road users,

(e) flows and travel-times of vehicles along the main roads,

(f) patterns of manoeuvres made at junctions and delays incurred there,

(g) access times and distances to addresses in residential areas,

(h) fuel-consumption of vehicles using roads in the area,

(i) patterns of pedestrian movement, including crossing-points on main roads,

(j) routes taken by drivers, riders and pedestrians, and

(k) operation of buses along affected routes.

In principle, such schemes could also affect the number of journeys made by affected people and their choice of means of transport, but it is assumed here that the measures taken are not radical enough to have appreciable effects of these kinds. There may well also be environmental effects: noise and pollution and their distribution over the road network may be changed; signs and markings may be visually intrusive but the narrowing or closure of streets may provide opportunities for attractive landscaping; scope for children to play in the street and elderly people to stroll near their homes may be increased. These environmental effects are by no means discounted, and may be monitored if required, but this paper discusses the monitoring of the foregoing effects (a)-(k) only.

It is recognised that routes taken by road-users can be fully monitored only by interview surveys or by following typical travellers, but these methods are rejected as being disproportionately costly and intrusive in relation to schemes of this kind. Simpler substitutes are recommended.

Because of the likely effects of a scheme on routes taken by road-users, the affected area, that is the area over which the pattern of movement is appreciably affected, will usually extend beyond the roads where the engineering measures are sited, and the monitoring of effects (a)-(k) should cover the whole of the affected area. The design of a scheme with the objectives set out at the end of Section 1 necessarily involves consideration of the existing and possible alternative patterns of movement, so little or no extra work should be involved in identifying the affected area for the purpose of monitoring.

In the short-term, monitoring should give indication not only of success in reducing accidents, but also of any undue inconvenience or additional accidents which might be occurring as a result of unforeseen features of the operation of any component of the scheme. In the medium-term, effects can be estimated more precisely and trends in the pattern of traffic and accidents, including requirements for further safety measures, can be detected.

3. MONITORING OF ACCIDENTS.

The occurrence of accidents in the affected area will be influenced not only by the scheme but also by national developments such as safety legislation or changes in the price of fuel, and local factors such as the general prosperity of the area. To the extent that such influences have a similar effect on accidents throughout the town in which the scheme lies, they can be controlled for in accident analysis by extending the monitoring of accidents to cover a control area elsewhere in the same town or, if necessary but as a second-best, in a similar town nearby. The control area should be similar in urban form to the affected area, and just in case the affected area has been underestimated, the two areas should if possible be well-separated. For a mixture of statistical and practical reasons, the two areas should experience similar number of accidents per year. For at least one and if possible several years before the scheme and, as far as can be foreseen for a similar period afterwards, the control area should not be subject to changes influencing accident occurrence substantially differently than in the affected area. Such changes after the scheme is introduced can of course not be completely ruled out, and the method of monitoring described here is vulnerable to them. An example would be a factory closure which caused substantially higher unemployment in the control area than in the affected area.

If no suitable control area can be found, analyses of the type described here can still be made, but they are then unable to distinguish between effects of the scheme and any concurrent changes in national or local trends.

For both the affected area and the control area it is necessary to have accident records on a comparable basis for at least one and if possible several years before the scheme is introduced and then to maintain such records for as long as the monitoring is to continue. The requirement of comparability of accident records means in practice in Britain that monitoring must be based on police records of injury accidents. Records of damage-only accidents reported to the police may provide supplementary indicative information, but variability in reporting makes it unwise to base firm conclusions on them.

The injury accident records provide the basis for monitoring effects (a)-(d) in Section 2, by means of before-and-after comparison. Data for a short period around the introduction of the scheme, during which necessary roadworks take place and road-users accustom themselves to the altered road system, should be analysed separately. With low-cost measures, careful planning of the roadworks, and full information to road-users (especially residents who may be obliged to alter their routes) this period can probably be reduced to 1-2 months. Any identifiable change in accident occurrence in this period should be included in overall evaluation of the scheme but is distinct from its subsequent and lasting effects.

3.1 Total numbers of accidents

Before-and-after comparison is a long-established technique, but its scope has been considerably extended in recent years by developments in the theory of log-linear statistical models (see, for example, Fienberg, 1979) and computer programs such as GLIM (Baker and Nelder, 1978) for fitting them by maximum-likelihood methods. These models enable the statistical significance of the effects of different factors upon given accident frequencies to be assessed, and estimates of the sizes of the effects to be made, provided that suitable assumptions about the variability of the accident frequencies are justified.

In particular, linear and additive effects on the logarithm of the accident frequency can be assessed and estimated if the frequency can be regarded as a Poisson variate. Work by Hutchinson and Mayne (1977) suggests that this may well be a reasonable assumption for small accident frequencies, but not for those exceeding about 100. It is therefore recommended that the numbers of injury accidents in the affected and control areas be divided into sufficiently short intervals in the before and after periods to bring the frequencies well below 100. The fitting of linear models to the logarithms of the resulting frequencies enables the effect of the scheme to be estimated after allowing for trends over time and, when time-intervals of fractions of a year have been used, seasonal effects, each of which may differ between the affected and control areas. The procedure also yields the standard error of estimate of the effect of the scheme, and hence a confidence interval. The model can easily be refitted as each new interval's data becomes available after implementation of the scheme, thus providing a regularly updated estimate, and indicating when any given level of statistical significance has been reached.

In the pilot study in Swindon, as a simple example, quarterly accident frequencies were used and these ranged from 6 to 18 over the 4 years before and 2 years after the introduction of the scheme. One of the fitted models without use of control area and without interaction terms took the form

$$\ln(n_{ijk}) = a + bi + c_j + d_k$$

where n_{ijk} = number of accidents in quarter j of year i,

$$k = \begin{cases} 1 & \text{before the scheme was introduced} \\ 2 & \text{after the scheme was introduced} \end{cases}$$

and a, b, and the c_j and d_k are fitted parameters. The parameter-difference d_2-d_1 was estimated to be -0.10, with a standard error of 0.13, corresponding to an estimated accident reduction of 9.6 per cent with 95 per cent confidence interval ranging from a 30 per cent reduction to a 17 per cent increase.

Nicholl has discussed (1981) how to extend analysis of accident frequencies from a single scheme to a set of several schemes at different sites, or a scheme spread over several separate sites, where each site has its own control, but the effects may differ from site to site.

3.2 Severity of accidents

In monitoring the severity of accidents, the numbers of accidents in the affected and control areas are unlikely to be large enough for the analysis of numbers of fatalities to be very meaningful. Under the categorisation of severity of injury in British accident records, therefore the best indicator of severity is probably the proportion of all casualties that are in the fatal and serious categories taken together. Linear models of the logarithms of numbers of casualties in the fatal and serious category and in the slight category can be used to estimate the effect of the scheme on this indicator of severity, with the slight reservation that numbers of casualties are somewhat more variable than corresponding Poisson frequencies. Subject to the same reservation, the overall effect of the scheme on the number of casualties can be estimated for comparison with the effect on the number of accidents.

3.3 Distribution of accidents

The distribution of accidents over the road network or among groups of road-user can be monitored by disaggregating the total accident frequencies in appropriate ways. In particular, it may well be of interest to monitor separately

(a) accidents at sites where particular measures have been applied - e.g. on roads equipped with speed control humps, or at junctions where opposed turns have been prohibited,

(b) accidents on main roads and within residential areas, and

(c) accidents involving particular groups, such as pedestrians, cyclists, children or elderly people.

Such categories of accident may well be relevant to discussion of any public dissatisfaction which may arise from the scheme, because of the tendency of people to focus attention on particular features of the scheme or particular types of accident. It may also be useful to distinguish within the affected area between roads and residential areas where safety measures have been introduced, and others which may have been affected by rerouteing of traffic but where no safety measures have been implemented.

These disaggregate frequencies can be analysed in the same way as the aggregate ones, except that time-intervals may well need to be combined in order to achieve meaningful frequencies, so that less allowance for trends and seasonal variation is possible.

4. MONITORING OF TRAFFIC

Monitoring of effects (e)-(k) in Section 2 is intended to provide estimates of gains and losses to travellers in terms of changed travel-times and vehicle operating costs resulting from the scheme, and also to identify any unforeseen operational difficulties which may give grounds for modifying particular components of the scheme. For these purposes it is necessary to make observations both before and after the introduction of the scheme. Those made before its introduction may well contribute usefully to its design.

4.1 Flows and travel-times of vehicles along the main roads

The overall level of traffic on main roads in the affected area can be monitored by placing automatic traffic counters on these roads. The number of counters required will depend on local circumstances, but where the roads form a roughly radial-and-orbital network, one counter on each radial and one on each orbital link between radials would usually be appropriate. In addition, two or three counters should be placed on main routes in the control area (or, if there is no control area, on typical main roads well away from but similar to those in the affected area) to control for general changes in the level of traffic in the town. The automatic counters should be in place for one whole year before the introduction of the scheme, and remain there for at least a similar period afterwards in order to detect any appreciable overall redistribution of traffic among alternative main routes.

Whether or not such redistribution has taken place, travel-times along the main roads may well have been affected by the safety measures, especially by changes in layout and control at important junctions and in the type and number of points of access from residential areas to the main roads. The travel-time in each direction along each section of main road between important junctions can be estimated by means of the moving observer technique (Wardrop and Charlesworth, 1954), and this needs to be done at similar times of the week and year before and after introduction of the scheme. Because peak-hour flows are often tidal and substantially higher than offpeak flows, it is necessary to measure travel-times in both of the peak periods and in the offpeak.

The number of runs required to obtain a given level of accuracy in the estimate of mean travel time at a particular time of day increases with the variability of travel-time, which in turn increases with the degree of congestion. For example, on the main roads surveyed in Swindon, travel-times of between 7 and 10 minutes were found to have standard deviations of between 20 and 80 seconds in offpeak periods and in the opposite direction to the peak flow in the peak periods. For the corresponding peak flow directions in peak periods, travel times ranged from 9 to 13 minutes with standard deviations of up to 6 minutes.

So that dependence on flow can be taken into account in before-and-after comparisons by means of analysis of covariance, flows need to be observed concurrently with travel-times as described by Wardrop and Charlesworth. The same moving observer surveys can be used to record travel-times through important junctions, as discussed in Section 4.2.

Results of measurements of flows and travel-times on the main roads can be combined to provide estimates on an annual basis of changes in vehicle operating costs and time spent by vehicle occupants on the main roads in the affected area. Measurements from the control area can be used to adjust for changes that would have been expected in the absence of the scheme.

4.2 Manoeuvres made and delays incurred at junctions

Schemes of the kind being considered are likely to include changes in layout and type of control at some junctions and the prohibition or physical prevention of some movements at other junctions.

Manual counts of flows and turning movements at important junctions on the main roads, at points of access from residential areas to the main roads, and if necessary also at key junctions within residential areas, before and after the introduction of the scheme, can provide information of several kinds about movement of traffic in the affected area. They provide a basis for disaggregating by class of vehicle the main road flows recorded by automatic counters. The turning movements at important junctions can provide further information about changes of flows on the main roads. Turning movements at all junctions can give indications of changes in the points at which drivers are choosing to enter and leave the residential areas. Lastly, at junctions where certain movements have been prohibited but are still physically possible, the counts of relevant movements before and after the introduction of the scheme provide a measure of the level of compliance with the prohibition.

For all these purposes it is necessary that the counts made before and after the implementation of the scheme should be representative and comparable. Because the number of junctions may well be large, at least three times of day have to be covered, and manual counts are labour-intensive, it is also necessary to use economical methods. The fact that there are 5 working days can be used as the starting point for a Latin square design in which the junctions are divided into 5 roughly equal groups, and counts are undertaken during 5 weeks

spread over the year before the introduction of the scheme and 5 corresponding weeks in the year after its introduction. Periods of counting at different junctions at any one time of day should be adjusted so that movements with low flows are counted for long enough to avoid undue variability in grossed-up results. The effort required to cover all turning movements at junctions between residential roads and main roads can be reduced if readings from nearby automatic counters can be used instead of counting large straight-ahead movements. This leads to a possible tradeoff between the number of automatic counters installed and the number of enumerators required for manual counts.

Measurement of delays incurred at junctions requires even more resources than manual counts of flows and turning movements, and comprehensive measurements covering all junctions on the main roads are unlikely to be justified. Fortunately, junctions which simply provide for relatively small flows of access traffic entering and leaving residential areas are unlikely to be major sources of delay and changes in delays incurred by turning traffic at such junctions are covered by the monitoring of access times to addresses in the residential areas, as described in Section 4.3. Junction delay to traffic on the main roads is covered by the moving observer surveys described in Section 4.1. This leaves one other substantial category of junction delay to be monitored, namely delay to side-road traffic at important junctions on the main roads. It is important to monitor this delay because schemes of the kind being considered here are likely to concentrate turning traffic at these junctions and to include changes in their layout and control, and the effects on delay should be monitored not only as part of the overall assessment of changes in travel-times and vehicle operating costs, but also to enable unforeseen congestion to be detected and any public complaints on this score to be handled in an informed manner.

It is recommended that this side-road delay be monitored by including suitable loops in the routes taken during the moving observer surveys, so that the junctions concerned are approached from the side-roads as well as along the main road. This decreases the length of main road that can be covered per survey car in a given period, but experience in the Swindon pilot study indicates that the alternative of time-lapse filming or video-recording is too time-consuming in analysis and subject to too many difficulties in siting cameras to be practicable on the scale that would be required.

Where adaptation of a junction includes the resiting of pedestrian crossing facilities at or near the junction, it is important that delay at the pedestrian crossings be treated consistently in the before-and-after comparisons. This means that if the crossings are at the junction in either period and a short distance away in the other, then delay at the crossings in the latter period should be treated as part of the junction delay when comparing with the former period.

Delays at junctions are even more strongly dependent upon flows than are travel-times along road links, so it is important for observations of junction delay to be collated with those of flows and turning movements at the junctions concerned for purposes of analysis.

4.3 Access to addresses in residential areas

Schemes of the kind being considered here are bound to affect the routes taken by those requiring vehicular access to addresses in the affected residential areas, including the residents themselves. To the extent that such traffic uses the shortest available routes in the existing road system, distances travelled will tend to be increased when junctions or short stretches of road are wholly or partly closed, or manoeuvres prohibited. Whether total times for the journeys concerned are also increased depends on whether any extra distance is offset by improved travel-times on the main roads.

To obtain ideal information about access times and distances would require sample surveys of actual journeys to and from relevant addresses, and such surveys were ruled out in Section 2. Information is needed, however, both because these times and distances contribute to the overall effect of the scheme on travel-times and vehicle operating costs and because difficulties in access may well give rise to complaints from residents, which means that elected representatives may well need to be satisfied that any detours imposed are not unreasonable. An example of this arose in the Swindon pilot study, when a group of doctors expressed concern lest they be delayed in reaching patients in emergency. Fire and ambulance services also need to be satisfied on this score, and special provision is sometimes made for them.

An alternative method of obtaining reasonably satisfactory information about access times and distances is to take a small sample of addresses in each affected residential area, and make journeys between these addresses and suitably chosen points on the main road network both before and after implementation of the scheme. Such points might be on the edge of the affected area and on roads leading to major destinations such as the town centre or main centres of employment. Routes can be chosen from general knowledge of the road system and traffic conditions, although it must be admitted that they may not be quite typical of those used by residents. The distances can be measured from maps, and only the travel-times need to be recorded when the journeys are made.

Journeys can be repeated at different times of day. Results can be grossed-up by means of numbers of movements in and out of the residential areas, as estimated from the junction counts described in Section 4.2.

The validity of this procedure depends mainly on that of the sample of addresses. Addresses in a residential area differ substantially in the number of vehicular journeys made to and from them, according to the size, composition, socio-economic characteristics and vehicle-ownership of the household living there. If the mixture of households is similar in all parts of a residential area, then addresses selected at equal intervals through a street index would form a suitable sample. If, by contrast, different parts of the area contained quite different mixtures of types of household, then the sample could be stratified between sub-areas and weighted in proportion to the vehicular trip-making propensities of households in different broad categories, as determined from suitable national statistics of travel. Sampled households could be associated with the chosen points on the main road network either with the help of existing local travel survey data or, failing this, on the basis of general local knowledge.

In the pilot study in Swindon, this part of the work had to be carried out at short notice, and the choice of addresses, points on the road network and routes between them was therefore rather arbitrary, but even so the information obtained proved useful.

4.4 Fuel-consumption

In view of current and probable future concern with energy conservation in transport, it may well sometimes be appropriate to monitor the effects of area-wide safety schemes on fuel consumption specifically, in order to corroborate or complement estimates which could be made from the various observations of travel times, traffic flows and access times and distances. If so, this can be done by means of suitably instrumented vehicles. In the pilot study in Swindon, for example, it was demonstrated (Wood and Griffin, 1980) that changes in the geometrical layout of a main road were associated with a reduction of about 2.5 per cent in fuel consumption, quite apart from any saving due to increased average speed of traffic.

4.5 Pedestrian movement

Pedestrian movement is difficult to monitor because of its complex and often diffuse patterns. Fortunately, schemes of the kind being considered here are very unlikely to affect pedestrian movement within residential areas adversely. It follows that if one is prepared to forego any quantitative estimate of benefit pedestrians obtain within the residential areas, monitoring of effects on pedestrians may be confined to the main roads in the affected area. The main effects on pedestrians on these roads are likely to stem from

(a) changes in the amount, speed, and pattern of flow of traffic,
(b) changes in the provision and location of crossing facilities, and
(c) changes in the length and position of guardrails.

Attention has so far been confined to changes (b) and (c), because it is felt that the measures envisaged are generally rather unlikely to make such great changes of type (a) that pedestrians would be substantially affected, and that if there were places where substantial adverse effects were foreseen, a crossing facility would be provided, thus making a change of type (b).

Where local changes of type (b) are made, it is possible to monitor the effects on the proportion of pedestrians using the crossing and the proportions crossing in nearby lengths of road by dividing the road into sections of about 50 metres in length and having one observer count the pedestrians crossing in each section, together with one observer for each crossing. Concurrent traffic counts enable the use of the crossing facilities to be correlated with traffic flow. The resulting data provide information about usage of facilities and can be used in conjunction with externally derived formulae (see, for example, Goldschmidt, 1977) to obtain rough estimates of delay, but the data are difficult to interpret in terms of lengths of detour accepted by pedestrians because, except in very simple cases, it is impossible to tell where the pedestrian would have liked to cross.

Similar problems arise with changes of type (c) where the pattern of crossing behaviour that the guardrails are intended to influence are complicated. In cases where a relatively clearly-defined flow of pedestrians is being channelled to a particular crossing point, however, the resulting detour may not be so difficult to estimate.

It would be desirable to obtain a fuller picture of the effects on pedestrians on main roads than has so far been possible, but it is hard to see how this can be done within the scope of monitoring outlined in Section 2.

4.6 Routes taken

As already discussed, the type of scheme being considered here does not warrant detailed surveys of routes taken by individual road users. Any appreciable shifts of traffic between alternative main roads are indicated by corresponding changes in the automatic traffic counts. Redistribution of traffic from particular residential areas among different points of entry and exit and therefore among adjacent main roads are reflected in the counts of flows and turning movements at the relevant junctions. Where it is thought important to detect particular shifts of traffic within residential areas, counts will be made at key junctions there for that purpose. The difficulties of monitoring routes taken by pedestrians, except in simple cases, have already been discussed.

There remains the question of routes taken by pedal cyclists, and these may well warrant special attention in view of the attention currently being given to provision for cycling (Department of Transport, 1978 and 1981). Cyclists using routes available to motor vehicles will have been included and distinguished in the traffic counts made at junctions, but a typical scheme is likely to include at least some special provisions enabling cyclists to use routes through residential areas instead of main roads, and to avoid at least some of the detours that may be required of motor vehicles. Even where no special provision is made, cyclists are likely to take short cuts via footways, whether strictly legally or not, where the distance saved is appreciable. There are therefore likely to be some points at which counts of pedal cyclists are required, in order to assess the scale on which routes available to cyclists but not to motor traffic are being used. It may also be appropriate to measure access distances by pedal cycle for the sample of addresses discussed in Section 4.3 separately from those by motor vehicle.

4.7 Operation of buses

In a well-designed scheme, buses will not be rerouted nor stops resited in ways which increase either bus or passenger journey times. Nor will buses be required to negotiate difficult road layouts (Department of the Environment, 1977). Indeed, the opportunity may well have been taken to improve access by bus to parts of the residential areas and to destinations along the main traffic routes in consultation with the bus operators (Addenbrooke and others, 1981). In any case, the scheme may well affect traffic conditions encountered by buses on the main roads, and there is always the possibility of unforeseen difficulties arising for buses at particular points.

For these reasons it may be appropriate for specific monitoring of bus operation to take place before and after the implementation of the scheme. This can take the form of standard on-bus surveys covering the relevant sections of all affected routes. In such surveys (Chapman, Gault and Jenkins, 1976), an observer travels in each bus and records numbers of passengers boarding and alighting at each stop, the time spent at each stop and times of passing other specific points on the route. From these data, any changes in patronage, numbers of people using the various stops, average travel time, regularity, and delay incurred at particular points on the route can all be estimated.

This concludes the discussion of monitoring of effects (e)-(k) in Section 2.

5. USES OF THE RESULTS OF MONITORING

The methods of monitoring described in this paper, though neither perfect nor comprehensive, do enable many of the effects of area-wide safety schemes to be identified and in many cases quantified. All of the resulting information is potentially relevant to operational assessment of schemes and identification of possibilities and requirements for improvements to the design.

Moreover, many of those effects that can be quantified can be summarised by means of conventional techniques of economic evaluation (OECD, 1981). In current British practice, a partly objective and partly subjective monetary value is attributed to savings in accidents (Department of Transport, annual). Changes in travel-time are also given standard monetary values, and operating costs for different types of vehicle are estimated from journey-distances and traffic speeds (Department of Transport, annual). In these ways, the results of monitoring can be used to estimate an annual net operating benefit in money terms at current prices. Annual maintenance costs are subtracted to give an estimated annual net benefit. The ratio of the net benefit in the first year to the cost of designing, implementing and monitoring the scheme is known as the first year rate of return. This is an appropriate indicator of cost-effectiveness for projects such as this in which most costs are incurred at the outset and a fairly steady stream of net benefit can be expected in subsequent years.

Because experience so far with area-wide safety schemes and their monitoring is limited, it is not yet clear just which kinds of monitoring are most necessary to operational and economic evaluation, or on just what scale they will be required in routine application, and in the formulation by local authorities of policies for accident reduction and prevention (Institution of Highway Engineers, 1980). In order to clarify these questions and to learn quickly and effectively by experience, it will be especially valuable for a few area-wide safety schemes in British towns to be particularly throroughly monitored on the lines described here in the near future.

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SESSION 4:
Product evaluation: accident studies

SESSION 4

Chairman: Mr. S.A. Holmsen (Norway)

Theme: Product-evaluation: accident studies

T. Boot, P. Wassenberg and H. van Zwam (the Netherlands)	: Changes in the road accident pattern as a result of a strike at the municipal public transport undertaking in The Hague
A. Douvier (France)	: Influence sur la securité routière de la mise en place des plans de circulation dans les villes
M. 't Hart (the Netherlands)	: Effects on accidents, eliminating throughtraffic of cars in city areas
S. Johannessen (Norway)	: Co-ordinated traffic safety studies in the nordic Countries. Experiences from the "Emma" Project
M. Slop (the Netherlands)	: Experiences in two investigations into the effect of one-way traffic on road safety
P.A.M. de Werd (the Netherlands)	: Study on the effect of eliminating intermittent signal from traffic light programmes in Eindhoven

CHANGES IN THE ROAD ACCIDENTS PATTERN AS A RESULT OF A STRIKE AT THE MUNICIPAL PUBLIC TRANSPORT UNDERTAKING IN THE HAGUE

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Note : Mr. S. Oppe (SWOV) is thanked for his help with the statistical analysis.

1. SUMMARY AND CONCLUSIONS

This paper presents the results of a study into the changes in the road accidents pattern in the Municipality of The Hague (450,000 inhabitants) as a result of a strike by the drivers at the Municipal transport undertaking (7 to 27 May inclusive 1981). The aim of the study was to find out in what manner and, to some extent, the degree to which the road accidents pattern can change when :

a. the level of public transport services is reduced;
b. a shift occurs in the modal split.

a. A statistical analysis was made of the road accident figures for the period 7 to 27 May inclusive for the years 1978 to 1981 inclusive to see whether any shift had occurred in the road accidents pattern during the period of the strike. Comparison of 1981 with 1978 to 1980 inclusive was the main issue. The following conclusions were drawn :
   - There was a significant difference between the number of road accidents in 1981 and the number in 1978 to 1980 inclusive. The number of road accidents in 1981 was 27% up on the average number of road accidents between 1978 and 1980 inclusive.
   - No significant differences were found for the years 1978 to 1981 inclusive regarding the severity of the road accidents, i.e. the ratio of accidents with injury to accidents with material damage only did not change substantially in the years in question.
   - The number of cars, mopeds and bicycles involved in road accidents was clearly greater and the number of buses and trams involved in road accidents (naturally) was clearly smaller in 1981 in relation to 1978 to 1980 inclusive. The differences were all significant.
   - Under the heading of types of collision a relatively large number of road accidents were encountered in which bicycles and mopeds only were involved in 1981 in relation to 1978 to 1980 inclusive.
   - No major differences were found between the years 1978 to 1981 inclusive regarding the road situation and the light conditions under which the road accidents occurred.

b. Few data are known on the change in the modal split during the strike.
   A very general picture of the change in the modal split can be obtained from the traffic counts of cars and of bicycles and mopeds prior to, during and after the strike at 19 locations in the municipality of The Hague.
   During the strike there was a very sharp increase in the number of bicycles and mopeds (44%) and a less sharp increase in the number of cars (10%) observed during the morning and evening rush hours.
   No general conclusions can be drawn regarding the effect of the change in the modal split on the change in the road accident pattern during the strike.

2. Introduction

The Integrated Traffic and Transport Studies Project Bureau

at the Ministry of Transport and Public Works recently set up a study to measure and analyse the effects of urban public transport in the agglomeration of the municipality of The Hague (450,000 inhabitants) being withdrawn as a result of the strike by drivers at the municipal public transport undertaking from 7 to 27 May 1981.
The aim of the study was to obtain some indication of the function of public transport in the urban traffic and transport system. The effects that were examined included the number of trips, in the choice of destination (particularly for shopping), and mode. The study described here gives the results of an investigation into the change in the pattern of road accidents in the municipality of The Hague during the strike. The aim of the road accidents is to ascertain in which manner and to some extent, the degree to which the pattern of road accidents can change when :

a. the level of public transport services is reduced;
b. there is a shift in modal choice.

The set up of the road accidents study is described in Chapter 3. The method of amassing and analysing the data on road accidents is explained and the validity of the data used is also discussed.

Chapter 4 attempts to answer the question of the extent to which the pattern of road accidents changed as a result of a reduction in the level of public transport services during the strike. The results of the analysis which was carried out by way of reply to this question are given.

Can the change in the pattern of accidents be related to the change in modal choice during the strike? To answer this question the shift in the pattern of traffic accidents would have to be related to the shift in total number of trips or the shift in traffic volume. Since few data are known on the shift in modal choice during the strike the question is dealt with in Chapter five in the form of a discussion.

3. The Set-Up of the Study

3.1 Determining the change in the pattern of road accidents

The road accident figures from 7 to 27 May inclusive in the years 1978 to 1981 were analysed to see whether a shift in the pattern of road accidents occurred in the municipality of The Hague during the strike. Apart from the particular year, attention was paid to the following accident factors : severity (relationship between the number of accidents with injuries in relation to the number of accidents with material damage only), modes of transport involved, type of collision, type of road situation and light conditions. A statistical analysis was carried out to see whether the road accident pattern changed over the period from 1978 to 1981. One area of the study was whether a relationship existed between

the following factors :

a) year x severity
b) year x type of collision
c) year x severity x type of collision
d) year x modes of transport involved
e) year x type of road situation
f) year x light conditions.

A chi-square analysis was used for the a, b and c interactions with chi-square values being calculated for predetermined sub-effects as well as for the overall effect. The Road Safety Research Foundation's Weighted Poisson Model programme (WPM) was used. 1)
The d, e and f interactions were examined with a chi-square test in which the overall effect alone was calculated.

The study was carried out with the aid of road accident data recorded by the police. The following points should be noted regarding the validity of the data :

- The number of road accidents recorded by the police constitute only a small proportion of the actual accidents occuring. Since the method of recording road accidents from 1978 to 1981 inclusive did not change it is assumed that the data available may be used as an aid in establishing whether the road accident pattern changed during this period.
- The strike lasted 'only' three weeks. It would seem plausible to assume that a change in the road accident pattern can be partially ascribed to the sudden change in the traffice picture. If the strike had lasted longer the effects might have diminished.
- Public holidays may affect the road accident pattern. Only Whitsun fell between 7 and 27 May in 1978; in 1979 only Ascension day; in 1980, Ascension day and Whitsun and in 1981 neither Ascension day nor Whitsun. The effect of these public holidays on the road accident pattern was not taken into account in the study.

3.2 Determining the effect of a change in modal choice on the change in the pattern of road accidents

As yet little is known about the change in modal choice during the strike. A very general impression of the change in the modal split was obtained with the aid of the traffic counts of private cars and of bicycles/mopeds prior to, during and after the strike at 19 locations throughout The Hague. In view of the limited data available an attempt is made in Chapter 5 by way of a discussion to relate the change in modal choice to the changed pattern of road accidents during the strike.

1) Log-linear models for weighted figures (in Dutch) by de Leeuw and S. Oppe (SWOV)

4. Results of the road accidents study

4.1 General

Table 4.1 gives the road accident figures arranged according to accident with injury and accident with material damage only between 7 to 27 May in the years 1978 to 1981 inclusive that were recorded in The Hague.

	1978	1979	1980	1981
Injury accident	156	144	142	175
Material damage only	644	803	703	928
Total recorded	800	947	845	1103

Table 4.1 Number of registered road accidents by injury and by material damage only between 7 to 27 May in the years 1978 to 1981 inclusive in The Hague.

A chi-square analysis was performed to see whether the number of road accidents in 1978, 1979, 1980 and 1981 differed significantly (Appendix 1); chi-square values were calculated for predetermined sub-effects as well as for the overall effect, using the Road Safety Research Foundation's Weighted Possion Model (WPM). The difference in the years referred to proved to be very significant ($\chi^2 = 58{,}28$; df = 3; $\chi^2_{.95} = 7{,}82$). The main factor was the high number of road accidents in 1981 (i.e. during the strike) in relation to the years 1978 to 1980 inclusive. The sub-effect in 1979 in relation to 1978 and 1980 is also significant (more road accidents in 1979) but this is of a smaller order than 1981 in relation to 1978 to 1980 inclusive.

At the same time the severity of the road accidents (i.e. the number of accidents with injury as opposed to accidents with material damage only) was examined to see if this had changed over the years (see Appendix 1). No significant differences were observed for the years 1978 to 1981.

4.2. Collision analysis

In the collision tables the accidents are classified according to the parties involved in the collision. This has been done in tables 4.2 and 4.3 for the total number of recorded road accidents and the total number of recorded accidents with injury in the period from 7 to 27 May and for the years 1978 to 1981 inclusive in The Hague. For example it can be seen in table 4.2 that 65 accidents occurred between private vehicles and bicycles in the period in question in 1981.
The explanation for the number of buses and trams involved in road accidents in 1981 not being zero is that coaches and regional buses were operating.
Another statistical analysis was carried out with the aid of the WPM (Appendix 1) to see whether there was any

		car		bus/tram		moped		bicycle		pedestrian		other		total	
car	1978	439												439	
	1979	507	2048											507	2048
	1980	457												457	
	1981	645												645	
bus/tram	1978	18		-										18	
	1979	35	95	-	-									35	95
	1980	33		-										33	
	1981	9		-										9	
moped	1978	45		-		1								46	
	1979	58	208	-	1	-	5							58	214
	1980	44		-		1								45	
	1981	61		1		3								65	
bicycle	1978	36		2		6		-						44	
	1979	48	195	4	9	5	29	2	12					59	245
	1980	46		2		7		4						59	
	1981	65		1		11		6						83	
pedestrian	1978	20		-		7		5		0				32	
	1979	14	73	-		7	24	2	9	0	-			23	108
	1980	21		2	2	5		1		0				29	
	1981	18		-		5		1		-				24	
other	1978	155		7		15		18		3		23		221	
	1979	199	754	5	18	8	39	21	67	7	15	25	92	265	985
	1980	173		6		8		9		3		23		222	
	1981	227		-		8		19		2		21		277	
total	1978	713		9		29		23		3		23		800	
	1979	861	3373	9		20	97	25		7	15	25	92	947	3695
	1980	774		10	30	21		14	88	3		23		845	
	1981	1025		2		27		26		2		21		1103	

Table 4.2 Number of road accidents recorded by type of collision in the period from 7 to 27 May in the years 1978 to 1981 in The Hague.

		car		bus/tram		moped		bicycle		pedestrian		other		total	
car	1978	35	130											35	130
	1979	34												34	
	1980	33												33	
	1981	28												28	
bus/tram	1978	-	1	-	-									-	1
	1979	-		-										-	
	1980	1		-										1	
	1981	-		-										-	
moped	1978	28	101	1	2	1	5							30	108
	1979	19		-		-								19	
	1980	19		-		1								20	
	1981	35		1		3								39	
bicycle	1978	17	88	1	6	4	21	-	9					22	124
	1979	21		2		3		2						28	
	1980	19		2		6		4						31	
	1981	31		1		8		3						43	
pedestrian	1978	18	64	-	2	1	16	5	7	-	-			24	89
	1979	10		-		6		1		-				17	
	1980	20		2		4		1		-				27	
	1981	16		-		5		-		-				21	
other	1978	12	57	1	3	10	23	16	55	2	12	4	15	45	165
	1979	16		1		2		16		6		5		46	
	1980	10		1		4		8		2		5		30	
	1981	19		-		7		15		2		1		44	
total	1978	110	441	3	13	16	65	21	71	2	12	4	15	156	617
	1979	100		3		11		19		6		5		144	
	1980	102		5		15		13		2		5		142	
	1981	129		2		23		18		2		1		175	

Table 4.3 Number of accidents with injury recorded by type of collision in the period from 7 to 27 May in the years 1978 to 1981 in The Hague.

connection between the factors year x severity x type of collision. As in Section 4.1 a distinction was made by year and by severity of accident in terms of injury or material damage only. The type of collision was classified into the following five combinations : (cc), (cb + cm), (cp + co), (mm + mb + bb), (mp + mo + bp + bo)

c = car
m = moped
b = bicycle
p = pedestrian
o = other

There was a very significant difference in the severity of the accident and the type of collision (χ^2 = 548.86; df = 4; χ^2.95 = 9,49), but the relationship did not alter in the various years (χ^2= 18.22; df = 12; χ^2.95 = 21.03).
The connection between type of collision and year is just significant (χ^2 = 21.04; df = 12; χ^2.95 = 21.03).
The relationship can almost be totally ascribed to the difference in 1981 in relation to 1978 to 1980 inclusive between the number of road accidents involving bicycles and mopeds only (mm + mb + bb) and the number of accidents between bicycles and mopeds on the one hand and pedestrians and other on the other (mp + mo + bp + bo).

4.3 Analysis of the modes

Table 4.4 gives the number of cars, buses and trams, mopeds bicycles and pedestrians involved in the traffic accidents recorded between 7 to 27 May in the years 1978 to 1981 inclusive. The explanation for the number of buses and trams involved in 1981 not being zero is that coaches and regional buses were on the roads during this period.

	1978	1979	1980	1981
car	1195	1433	1303	1752
bus + tram,	31	47	46	11
moped	85	82	65	100
bicycle	71	87	76	114
pedestrian	37	32	32	28

Table 4.4 The number of cars, buses and trams, mopeds, bicycles and pedestrians involved in road accidents recorded in the period from 7 to 27 May in 1978 to 1981 in The Hague.

A chi-square test was used to see whether the number of cars, buses and trams, mopeds, bicycles and pedestrians involved in the registered road accident figure charged in the course of the years 1978 to 1981 inclusive (see Appendix 2). The trend has not been taken into account.

Apart from the pedestrians significant differences were found for the modes of transport given. The number of cars, bicycles and mopeds was higher than expected in 1981 and the number of buses and trams (naturally) was lower than expected.

4.4 Analysis of the road situation

Table 4.5 gives the number of road accidents recorded between 7 and 27 May in the years 1978, 1979, 1980 and 1981 by road situation in which the accidents occurred :

	1978	1979	1980	1981
straight	361	468	389	548
junction	257	304	290	357
X/Y-junction	152	136	142	176
roundabout	11	17	13	5
bend	19	22	11	17
total	800	947	845	1103

Table 4.5 Number of road accidents recorded between 7 to 27 May inclusive in the years 1978, 1979, 1980 and 1981 by road situation in The Hague.

The hypothesis that the number of registered road accidents by road situation differed for the years 1978, 1979, 1980 and 1981 was refuted with the aid of a chi-square test. This means that no relation was found between the road situation and the year. (Appendix 3)

	1978	1979	1980	1981
daylight	683	795	713	941
darkness	104	127	117	143
dusk	13	25	15	19
total	800	947	845	1103

Table 4.6 The number of road accidents recorded between 7 to 27 May inclusive in the years 1978, 1979, 1980 and 1981 by light conditions in The Hague.

4.5 Analysis of light conditions

The number of road accidents recorded between 7 and 27 May in the years 1978, 1979, 1980 and 1981 arranged according to the light conditions at the time of the accident - daylight, darkness, dusk - is given in Table 4.6.

The hypothesis that the number of registered road accidents arranged according to light conditions differed in the years 1978, 1979, 1980 and 1981 was refuted with the aid of a chi-square test (Appendix 4). This means that no relation was found between light conditions and the year.

5. DISCUSSION

To relate the shift in the road accident pattern to the shift in the modal split during the strike an idea will have to be obtained of the relationship between the number of road accidents and the total number of trips /traffic volume by mode prior to, during and after the strike.

During the strike, public transport users either chose another mode or did not make any trips. However, little is known as yet about the changed modal split during the strike. Only the traffic counts at 19 locations throughout The Hague provide a rough picture of the changes in the use of cars, bicycles and mopeds during the strike. The counts took place in April, May (during the strike) and June 1981.

Table 5.1 gives the sum of the cars and bicycles and mopeds in the morning and evening rush hours in April, May and June 1981.

	April	May (during the strike)	June
cars	31946	33895	29581
bicycles + mopeds	9710	15642	11877

Table 5.1 Traffic volumes at 19 locations throughout the municipality of The Hague in the morning and evening rush hour in April, May and June 1981.

It is assumed that the lower figure for cars and the increase in the figures for bicycles and mopeds in June in relation to April can be ascribed to seasonal influences. The expected traffic volume for May can be calculated as given in Table 5.2.

Cars			
	expected volume in May	actual volume in May	Difference
$\frac{31946 + 29581}{2}$	= 30764	33895	10%

Bicycles + mopeds			
	expected volume in May	actual volume in May	Difference
$\frac{9720 + 11877}{2}$	= 10794	15642	44%

Table 5.2 Determination of difference between actual and expected number of cars and bicycles and mopeds in May 1981.

The extremely high figures for bicycles and mopeds at the count locations in May in relation to the averages for April and June stand out. It is assumed that the high figures for bicycles and mopeds in May can partly be ascribed to the favourable weather during the strike but the main reason will have to be sought in the fact that public transport users on the whole switched to the bicycle during the strike.

If it is assumed that the higher numbers of road accidents in the period 7 to 27 May inclusive in 1981 in relation to 1978 to 1980 inclusive can be ascribed to the changed traffic picture during the strike, then it is an obvious step to relate the road accident figures to traffic volume.
A difficulty here is that only rush hour data on traffic volume have been gathered. The increase of 44% in the number of bicycles and mopeds would be lower if the data had been gathered on a 24-hour basis. Because it is not known which of the road accidents took place during the rush hours it is not really possible to relate the road accident figures to the traffic volume.
A number of data have been listed together in Table 5.3 to give a general picture.
The table indicates the change in the number of accidents with injury between cars, between bicycles and mopeds and between car and bicycles and mopeds in 1981 in relation to the average for 1978 to 1980 between 7 and 27 May inclusive.
The data have been taken from Tables 4.2 and 4.3.
The product of the volumes has been taken as a measure of the number of encounters between these modes of transport.
The change in the product of the volumes in May 1981 in relation to the average for April and June 1981 is also given by type of collision in Table 5.3. The data have been taken from Table 5.2.

	number of encounter during the strike by comparison with the number before and after the strike	Number of accidents with injury			Total number of accidents		
		average 1978 to 1980 inclusive	1981	difference	average 1978 to 1980 inclusive	1981	difference
between cars	+ 21%	34	28	- 18%	468	645	+ 38%
between cars and bicycles and mopeds	+ 60%	41	66	+ 61%	92	126	+ 40%
between bicycles and mopeds; mopeds and mopeds; bicycles and bicycles	+110%	7	14	+100%	9	20	+122%

Table 5.3 Comparison of encounters and accidents (with injury)
Notes :-The product of the volumes was used as a measure of the number of encounters.
-The accidents with injury given all took place in the period from 7 to 27 May inclusive of the years in question.

APPENDIX 1

Overview of the tables produced with the aid of the Weighted Poisson Model method:

I	:	year
II	:	year x severity
		year x type of collision
		year x collision x severity

Design matrices used:

Year	1. 1981	⟷	1978 + 1979 + 1980
	2. 1979	⟷	1978 + 1980
	3. 1978	⟷	1980
severity	1. injury	⟷	material damage only
type of collision	1. (cc) + (cp, co)	⟷	(cb, cm) + (mm, mb, bb) + (mp, mo, bp, bo)
	2. (cc)	⟷	(cp, co)
	3. (cb, cm)	⟷	(mm, mb, bb) + (mp, mo, bp, bo)
	4. (mm, mf, bb)	⟷	(mp, mg, bp, bo)

c = car
m = moped
b = bicycle
p = pedestrian
o = other

Appendix 1 continued

Table	effect	chi-square	df	righthand chance of being outside χ^2 .95	significance	sub-effects: effect	sub-effects: standard score
I	year	58.28	3	7.82	*	1 2 3	6.86 3.46 1.11
II	year x severity	2.47	3	7.82	-		
	year x type of collision	21.04	12	21.03	*	1 4	2.76
	year x type of collision x severity	18.22	12	21,03	-		

* : significant - : not significant
Only the significant sub-effects have been indicated. The figures show which sub-effect indicated in the overview of the design matrix used is referred to. The calculated standard score for the sub-effects given must be compared with the 5% chance of being outside the normal distribution; the value for this is ± 1.96.

Appendix 2 Chi-square; year x vehicle or person involved

	1978 - 1980		1981						
	O	E	O	E	O-E	χ^2	df	$\chi^2.35$	sign.
car	3931	4262	1752	1421	331	102.81	1	3.84	*
bus + tram	124	101	11	34	23	21,8	1	3.84	*
moped	232	249	100	83	17	4.64	1	3.84	*
bicycle	234	261	114	87	27	11.17	1	3.84	*
pedestrian	101	97	28	32	4	0.66	1	3.84	-

* = significant - = not significant
O = Observed
E = Expected

Appendix 3 Chi-square year x situation

	1978			1979			1980			1981			total
	O	E	O-E	O	E	O-E	O	E	O-E	O	E	O-E	
straight	361	382	-21	468	453	+15	389	404	-15	548	527	+21	1766
junction	257	262	-5	304	309	-5	290	276	+14	357	361	-4	1208
X/Y junction	152	131	+21	136	155	-19	142	139	+3	176	181	-5	606
roundabout	11	10	+1	17	12	+5	13	10	+3	5	14	-3	46
bend	19	15	+4	22	18	+4	11	16	-5	17	20	-3	69
Total	800			947			845			1103			3695

χ^2 = 7.18 df = 12 $\chi^2.95$ = 21,03

not significant

O = Observed
E = Expected

Appendix 4. Chi-quadrate : year x light conditions

	1978			1979			1980			1981			Total
	O	E	O-E	O	E	O-E	O	E	O-E	O	E	O-E	
daylicht	683	678	+5	795	803	-8	713	716	-3	941	935	+6	3132
darkness	104	106	-2	127	126	+1	117	112	+5	143	147	-4	491
dusk	13	16	-3	25	18	+7	15	17	-2	19	21	-2	72
	800			947			845			1103			3695

χ^2 = 4,19 df = 6 $\chi^2.95$ = 12.59

not significant

O = Observed
E = Expected

INFLUENCE SUR LA SECURITE ROUTIERE DE LA MISE EN PLACE DES PLANS DE CIRCULATION DANS LES VILLES

A. DOUVIER - CENTRE D'ETUDES DES TRANSPORTS URBAINS (FRANCE)

1 - Face à l'augmentation croissante des déplacements dans les villes et aux nuisances qui en résultent, l'Etat a lancé au début des années 1970 un programme de plans de circulation dans les villes de plus de 20.000 habitants pour inciter les Collectivités Locales à rechercher et à mettre en oeuvre des solutions immédiates.

Le plan de circulation vise trois objectifs fondamentaux : (1)

- améliorer les conditions de circulation et de fluidité du trafic
- réduire les accidents urbains
- préserver et même améliorer les conditions d'environnement. en réduisant les nuisances dues au trafic et en créant des zones particulièrement accueillantes et propices aux échanges.

Il s'agit de tirer le meilleur parti des infrastructures existantes en utilisant des moyens réglementaires d'organisation de la circulation et des moyens techniques d'équipements des chaussées (2) au niveau de la ville.

Pour assurer son rôle incitatif, l'Etat apporte une aide financière en participant aux dépenses qui portent à la fois sur les études et sur les équipements entrant dans le cadre des plans de circulation.

Sept ans après le lancement du programme, un bilan "sécurité" des plans de circulation mis en place a été réalisé au niveau de la France entière. L'objet de la présente communication est de fournir la méthodologie utilisée et les principaux résultats obtenus. Cette étude a été effectuée par le Centre d'Etudes Techniques de l'Equipement de ROUEN en 1978-1979 (3).

2 - **La méthodologie repose sur l'évolution comparative des accidents corporels selon les différents types de villes sur une période de 8 ans et sur la recherche de corrélation entre les écarts observés dans les évolutions ci-dessus et les coûts d'investissements des plans de circulation (y compris la participation de l'Etat).**

L'étude a porté sur l'ensemble des villes de plus de 20.000 habitants (à l'exclusion de celles situées en Région Parisienne qui ont dû être éliminées pour assurer la meilleure cohérence possible).

Parmi ces 226 villes, 66 avaient obtenu une participation de l'Etat dans le cadre des plans de circulation avant 1978. Une enquête locale auprès de ces dernières a permis de définir le montant total des investissements réalisés chaque année (il existe un décalage entre le déblocage des crédits et la date de réalisation des équipements) selon le type d'aménagement (aménagement de carrefour, signalisation, régulation, aménagements piétonniers, autres actions). Des réponses complètes ont pu être obtenues pour 52 villes que nous désignerons par villes ayant utilisé des subventions "connues" par opposition aux 14 villes ayant utilisé des subventions "inconnues".

Parmi les 160 villes n'ayant pas reçu de subvention de l'Etat, on a éliminé 21 villes importantes qui ont beaucoup investi sans l'aide de l'Etat pour traiter certains de leur problème circulation.

Les 139 villes restantes, non subventionnées et n'ayant pas investi, on constitué le groupe de référence, c'est-à-dire ce qui aurait dû se passer si le programme des plans de circulation n'avait pas été lancé.

3 - Une partition en 4 strates des villes a donc été obtenue et une exploitation spéciale du fichier national des accidents corporels a fourni le nombre d'accidents, de tués, de blessés graves et de blessés légers pour chacune de ces 4 strates et pour chaque année (de 1970 à 1977). Ces mêmes données ont été également sorties individuellement pour chacune des 52 villes de la première strate, mais les essais d'analyse au niveau d'une ville isolée n'ont jamais permis de conclure.

4 - Le tableau ci-après donne l'importance de l'échantillon et l'évolution du nombre d'accidents corporels entre 1970 et 1977 pour chacune des 4 strates :

STRATE	Nombre de villes	% d'accroissement de la population de 1968 à 1975	Accidents corporels			
			Nombre 1970	Indice 1970	Indice 1977	
1. Villes ayant utilisé des subventions "connues"	52	+ 2,6 %	33.200	100	96,8	97,7
2. Villes ayant utilisé des subventions "inconnues"	14	+ 6,2 %	5.400	100	103,1	
3. Villes non subventionnées ayant investi	21	+ 4,3 %	18.600	100	115,7	119,-
4. Villes non subventionnées et n'ayant pas investi	139	+ 6,6 %	18.600	100	123,1	
Ensemble	226	+ 4,4 %	75.800	100	108,2	

Malgré l'évolution légèrement différente des populations selon les strates, l'étude met en évidence une différence significative entre l'évolution des accidents corporels.

Le lancement du programme de plan de circulation en 1971 aura donc permis d'éviter environ 10.000 accidents corporels en 1977 dans les villes de plus de 20.000 habitants.

5- L'analyse de l'évolution de la gravité des accidents (nombre de tués, nombre de blessés graves) par strate n'a pas permis de conclure de manière significative.

6- Les écarts ainsi mis en évidence peuvent être corrélés avec le montant des investissements réalisés. Diverses corrélations ont été testées en jouant sur la référence (strate 4, ou strate 3 + 4), sur les villes subventionnées (strate 1 ou strate 1 + 2) ; en introduisant soit les données annuelles, soit les données cumulées depuis 1970. Les meilleures corrélations (coefficient de corrélation égal ou supérieur à 0,98) sont obtenues en décalant d'un an les écarts entre accidents corporels par rapport aux investissements : ceci se justifie par le fait qu'un investissement réalisé en cours d'année n'est pleinement profitable que l'année suivante.

Toutes ces corrélations semblent indiquer qu'un investissement de 10 Millions de francs entraîne une diminution du nombre des accidents corporels de l'ordre de 2 %.

7 - Un bilan économique sommaire sur les villes de la première strate montre enfin que le gain obtenu par la réduction des accidents (coût des accidents corporels en valeur 1975) dépasse largement les investissements réalisés (plus du double).

8 - En conclusion, le bilan des plans de circulation est très nettement positif en ce qui concerne la sécurité routière. Ce résultat est d'autant plus remarquable que dans les études des plans de circulation et dans l'établissement des projets, on ne sait pas très bien comment prendre en compte les problèmes de sécurité d'une manière globale.

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EFFECTS ON ACCIDENTS,

ELIMINATING THROUGHTRAFFIC

OF CARS IN CITY AREAS

M.'t Hart

1. Introduction

Reducing traffic-accidents in towns is a part of improving environment.
In the post war period the town was overcrowded with cars (fig.1)

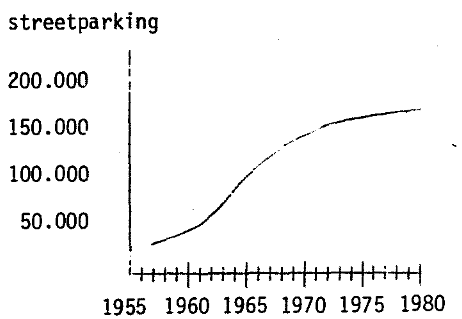


fig.1. Number of cars parked overnight on the streets of Amsterdam.

The face of the public space changed considerably.
The car dominates in the town in size, noise, airpollution and in danger, but not in quantity.
As an example, the total number of moving people in the whole public space of the built-up area of Groningen (30 square kilometers, 165.000 inhabitants) is given for two moments on a working-day in 1975.

* estimation	pedestrians	moped/ bicycle	persons per car	bus	total
3.30 p.m.	8.100	3.200	4.900	1.300*	17.500
5.00 p.m.	9.700	4.700	6.000	1.800*	22.200

table 1. Number of moving people in Groningen at an off-peak and a peak moment in 1975.

Less than one third of the moving people used the car, whereas the shape of the public space suggests a domination of the car.

In the Netherlands the central Government is now stimulating priority in the towns to pedestrians, bicycles and public transport.

Within the scope of a restoration of the balance between the available space for the different means of transport, in towns, the aspect of traffic-accidents will be treated in this paper.

2. Traffic-injuries in built-up areas

In the built-up areas in the Netherlands, 123041 injuries were registrated in the three years 1978, 1979 and 1980 together.
In table 2 the accidents have been divided in persons with injuries using different means of transport.
Per vehicle-catagory the accidents are divided in:
- single, not direct in contact with another moving person
- double, in contact with one other moving person
- complex, in contact with more than one moving person.

	car	motorscooter	moped	bicycle	pedestrian	total
single	7.734	1.307	7.177	5.078	11	21.307
double	17.624	4.054	26.866	23.574	14.142	86.260
complex	8.821	693	2.047	2.179	1.734	15.474
total	34.179	6.054	36.090	30.831	15.887	123.041

table 2. Number of injuries per means of transport in the built-up areas in the Netherlands during 1978, 1979 and 1980.

To get any idea about the chance of an injury per time-unit, figures of table 1 are divided by those of table 2 roughly assuming that;
- the numbers of moving people from table 1 af 3.30 p.m. are representative for the average moment of the day;
- the Groningen figures are representative for all built-up areas;
- 1/6 of the total moped/bicycle-traffic is moped.

	car	moped	bicycle	pedestrian
- total injuries in all built-up areas	34.179	36.090	30.831	15.887
- moving persons at 3.30 pm in Groningen	4.900	530	2.670	8.100
Ratio	7.0	68	11.5	2.0
Or	3.5	34	5.8	1

table 3. Ratio chance on an injury per time-unit

The figures of table 3 have hardly statistic value. Nevertheless is illustrated how different the chances on an injury might be using, during a certain time-unit, the different means of transport. Particulary it is dangerous to drive a moped.
Ratios of chances on an accident are mostly given per distance. If lifetime as such should be appreciated more than the covered distance in a lifetime, the time ratio might be more interesting.

To arrive at a suggestion avoiding accidents the number of 86260 injuries in the built-up areas in the Netherlands are split-up in the contacts of the injured people per means of transport with all different means of transport.

injured in / collission with	car, motor or scooter	other	total
car, motor or scooter	19.793	50.899	70.692
other	1.855	13.683	15.568
total	21.678	64.582	86.260

table 4. Injured motorised (excluded moped) and non-motorised (included moped) people divided in collissions with motorised and other people.

Table 4 shows that in the majority of the injuries (84%) the motorised traffic is involved.

Would the motorised traffic be totally separated from the other traffic, the number of injured in the catagory "other" should at least reduce with 50.899 (59%). The number of injuries between other/other and car/car will be, for a part, caused by the complexity of the mixed traffic.
Complete separation between motorised and non-motorised traffic would give a reduction of more than 59% of all injuries.

Complete separation of motorised traffic outside the built-up areas and incidently, inside the built-up areas, has had already a successfull effect.

Complete separation of motorised traffic inside the existing built-up area is hardly opportune.

The following part of this paper deals with the possibillities and effects of partial separation of motorised traffic in built-up areas. The suggestion is;
- use the main arteries mainly for the cars;
- avoid through-traffic of cars in the areas between the main arteries;
- supply bicycle, pedestrian and publictransport facilities off the main streets within the areas.

These suggestions reduce the unhampered two dimensional freedom of motorised traffic : the trip ends, entering an area.
In general hardly any quantitive problems arise. In general the number of cars using dwelling-streets is low.
The few cars passing through dwelling-areas can be added to those on the main arteries.
The main arteries can handle more capacity, when pedestrians, bicycles and public transport could be reduced at the main roades, crossing the main arteries between the main nodes.

3. Through-traffic of cars in the innercity

3.1. The sector-system

In the years 1960-1980 it became clear, that with traffic-regulations and parking-facilities the cities could not be equipped to handle the ultimate car-ownership and car-traffic.
The traffic-volumes of cars in the streets stopped growing in many cities, whereas outside the cities traffic-volumes increased yet.

A countermovement started. Already in 1960, through-traffic of cars had been eliminated in the innercity of Bremen, applying the sector-system.
During the next years Gothenborg, Nottingham, Besançon, Nagoya and Groningen did about the same. Many other cities took other measures to relieve the dominance of the car in the innercity with more or less effect.
The effects of the sectorplan on injuries amounted for the innercity of Gothenborg to 50% reduction in the C.B.D. and 25% in the ring around.

3.2. Groningen

3.2.1. The sectorplan and some figures
Groningen will be treated as a possible example for an area-wide evaluationprocess of measures reducing accidents in an innercity-area.
In 1977 the sectorplan was introduced.
In the innercity (about one square kilometer) a north-south and east-west barrier for the car was introduced (fig. 2).
The car-traffic with a destination in the innercity could reach their destination via the ring. Further trips were only possible, going back to the ring. Through-traffic of cars was eliminated.

The average number of cars moving on the roads of the innercity at one moment (3 p.m.) of a working day in 1976 and 1978 has been given in table 5 and figure 3 and 4.

	1976	1978
the core	37	6
within the ring (included the core)	302	168
on the ring	268	415
included the ring	570	583

table 5 Moving cars at 3 p.m. moving in the innercity

The total number of cars in the innercity (included the ring) before and after the introduction of the sectorplan, remained about the same.
In the core of the innercity (the marketplaces) a sharp decline of car-use was observed (from 37 to 6)

figure 3
Number of cars moving at one moment, averaged over 20 workdays at 3 p.m. autumn 1976 in the innercity of Groningen.

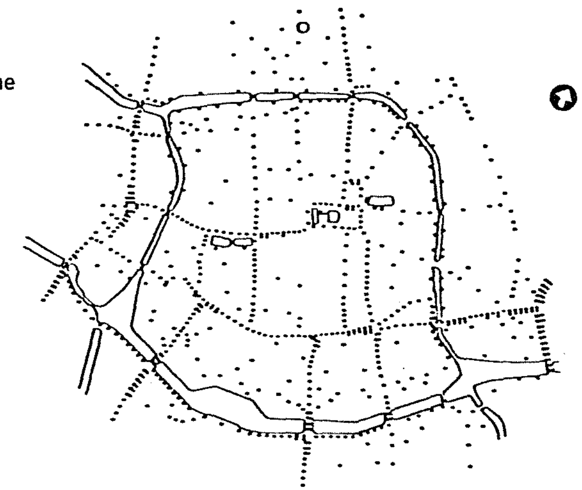
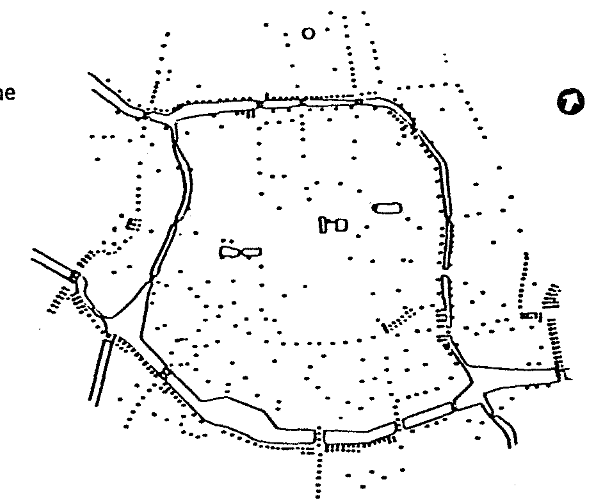


figure 4
Number of cars moving at one moment, averaged over 20 workdays at 3 p.m. autumn 1978 in the innercity of Groningen.



Within the ring a fall of 43% was been observed (from 302 to 168).

The relocation of the car had an effect on the ratio of the numbers of pedestrians and cars. In table 6 the ratio of the number of pedestrians per one moving car has been given per part of the innercity, before and after the introduction of the sectorplan.

	1976	1978
the core	22	153
between the core and the ring	8	10
within the ring	10	15
on the ring	3,1	0,9
the innercity included the ring	6,6	7,1

table 6 Number of pedestrians per one moving car.

The main conclusions, derived from the table are;
- at the main pedestrian-concentration, the core, the car is yet allowed but the pedestrians determine the climate on the public space;
- between the core and the ring the number of pedestrians per one car enlarged a bit. In that area the destinating car-traffic is playing yet an important role. The congestion has been eliminated;
- on the ring the ratio pedestrian/car diminished from 3.1 to 0.9. The ring handled 55% more cars and a considerable part of the pedestrians stayed away from the ring.

3.2.2. Injuries
As has been described in paragraph 2, the car is most involved in injuries.

Table 5 shows that the number of cars moving on the streets of the innercity within the ring diminished from 302 to 168.

A simple expectation would be that the number of injuries should go down someting less than proportional.
The number of injuries amounted in the year 1976 (before introduction of the plan) to 65.
In 1978, 1979 and 1980 resp. 55, 41 and 59, and estimated for 1981: 50.
On the ring the number of injuries amounted in the year 1976 to 58. In 1978, 1979 and 1980 resp. 56, 62 and 31 and estimated for 1981: 41.
The cartraffic on the ring increased with 55% (table 5).

According to the above mentioned simple expectation an increase of injuries on the ring should be likely. Nevertheless, the first two years after the introduction of the plan the number of injuries remained about the same and in 1980 a sharp decline was observed.

Hypothesis

- Within the ring the road-space for the car remained about the same, whereas the congestions have been eliminated. The lower level of the cartraffic, like a alternative current, caused alternate empty streets and streets with moving cars. The pedestrians and the cyclist used the space for the car, insufficiently aware of the dangers. Possibly, the subjective feeling of safety enhanced the chance on accidents.

- On the ring the public space was more labelled as an area for the car. Pedestrians and cyclists took, after the introduction of the plan, for a part other routes. The remaining vulnerable participants in traffic were at every moment, due to the always present cars, confronted with their danger. Possibly the subjective feeling of unsafety diminished the chance on accidents.
  These are only hypothesis. A scientifical analysis might help to discover, which measures would reduce accidents.

3.3. A combined areawide- and casestudy

In paragraph 2 was concluded that complete separation between motorised and non-motorised traffic would lead to a considerable decline in accidents. This conclusion is sufficient to start a policy that tends to separation. Complete separation in existing cities is not a realistic aim. In practice only more or less separation as applied e.g. in Bremen, Gothenborg, Nottingham, Besançon, Nagoya and Groningen, are opportune. The effects on accident-reduction are in Groningen not as clear as in Gothenborg and Nagoya (see par.4).
But it is a realistic premise that the high rate of accidents in cities is closely related to the mixing-up of all means of traffic.
In the struggle for better cities, in this case, less dangerous cities, possibilities are present. No costly infrastructural projects but small, precise and scientifical well-considered operations are necessary.
The main premise to go into such a policy is an objective thoroughly thinking over the combined traffic situation. In Groningen, the majority of the politicians could operate as root and branche reformers introducing the sectorplan.
The public opinion, guided by those who believed that the car is the only stable

thing in a city, are yet now searching for the evil effects of the plan, but they can hardly find anything. It is true that the car traffic lost some freedom of movement in the innercity. But the politicians showed their positive face concerning the necessity to arrive at the innercity by car, planning garages.
The result is a satisfactory use of the garages, with a slight overcapacity and a slight decline of visitors by car to the innercity.
The public talk searching for evil effects is hampering an objective and constructive further planning. Especially the hesitating decline of injuries in the traffic asks for more research. This research has to suggest which detailed measures will lead to less accidents.

The following evaluationprocess of accident-analysis of structural measures in traffic, as in Groningen, might be constructive;

- apply structural measures in areas with the aim of a certain separation of motorised and non-motorised traffic;
- registrate during some years, before and after the introduction of the measures, the number of accidents;
- observe, before and after, photo-like pictures of the moving people (see appendix);
- based on the changed traffic-picture presumed accidents are compared with the observed;
- after this overall impression, go in detail especially in case the observed data are not analogous with the presumed
- experiments are executed based on expectations. Especcially concerning the gap between expectation and reality, questions arise that have to be answered. Studying the changes in the location and the nature of the accidents might lead to advises for further detailed measures. Especially broad city-streets abandoned by most of the cartraffic need a new face expressing the dominating use by the vulnerable traffic.

4. Through-traffic in dwelling areas

4.1 Complete and partial separation

Complete separation of motorised and non-motorised traffic took place in the new south-east part of Amsterdam, the Bijlmer.
Without observation can be predicted that the number of injuries of the vulnerable

traffic will tend to zero.
Stevenage (U.K.) had ainly experiences with the bicycle-paths free from the motorised traffic.
Partial separation was applied in Nagoya. Not only the innercity, bus also over a wide dwelling area (about 70 square kilometers) the sector-system had been applied. The number of injuries reduced with 31% from 4617 per year to 3173.

4.2 Groningen (30 square kilometers)

With a kind of brainstorming mixed up with more or less measured and estimated data, a presumed location of the different means of transport will be related to presumed accidents.
Two catagories are considered: main streets and all other streets.
Assumed is that such measures have been taken that all over the town the cartraffic has shifted a bit from the secondary streets to the main-streets and the vulnerable traffic in the opposite direction.
In table 7 rather accurate figures have been given from the total number of moving people (except public transport) at 3.30 p.m. in the built-up area of Groningen.

	persons by car	moped/bicycle	pedestrian	total
mainstreets	2800 (3800)	1200 (600)	1100 (600)	5100
other streets	2100 (1100)	2000 (2600)	7000 (7500)	11100
total	4900 (4900)	3200 (3200)	8100 (8100)	16200

table 7 Moving traffic at one moment 3.30 p.m. on main and other streets in the built-up area of Groningen.

Between brackets, a rough estimation of the possible changes at practically optimal separation measures, have been given.

Presumed is, that the number of injuries between two moving people on the main- and other streets is correlated with the products of the number of people moving on the streets per means of transport.

In table 8 a rough estimation of the number of accidents is given (only the total number of accidents per year is exact).

collisions between →	car: car	car: moped	car: pedestrian	non-car: non car	total
mainstreets	80	120	12	69	281
other streets	72	178	65	48	365
total	152	298	77	117	646

table 8 A rough estimation of injuries per means of transport due to collisions between two moving persons.

Now is played with the unscientiffical thinking idea that the number of injuries is only related to the product of the number of dashing catagories of traffic.

For the catagories in table 8 the ratio of the changed products, above mentioned, derived from table 7 have been given in table 9.

	car: car	car: moped/bicycle	car: pedestrian	non-car: non-car
mainstreets	$\frac{38x38}{28x28} = 1,8$	$\frac{38x\ 6}{28x12} = 0,7$	$\frac{38x\ 6}{28x11} = 0,7$	$\frac{12\ x12}{23x23} = 0,3$
other streets	$\frac{11x11}{21x21} = 0,3$	$\frac{11x26}{21x20} = 0,3$	$\frac{11x75}{21x70} = 0,6$	$\frac{101x101}{90x\ 90} = 1,3$

table 9 Ratio of the changed products of the numbers of dashing catagories of traffic.

The figures in table 9 are multiplied with the figures in table 8 to arrive at a possible reduction of injuries.

	car: car	car: moped/bicycle	car: pedestrian	non-car: non-car	total
mainstreets	147	81	9	19	256
other streets	20	121	36	60	237
total	167	202	45	79	493

table 10 A possible reduction of injuries.

According to the calculations above surely not in the reality a reduction from 646 to 493 injuries should take place.

4.3 First research, than proposals

It is clear that the exercise above is merely a start thinking about reduction of accidents, restructuring motorised and non-motorised traffic in towns.
Just as the cargirdle has been introduced not knowing all favourable and unfavourable aspects, one has to start collecting all know-how and that will be a lot more than discribed above. A thorough evaluation of the existing experiments, and comparison of the accidents in areas with unequal mixtures of the means of transport has to be executed. After that, proposals for separation of traffic can be offered.
Also the new plans need a thorough conduct with evaluation.
Practice makes perfect.

5. Separation, not only an accident effect

In fig. 1 has been illustrated how the car occupied the city as a grasshopper-plague.
Without denying the functioning of the car in the city, much is possible to redress the face of the public space.
The innercity strongly dependant of the attractiveness, proved to be able to get a face-lift, eliminating through-traffic. The innercity became more attractive, with parallel consequances for the economy.

The more must be possible in the dwelling areas. The streets are dimensioned for parking. The low level of cartraffic in the dwelling areas can be brought down,

moving pedestrians and vehicles at one moment on the road

autumn 1976, before introduction circulationplan

± 15.00 p.m., on saturday
(as an average of 4 saturdays)

explanation

- pedestrian
- (mo-ped)bicycle
- car (incl. trucks)
- bus

eliminating throughtraffic of cars. The overdimensioning of the asphalt pavement in the dwelling areas is expressing an isolated gathering;

- the houses on both sides of the streets have a barrier in between, young children are learnt to be afraid of that barrier, close for the door, due to the high rate of injuries of young children.
- the cartraffic itself is expressing isolation, passing eachother without recognising.

One of the main things the city has to express is not only the living together but also the belonging together.
The Dutch movement to reshape residential precincts in more cosy and quiet surroundings (woonerf) is one of the efforts to soften the dominating car-imprint in living-surroundings.
A few months ago the Royal Dutch Institute of Engineears published a brochure "Van woonerf naar woonwijk" (from residential precinct to residential area).
With this paper the reorientation on the public space in a wider area has been started.

It would be of great importance if the responsible people for the accident-analysis could contribute facts ans suggestions on their special field in the scope of better towns with reorganised traffic.
Their contribution will be of much more importance than my vague picture. Imagination is needed to assume the restructuring of the whole town traffic and arrive at scientifically based prognoses about the expected reduction of accidents.

CO-ORDINATED TRAFFIC SAFETY STUDIES IN THE NORDIC COUNTRIES. EXPERIENCES FROM THE "EMMA" PROJECT

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ABSTRACT

This paper is a summary of a joint Nordic traffic safety project called EMMA - "Evaluation of the traffic safety effects of minor road improvements". The contents include an introduction to the organization of the project, a summary of the most important results, as well as a discussion of the benefits and drawbacks with the research method that is applied in this study.

1. THE EMMA PROJECT

1.1 Introduction

The Emma project ("Evaluation of the traffic safety effects of minor road improvements") is a joint Nordic traffic safety study of the effects of minor road improvements. The project began in 1978 and was completed in February 1982. It has been financed by the Nordic Ministerial Council.

One of the main parts of the EMMA project was a concern with the implementation of effect studies in four separate studies. The results from the four before-and- after studies are summarised in this paper.

The results from these analyses form, in part, the base for the other main part of the EMMA project - the preparation of a catalogue of traffic safety effects from about 35 smaller road and traffic control measures along road sections or junctions.

1.2 Aim

There does exist a series of before-and-after studies, and other road safety studies that form the basis for such evaluations. The results from these studies, however, have not been sufficiently systematised. The main purpose of the EMMA project has therefore been to formulate a catalogue which summarises what is known about road safety effects of the various road and traffic control measures in the Nordic countries. The Effect Catalogue is written primarily for local road authorities to be of use in their traffic safety undertakings.

1.3 The Project's Contents and Implementation

Figure 1. Summary of general arrangement for the EMMA investigation and completed reports.

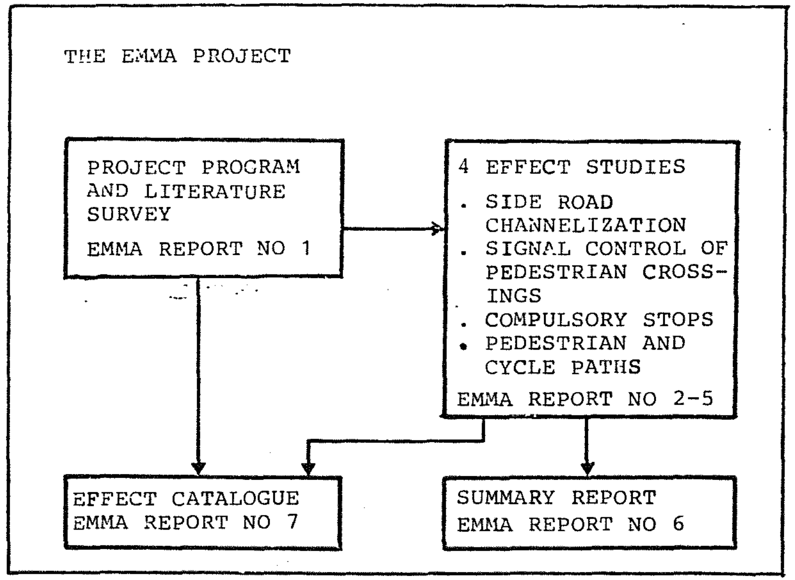


Figure 1: Summary of general arrangement for the EMMA investigation and completed reports

The most important base for the Effect Catalogue has been a literature survey of previously conducted traffic safety studies. The main investigations here comprise before-and-after studies carried out in one or several of the Nordic countries, together with well documented studies from other countries.

In the project, additional before-and-after studies of four individual measures have been carried out, based on empirical data from the 5 Nordic countries. These measures were selected to supplement existing knowledge in areas considered to be of importance. These four individual measures for which the results have been summarised in section 2, are:

- side road channelization at priority junctions, such as the introduction of traffic islands in the side roads
- signal control of pedestrian crossings between junctions
- application of compulsory stop signs at priority junctions
- construction of pedestrian and cycle paths separate from driving lanes

The measures have in common that their application was of interest in the Nordic countries when the EMMA Project was set up. At the same time, the situation was that there was little concrete knowledge of the road safety effects of these measures. There also were insufficient sites in each country, so that the possibilities for effect studies at a national level were limited.

All these conditions made it appropriate to undertake a joint Nordic investigation.

The EMMA Project was conducted as a joint venture among several research institutions and road authorities in individual Nordic countries. A summary of the completed reports, and which institutions have carried out the analyses, is evident from the bibliography. The work was headed by a project leader at the Division of Transportation Engineering at the Norwegian Institute of Technology.

2. THE FOUR BEFORE-AND-AFTER STUDIES

2.1 Data Base

The channelization of side roads, signal control of pedestrian crossings, introduction of compulsory stops, and construction of pedestrian and cycle paths, were selected for closer analysis from definite criteria. For all of the four measures, there was the requirement that they should be completed during the years 1970-1977, and that no other major road or traffic control measure was conducted at those places during the study period. Traffic counts should, if possible, be given both for the "before period" and the "after period" to enable corrections for the effect of changes in traffic volumes.

In all, the investigation included approximately 500 sites, see Table 1.

Table 1. Total number of sites in the before-and-after studies, arranged by country and type of measure

	Side road channelization	Signal control of pedestrian crossing	Compulsory stop	Pedestrian and cycle paths	Total
Denmark	15	20	9	29	73
Finland	6	9	56	75	146
Iceland	0	17	4	0	21
Norway	23	20	21	95	159
Sweden	9	46	34	19	108
Total	53[1)]	112[2)]	124	218	507

1) 27 sites with no accidents in both the before period and the after period, are not analysed or included in this total.
2) 16 sites of the same kind as described in 1)

It is evident from the table that the number of sites for the different measures were unevenly dispersed in the separate countries. This fact can have a certain significance for the achieved results.

The conclusion, however, is that overall, quite comprehensive material has been provided for the four measures. Data on design and other factors have, to some extent, provided a basis for evaluation of how the accident reduction effect varies with such factors. This is summarised in subsection 2.4.

2.2 The Accident Material

The four effect studies are based on police-reported accidents involving personal injury. The accident material from Finland, Norway and Sweden also include some accidents with only material damage, but these were not included in the analyses.

For each separate measure within the four groups, accidents are registered in a "before period" of 1-5 years and in an "after period" of 1-3 years. In most cases, each period comprises a complete calendar year. But accidents that occured in the year the work was carried out, are omitted from the analysis.

2.3 The Control Material

In calculating the safety effects of the four measures, control material has been used. This has made it possible to correct for different lengths of the "before period" and the "after period" and for the general accident trends. This means that, as far as possible, there have been corrections for the effect of conditions such as changes in general speed limits, alterations to traffic volumes, altered safety belt use and other external factors.

It was up to the individual countries to select the most suitable control material. Therefore, there are large variations from country to country, but it is supposed that this factor has no significance for the conclusions that are drawn.

2.4 Results

The most important results from the four before-and-after studies are summarised in Table 2. It is shown that for all the measures, clear positive effects were found, especially for the accident types they were primarily intended to influence.

Table 2. Summary of results from the four before-and-after studies.

Measure	Observed effect on accidents involving personal injury	Special effects
Side road channelization (53 junctions)	- 7% (T-junctions) - 49% (crossroads)	Accidents with cars coming from the side-road are reduced by 60%
Signal control of pedestrian crossings (112 sites)	- 20%	Pedestrian accidents: -35% Other accidents: - 8% Fatal accidents are reduced from 10 to 2 Best effects are found for crossings on broad main roads with pedestrian refuges
Compulsory stops (124 junctions)	- 38% (T-junctions) - 45% (crossroads)	Accidents with cars coming from the side road are reduced by 65-70%. Best effects are observed when a large part of the traffic is coming from the side road
Pedestrian and cycle paths (218 sites)	- 14%	Pedestrian accidents: -37% Bicycle accidents: -44% Other accidents: small changes

What is indicated in the table is the observed effects, which means that the so-called "regression-to-the-mean" effect can comprise a larger or smaller part of the effect that is observed. It has not been possible to enumerate the extent of the regression-to-the-mean effects in the EMMA Project and the consequences of this are discussed more fully in section 4.

The analyses showed some variations from country to country. Examples where the variation was smallest are shown in Figures 2,and 3.

The differences can be due to circumstances or variations in the use and design of the measures. The data material has mainly been too limited to explain the differences. Therefore, the average effects are considered to be of primary importance. Conclusions about the effect of factors connected to the design and control are also based on analyses of the overall material.

3. THE EFFECT CATALOGUE

3.1 Contents

The Effect Catalogue contains a summary of the traffic safety effects of approximately 35 smaller road and traffic control measures which can be employed to reduce accident numbers at

junctions, other dangerous points such as sharp curves or narrow bridges, and particularly dangerous sections of the road system. Larger works such as building new roads, comprehensive reconstruction of existing roads and traffic management schemes over a larger area, are not included in the catalogue.

Figure 2: Personal injury accidents, arranged by country, before and after signal control of pedestrian crossings

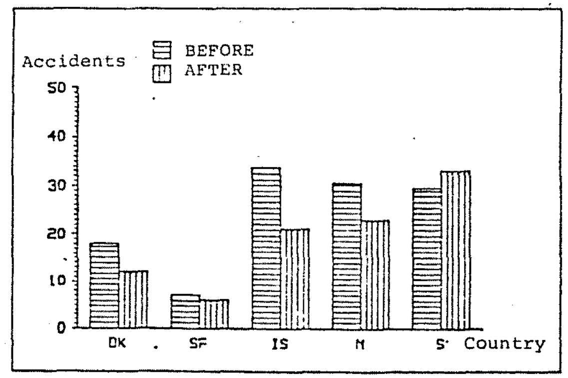
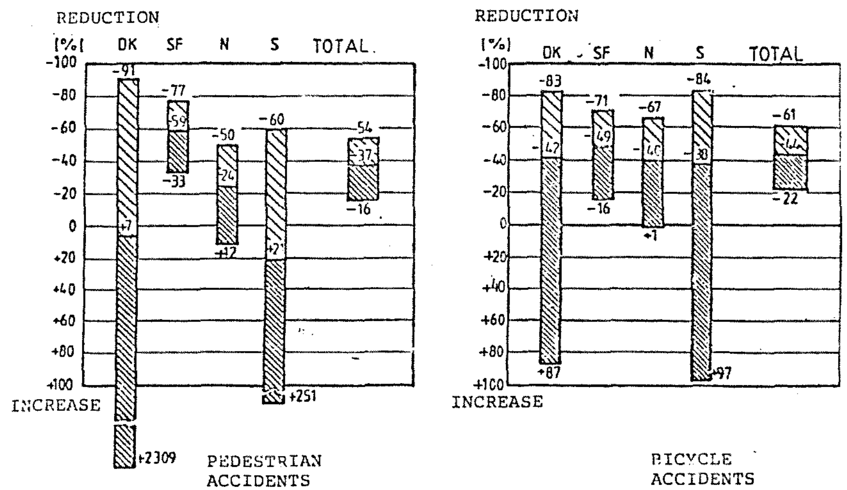


Figure 3: The effects of pedestrian and cycle paths on personal injury accidents, arranged by country. Average effect and 95% confidence interval



In the Effect Catalogue traffic safety effects are of primary concern but other conditions are to some extent commented on.

The direct costs of the separate undertakings are necessary to be able to select out the most effective measures. However, it was not practical to include such direct costs factors in the catalogue and therefore available cost summaries in the individual countries can be referred to.

3.2 Efforts to reduce uncertainties

The results from the completed before-and-after studies, and the use of such results for effect evaluation, contains uncertainties. These uncertainties are mainly connected to the following factors:

- accident data base
- the effect of the measure on the accident pattern
- different criteria for the application of the measure
- the "regression-to-the-mean" effect
- external influences

In the writing of the Effect Catalogue, consideration is given to the reduction of these uncertainties as far as possible. It was found important in this respect:

- to relate the effects to influences on personal injury accidents
- to emphasise the different effects on the separate accident types and to recommend that accident patterns, as far as possible, are used as the basis for effect evaluations
- to describe the criteria which are usually employed as a basis for the use of the different measures in the Nordic countries, and
- to mainly base effect descriptions on the results from the Nordic before-and-after studies. For these investigations it has been easier to evaluate the accident base, application criteria, and possible effects of other resultant conditions such as increasing seat belt use, changes in the use of car lights, changing weather conditions etc.

In addition to this, it is recommended that effect evaluations are carried out in two different ways:

1) To estimate expected accident reduction from experienced effects from earlier before-and-after studies.

2) To estimate expected accident numbers and expected accident reductions from experienced accident rates for different types of junctions and road sections.

The Effect Catalogue contains, in the main, basic data for application of method 1, but for method 2 references must be made to relevant national accident rates which most countries have produced. It is expected that the combined application of the two methods can reduce uncertainty of the regression-to-the-mean effects. (Refer also section 4).

4. ADVANTAGES AND DISADVANTAGES OF THE RESEARCH METHOD APPLIED IN THE "EMMA" STUDY

4.1 Summary of advantages and disadvantages

The research method applied in the EMMA study can briefly be described as a before-and-after study of empirical data from 5 countries, including control data to correct for the general trend in accident figures.

Some clear advantages of this method of research were

- the necessary data was readily available
- an inter-Nordic study made it possible to base the analysis on more extensive data than what would have been possible for national studies
- the organization of this research brought different research institutes in the Nordic countries in close contact with each other. This is an important fringe benefit of this project.

The main disadvantage of the research method is that some important questions are left unanswered, i.e.

1. What is the numeric size of the "regression-to-the-mean"-effect compared to the observed percentages of accident reduction, in other words - what is the "real" effect of the four measures studied?
2. What are the reasons for the positive results found in the EMMA before-and-after study, in other words - which changes in behaviour have taken place?

The discussion of the "regression-to-the-mean" effect in the Nordic countries has mainly taken place from the autumn 1981 and onwards, that is during the last phase of the EMMA study. Time and economy were not available then to carry out any thorough analysis of this problem. The discussion in the project group, however, lead to the conclusion that a need for improvement of the research method was evident if questions such as those above are to be answered in later studies. The remaining part of this paper is a discussion of needs and possibilities in this respect.

4.2 The possibilities for and the need for improvement of the research methods

In this discussion I will consider the problem both from a research and a more practical point of view. In particular the last aspect has not been considered very much in the discussion up to now, but it is still of significant importance.

4.2.1 Need for improvement from a research point of view

The numeric value of the "regression-to-the-mean" effect, and the possibility to correct for this source of error, have been considered in British and Swedish studies (L9, L10, L11, L12). These studies have clearly shown that this effect can influence significantly, observed changes. The Swedish studies also show that the numeric value of the "regression-tothe-mean" effect can be about 50% when site improvements are decided on the basis of the number of accidents, and this criterion only.

This uncertainty is so important that the method of research would have been changed if a new EMMA-type study was to be carried out. Possible methods would then have been

a) Controlled experiments. A number of sites where measures are carried out, are randomly chosen from a larger number of sites. Sites which are maintained unchanged will form a control group. This method of research is available for more long-term studies.

b) Adjusted before-and-after studies of empirical data. The adjustment will either consist of a separate analysis of black-spots, or an analysis where single years with a high number of accidents are taken out of the "before-data" before the effect is calculated.

c) Accident rate studies, i.e. studies of how the accident rate varies with geometrical factors and method of control, to establish knowledge of significant variations of the level of risk.

d) Studies of behaviour, where changes in the pattern of behaviour are studied to obtain more knowledge of the direct effects of a measure.

All these methods have disadvantages and involve sources of error. A judgement, based on an application of two or more parallel methods, will then usually give the most certain results.

This method of working has partly been applied in the EMMA study.

In the four before-and-after studies, the conclusions about the positive effects are based on an analysis of how the four measures have influenced different types of accidents (related to logical changes in behaviour). In the Effect Catalogue one has, as mentioned before, recommended that estimates of expected effects are based both on experiences from before-and-after studies, and on existing knowledge of typical accident rates for various types of junctions and road sections. These methods will decrease the possible errors resulting from the "regression-to-the-mean" effect.

4.2.2 Need for improvement from a practical point of view

I choose to start this section with the following postulation: the "regression-to-the-mean" effect is not of very much importance for the practical traffic safety work in the local road authorities. This is based on the following arguments:

1. The number of accidents is applied as a systematic criterion for carrying out countermeasures to a smaller extent than the researchers seem to believe. Some examples of other common criteria are the need to design junctions and roads in a homogeneous way, pressure from local groups to reduce the feeling of unsafety, the need to improve capacity etc.

   The importance of such criteria is underlined by an analysis of accidents at 800 Norwegian junctions (L13). In this study, sites where changes had been made during the study period, were studied separately, and a so-called "black-spot-rate" was calculated. This rate is the part of the sites which could be defined as especially accident-loaded (more accidents than the 95-percentile) in the "before-situation". The black-spot-rates were quite low, 10% for measures like speed limit reductions and right-of-way regulations, about 20% for signal control, and about 30% for channelization. This shows that other criteria must have played an important role.

   The EMMA before-and-after studies also give evidence in this respect. Table 3 shows the percentage of sites studied where no accidents were observed during the before period. These percentages were between 16 and 54%, which means that the consequences of the "regression-to-the-mean" effect are reduced significantly. The reason for this is that the increase in the number of accidents at the "zero sites" to some extent will balance the accident reduction at the black-spots included in the study.

2. The "regression-to-the-mean" effect will rarely lead to wrong conclusions about whether a measure has a positive effect or not. In most cases studies of the observed reduction of the total number of accidents will be combined with other types of studies such as behavioural research, surveys of the effects on different accident types, accident rate studies etc. The final conclusion about a positive effect will normally be based on a common consideration of all these

Table 3 The EMMA study. Percentage of sites with no accidents in the before-situation

Measure	Total number of sites	Number of sites with no accidents in the before-situation	Percentage "zero sites"
Channelization of the minor road	80	32	40%
Signalization of pedestrian crossings	128	31	24%
Stop-signs at junctions	124	67	54%
Pedestrian and cycle paths	218	34	16%

studies, which reduces the possible risk of error arising from the "regression-to-the-mean" effect. Still there will be uncertainty about the numeric size of the "real" accident reduction related to a measure.

3. Erroneous conclusions of the "regression-to-the-mean" effect will hardly lead to a situation where too much money is spent on improvements at black-spots. If one supposes that various measures applied at black-spots reduce the number of accidents by, say 50%, while the "real" effects are between 20 and 30%, one might fear that too many resources will be spent on black-spots, and too little on other measures. However, the situation in Norway today, and probably in the other nordic countries as well, is such that there seem to be no real danger in this respect. In fact, the situation rather seems to be that too few resources are spent on improvements at black-spots, and that the potential for accident reduction at such sites are far from exhausted.

4.2.3 Conclusion

My conclusion is that the possible consequences of the "regression-to-the-mean" effect are considerably overestimated. I believe that further studies of sites where changes have been made, will show the same tendency with respect to the "black-spot-rate" and the number of "zero-sites" as the results given above, to support this conclusion.

This does not prevent me from seeing many reasons to continue with the ongoing effort to improve the research methods. But I also see many reasons to reduce some of the scepticism about the value of the many before-and-after studies which are available, and in which the analysis is based on the "old" method.

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Experiences in two investigations into the effect of one-way traffic on road safety

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1 Introduction

This contribution gives a report of some practical experiences that have been gained in two statistical investigations. The subject of these investigations was the effect of one-way traffic on road safety in residential areas.

The numerical data for both investigations consisted of accident statistics covering several years. A fairly conventional evaluation method was used, which cannot exactly be considered as "short-term". The short-term character was obtained in this case by using exclusively historical data. If the design of the investigation has been adequately worked-out and the input data are at the disposal of the researchers, such a "post-hoc" study should in principle demand very little time. (In practice, however, this expectation is unfortunately found to be over-optimistic in many cases.)

It will shortly become clear from the brief descriptions that the two investigations can be regarded as "area-wide".

One-way traffic is in most cases introduced for reasons other than the improvement of road safety. It does not, therefore, represent a specific safety measure. However, the effect of this measure on road safety was the central factor in the investigations. In this respect too, the contribution falls within the scope of the seminar.

The first investigation is described briefly in section 2. A reasonably well known statistical technique was used here. For this reason, the experiences described in section 3 refer primarily to the problems related to the subject to which the technique was applied in this case.

Some of the remarks made refer equally to the second investigation, which is described briefly in section 4. In this investigation, an attempt has been made to obtain more specified results from the same data by means of a different statistical technique. Since this technique is less well known, the experiences recorded in section 5 apply more to the method used in this second investigation.

2 Brief description of the first investigation

The introduction of one-way traffic in residential areas can be aimed at achieving various objectives, such as offering more parking space, improving traffic flow or, by contrast, restricting through traffic. The improvement of road safety is also said to be the objective in many cases.

However, little information is available about the effect of one-way traffic on road safety. Some people even claim, without having any research data at their disposal, that one-way traffic in residential areas is detrimental to road safety. For this reason a statistical investigation of the subject was initiated in 1973 by a working group of municipal traffic experts. The working group compared the road-safety developments in a number of residential areas in the Netherlands following the introduction of one-way traffic with those in areas in which one-way traffic had not been introduced.

The selected research method was that of a before-and-after study with a control group, using the chi-square test. The investigation is described at length in an interim report (Werkgroep Eenrichtingverkeer, 1977); a shorter version of this report is published in "Verkeerskunde" (Slop, 1977).

The conclusion of the investigation implied that one-way traffic in residential areas can be presumed "in general to have neither a positive nor a negative effect on the number of accidents".

However, as is the case with most countermeasures, the total effect of one-way traffic on the occurrence of accidents is a composite of sub-effects. The neutrality observed in the total effect could have been the result of a number of opposing sub-effects.

A positive sub-effect can arise from the simplification of the traffic flows, as a result of which the traffic pattern becomes easier to follow and predict. The positive effects also include the favourable influence resulting from a reduction of traffic volumes, in those cases where one-way traffic was introcuced with the aim of diverting through traffic from a residential area.

Negative effects can result from the way in which road users respond to the measures taken. A first example of this may be that road users will have to choose a different route in many cases, either in the area concerned or on the roads surrounding it, which will involve covering a greater number of kilometres. A further negative effect may arise from a reduction in the level of attentiveness, or from driving at a higher speed than before.

The objective was to enable such positive and negative sub-effects to be determined by splitting-up the statistical data gathered. On the basis of these results it should become possible to aim at achieving only the positive sub-effects, by means of carefully directed application of one-way traffic, whereby an improvement of road safety could in fact be brought about. The splitting-up of the results could be applied to the investigated <u>units</u> (roads and/or areas), to the <u>measure</u> taken (various ways of implementing one-way traffic), and to the <u>criterion</u> used for assessing road safety (only those accidents with injuries, the number of victims etc.).

The first investigation was not successful in achieving the stated objective. For practical reasons, the splitting-up of the investigated units and of the implemented measure could not be carried out. A splitting-up of the road-safety criterion was carried out, but could not be made use of for methodological reasons.

A number of practical problems that were encountered in performing the first investigation are discussed in section 3.

3 Experiences in the first investigation

3.1 In considering the accident statistics, it was possible to choose from a number of alternatives with respect to the units to be investigated. These included:

<u>a</u>. separate streets or street sections in which one-way traffic had been introduced;

<u>b</u>. intersections of one or more of these streets, either with each other or with streets carrying two-way traffic;

<u>c</u>. streets in which two-way traffic had been retained but whose pattern of use had been changed by the introduction of one-way traffic in other streets;

<u>d</u>. areas of which the elements named in <u>a</u>, <u>b</u> and <u>c</u> formed a part;

<u>e</u>. the total of a number of areas named in <u>d</u> considered together.

Depending on the choice made, it should for example be possible to arrive at conclusions indicating the difference between the effect in streets and at the crossroads.

An argument against the choice of small units, such as in cases <u>a</u>, <u>b</u> and <u>c</u>, was the fact that the numbers of accidents become too small to be able to draw conclusions that are statistically well founded. An argument against option <u>e</u> was that the various areas differed greatly in character from each other, and that the introduction of one-way traffic took place on a different date in each case. The choice therefore fell on alternative <u>d</u>.

3.2 A particular problem was found to be defining the boundaries of the investigation areas. These took on extremely irregular shapes if they were composed exclusively of street sections with one-way traffic. The intersections at the ends of these street sections were sure to be considered in the investigation. It could, however, be assumed that neighbouring streets in which two-way traffic was retained had also been affected by the introduction of one-way traffic, certainly in terms of traffic volumes, but possibly also in the number of accidents. For this reason, it was considered desirable to round-off the areas by the addition of a number of neighbouring streets with two-way traffic.

On the other hand, if too many street sections with two-way traffic are added to an area, any conclusions can be less clearly attributed to the introduction of one-way traffic. There is then a chance that the accident figures from the streets with two-way traffic will become dominant in the overall figures.

No precisely described solution was found for this problem. It was finally decided to allow the researchers carrving out the investigations in the cities concerned to determine the boundaries of the areas using their own judgement, taking into account the above.

3.3 The effects to be determined had to be primarily attributable to the one-way traffic. This implies that use had to be made of estimates of the changes that would have arisen without this measure. Control areas were used for this purpose. The requirement placed on these control areas is that they must be fully comparable with the investigation areas; in other words, that they would have had just as much chance as the investigation areas of having one-way traffic introduced in them.

Since the study carried out was post-hoc in nature, it appears unlikely that this requirement was met. There are all kinds of reasons why one-way traffic was introduced in the investigation areas and not in the control areas. One of the reasons for the introduction of one-way traffic in an area may even have been that the number of accidents occurring in that area was (by coincidence) relatively high!

3.4 It was found to be difficult to find a suitable control area for each investigation area. For this reason the choice of control area in a number of cases fell on an area in which, in a later year, one-way traffic was also introduced.

This choice of (a limited number of) areas that were first used as control area and later as investigation area is a questionable practice. In particular, any overall testing of the numerical data then harbours a number of interdependencies that cannot be identified.

In a number of cases the same control area was used for more than one investigation area. If the investigation periods (before and after periods together) do not overlap there is little objection to this practice, but in some cases such an overlap did occur.

3.5 Repeated changes in the accident-recording practices of the various cities formed a great obstacle in the selection of the investigation and control areas. A further restriction was that there should be the lowest possible incidence of disturbing influences during the before and after periods, in both the investigation and control areas. This applies mainly to the implementation of other traffic measures such as the installation of traffic lights at an intersection or the establishment of pedestrian crossings; although, for example, the opening of an old peoples' home could also have had a disturbing influence in this respect.

For this reason, the before and after periods were each limited to one year. In spite of this, quite a number of areas had to be discarded. The number of investigation areas that were finally found to be usable was 29, located in Amsterdam, Eindhoven, Rotterdam and Utrecht.

3.6 To reduce the disturbing effect of seasonal variations the before and after periods, each of one year, were not further sub-divided. This means that only one measurement before and one after was at the reasearchers' disposal in each area.

A disadvantage of this design is that no estimate can be made of the variations in time. Consequently, any significant conclusions cannot be attributed exclusively to the implemented measure. Whatever the result, some room for doubt therefore remains.

3.7 One complication experienced was that relatively few accidents in fact take place in residential areas; and when they do occur the chance that they are reliably recorded is not great, particularly in cases where there are no injuries. In carrying out the statistical tests, numerical data were available from two times (before and after) approximately 3000 accidents in investigation areas, and two times approximately 4000 accidents in control areas. These numbers were found to be adequate to allow general conclusions to be drawn.

As soon as attempts were made to specify the results (for example with regard to the character of the accident hazard), it was found that the necessary splitting-up of the data often made the number of accidents too small to allow statistically sound conclusions to be drawn.

3.8 To allow the differences in the development of the accident hazard between the investigation and control areas to be attributed to the introduction of one-way traffic, the development within the group of control areas must not diverge during the same period. For this reason the control areas were subjected to a test of the null hypothesis "development of accident hazard is not area-dependent" against the alternative hypothesis "development of accident hazard is area-dependent". The chi-square test was used for this purpose.

If the total number of accidents (resulting in death, injury or material damage) was taken as a measure of accident hazard, it appeared to be a justifiable assumption that the development was not area-dependent. However, if only those accidents resulting in injury (including death) were considered, it was found that the null hypothesis could no longer be accepted. Neither was this the case if the number of accident victims was taken as a measure of accident hazard.

In other words: the development of the total number of accidents in the various control areas always followed approximately the same trend, but this could not be said for the accidents in which injury had been caused and for the numbers of victims of these accidents. Consequently, it was found to be impossible to use the control areas as such for the development of the number of accidents in which injury had been caused, and for the numbers of victims of these accidents. It was therefore also impossible to examine the investigation areas using these two measures of accident hazard. As a result, no specified conclusions could be drawn about the character of the accident hazard. It was possible to draw conclusions only about the effect of one-way traffic on the total number of accidents.

3.9 The statements made in the preceding paragraph give an indication that the development in the number of accidents causing injury, and in the numbers of victims of these accidents, may have been area-dependent. The working group was therefore of the opinion that an investigation would have to be made of the relationships between the types of accidents and the characteristics of the areas. These may include infrastructural characteristics such as the total length of the streets, the number of intersections (divided into T-junctions and four-way intersections), the lane widths, the distances between the intersections, the lengths of the separate cycletracks or the sites of pedestrian crossings. They may also include traffic characteristics, such as volumes, mileage covered, speed data or the number of pedestrians crossing the roads. These factors could possibly lead to conclusions about characteristics that can determine the suitability of streets and/or areas for one-way traffic, from the point of view of road safety.

However, a supplementary reconnaissance of the investigation and control areas was regarded as necessary for a thorough splitting-up of the results. It was decided to dispense with this splitting-up since it was found that all the required data could afterwards no longer be obtained, among other reasons. The fact that the numbers of accidents could often be expected to become too small in such far-reaching splitting-up of the results also contributed to this decision.

3.10 The introduction of one-way traffic can also take place on different scales and in different ways. Indicators for this may be: the percentage of street sections in which one-way traffic had been introduced, the type of one-way traffic (i.e. with or without exceptions), supplementary measures with regard to parking etc.

For the same reasons as in the preceding paragraph, it was also decided to dispense with this splitting-up of results. This unfortunately meant that no conclusions could be drawn about the differences in the effect of one-way traffic with and without exceptions for cyclists, for example, or with and without accompanying parking restrictions.

4 Brief description of the follow-up investigation

The design of the first investigation with one measurement before and one after in each investigation area and control area led to frequency matrices with four cells. By using the chi-square test on these four cells, it was checked whether the ratio of the number of accidents in the investigation area to that in the control area was the same before and after the introduction of the measure.

In such a procedure, both of these ratios are regarded as random samples from a population with a fixed relationship. This population ratio is estimated as a (weighted) mean of both random-sample ratios. As a result, only half of a possible effect is in fact brought forward.

In the follow-up investigation, carried out by Riemersma and Sijmonsma, the ratio in the before period is therefore regarded as a point-estimate of the ratio in the after period. In this case Tanner's test (1958) can be used. This estimates the effect of a measure as the quotient of the actual number of accidents in the after period and the number that was expected on the basis of the trend in the control areas. The tenability of this procedure increases as more control areas of a homogenous nature are used as a basis for the estimate.

The details of the test procedure will not be further discussed in this contribution. An extensive description of the follow-up investigation is given in a communication from the "Studiecentrum Verkeerstechniek" (1979).

The conclusion of this investigation was that "one-way traffic has a decreasing effect on the total number of accidents, and that this effect is sometimes related to specific areas. However, no relation could be found between the effect and specific traffic situations (like intersections etc.). Moped riders turned out to be the only category of traffic participants for which a (positive) effect could be shown".

As such, the results of the follow-up investigation are also relatively insubstantial. Some of the practical problems experienced in carrying out this follow-up investigation are discussed in section 5.

5 Experiences in the follow-up investigation

5.1 For the application of both the chi-square test and Tanner's test the observations must be derived from a stationary Poisson process. This is often tacitly assumed in accident statistics.

However, since Tanner's test gives grounds for concluding that an effect exists sooner than the chi-square test, it was considered desirable to obtain more certainty on this point.

An ideal design would have been based on at least two before and two after measurements, in both the investigation areas and the control areas. It would then have been possible, by using a covariance analysis, to test whether the contribution to the variance as a result of the measure itself differed significantly from the "random variance" in the before and after periods.

5.2 Since only one before and one after measurement was at the researchers' disposal in each case, another method was used to examine whether the accident frequencies could be regarded as the result of a stationary Poisson process. The method used was a further study of the time intervals between the accidents. This can for example be done by examining whether the standard deviation of the time intervals is equal to the mean interval, as is the case in a stationary Poisson process.

If the variance deviates significantly from the mean value, it is necessary to reject the hypothesis that the occurrence of accidents in a particular area and time period can be regarded as a stationary Poisson process. Such a situation can arise if there is a Poisson process with a time-dependent parameter, like a period of road resurfacing, the temporary closure of routes etc. In these cases there appears to be sufficient uncertainty to discard such areas as investigation or control areas.

5.3 Representing the accident frequencies in the form of a survey of the time intervals between the accidents, however, was found to open-up more possibilities. Any time-dependent variations in accident probabilities are not easy to identify in the frequencies, but can much better be seen in a time-dependent variation of the intervals. The only handicap here is that the variance increases and decreases with the mean value.

This last problem can be counteracted by expressing the intervals not in units of time, but in the logarithms of these units. The variance in the log-time intervals can be tested against that of a stationary Poisson process, i.e. $\pi^2:6$.

5.4 A first examination of the interval distribution showed that a stationary Poisson process could not be assumed in many areas. Although it is true that short-term periodicities such as daily and weekly cycles of activity could cause an increased variance of the intervals, this effect was found to be small. The deviations could more readily be explained by the predominance of short intervals. The question arose of whether the very short intervals within a single area still related to mutually independent events, which is also a condition for the application of a random process.

Inspection of the original police documents revealed a small number of cases in which a certain degree of dependence could be considered to exist between two accidents. These were then counted as a single accident. The same was done with a number of accidents which were wrongly recorded twice.

5.5 After this operation, a number of zero intervals still remained, primarily the result of rounding-off to within 5 minutes of the time at which the accidents had taken place. These zero intervals, as might be expected, caused problems in the log-transformation. This applied to approximately 1% of all intervals, although the number was nearly 3% in some areas.

To avoid such problems in the log-transformation, the investigation into the presence of a stationary Poisson process was carried out not by considering the intervals between successive accidents, but by considering those between accident i and i + 4, i + 4 and i + 8, and so on. The corresponding theoretical distribution that results from a Poisson process is less skewed than the original Poisson distribution; a test of the variance of the observed sum intervals against the theoretical value still remains possible.

5.6 A second condition for the test procedure used was that the number of accidents in the control area must be greater than 50 in both the before and after periods.

This condition, together with that demanding that all the numbers of accidents can be regarded as the result of a stationary Poisson process, led to a large part of the intended tests having to be omitted.

5.7 Nevertheless, it appeared that the methodological obstacles could to some extent be overcome by choosing the other statistical investigation technique.

The practical problems caused by the need to gather data afterwards about the characteristics of the areas and the way in which the measures had been implemented continued to be present, of course. For this reason, the follow-up investigation was also unsuccessful in indicating the opposing sub-effects whose existence was suggested earlier in this contribution. Only a few fairly vague conclusions can be drawn.

5.8 However, the investigators were left with the impression that one-way traffic does in fact bring about various sub-effects which could result primarily from differences in the urban and traffic situations between the separate investigation areas. Although efforts were made during the investigation to minimise these differences, their influence was still felt.

An illustration of this is the difference in effect on the total number of accidents between the investigation areas in Amsterdam and Rotterdam (i.e. a fall in the number of accidents in Amsterdam, and a rise in the number in Rotterdam, following the introduction of one-way traffic). This difference in effect between cities had not been aimed at in the investigation, but was one of the clearest matters to be revealed by the statistical method used. It so happened that, after discarding a number of investigation areas because of observed deviations from a stationary Poisson process, the Amsterdam data were more strongly represented than those from Rotterdam. This circumstance may have had an influence on the general conclusion that "one-way traffic has a decreasing effect on the total number of accidents".

5.9 Since the relationship between area and traffic characteristics on the one hand, and the nature of the accidents on the other hand, were not examined, no attention could be given to a possible explanation of any effects that were found to exist. Detecting these effects was considered to be sufficient. Furthermore, in this case, the effects do not need to be corrected for any changes in the traffic pattern in the various streets of an area under consideration as a result of the introduction of one-way traffic. Only the gross effects are important, regardless of the way in which they have arisen (as a result of changes in traffic mileage, traffic speed etc.).

One consequence of this is that the results can be generalised to only a limited extent, in principle only to residential areas of a similar nature.

5.10 A possible disturbance of the stationary Poisson process could have been caused by transitional effects following the introduction of the measure. One-way traffic reduces the freedom of movement of the road users, and drivers will often have to take new routes. The (temporary) effect of the newness of the traffic situation could have resulted in either more or less accidents; more because of the occurrence of unexpected situations, and less because of an increased level of attentiveness.

To examine whether effects of this type occurred, a further split was made between accidents during the first and second half-years after the implementation of the measure. This was also done for the control areas. Since the number of accidents was approximately halved by this process, only two areas then remained able to be tested. No start-up effect could be shown.

6 Conclusion

In a comment on the results of the follow-up investigation, it is stated that one-way traffic appears to have no generally predictable effect on the occurrence of accidents: the circumstances from case to case to a large extent determine the total effect. This being the case, no sound result can be expected from any broad statistical investigation into the

effect of one-way traffic on road safety. Only investigation methods in which the circumstances are considered in detail (characteristics of streets and/or areas, way in which the measure is implemented) offer any prospects. It is possible that an explanation of the observed effects could then also be given. The test procedure used in the follow-up investigation could then be applied. However, the results of such a more strongly differentiated investigation could then hardly be generalised, if at all.

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SUMMARY

1 A report is made of the practical experiences in two statistical investigations into the effect of one-way traffic in residential areas on road safety. These investigations can be regarded as falling under "short-term and area-wide evaluation of safety measures".

2 The first investigation consisted of chi-square tests on the development of accident hazard in a number of residential areas following the introduction of one-way traffic, also using a control group without one-way traffic. An attempt to split-up the neutral effect determined into positive and negative sub-effects was unsuccessful.

3 Some experiences of the first investigation were:

3.1 It proved to be almost impossible to avoid selecting entire areas as the units of investigation.

3.2 Defining the boundaries of the areas was problematical.

3.3 The vaildity of the control areas is subject to doubt.

3.4 The choice of some of the control areas led to interdependency of data.

3.5 The before and after periods had to be restricted to one year each.

3.6 Since only one measurement before and one after were at the disposal of the researchers for each area, no estimate was possible of the variance in time, as a result of which grounds for doubt always remain.

3.7 Since relatively few accidents take place in residential areas, and these are not very reliably recorded, the issues could not be specified satisfactorily.

3.8 The development in particular aspects of road safety was found to be area-dependent in the control areas; this was a further obstacle to differentiation of the results with regard to these aspects.

3.9 A supplementary reconnaissance was necessary for examining the relationship between the nature of the accidents and the characteristics of the areas; but it was decided not to carry this out for practical reasons.

3.10 For the same reasons, no specific conclusions could be drawn about the various ways in which one-way traffic may be implemented.

4 In a second investigation, Tanner's test was applied to a selection from the same data. However, the aimed-for differentiation in the issues could be achieved to only a very limited extent.

5 Some experiences of the second investigation were:

5.1 In a design using at least two measurements per area, both before and after, it would have been easier to determine which accident frequencies could be considered the result of a stationary Poisson process.

5.2 For this check, which was considered to be necessary for applying Tanner's test, the time intervals between the accidents have been studied instead.

5.3 The problem of the time-dependent variance increasing and decreasing with the mean value of the intervals was counteracted by a log-transformation.

5.4 To restrict the number of very small intervals, interdependent accidents have been considered as a single event; duplicated accident recordings were also removed.

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5.5 To avoid the problem of the remaining zero intervals, the intervals have been taken four by four.

5.6 A large portion of the intended tests had to be omitted, also because of the requirement that the number of accidents in a control area must be more than 50 in each before and after period.

5.7 The practical problems associated with afterwards obtaining supplementary data formed an obstacle to getting more differentiated issues, also from this follow-up investigation.

5.8 Concealed effects of area structures may still have coloured the issues given.

5.9 Since the investigation carried out was into gross effects, the results could not be explained, and could therefore be generalised to only a limited extent.

5.10 No start-up effect could be determined.

6 Since the effect of one-way traffic appears to a large extent to be determined by the individual circumstances, results can be expected only from investigation methods in which these circumstances are considered in detail. These results can then, however, not be generalised.

Mededeling: 7

A study into the effects of one-way traffic on traffic safety in residential areas of four towns in the Netherlands

Summary
Accident data of residential areas in four towns in the Netherlands (Eindhoven, Amsterdam, Utrecht and Rotterdam) were used to uncover specific relations between one-way traffic measures and indicators of traffic safety.

It was found that establishing one-way traffic has a decreasing effect on the total number of accidents, and that this effect is sometimes related to specific areas. However, no relation could be found between the effect and specific traffic situations (like intersections, etc.). Moped-riders turned out to be the only category of traffic participants for which a (positive) effect could be shown.

Het effect van eenrichtingverkeer
op de verkeersveiligheid in woonwijken

Studiecentrum Verkeerstechniek

Study on the effect of eliminating
intermittent signal from traffic
light programmes in Eindhoven.

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1. Introduction.

In many towns one can see that in the late evening and during the night a number of traffic lights give only a flashing orange signal. The reason is the low number of passing cars at those times.
In Eindhoven this situation also existed.
However, based on an analysis of the nightly accidents it was decided to start an experiment on continuous functioning traffic lights installations, situated in the inner city cordon.
One year after this measure an evaluation was carried out. A reduction of about 75% of accidents at night had taken place.
Apparently, the measure was right and should be taken for all traffic lights in the town.
However, the intersections involved were in a specific part of the town, so there was some doubt as to whether one could generalize the results.
After some discussion it was decided to apply the measure to all traffic lights in Eindhoven, again as an experiment. The evaluation was to be carried out as soon as possible.
This paper gives a description of the evaluation method used.

After 1 year it was found that on those intersections also a 75% decrease in accident occurrence had been achieved.
The conclusion could be drawn that continuous functioning, used as a universal application, can contribute considerably to road safety at night.
For Eindhoven (population 195,000) this means a decrease of 80 accidents per annum, including 25 (mostly severe) injuries.

In chapter 2 of this paper you will find the evaluation method.
Chapter 3 contains the results of both experiments as far as known at the moment.(1980)
The accident data of the year after the starting date could periodically be filled in these tables.

On every completed table a statistical test is applicable. For small frequencies the Fisher exact probability test can be used; otherwise the chi-square test for a 2x2 contingency table will be appropriate.

This method gives the opportunity to have at an early stage an impression of the direction of the effect, if any. At least it will be possible to decide if continuation of an experiment is justified.

On the other hand extended evaluation may be useful if significance cannot be stated after one year.

The accident data for the intersections of group II have also been gathered.
It turned out that in the year before the measure, very few accidents occurred (experimental group: 3; control group: 0)

Short term evaluation on such small frequencies is not possible.
These small frequencies can be explained by the small proportion of time that the measure applies on those intersections (about 7%).

2. Evaluation method.

In 1980 (Easter, april 6-7) the flashing signals were eliminated from all traffic light installations in Eindhoven.
The measure was taken on 39 intersections (the experimental group).
The effects could be stated as the difference in numbers of accidents during 1 year before and 1 year after the change, corrected for the trend-influence. In order to eliminate this trend-influence, the same accident-data was collected from all 38 other traffic light

installations where continuous functioning had been the rule for many years. (control group)

A survey showed that, depending upon the time of intermittent signals the experimental intersections had to be divided into 4 groups.

group 1 (16)	from 22 until 07 h.	(daily)
group 2 (2)	from 23 until 07 h.	(daily)
group 3 (1)	from 24 until 07 h.	(daily)
group 4 (20)	from 03 until 08 h.	(Saturdays and Sundays only)

For practical reasons these subgroups were reformed into 2 groups:

I 19 intersections with daily intermittent periods

II 20 intersections with intermittent periods only during the weekends.

N.B. The fusion of the first 3 groups may introduce a slight fault, because each experimental group must have its "own" control group.
In chapter 3 this matter will be treated.

The first months after the starting date offered the opportunity to gather accident data for the period preceding the change, both for the experimental group and the control group for the appropriate hours.

Depending upon the availability of accident data, a 3 month period was chosen as the shortest term for testing the results.
For 1 year 4 (incomplete) tables could be prepared:

table I : results after 3 months

accidents during hours under study	period 1979 week 14...26	1980 week 14...26	total
experimental group I	8 *	**	
control group	21**	**	
total	29		

* flashing signal
** continuous normal operation

table II : results after 6 months

accidents during hours under study	period 1979 week 14...39	1980 week 14...39	total
experimental group I	16		
control group	28		
total	44		

and so on for 9 and 12 months.

3. Results.

3.1. Experimental group I.

About 4 months after the starting date the first table could be completed:

table I* : 3 months evaluation

	B	A	total
E I	8	2	10
C	21	15	36
total	29	17	46

B = Before
A = After

* E = Experimental group
C = Control group

There seems to be no reason for not proceeding with the experiment. The direction of the effect is as expected.

Three months later the findings were:

table II : 6 months evaluation

	B	A	total
E I	16	4	20
C	28	22	50
total	44	26	70

These figures confirm the first result.
One can see that accidents in the controlgroup hardly change, while in the experimental group a clear decrease takes place.
This picture turned out to be very stable for the rest of the year:

table III : 9 months evaluation

	B	A	total
E I	23	5	28
C	39	31	70
total	62	36	98

table IV : 1 year evaluation

	B	A	total
E I	36	6	42
C	46	45	91
total	82	51	133

(chi-square : 13,56 ; $p < 0.001$)

We may conclude that the measure i.e. full time normal operation is very effective.

3.2. Experimental group II

In this group we find 20 intersections with during 1 year only 3 accidents.
In the controlgroup (38 intersections) we couldn't find any accident.
After 1 year this table could be made:

table V : 1 year evaluation

	B	A
E II	3	6
C	0	4

No conclusions can be drawn.

3.3. Original groups out of group I

As said group I had been composed of 3 original groups.
Here are the results of each group after a one year evaluation.

table VI : group 22-07 (16 intersections)

	B	A	total
E	31	6	37
C	46	45	91
total	77	51	128

table VII : group 23-07 (2 intersections)

	B	A	total
E	5	0	5
C	35	33	68
total	40	33	73

In group 24-07 (1 intersection) no accident was found neither 1 year before nor after the starting date.

We conclude that fusion did not affect the results.

3.4. Results of the first experiment (1975)

Extended evaluation has taken place on the experiment in 1975. After 6 years the findings are still in accordance with earlier results:

table VIII : long term evaluation

	3 years B	6 years A	total
E	189	45	234
C	114	113	227
total	303	158	461

4. Conclusion.

In this paper a method of short term evaluation has been worked out. The subject, however interesting, was only used as an example. Therefore there has been no specification of accident data such as:

- exact accident time
- types of accident
- means of transport
- characteristics of the persons involved
- causes
- consequences, injuries.

It will be clear that all this information could have been gathered. It was considered not to be of importance for this paper.

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SESSION 5:
Product evalution: conflict studies

SESSION 5

Chairman : Mr. S.A. Holmsen (Norway)

Theme: Product-evaluation: conflict-studies

R. Albrecht (Germany) : Evaluation of traffic restraint in residential areas with respect to pedestrian safety

V.A. Güttinger (the Netherlands) : From accidents to conflicts: alternative safety measurement

C. Hydèn, P. Garden and L. Linderholm (Sweden): Short-term evaluation of safety counter measures - two examples of experimentents with speed-reducing countermeasures in Sweden

R. Kulmala (Finland) : Traffic conflict studies in Finland

D. Mahalel,A. Peled and M. Livneh (Technion): Safety evaluation of flashing operation at signalized intersections

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Evaluation of traffic restraint measures in residential areas with respect to pedestrian safety

(Research Contract 7613/5 of Bundesanstalt für Straßenwesen -- BASt -- Köln)

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1. Definition of Problem

An important aim of traffic restraint in residential areas, by means of street network alteration schemes, is to achieve that pedestrians and drivers show more consideration for one another and to improve pedestrian safety in particular. The text below, exclusively deals with the methodological aspects of the problems associated with the control of these effects by means of before-and-after and with-and-without studies.

The historical residential quarter surrounding the Klausen(er) Square in Berlin-Charlottenburg was selected for the empirical investigation. It is a residential area in the city of Berlin; its streets are relatively quiet, with no special traffic control measures (within the limits of this area drivers on the left have to yield right-of-way to drivers on the right). Around the area there are major roads or arteries carrying heavy traffic volumes.

After preliminary surveys had been completed, traffic restraint measures were undertaken in the area under study within the frame of a model project attempted by the Senate of Building and Housing of the State of Berlin (Senator für Bau- und Wohnungswesen des Bundeslandes Berlin). The objectives of the project were:

- better raod safety
- more freedom of movement for pedestrians
- improved quality of the residential environment.

The following marginal conditions were to be maintained:

- maintaining the streets' function of providing services
- maintaining traffic in both directions
- maintaining places for cars to park
- not interfering with the historical character of the quarter.

The measures included new parking schemes and alterations of the street space by means of narrowing raod sections or allowing for deviation alinements. Traffic management and control measures were not interfered with. When the overhaul had been completed,sidewalks were still areas of movement strictly separate from the roadway. Mixed traffic areas as in the Dutch concept known as a "Woonerf" had not been the objective in the area under study (See Fig. 1).

The redesigned parts of the street network were marked by special traffic signs

(325/326 StVO -- German Highway Code) and thus made known as protected residential areas.

With respect to the contents of this research project, the following question may serve to outline the problem raised: are traffic restraint measures maintaining the separation between sidewalk and roadway and maintaining the streets' function of providing services appropriate means of improving pedestrian safety in the crowded conditions of downtown residential areas? This requires distinguishing between the effects of the measures as a whole and the effects of each individual measure (types of measures). And it further needs to be found out whether changing a streetscape might create traffic risks unknown before.

With respect to the methodological aspects of this research project, there was the question of how to check the effects of the street alteration schemes on pedestrian safety and obtain results in a short period of time.

2. Methods of Indirect Measurements

So far, road safety has generally been described mainly in terms of accidents, e.g.:

- absolute accident figures
- spacial distribution of accidents
- composition of accidents
- accident characteristics (accident rate, density, load).

Since this research project concentrates on pedestrian safety, the use of accidents as road safety criteria does not seem to be quite appropriate for the purpose of analyzing the effects of traffic restraint measures:

- In residential areas pedestrian accidents are rare events.
  The analysis would therefore require data collected over long periods of time before and after the measures of redesign.
- Much time would have to go by before being able to analyze the effects of remodelling the streetscape.

For that reason, a method of indirectly measuring pedestrian safety by means of systematic behavior studies, volume counts and studies of driver behavior was used for the purpose of the analysis planned.

2.1 Use of the pedestrian conflicts technique for checking effectiveness

A method specially designed to study the safety of pedestrians crossing roadways was developed by ERKE (1979). This method enables systematic observations of traffic behavior and critical situations between pedestians and drivers to be carried out.

The method is based on the definition of encounters between pedestrians and drivers on the roadway where their lines of movements are likely to intersect. An encounter is thus defined as follows:

A car-pedestrian encounter takes place when both have come so close to one another that mutual behavioral adjustments are necessary.

According to ERKE's definition (1979), a car-pedestrian encounter, depending on the degree of danger inherent in the situation, can be in the form of a safe encounter or develop into a conflict:

A safe form of encounter is defined as a car-pedestrian approach leaving sufficient time for behavioral adjustments to both parties.
An encounter turns into a conflict when the car-pedestrian approach has come to a point that collision is imminent unless one or both parties hurry to change their course of movement. Evasive action on the part of pedestrians (e.g., stopping, walking faster) or that of drivers (e.g., braking, accelerating,swerving) indicate the presence of a conflict and also enable the degree of seriousness of the conflict to be distinguished.

The seriousness of a conflict can be described by the time left to the parties involved to make their intention to change their behavior known to each other.

In validation studies, ERKE was able to confirm the relationship between pedestrian accidents and conflicts for signal-controled intersections and segments of major raods. The relationship between encounters and pedestrian accidents was furthermore confirmed by experiments relating to segments of major roads. However, the results cannot be directly applied to the residential quarter of Berlin under study, since in this case only local roads or streets without any special pedestrian traffic control measures were investigated.

The technique applied is a modification of the concept developed by ERKE, ZIMOLONG and GSTALTER, mainly consisting in the recording of data in diagrammatic form. The definitions of conflicts and encounters are consistent with the ones provided by ERKE. Great significance was attached to a high rehability of observers.

The sites selected were under observation for the period of a day each in the before-and-after study. Data was collected from 7:30 a.m. to 5:45 p.m. and during observation periods of 5 hours.

The field observations -- from the viewpoint of the pedestrian -- covered various forms of car-pedestrian interactions and, additionally, some obeservations of the behavior of drivers and pedestrians on the traffic scene:

- conflicts, encounters and conflictless infractions of regulations by pedestrians (FV) were plotted in the form of arrow diagrams (similar to accident diagrams);
- results from the additional observations of behavior were recorded in tabular form.

The observations were linked with traffic volume counts:

- number of pedestrians crossing the roadway (crossings) with a breakdown by age, location and site;
- number of vehicles (car volume) with a breakdown by direction of travel and type of vehicle.

Sites of observation were access points to the residential area, intersections and street segments. Separate records were used for each site.

The records of the encounter, conflict and FV data enable a description of each event to be made using the following parameters:

- location of event
- road users involved in an event
- direction of car travel
- type of car maneuver
- direction of pedestrian movement from the point of view of the driver
- actual direction of pedestrian movement.

The four last mentioned parameters are the ones establishing the type of encounter, conflict or conflictless pedestrian infraction (FV).

Other entries provide information on:

- time of event
- degree of seriousness of conflicts
- pedestrian behavior (with respect to encounter, conflict, conflictless pedestrian infraction)
- driver behavior (only in connection with encounter or conflict).

2.2 Measurement of driver behavior

Traffic restraint measures are designed to slow the traffic stream and allow drivers sufficient time to stop for pedestrians to get by. The traffic sign 325 StVO (German Highway Code), used to mark protected residential areas, requires that drivers operate their cars at pacing speed. However, since driver behavior depends on a number of parameters, such as the ones named below, it would not be reasonable to expect all drivers to drive at pacing speed in protected residential areas:

- driver : experience, attitude, psychic pattern, trip purpose
- vehicle : type of vehicle
- roadway : width, alinement, roadway surface
- traffic : traffic density and flow
- weather conditions: rainfall, visibility (daylight, dusk, darkness).

Traffic restraint measures can be designed to change the roadway parameter by means of necked-down sections, allowing for deviation alinements or raised paving. To find out the effects of changing the roadway parameter, it is important that other parameters be kept as constant as can be accomplished. Therefore measurements were based on the following marginal conditions:

- vehicle : only passenger cars were counted (because of the small size of the sample, other vehicles were left out of consideration)
- traffic : only undisturbed trips were recorded[1)]
- weather conditions: measurements were only conducted in daytime, dry pavement and good visibility conditions.

1) An undisturbed trip is defined as a trip not hampered or hindered by preceding or oncoming cars, crossing pedestrians or pedestrians walking on the roadway along the street at any time.

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Driver characteristics had to be left out in this connection.

The measurement of undisturbed trips enabled direct information about the effects of constructional measures on driver behavior to be obtained because drivers, under conditions of undisturbed travel, chose to travel at the speeds they consider to be optimal for their purpose.

The measures designed to narrow the roadway, provide for deviation alinements or the raising of certain roadway sites had been expected to lead to breaking and acceleration reactions. To be able to also record and study these effects, the spot speed spectrum or the spectrum of maximum speeds over a stretch of road would not have been satisfactory by themselves. It was necessary to determine and evaluate the pattern of speeds on defined stretches of road (areas where traffic restraint were applied) as well.

Due to the catalogue of requirements laid down, a technique was used enabling continous speed measures to be carried out (cf. WIMBER u. ERKE, 1981).
The measuring technique consisted of a speed sensor (double-radar system developed by AEG-Telefunken) for automatic data detection and recording.
Speed measurements over long stretches of road, however, are problematic on urban roads because crossing traffic (pedestrians and cars) disturbs the process of resording. For that reason, test sections of about 40 m lenght each were selected. In the redesigned street network, these were the sites including slightly raised pedestrian pavings, deviation alinements or intersection areas.

For the purpose of evaluation, the analogue speed plotting that were available had to be converted into digital form. Further data processing was performed by means of a large-scale computer and included:

- speed differentiation (= acceleration)
- integration of speeds (= travelled distance)
- graphical representation of the speed-acceleration-travelled path relationship on a graphic display system
- correction of speeds (removal of disturbance factors without falsifying the actual pattern of speed)
- printing of speed (v) data in terms of (m/s) and (km/h), acceleration (b) in (m/s^2), and travelled path (s) in (m), based on t = 0,1 s
- graphic representation of the plotted curves for v and b over s
- evaluation of statistical characteristics (parameters).

3. Problems Involved in Checking Effectivness

3.1 Pedestrian traffic behavior

The central problem of checking the effects of measures is finding the right measurements by which the effectiveness of pedestrian safety measures can be checked. Since conflicts between pedestrians and cars are bound to occur also in protected residential areas, the assessment of traffic facilities with respect to pedestrian safety is essentially an assessment of the relative safety of such facilities for pedestrians. This was to be established by means of before-and-after comparisons or simultaneous comparison of traffic facilities of different configuration.
The problem involved in checking the effects of measures can be best exxpressed by asking the following questions:

(1) How does a certain increase or decrease in the number of encounters or conflicts affect road safety?

(2) Which variables are to be assigned to conflicts or encounters to describe them as relative in order to obtain information about the risks of traffic?

(3) Based on which variables can conclusions on the agreement or discrepancy between objective and subjective safety be drawn?

(4) By what means are conclusions, based on the behavior observed, to be drawn with respect to the acceptance of measures?

To (1) - The number of encounters describes the number of situations in which accidents can occur. The number of encounters also includes safe forms of encounter, that is to say encounters not involving a risk of collision.
- The number of conflicts describes the number of situations in which collisions are imminent, unless road users change their course of approach.
- A change in the number of conflicts or encounters is thus only indicative of a possible change in pedestrian safety. The examination of the effects of restraint measures requires that more complex interactive relationships be considered.

To (2) - The assessment of pedestrian safety on streets in protected residential areas might at first be approached by means of the relationship between the number of conflicts and the number of pedestrians crossing the roadway or using it to walk along the street. This relationship describes the risk of conflicts pedestrians using the roadway are exposed to.

- One of the objectives of traffic restraint measures is to ensure greater safety for pedestrians in car-pedestrian encounters, since the measures are not designed to do away with these. Instead, care should be taken to provide an environment in which drivers and pedestrians alike will feel naturally inclined to be more considerate to one another.
- Applying the method of conflict observation selected, conclusions as to this question are possible based on the relationship between the number of conflicts and the number of encounters. This relationship -- let it be called conflict rate in the following -- is a means of describing the risk of conflict inherent in a car-pedestrian encounter.
- A number of studies performed by ERKE (1979) and ALBRECHT and SCHÜTTLE (1979) revealed that this measure of risk can well be used to obtain confirmation of the risk exposure of pedestrians of different age groups and involved in different traffic situations.

To (3) - It can be expected that pedestrians of different age (children, juveniles, adults, elderly pedestrians) react differently to an altered streetscape. The effects on pedestrian safety will vary accordingly with age and the situation at hand (pedestrian walking alone, in a group, child in the company of an adult).

- These differences can be explained by means of the objective and subjective safety model (KLEBELSBERG, 1977).
- For that reason, apart from the conflicts and encounters, the modes of pedestrian behavior indicative of feelings of subjective safety and acceptance of measures are also taken into consideration.
- The following modes of pedestrian behavior were identified as indications of subjective safety:
  - breaking traffic rules without the consequence of a conflict because vehicles are not on the scene and an encounter thus out of question (crossing the roadway at an oblique angle, walking along the roadway, crossing intersections diagonally);
  - playing of children on the roadway;
  - not minding car traffic when crossing the roadway;

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  - accompanying children crossing the roadway.

To (4) - The following modes of pedestrian behavior were identified as indications of the acceptance of measures:

  - choice of the location to cross the roadway (intersection or road segment);
  - utilization of facilities provided for greater relative safety in crossing the road.

3.2 Driver behavior

Speeds and acceleration

The method of measurement selected was designed to provide the spread of speed and acceleration data over a section of road of each vehicle observed. Speed data are recorded every 0.02 s and converted into speed and acceleration data based on o.1 s intervals.

Each plotted curve represents the behavior, conditioned by personal, situative and local factors, of a driver of a particular car. By superimposing all (up to 118) curves, information about the spectrum of driver behavior can be obtained. However, for the reason that the reading of so many superimposing curves is not an easy matter, the representation of driver behavior in relation to the various restraint measures performed was limited to some typical curves in each case.

However, the representation of driver behavior by means of the typical speed and acceleration data obtained from the before-and-after and with-and-without studies only provides trend data on the effects of the alteration measures. Statistical driver behavior characteristics are a more appropriate means of assessing the very effects of the various types of alteration measures carried out.

The criterium selected to evaluate the effects of alteration measures on driver behavior is the aforementioned speed of 20 km/h, defined as the upper limit of "driving at walking pace". Necked-down roadway sections, slightly raised paving, and deviation alinements should not be the cause of abrupt braking or acceleration reactions. Accelerating to 20 km/h after having passed an intersection or made a turn is considered as "permissible" range of acceleration. On the test sections, which are all beginning at least 30 m behind an intersection, the acceleration values should ideally again be close to the zero range.

Speed spectra

The information on driver behavior by means of typical speed and acceleration data can be substantiated by means of statistical speed spectrum characteristics.

For the representation of driver behavior the accumulated frequency curve of the speeds exceeding the average speed and of changes in speed on the test section are used.

Since it cannot be expected that all drivers drive at walking pace (max. 20 km/h) in protected residential areas, a permissible range of average speeds by which the success of restraint measures can be evaluated needs to be defined:

The large-scale experiment "Traffic Restraint in Residential Areas" performed by the State of North-Rhine Westphalia was based on the following requirements: 85 per cent of the speed measured in protected residential areas were to be below 20 km/h and none was to exceed 30 km/h.

4. Final Remarks

4.1 Use of the pedestrian conflicts technique (FKT)

Compared with the analysis of accidents, the FKT has the advantage that -- under the condition that conflicts and accidents be closely related -- other fairly frequently observed events (infractions, conflicts, encounterd) can additionally be used to determine the risk road users are exposed to. It is furthermore possible to survey and record, simultaneously with conflicts, several other characteristics features of a site under observation, such as traffic volume, weather, constructional pavement elements, etc. Given careful training of the observation staff, conflicts should be recorded with adequate reliability.

4.2 Continuous speed measurements

The method designed to provide continuous speed data is simultaneously providing a considerable amount of driver behavior data and a wide field for exploration and evaluation of test results therewith. The most important evaluations carried out within the frame of this program of testing are represented in the

form of typical speed and acceleration patterns and in the form of the frequency distribution of speed spectra.

The measuring technique applied has so far only been used in the case described and is thus limited to basic research schemes, such as the experimental alteration of residential areas by means of implementing restraint measures. The method of continuous speed measurements can be used in this context to optimize measures of speed restrictions planned.

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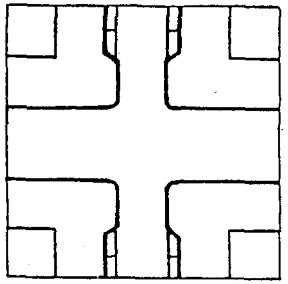
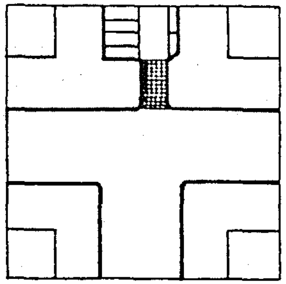
Fig. 1: Types of Restraint Measures Applied in the Area Under Investigation



INTERSECTION 1: NECKED-DOWN APPROACH

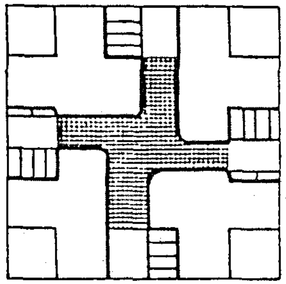
INTERSECTION 1.1

- Necked-down roadway on one or two approaches to the intersection



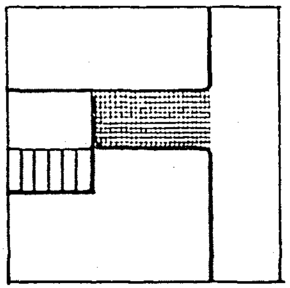
INTERSECTION 1.2

- Necked-down roadway with raised paving on one approach



INTERSECTION 2: DEVIATION ALINEMENT

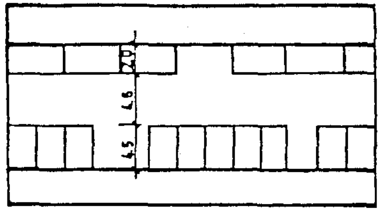
- Necked-down roadway on all approaches to the intersection
- Raised paving on the whole intersection area (or red gussasphalt)
- Deviation alinement (to the right)



DRIVEWAY: NECKED-DOWN PAVEMENT

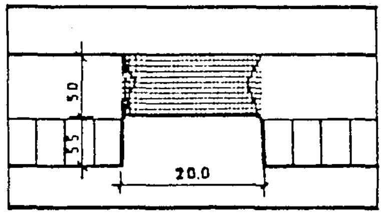
- Necked-down and raised paving or specially marked crossing

Fig. 1 (continued):

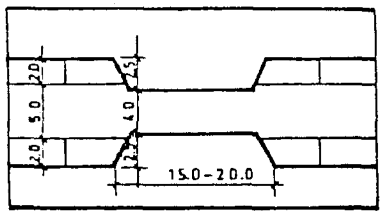


SEGMENT 1: NECKED-DOWN PAVEMENT

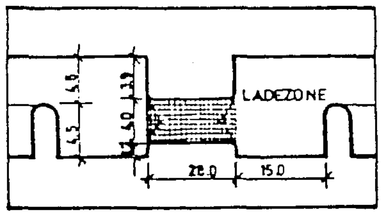
SEGMENT 1.1
- Roadway narrowed in its entirety
- Parking places marked on both sides (parking parallel to curb at night-time only)
- Parking places are interrupted by driveways



SEGMENT 1.2
- Roadway narrowed in its entirety
- Parking places on one site only
- Parking Places interrupted by circular beds around trees
- Wide raised paving and marked crossing

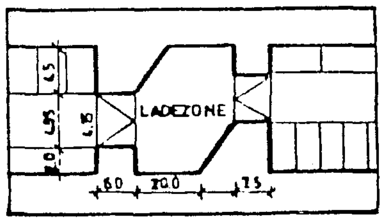


SEGMENT 1.3
- Roadway narrowed in its entirety
- Parking places on both sides
- Parking places interrupted by circular beds around trees
- Cobblestone pavement on both sides in addition to necked-down roadway



SEGMENT 2: DEVIATION ALINEMENT

SEGMENT 2.1
- Roadway narrowed in its entirety
- Parking places on one side only
- Parking places interrupted by raised paving (in the form of "ears")
- Wide raised paving and marked crossing
- Deviation alinement in front of and behind the crossing including loading zone (red asphalt pavement)



SEGMENT 2.2
- Roadway narrowed in its entirety
- Parking places marked on both sides (parking parallel to curb at night-time only)
- Parking on alternate sides of the street possible
- Raised Paving with marked crossings
- Deviation alinement in the loading zone (red asphalt pavement)

FROM ACCIDENTS TO CONFLICTS:

alternative safety measurement

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ABSTRACT

The danger of traffic is commonly determined by the occurence of accidents. This paper presents some of the history of alternative measures for describing traffic unsafety (measurement of so-called conflicts). It also gives the results of a series of research projects aimed at the development of a conflits observation technique for the estimation of the safety of child pedestrians in residential areas.
The reliability, practical applicability and validity of the developed technique prove to be satisfying.
It is concluded that the use of this technique seems to be justified for those situations in which accident rates are relatively low, e.g., in residential areas. This is not only because of the strong relationship between serious conflicts and accidents but also because other potential alternative indicators for the estimation of traffic unsafety often used in practice, such as traffic volumes and subjective estimation of risk by residents, had little success in predicting accidents.

Introduction

When speaking about the dangers of traffic, most of us think of accidents. The extent of traffic unsafeness is usually described by the occurence of accidents.
However, recorded accidents are rather unsatisfactory indicators for traffic unsafety.

a) The registration of accidents is limited and not always reliable or complete. With respect to the first, the extent of limitation of the registration depends on the definition of accidents. If one defines an accident as "a collision which results in the death of one (ore more) of the participants", all accidents in Holland are recorded. If one chooses, as we do, a definition of an accident as "a collision between an traffic participant and another participant or an object regardless of the results of that accident in terms of victims or material damage", only a small, unknown fraction of all accidents is recorded.

b) Although (even if one only speaks about recorded accidents) accidents happen frequently and qualifications such as "a modern epidemic" (1979) seem to be quite apt, they are still relatively rare events. It is, e.g., hardly possible to trace, within a short time, unsafe locations or to evaluate traffic safety measures.

c) The fact that accidents must take place before one can determine the risk of locations is, from an ethical point of view, a basic disadvantage.

There is a need for a more frequently occuring and measurable phenomenon than the accident as a criterion for traffic safety.

Conflict observation

To gain some insight into the effect of safety measures in a relatively small area, we decided to follow a trend in the research that concentrates on finding an alternative indicator for safety that, in its origin, started back in the nineteen forties. In aviation, "pilot errors" or "critical incidents" were then used as measures of safety performance (Fits & Jones, 1947; Flanagan, 1954).
The term "conflict" in traffic safety resarch was introduced by Perkins and

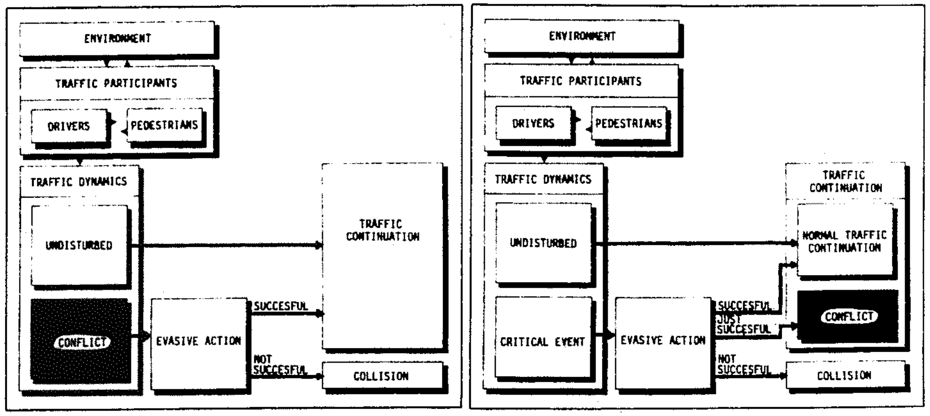
Harris (1967). All research in this area originates from their work, although it must be mentioned that it was Spicer (1971) who, by means of introducing a new concept (severity grade), did much to promote the conflict observation technique.

There is agreement among the research workers in this area on the use of the term "conflict" and even on the main aspects of the operational definitions of conflicts (namely, evasive or avoidance actions).

However, there seems to be some confusion regarding the place of the conflict in the traffic process, as illustred in figure 1.

For some, the conflict is an event that precedes an evasive action that can be either succesful or not succesful (collision). For others, it is the same as a near-miss situation after an evasive action. In this last view, a conflict cannot lead to collision but is an event parallel with a collision.

Figure 1. Place of the conflict in the traffic process



a) Conflict as potential accident. Evasive action - sometimes combined with distance between participants - indicates previous conflict.

b) Conflict as near-miss situation. Just succesful evasive action (see text) - sometimes combined with distance between participants - indicates conflict.

At the time that we started our research in this area, three main conflict techniques existed, each with their advantages and shortcomings (table 1):

a) the traffic conflicts technique of Perkins and Harris (1967, 1968, 1969);
b) the traffic conflicts technique of Spicer (1971, 1972, 1973);
c) the time - measured - to collision technique* of Hayward (1972).

Table 1. Positive and negative aspects of the three conflicts techniques

technique	advantages	disadvantages
Perkins and Harris (1967, 1968, 1969)	- objective definitions in terms of evasive actions and traffic violations - easy applicable (direct observation at spots)	- reliability not tested - no substantial and stable relationship with accidents (validity)
Spicer (1971, 1972, 1973)	- introduction of severity grade: distinction of serious and less serious conflicts (5 levels) - strong association between serious conflicts and accidents	- subjective operational definitions of conflicts - reliability not tested*
Hayward (1972)	- objective registration of the time-measured-to-collision by means of video- and computer equipment	- validity not tested - expensive equipment - practical application not always possible

* Given the estabilished relationship between conflicts and accidents, a reasonable amount of reliability (in this case intra-rater-reliability) must exist.

In terms of our interest - the safety of pedestrians, especially children - a general disadvantage was that none of the above-mentioned techniques took pedistrians into account.

The development of a conflict observation technique

Despite the mentioned disadvantages of the conflict techniques, this approach seemed to be the most promising with regard to the problem we faced: the estimation of the safety of (child) pedestrians in situations where accident data are

* The time-measured-to-collision (TMTC): "The time required for two vehicles to collide if they continue at their present speeds and on the same path" (Hayward, 1972, p. 9).

very scarce. Especially the results of the work of Spicer (1971, 1972, 1973) seemed to be encouraging enough to justify attemps in this direction.
Our work which was aimed at developing a reliable and valid conflict observation technique that could be used for the prediction of the safety of children as pedestrians consisted of four steps:

1) operationalisation of the concept "conflict". Operational definitions of conflicts have to be objective. If strict objectivity is not possible, intersubjective agreement between expert observers can replace objectivity (de Groot, 1966);
2) a test of the reliability: do observers using the operational criteria for conflicts reach agreement in the judgement of situations (inter-rater-reliability) and are individual observers stable in their judgements (intra-rater-reliability);
3) a test of the practical applicability of the conflict observation technique in field situations;
4) a test of the validity of the conflict technique

Operationalisation

Following the work of others (particulary Spicer, 1971), we defined a serious conflict as: "a sudden motor reaction by a party or both of the parties involved in a traffic situation towards the other to avoid a collision, with a distance of about one metre or less between those involved".
The criterion of "sudden" was determined empirically: observers had to judge reactions of participants in traffic situations to see whether they used certain common criteria in their judgements (the traffic situations were recorded on videotape). A discussion afterwards resulted in a detailed list of criteria that could be used to indentify four types of reactions (from "no reaction", scale value 0, up to "sudden reaction", scale value 3) of different kinds of road users.

Reliability

With respect to the reliability, the following can be stated: even unselected, untrained observers were fairly capable (by using the developed list of criteria) of judging the reactions of traffic participants.
The mean coefficient for the intra-rater-reliability (10 observers jugded 54 evasive actions) varied from r = .85 (judgement of the reactions of wheeled traffic) to r = .95 (judgements of the reactions of pedestrians). The results of the test of the inter-rater-reliability were smaller: r = .75 (reactions, wheeled traffic) and r = .87 (reactions, pedestrians). Selection and training of observers yielded better results with respect to the inter-rater-reliability: r = .85 and r = .94 (a new team of 8 observers judged 54 reactions).

Some definitions

Besides "serious conflicts" (characterized by "sudden evasive actions with a distance of about one metre or less between those involved"; popular: "just succesful evasive actions"), we distinguish "conflicts", "intensive contact-conflicts", "contact-conflicts" and "contacts". These distinctions are based on 6 different combinations of "sudden", "less sudden" and "nonsudden" reactions with "short distance" (± one metre or less) and "less small distance" (± 2 - ± 20 metres). The covering concept is called "an encounter", which is defined as "a motor action by a party or both of the parties involved in a traffic situation towards the other to avoid a collision, with a distance of 20 metres or less between those involved".

Practical applicability

In two field studies (Güttinger, 1976; 1979) the practical applicability of the conflict observation technique by means of so-called sector and personal observation was found to be satisfactory.
The method of sector observation is especially suited for the determination of the risk of certain spots, e.g., an intersection or a part of a road.
In the case of personal observation, individual road users (in our situation, child pedestrians) are followed for a certain time. This method is suited for the comparison of larger environmental units (e.g., neighbourhoods), for the detection of high risk spots within large areas or to trace the relative risks for certain child pedestrians or groups of child pedestrians.
With both methods, an amount of information which gives a good idea of what happens between child pedestrians and wheeled traffic in residential areas can be collected within a fairly short time period.
If accident figures are used as criteria for road safety in the same situation, nothing can be said about traffic dangers for pedestrians in a comparable short time.
The possibility to use serious conflicts as an alternative measure of traffic

safety, of course, depends on the relation between these serious conflicts and accidents.

Validity

A study of the predictive validity of serious conflicts constituted the fourth step in our research.
Such a study has its limitations. Those factors that were the motivations for our attempts to find alternatives for accidents as indicators of traffic safety (the fact that accidents are relatively rare and the poor accident recording) interfere with the validation of the conflict observation technique.
Some remarks must be made with respect to the statistical testing of the relationship between conflicts and accidents.
If a correlational model is chosen, it is necessary to take a random sample of locations from the population of all locations.
Here, we are faced with two problems:

1) we do not know the population of locations;
2) to assure that the sample contains locations where accidents have taken place, it has to be of rather large size (because accidents per location are rare).

If one chooses a regression model for testing the relationship between conflicts and accidents, where random samples of locations with 0,1,2,3,4, etc., accidents must be taken, one is confronted with a comparable problem: we do not know the populations of locations with 0,1,2,3,4, etc., accidents.

What was our solution?

Based on the accident records of 4 municipilities of 1972 up to and including 1976, we selected a total of 25 road sections (max. length = 100 metres). The number of accidents (involving child pedestrians) per location varied from 0 to 5 (in five years). Each section was observed for 34 hours (after school hours and not during the weekend).
We will present the relations between conflicts as we observed them and accidents that happened in the previously chosen years in terms of product-moment correlations (but note that, because our sample was selected, estimation of the correlation coefficient of the population is not possible). If we find a relationship between conflicts and accidents, how strong must it be to indicate a certain validity of our method?

We formulated two demands.

1) The relation must be stronger than between exposure variables (traffic volume, volume of pedestrians, products of both) and accidents. In other conflict studies (Baker, 1972; Paddock, 1974; Glennon & Thorson, 1974), exposure seemed to be the explanatory variable of estabilished relations between conflicts and accidents.
2) The relationship must be stronger than between subjective feelings of the residents regarding the safety of the locations under study and accidents. If this subjective safety is strongly correlated with accidents, the need for an instrument such as the conflict observation technique is doubtful.

Results: a) conflicts and accidents.

Of all types of encounters, serious conflicts correlated best with accidents: $r = .51$, $p < .01$ (see table 2).

Table 2. Matrix of correlations of the different types of encounters and reported accidents 1972 - 1976

	SC	C	ICC	CC	IC	C	E	A
serious conflict	1	.65 $p<.001$	.68 $p<.001$	.63 $p<.001$	.68 $p<.001$	.61 $p<.001$	.73 $p<.001$	.51 $p<.01$
conflict		1	.75 $p<.001$	.91 $p<.001$	.74 $p<.001$	.89 $p<.001$	.96 $p<.001$	.23 $p>.05$
intensive contact - conflict			1	.81 $p<.001$	.80 $p<.001$	.69 $p<.001$	.85 $p<.001$	.34 $p<.05$
contact - conflict				1	.65 $p<.001$	.90 $p<.001$	.96 $p<.001$	.37 $p<.05$
intensive contact					1	.64 $p<.001$	.80 $p<.001$	.15 $p>.05$
contact						1	.94 $p<.001$	.36 $p<.05$
total of encounters							1	.35 $p<.05$
accidents 1972 - 1976								1

It can be concluded from table 2 that the combination of the two variables distance and reaction is essential in defining the different types of encounters.
Encounters characterized by short distances do not correlate better with accidents than those characterized by greater distance, nor do encounters featuring sudden evasive actions show a better correlation with accidents than those characterized by nonsudden actions.

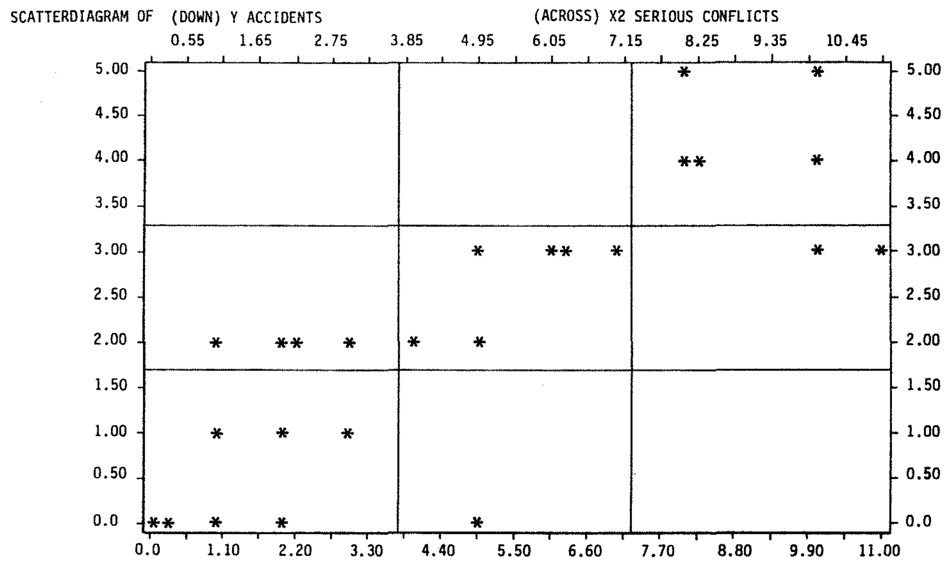
Although serious conflicts show the strongest relation with accidents (a confirmation of Spicer's findings (1971, 1972, 1973)), they explain only 25% ($r^2 \times 100$) of the variance in recorded accidents.
This does not seem to be high enough to justify the use of serious conflicts as a criterion for traffic safety.
Addition of the other encounters as predictor variables (multiple correlation) yielded a correlation of $r = .68$, $p < .001$, which explains about 50% of the variance.

Table 3. Matrix of correlations between the different types of encounters (leaving cyclists out of the calculations) and reported accidents (1972 - 1976)

	SC	C	ICC	CC	IC	C	E	A
serious conflict	1	.57 p<.001	.55 p<.001	.62 p<.001	.66 p<.001	.62 p<.001	.68 p<.001	.82 p<.001
conflict		1	.73 p<.001	.91 p<.001	.79 p<.001	.90 p<.001	.95 p<.001	.26 p>.05
intensive contact - conflict			1	.82 p<.001	.85 p<.001	.66 p<.001	.82 p<.001	.31 p<.05
contact - conflict				1	.77 p<.001	.91 p<.001	.97 p<.001	.38 p<.05
intensive contact					1	.71 p<.001	.85 p<.001	.34 p<.05
contact						1	.95 p<.001	.41 p<.05
total of encounters							1	.41 p<.05
accidents 1972 - 1976								1

It must be noted, however, that recorded accidents do not include collisions between pedestrians and cyclists, because these collisions seldom result in injury (criterion for recording). In our observations, we also recorded encounters between pedestrians and cyclists.
Leaving these kinds of encounters out of the calculations, we found a correlation of serious conflicts with accidents of $r = .82$, $p < .001$ (table 3). If all types of encounters are used as predictor variables, the multiple correlation is $r = .88$.
If we plot the relation between serious conflicts and accidents, the regression shows a strong linear component.

Figure 2. Serious conflicts (X) versus accidents (Y)



CORRELATION (R)-	0.81525	R SQUARED -	0.66464	SIGNIFICANCE <	0.001
STD ERR OF EST -	0.91962	INTERCEPT (A) -	0.43776	SLOPE (B) -	0.36713
PLOTTED VALUES -	25	EXCLUDED VALUES -	0	MISSING VALUES -	0

b) exposure data and accidents.

Of all of the exposure variables we used, none yielded a better correlation with accidents, as can be seen in table 4.

Table 4. Matrix of correlations between exposure variables and recorded accidents (1972 - 1976)

exposure variable	r	p
traffic volume	.30	>.05
volume motor traffic*	.35	<.05
volume child pedestrians	.42	<.05
volume protected child pedestrians**	.31	>.05
volume unprotected child pedestrians	.44	<.01
product of 1 and 3 = exposure 1	.39	<.05
product of 2 and 3 = exposure 2	.40	<.05
product of 1 and 5 = exposure 3	.41	<.05
product of 2 and 5 = exposure 4	.41	<.05

If we add exposure variables to serious conflicts in our prediction of recorded accidents, we can see that they explain very little variance in addition (table 5).

Table 5.

	multiple correlation	partial correlation serious conflicts and accidents. Exposure constant	partial correlation exposure and accidents . Serious conflicts constant
serious conflicts + volume motor traffic	.82	.79	.14
serious conflicts + volume child pedestrians	.82	.77	-.12
serious conflicts + volume unaccompanied child pedestrians	.82	.77	.11
serious conflicts + vol.mot.traf. x vol. child pedestrians	.82	.78	.05
serious conflicts + vol.mot.traf. x vol. unacc. child pedestrians	.82	.77	.04

* Because of aforementioned reasons (collisions between cyclists and pedestrians do not result in recorded accidents), cyclists are left out of the calculation.
** Protection: presence of adults.

c) subjective safety and accidents.

Subjective feelings of the residents regarding the safety of the locations under study did not show much relation with the actual safety or hazards for children*.

Conclusion

Considering these results and considering also that

a) pedestrian accidents involving children in residential areas happen so infrequently that they cannot be used to arrive at statements about traffic safety; and

b) if after years of data collection there are "enough" accidents to make statements about the traffic safety, these statements are of little value because too much has changed,

we feel that serious conflicts (as we defined them) between child pedestrians and wheeled traffic can be used to arrive at statements about traffic safety. However, the conflict observation technique is not yet suited to predict accident rates. It can be used for comparing situations (areas, roads, intersections, etc.) and for arriving at statements in terms of relative safety.

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* Within a radius of 100 metres of each location, parents were asked questions like: "does your child play at that location";"has your child to cross that location";"if so, do you assist your child"; what is your opinion of the safety of that location", etc. Only one significant correlation was found: at locations where children of ages 0 - 4 years were allowed to play, more accidents had occurred ($r = .40$, $p < .05$)!

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SHORT TERM EVALUATION OF SAFETY COUNTERMEASURES - TWO EXAMPLES OF EXPERIMENTS WITH SPEED-REDUCING COUNTERMEASURES IN SWEDEN

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ABSTRACT

The need for surrogates to accidents for the evaluation of accident-risks resulted in the development of a Traffic Conflicts Technique at the department. The Technique was first presented in 1976. Modifications have been made during the last years and right now a project is on-going aiming at validating a new technique with a modified definition of a serious conflict. An international cooperation in the area is established and joint activities are planned aiming at comparing techniques developed in different countries.

The paper also deals with the extensive research work that is under way at the department on the effects of actual speed-reductions in urban areas. The speed reduction is achieved by physical measures such as humps etcetera. Experiments are carried out on different types of streets, ranging from local residential streets to arterials carrying ten to fifteen thousand vehicles a day. The results so far are very promising and it seems as if speed-reduction is a very interesting complement or alternative to the traffic-safety measures traditionally used.

1. INTRODUCTION

The traffic safety research at the department has during the last years focused on safety in built-up areas. In these areas the unprotected road-users, especially pedestrians and bicyclists, have been the main groups of interest.

Strong efforts have been made to develop techniques of observing road-users in spontaneous traffic situations. The most important technique that may be mentioned is the Traffic-Conflicts Technique first time presented in a report 1976 (1). Since then the technique has been applied to a lot of different research projects. The most important areas of concern are:

- The effects of speed-limits outside schools
- The effects of different signal-control systems at intersections
- Ditto for mid-block signalisation of pedestrian and bicycle crossings
- The relations between geometrical layout and safety for pedestrians and bicyclists
- The effects of speed-reduction through physical measures (humps, etcetera) in residential areas
- The effects of a general speed-reduction in urban streets where an effective separation of road-users in time or space can't be achieved
- The further development of the Traffic-Conflicts Technique.

This paper starts with a presentation of the Swedish Traffic Conflicts Technique. In the last part of the paper results from two research projects are presented. The studies deal with the short-time evaluation of the effects of speed-reducing countermeasures.

An estimation of the short-time effects on safety may include a great number of indirect measures. Below, there is a presentation of the department's most commonly used measures at before and after studies.

1) Serious conflicts

Conflicts are in most studies used as the primary measure to indicate changes in accident-risks as police-reported accidents at most occasions are too few.

2) Vehicle speeds (85-percentile speeds, mean speeds and speed variations).

In some studies even the conflict-frequency is too low. Vehicle speeds are then one out of a number of measures used to indicate changes in accident-risks.

3) Road-user volumes

Exposure might have changed, i e vehicle-drivers may use alternative routes after the change.

4) Road-user behaviour

Generally these behavioural studies are used to follow up whether the countermeasures introduced fulfil the operational criterias set up. The behavioural measures also indicate the road-user "acceptance" of the countermeasures introduced.

Behavioural studies are often carried out at more than one occasion after the implementation of the countermeasure. This gives the opportunity to follow in detail the adaption of the road-users to the countermeasures. A fairly great number of behavioural studies are normally carried out. Some of the most important studies may be mentioned:

- Eye movements by drivers.

- Head movements by pedestrians and bicyclists.
- Pedestrian, bicyclist, car driver gap acceptance.
- Crossing location for pedestrians and bicyclists (related for instance to the existance of zebra crossings, the distance to an intersection etcetera).
- Accelerations and deceleration by car drivers.
- Road-user behaviour at traffic signals.

5) Attitudes of road-users, residents, etcetera

Indicates changes in the subjective feeling of safety, views on the operation of different countermeasures, etcetera.

A safety evaluation normally include studies of as many of those measures mentioned as possible. The results are combined and different models are used to achieve as accurate estimations of safety as possible.
Safety is only one aspect that may be influenced by the implementation of the countermeasure. A lot of other aspects has to be taken into account. So far the following aspects have been included in our studies.

- Delays
- Capacity
- Service level
- Vehicle costs (including fuel costs)
- Maintenance
- Noise pollution
- Air pollution
- Vibrations
- Implementation costs.

The results are not, so far, combined to give some kind of benefit-rate of different countermeasures. In a coming project a model for a widened cost-benefit analysis will be developed.

2. DEVELOPMENT OF A SWEDISH TRAFFIC-CONFLICTS TECHNIQUE

2.1 Background

It is of obvious interest to be able to estimate risks for different road-users at various locations e.g. when prioriting safety-measures between different sites, when choosing counter-measures, and when evaluating their effects. The lack of an effective method to evaluate these effects makes traffic safety planning on local and federal levels ineffective. This means that the most cost-beneficial solutions rarley are chosen and sometimes even that supposedly safety-beneficial solutions have a negative effect on the safety without so beeing found out until many years after the implementation of the countermeasure.

Traditionally the only method of estimating risks has been by analysing accidents. This is however very time-consuming and there are often interfering changes in the variables that preferrably should be kept constant during the period of analysis (i e traffic intensity). Furthermore, information of how and why the accidents have occured is lacking. These facts combined with the low percentage of occured accidents that ever get reported naturally make accident analysis far from perfect.

Many of the problems related to the analysis of accidents could be solved by estimating the risks indirectly by a "Conflict-Technique". Work with developing such a technique started at our department in 1973 and a technique for operational use was specified in 1974. Since then the technique has been modified and is still under further development, but many of the bases are unchanged.

The basic hypothesis, unchanged since 1974, says that there is a distinct relation between conflicts with a certain degree of seriousness and accidents. When these relationships have been determined the technique is practically useful. This means that after a conflict study has been undertaken actual accident risk can be calculated with a known degree of uncertainty.

Below the different phases of the development of the swedish technique will be described.

2.2 The original technique

The following definition was used: A serious conclict occurs when two road-users are involved in a conflict-situation where a collision would have occured within 1,5 seconds if both road-users involved had continued with unchanged speed and direction. The time is calculated from the moment one of the road-users starts braking or swerving to avoid the collision.

The recording of conflicts was and still is made by observers at the traffic site. Tests show that observers, after approximately four days of training, are able to recognise serious conflicts with a large degree of certainty.

To analyze the relations between accidents and serious conflicts, studies were made in a total of 115 intersections in three stages:

1. Malmoe 1974-75, 50 intersections
2. Malmoe 1976, 15 intersections
3. Stockholm 1976, 50 intersections

At each intersection, conflict registration was made during approximately seven hours and then compared with previous accidents of personal injury during seven to eight years.

Analysis showed that two factors had a definite influence upon the relations between police reported accidents with injuries and serious conflicts, namely the kind of road-user involved and the general speed level at the intersection. The following average connections were obtained between the number of police reported accidents with injuries and the number of serious conflicts during the same period of time.

TABLE 1: ORIGINAL CONVERSION FACTORS BETWEEN SERIOUS CONFLICTS AND INJURY ACCIDENTS.

	ROAD-USERS	
SPEED LEVEL	CAR-CAR[1)]	CAR-PEDESTRIAN CAR-BICYCLE
LOW-SPEED SITUATIONS, i.e. situations with turning motorvehicles involved, and situations with straight-on driving motor-vehicles in low-speed intersections (non-signalized, mean speed < 30 km/h from all accesses)	3,2 (2,2-5,1)[2)]	14,5 (12,2-17,4)[2)]
HIGH-SPEED SITUATIONS, i.e. situations with straight-on driving motor-vehicles in signalized- and highspeed intersections (non signalized with a mean speed ≥ 30 km/h from at least one access)	13,2 (11,2-15,1)[2)]	77,2 (64,8-91,9[2)]

Attention! All values in the table should be multiplied by the factor 10^{-5}

1) The concept "car" includes lorries and buses.

2) Confidence interval with 90 % degree of confidence.

The results obtained in the project shows that the developed conflict-technique offers practical application, mainly within the following areas:

- Description of present state of situations involving risk in urban traffic. This description includes causes likely to arise situations involving risk, suitable countermeasures for increasing traffic safety and their probable effect.

- Pilot and follow-up studies to establish the effect on traffic safety of countermeasures implemented. The conflict-technique offers possibilities to study both the immediate and long-range effect of countermeasures.

The only preparation needed, is a few days training of conflict-observers.

2.3 New calculation of conversion rates

The original technique, as described above, proved to work fairly well in operation but had some weaknesses. Therefore the technique was slighly changed in order to give better accident-risk-predictions.

The most important weaknesses of the original technique were:

1) that the method did not give satisfying results for predicting accident risks in car-car situations, when dividing these into different types of accidents

2) that the predicted risk of accident for two identical conflicts could be different in different types of intersections.

To solve weakness 1) analyses were made that showed that car to car situations should be divided into at least two groups, considering the risk of injury, namely

A) situations where the angle between the directions of the involved cars is under 90°. These situations are symbolized with "Car-Car //".

B) situations where the angle is over or equal to 90°. These situations are symbolized with "Car-Car ⊥".

Conflicts of type A turned out to be approximately four times as frequent as type B per reported accident with injury of the same type.

Weakness 2) that two identical conflicts lead to injury accidents with various probability depending on where they occur have been solved by developing a new model for calculation of risk. The new model is built on the assumption that serious conflicts can lead to personal injuries with different probabilities, depending on their degrees of seriousness. Because of the basic structure of the data a division of conflicts has only been made into two classes of seriousness. A new method of calculation has also been used to determine the connection between police-reported accidents with injuries and serious conflicts.

The following average conversion rates were received between the number of serious conflicts and the number of accidents with injuries.

TABLE 2: NEW CONVERSION FACTORS BETWEEN SERIOUS CONFLICTS AND INJURY ACCIDENTS.

SITUATION / CONFLICT	CAR-CAR //	CAR-CAR ⊥	CAR-PEDESTRIAN CAR-BICYCLE
Class 1 Speed < 35 km/h 1,0 ≤ TTC ≤ 1,5 sec	0	2,4	9,6
Class 2 Other conflicts with TTC ≤ 1,5 sec	2,8	11,9	33,9

Attention! All values in the table should be multiplied by the factor 10^{-5}.

2.4 Present work

The conversion rates between conflicts and injury-accidents

will in the continuing work be determined in two stages:

1. to determine the probability of each conflict leading to an accident
2. to determine the probability of each accident leading to personal injury

It should be possible to describe the probability of a conflict leading to an accident by the degree of seriousness of the conflict, which mainly depends on speeds, time-margines and possibilities of avoiding the accident.

The factors determining the probability of an accident leading to personal injuries are mainly type of road-users involved, speed at collision and angle of collision.

The conclusion of this theoretical discussion is that a threshold-level depending on the actual speed should be used instead of the fixed 1,5 seconds.

A number of smaller studies in rural areas at intersections with varying speed-limits led us to set up the following tentative definition of a serious conflict:

<u>A conflict is serious if</u> the time-margin that remains when the evasive action is started is not more than the braking-time at hard breaking on slightly wet pavement plus half a secound. The half of a second can be regarded as the remaining reaction margin. The relationship is illustrated in the figure

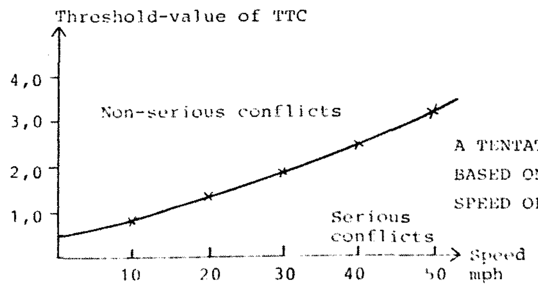

FIGURE 1

A TENTATIVE DEFINITION OF A SERIOUS CONFLICT BASED ON TIME TO COLLISION AND THE ACTUAL SPEED OF ROAD-USERS INVOLVED

During the years 1980 to 1983 a 0,7 million kronor (US $ 130 000) project is carried out sponsored by state funds. This project aims at finding the most relevant definition of a serious conflict. The definition mentioned above is one that is going to be tested. When the optimal definition has been chosen the technique will be validated. To be able to test as many definitions as possible the conflicts are recorded with extended information in comparison to what the final recording-procedure probably will include.

2.5 International cooperation

The international cooperation in this area was started through a meeting of researches from twelve different countries in Oslo, Norway, 1977. State of the art papers from all countries were presented and discussed (6).

A second meeting took place in Paris, France, 1979 (7). This meeting was preceeded by a joint comparative study in Rouen, France. Five countries, Germany, Great Britain, France, Sweden and the USA, participated in the study. The comparisons of the results indicated rather big differences in what was recorded and judged as serious conflicts. However all the teams identified approximately the same safety problems.

One of the outcomes of the Paris-meeting was that an international organisation was established. (International Cooperation of Traffic Conflict Techniques (ICTCT)).

The main purposes with this organisation are to maintain contacts and distribute information among the researches. A Steering group was also formed wich right now is planning a follow-up of the pilot study in Rouen.

3 A GENERAL SPEED-REDUCTION AS AN EFFECTIVE TRAFFIC SAFETY MEASURE

3.1 Introduction

The safety of unprotected road-users has latterly been given increased concern by the politicians. Strong efforts have been made to provide a safe separation between different road-users. The best examples of this, influencing unprotected road-users, are signalization of intersections or mid-block crossings for pedestrians and cyclists and construction of tunnels/bridges for pedestrians and bicyclists.

Signalization of intersections has proved to have a positive effect on the total number of injury accidents. Looking at pedestrian safety, however, the effect of signalization varies considerably from one intersection to another, and the average effect seems to be less positive than for other classes of road-users. Two old studies are found illustrating the effects on accidents of signalization of intersections.

TABLE 3: THE NUMBER OF ACCIDENTS BEFORE AND AFTER SIGNALIZATION OF 21 INTERSECTIONS IN LONDON (2)

Involved	The number of Accidents 2 Years Before	2 Years After	Control Coefficient	Accident Rate
Pedestraians	36	33	1.10	0.83
Bus-pass	9	12	1.02	0.31
Bicyclists	51	29	1.05	0.54**
Motorcyclists	31	20	1.32	0.44*
Others	41	22	1.28	0.42**
Total	168	116	1.16	0.60**

* = Significant difference on the five-percent-level

** = Significant difference on the one-percent-level

Control Coefficient = The ratio between the number of accidents before and after periods in the same district as the observed location

Accident Rate = The ratio between the number of accident after signalization and the adjusted number of accidents before signalization.

TABLE 4: THE NUMBER OF ACCIDENTS BEFORE AND AFTER SIGNALIZATION OF 12 INTERSECTIONS IN STOCKHOLM (3)

Involved Type	The Number of Accidents Before	After	Number of accidents after / Number of accidents before
Car-car right angle	124	15	0.12
Car-car, other	66	81	1.23
Car-pedestrian	7	15	2.14
Total	197	111	0.56

With these studies as a basis, it seems difficult to prove the hypothesis that signalization of intersections has reduced the number of pedestrian accidents. The reason may be found in the following analysis of pedestrian accidents at signalized intersections.

TABLE 5: THE DISTRIBUTION OF PEDESTRIAN ACCIDENTS AT SIGNALIZED INTERSECTIONS ACCORDING TO CAR DRIVER AND PEDESTRIAN BEHAVIOUR.

City	Number of intersections	Number of pedestrian accidents	Percentage of accidents where pedestrians walked against red	Percentage of accidents where driver drove against red	Percentage of accidents where both parties travelled against green
Stockholm	22	54	50	13	37
Malmo	12	41	41	12	47

Thus, most accidents were due to a disregard for the traffic regulations. There is obviously a great discrepancy between behaviour anticipated by planners and actual behaviour.

Pedestrian behaviour at signalised intersections has been studied in a special project at the department (4). This study focused on finding out why pedestrians walk against red light. It can be concluded from this study that it seems difficult to decrease the number of red-walking pedestrians dramatically only by changes of intersection design or signal timing. A great change of attitudes seems to be the only realistic way of reducing the walking against red. There is however no easy and short-term solution to this problem. New measures therefore have to be considered that are based on the actual behaviour of different types of road-users. This includes driving against red as well as walking against red and walking nearby the crossing.

Signalization of mid-block crossings is a relatively new type of regulation in Sweden. Studies of the safety effects through accident-analyses have not yet been carried out. There are, however, a number of behavioural studies carried out that clearly illustrate the problems.

TABLE 6: PEDESTRIAN USE OF MID-BLOCK SIGNALIZED CROSSINGS

City	Pedestrian Crossings: On the marked crosswalk, Against green light #	%	Against red light #	%	Outside the crosswalk but less than 20 meters away from the crosswalk, Against green light #	%	Against red light #	%
Malmo	868	76	179	16	0	0	92	8
Gothenburg	55	24	70	31	15	7	88	38

TABLE 7: CAR-DRIVER BEHAVIOUR AT MID-BLOCK PEDESTRIAN SIGNALIZED CROSSINGS

City	Cars stopping at red light #	%	Cars driving against red light #	%
Malmo	1340	97	43	3
Gothenburg	146	87	21	13

These studies seem to establish the general problem as one of traffic disobedience. Many studies have shown the extreme risks associated with walking or driving against red lights or with walking near but not within a signalized crosswalk. When risk-figures are applied to the shown figures for pedestrian and driver behaviour, the rate of pedestrian accidents hardly drops when mid-block signalization is introduced. Instead, new types of accident problems arise.

Pedestrian and bicycle tunnels or bridges seem to have the same kind of problems that are described before for signalization namely disobediance of the rules. Many different studies have shown that the number of at-grade crossing pedestrians and bicyclists normally is high. Both pedestrians and bicyclists won't accept detours (even small ones) and they for instance don't accept to walk "in the wrong direction" to get to the tunnel or bridge entrance. These problems are clearly demonstrated in a study from the city of Vetlanda in Sweden (5).

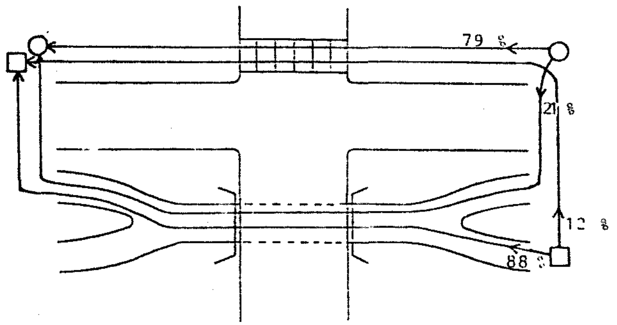

FIGURE 2: THE PEDESTRIAN USAGE-RATE OF A PEDESTRIAN/BICYCLE TUNNEL RELATED TO THE DIRECTION OF MOVEMENT.

As can be seen a detour of 30 meters is not accepted by 79 % of the pedestrians. When there is no detour 88 % accepts to use the tunnel.

3.2 Conclusions regarding the present safety situation

It can be concluded that the present organisation of urban traffic creates a lot of unsafe situations. A real separation in time or space of different road-users seems to be impossible to achieve, at least in built up areas not originally planned for separation.

The different countermeasures mentioned before primarily aims at solving the problems at one point. As was demonstrated not even this goal is achieved. Besides new types of risks are introduced, risks that often are much higher than those present before the implementation of the new countermeasures.

A final conclusion must be that new types of countermeasures has to be tested, countermeasures that may have a more general effect on all kinds of accident risks over the whole street network.

One such countermeasure of great interest is a general speed reduction. In the following arguments are given to support this statement. There are also the results of two empirical studies of the effects of speed reductions.

3.3 Vehicle speeds from safety point of view

Vehicle speeds play an important role in most accidents. Even if the speed not always is a primary cause a lower speed would have influenced the outcome of the vast majority of the situations. A lower speed has a positive influence on many factors. The most important ones are:

- The time offered for each part in the process of information collection. Lower speeds mean more time for information collection and the probability of a succesfull detection and a relevant action increases.

- The possibility of communication with other road users Normal travelling speeds on arterials today are 50-60 km/h. These speeds are too high and they don't make communication possible. The car driver simply isn't prepared for conflicts for instance with intersecting pedestrians or bicyclists. If a pedestrian mis-judges the speed of an approaching car and starts crossing, the car driver therefore is not prepared to avoid an accident.

- The probability of an accident if a car driver gets involved in a conflict. The most common accident-avoiding manoeuvre is braking. The braking distance is proportional to the square of the speed. A lower speed therefore means a great increase in the probability of a succesful avoiding-action.

- The severeness of an accident involving a motor-vehicle The relation between accident-severeness and vehicle-speeds is well established.

The additive effect on safety of all the factors mentioned above means that even fairly small reductions of the average vehicle speeds might increase safety considerably.

Except for reducing the average speeds there is from the safety point of view an interest in decreasing the speed variation. One extreme, but very good example on this is the speed variation at signals when approaching vehicle-drivers face the change between green and red signal.

In Sweden most vehicle-drivers seem to have a definitive wish not to stop. Most of them even increase their speed to reach the goal. Some drivers however make the opposite, they slow down and stop for amber. This variation in behaviour creates

very many rear-end accidents at signals today.

3.4 The relation between vehicle speeds and delays

High vehicle speeds on parts of the urban street network not necessarily mean that road-user delays are minimized. For instance the accepted time-gap of intersecting road-users is related to the speeds of the vehicles travelling along the street that has to be passed. If speeds are reduced the average waiting time for intersecting road-users decrease. This reduction of the average waiting times may be quite large even at fairly small speed-reductions.

Intersections on arterial streets are quite often provided with traffic signals. Signals however creates an increased delay for a great part of the road-users compared to non-signal situation. One reason for this is that signals have to be provided with a so called "safety time" between each change of phases. During this "safety time" no road-user is supposed to use the intersection.

3.5 Other aspects on vehicle-speeds

A general reduction of vehicle speeds may have various effects on fuel consumption. If speeds however become more homogenized the number of accelerations and decelerations (including full-stops) will decrease and the fuel consumption most probably also will decrease. In spite of a reduction of vehicle speed below the optimal one the fuel consumption might be reduced if the average waiting time and number of stops are decreased. It's not yet clear in what types of intersections, and under what circumstanses, this will occur.

4 RESEARCH ON THE EFFECTS OF SPEED REDUCTIONS

4.1 Introduction

It can be concluded from last chapter that speed-reduction is a very interesting general safety-measure. This might be true for a big part of the urban street-network ranging from local residential streets to arterials carrying heavy traffic-volumes.

A general speed-reduction has the potential of solving the safety problems much more generally than the countermeasures used so far. Thus a reduced speed may lower the accident-risks for <u>all</u> kinds of road-users in <u>all</u> environments under <u>all</u> conditions.

The discussions in the last chapter also indicated that speed-reductions may be beneficial to delays for all kinds of road-users and for fuel consumption.

The main questions are how great the safety-benefits might be at various speed-reductions and what other effects will be the result of the different reductions of speeds.

Earlier research activities have made it quite clear that the only possible way of achieving an effective speed reduction on a short-time basis is to implement physical countermeasures that force the driver to slow down. The most common ones are humps, extreme narrowing of streets and boxes organised so that vehicle drivers are forced to winding manoeuvres. The countermeasures are also used in combination.

During the last years a number of different speed-reducing countermeasures have been developed and tested at the department. Countermeasures are developed for different types of roads and for various speed-reductions. Special humps are also developed that enables buses to pass with a maintained high degree of comfort.

The research activity in this area is very high at the department right now. Experiments are carried out on various types of roads, areas etctetera. All possible aspects of a speed reduction are tobe studied.

In the next section of this paper two studies of the effects of speed-reductions will be presented.

4.2 The effects of a speed-reduction in an ordinary four-way street intersection

In the city of Malmö (250 000 inhabitants) the first experiment with speed-reduction at an intersection was carried out. The intersection is located semicentrally in the city. The intersection is totally uncontrolled; that is, the right-hand priority rule is valid. Each of the two intersecting streets carries around 4.000 vehicles a day. Pedestrian and bicycle volumes are great. Speed reduction was achieved by road humps which were found to be effective in reducing speeds in other studies. The humps were located as illustrated in the figure

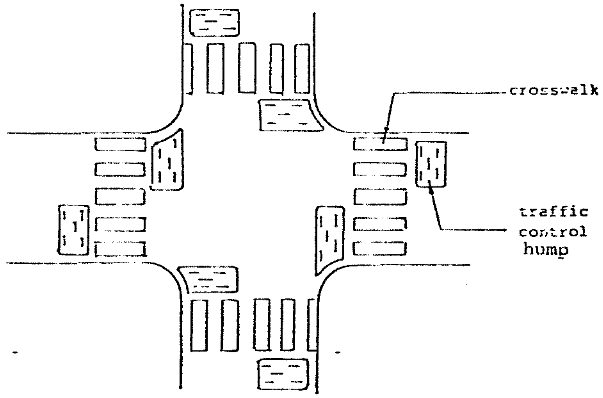

FIGURE 3: INTERSECTION WITH ROAD HUMPS IN MALMÖ

The humps are of the type recommended by the National Road Safety Department in Sweden, and were originally introduced and tested by Watts at TRRL in the United Kingdom.

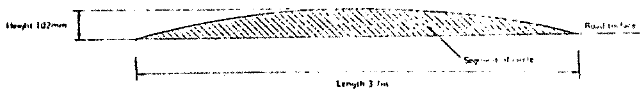

FIGURE 4: RECOMMENDED HUMP DESIGN

Before and after-studies were carried out as follows:

Oct/Nov -78	May -79	Oct/Nov -79	Sept/Nov -80
Before-study	Humps installed	After-study I	After-study II

SAFETY

The Traffic Conflicts Technique was used to enable a quick evaluation of safety effects and to enable more than one check after the installation of the humps. Observations were carried out five weekdays in each study, five hours a day.

TABLE 8: THE NUMBER OF SERIOUS CONFLICTS BEFORE AND AFTER THE INSTALLATION OF THE HUMPS

	Car-car		Car-bicycle		Car pedestrian		Total	
	#	%	#	%	#	%	#	%
Before	40	100	36	100	33	100	109	100
After I	18	45	9	25	5	15	32	29
After II	16	40	(29)*	---	10	30	(55)*	---

* Since the initial survey the number of bicyclists has increased by 60 percent.

In Table 8 the marked percent reduction in the number of serious conflicts for all types of road users is significant (at least on the one percent level) between the before and after studies.

The safety effect of the speed-reducing humps is strengthened by the fact that cars involved in conflicts travel at lower speeds.

Speeds

Speeds for approximately 6 000 vehicles were measured during two week-days.

TABLE 9: MEAN SPEEDS AND REDUCTIONS OF SPEEDS CAUSED BY HUMPS

	Private cars		Heavy vehicles	
	Mean (km/h)	Percent	Mean (km/h)	Percent
Before	20.6	100	20.0	100
After I	15.1	73	14.3	72
After II	15.8	77	14.9	75

TABLE 10: 85-PERCENTILE-SPEEDS AND REDUCTIONS OF SPEEDS CAUSED BY HUMPS

	Private cars		Heavy vehicles	
	85%-ile (km/h)	Percent	85-%ile (km/h)	Percent
Before	31	100	29	100
After I	21	68	19	66
After II	21	68	21	72

The proportion of the total number of vehicles driving faster than 30 kilometers per hour were 13.8 % in the before study, 1.7 % in the first after study and 1.3 % in the second one.

It can be concluded from the study that:

- Speed was reduced most in traffic flows that were the fastest before the installation of the humps.
- The results of the two "after" studies are essentially the same.
- The speed of all vehicles is low after installation of

the speed-reducing humps and the range of vehicle speed within flows is small. Thus, speeds are homogenized and more compatible to that of bicyclists and pedestrians.

Vehicle volumes

Vehicle volumes are unchanged.

Vehicle delays

The calculations of actual delay caused by the humps are derived from the speed measurements. Delay is also theoretically calculated for a signalization of the intersection:

- Actual vehicle delay caused by speed reduction due to humps: 2.8 seconds.
- Theoretical vehicle delay caused by a signalization of the intersection: 6.7 seconds.

Attitudes

Many different studies were carried out. Interviews and enquetes including different classes of road-users as well as people living close to the intersection were made.

Generally people were very much in favour of the hump installation. For instance 84% of the car drivers ment that the humps should be kept in this intersection and 77% of them agreed with the statement that humps should be installed in "many more similar intersections".

Most road-users, except for drivers of emergency vehicles, had no bad experiences of passing the intersection and most of them had the opinion that safety was increased.

Costs

The hump installation costs were 25 000 SEK (appr. 4 500 US$). This may be compared to the implementation costs of a traffic signal that would have been 300 000 SEK (55 000 US$) at this intersection. Maintenance costs are roughly 3 000 SEK (550 US$)

per year for the humps and 20-30 000 SEK (3 600-5 500 US$) for the traffic signals.

4.3 The effects of area-wide speed reductions

In the last decade a number of area-wide traffic regulations have been introduced in Sweden. The basic idea is that through-traffic, should not be able to pass through an area on local roads but have to use the surrounding arterial roads instead. These regulations are implemented through the introduction of one-way streets, cul-de-sacs, special streets for buses only, etcetera.

The safety effects of such regulations have proved to be fairly beneficial especially within the areas. (Excluding the surrounding roads). There are however some obvious disadvantages:

- The surrounding roads are often carrying large traffic volumes even before the regulations. After the regulations they have to carry more vehicles, thus worsening the great problems according to safety, air and noise pollution on these roads.

- The surveyability of the area is reduced.

- A large portion of the vehicletrips in the area will include a detour, which means longer travel-times, larger fuel consumption etcetera.

- Less traffic within the area often means higher vehicle speeds which might increase accident-risks related to the number of vehicle-kilometers travelled.

To meet with these problems a general speed-reduction has come up as an interesting alternative to road-closures, one-way streets etcetera.

One of the first experiments has been carried out in the part of Stockholm called Vasastan. In cooperation with the local authorities the department has carried out a short-term evaluation of the effects. A draft report has been produced by the local authorities of Stockholm (8).
The countermeasures introduced can be seen in the figure below.

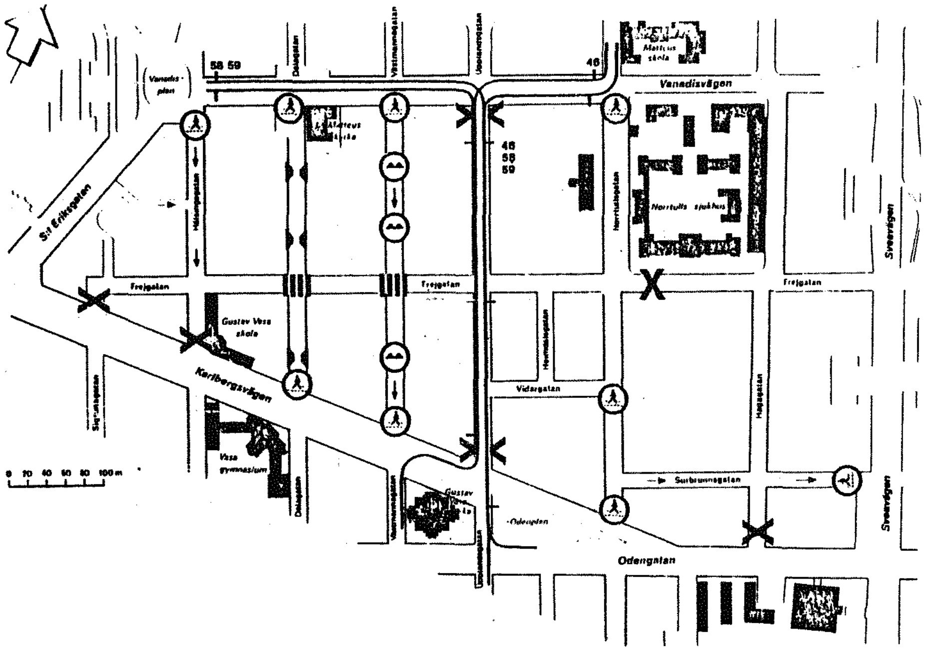

FIGURE 5: TRAFFIC REGULATIONS IMPLEMENTED.

Road closed for all motor-vehicle
The road closed for all motorvehicles except for buses and taxis
The level of the zebra crossing is increased to the level of the sidewalk
Humps (same type as in the Malmö-experiment)
Street narrowed to 3.0 metres
The level of the pavement in the intersection is raised to the level of the sidewalk
Regular bus-routes

In addition to the speed-reducing measures some street-closures were considered necessary. The regulations were implemented in October/November 1980. At the same time a general speed limit of 30 km/h was introduced in the whole area. Due to big house-construction activities in the east part of the area almost no measures were implemented in that part.

Down below a summary of the findings are presented.

Traffic volumes

In the figure on next page traffic counts before and after the introduction of the regulations are presented.

The total vehicle volumes doesn't seem to have been influenced. There is however a big variation in the route choice before and after. Traffic has been moved to the surrounding streets. This is mainly due to the street-closures that were carried out. It is obvious however that even the speed-reducing measures may have an influence on the route choice. On Västmannagatan for example, where speed-humps are installed and no street-closure have had any important influence, the vehicular traffic has dropped by approximately 35 %.

Traffic safety

The accidents one year before and one year after has been analysed. In the western part, where the speed-reducing measures were introduced, the total number of accidents within the area has dropped from 20 to 3 and the injury accidents from 5 to 0. On the surrounding streets the total number of accidents has increased from 35 to 39 and the injury accidents from 16 to 17.

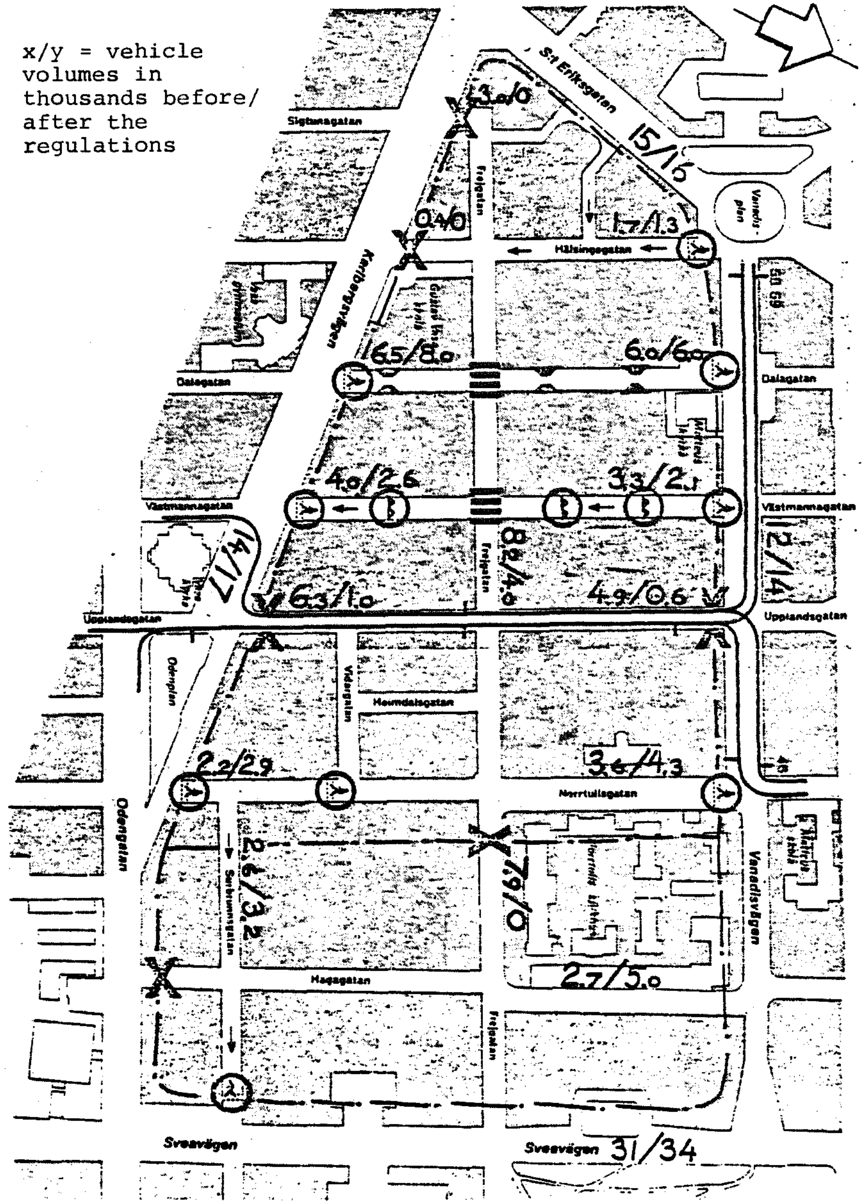

FIGURE 6: VEHICLE VOLUMES BEFORE AND AFTER REGULATIONS

Even though the accident figures are fairly small there is a very significant drop in the number of accidents within the area. The accident rate (accidents per vehicle-kilometres) has decreased by 75 % in the area.

The department has carried out conflict-studies in the two intersections where the level of the pavement is raised to the level of the sidewalks. The results of these studies are very similar to the results mentioned before from the study of humps at the intersection in Malmö. The results indicates that accident-risks have decreased by 70 %.

Vehicle speeds

A great number of speed measurements have been carried out before and after the implementation of the measures. Figure 7 gives an oveview of the 85-percentile speeds.

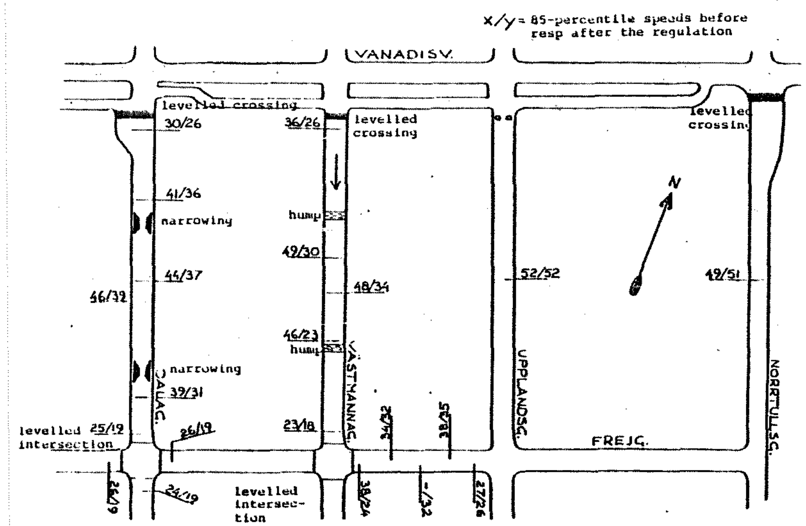

FIGURE 7: VEHICLE SPEEDS.

The speeds on streets where only a 30 km/h speed-limit was introduced are not changed. On streets furnished with different physical measures however, speeds are reduced considerably. Speed-humps seem to be the most effective measure tested. At the passing of one of the humps on Västmannagatan the 85-percentile speed is reduced by 23 km/h. Half-way between two humps, 60 metres apart, the 85-percentile speed has decreased by 14 km/h.

At the two intersections where the pavement level is raised the 85-percentile speeds of approaching vehicles in all directions is 18-19 km/h, a decrease by 5-7 km/h.

Generally it can be stated that the speed-reducing measures, especially the humps, have proven to be very effective in reducing speeds even on longer distances, presupposed the distance between two consecutive measures do not exceed 50-100 metres.

Attitudes

A questionnaire was distributed to people living in the area. On the question "Are the regulations good or bad if all consequensies are considered?" the following answers were obtained:

Good	47 %
Neither good nor bad	18 %
Bad	26 %
Don't know	9 %

The question "What should be done by the local authorities according to the speed-reducing measures introduced?" was answered as follows:

Extend the number of speed-reducing measures	34 %
Just keep the present measures	25 %
Reduce the number of speed-reducing measures	10 %
Get rid of all the speed-reducing measures	14 %
Don't know	17 %

4.4 Implications of Speed Reduction on Urban Transportation

Some important hyphoteses can be offered based on the experience collected so far:

- o The main hypotheses is that an actual speed reduction of 10-15 kilometers per hour in urban areas will reduce the number of injury accidents to less than half.
- o For cars on arterials, travel time will increase, but in most cases by less than 2-3 minutes for a single trip (for distances not exceeding 10 kilometers).
- o Waiting time for all road users crossing arterials will be heavily reduced.
- o Capacity will increase when speeds are reduced to 35-40 kilometers per hour. This means that the need for signalization of intersections from a capacity point of view decreases. (The main hypothesis implies that there is no need of signalization from a safety point of view).
- o Lower and more even speeds will lead to a more comfortable way of driving with fewer accidents and operational difficulties.
- o Speed reduction may be of great interest according to fuel consumption as an alternative to signalization of intersections.
- o Speed reduction might be an interesting alternative to areawide regulations based on streetclosures, one-way streets etc.

These and other hypotheses are going to be further tested in a number of ongoing projects at the department. The effects of actually implemented speed-reducing measures will be evaluated through before and after studies. Special studies are also going to be carried out to evaluate the long-term effect.

PAPER PRESENTED AT THE OECD SEMINAR ON SHORT-TERM AND AREA-WIDE EVALUATION OF SAFETY MEASURES IN AMSTERDAM, NERHERLANDS
APRIL 19. - 21. 1982

Risto Kulmala, Technical Research Centre of Finland

TRAFFIC CONFLICT STUDIES IN FINLAND

1. THE EVALUATION OF TRAFFIC SAFETY WITH THE TRAFFIC CONFLICT METHOD

Accidents vs. conflicts

Usually traffic safety has been measured either by the number or the risk of traffic accidents. In many cases this evaluation based on traffic accidents has not been sufficient.

Traffic accidents are very rare and random events. Because of this reliable conclusions about the effects of different safety measures and devices can be drawn only after a sufficiently large material has been gathered. This usually means a wait of 3 to 10 years after the implementation of the studied measure if the measure was applied on just a few locations. In addition, many, if not most, accidents are not even reported to accident statistics. This causes systematic errors and bias in the statistics, which can result in false conclusions about the effects of the studied devices.

Because of the rareness and randomness of accidents researchers should study traffic situations, which are a) sufficiently close to accidents to describe traffic safety in a valid way and b) statistically frequent enough events. This is portrayed in Fig 1.

The most suitable traffic situation for research purposes can be found at the maximum of the product between severity and frequency p x n. Conflict situations are presumably very close to such optimal situations. It is often reasonable to classify conflict situations according to their seriousness (see Fig. 2).

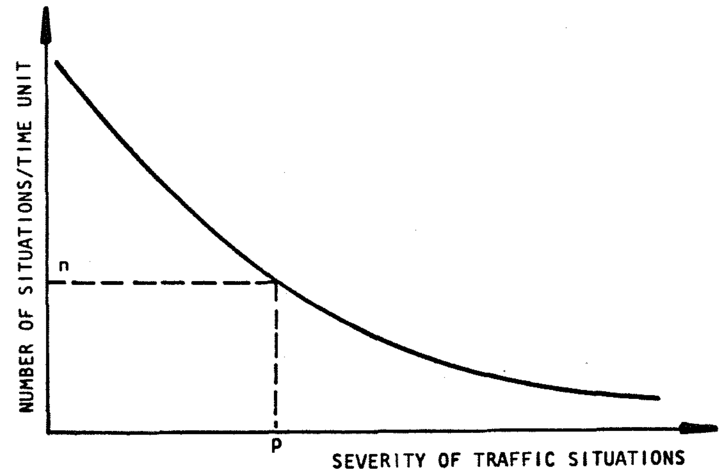

Fig. 1. The frequency of traffic situations in regard to their severity.

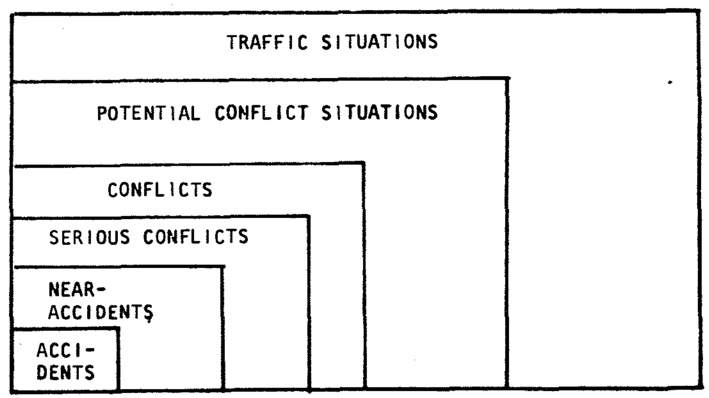

Fig. 2. Traffic situation classification.

Conflict risks

Conflict and accidents are, as seen before, closely related. This is why it can be assumed that the probability for a conflict to result in an accident is approximately constant in regard to road and traffic conditions. In such case traffic safety can be measured with conflict risks instead of accident risks. This can be written:

$$R = \frac{A}{E} = \frac{A}{C} \times \frac{C}{E} \quad ,$$

where A is the number of accidents in time T,
E is exposure to accidents (or conflicts) of the studied type in time T and
C is the number of conflicts in time T.

When the accident risk of conflicts $(\frac{A}{C})$ is constant, accident risk is proportional to the conflict risk $(\frac{C}{E})$. The use of conflict risks $(\frac{C}{E})$ as quantities describing traffic safety is very practical as these risks can be estimated directly by observing traffic on location or by simulation.

2. STUDIES BASED ON CONFLICT OBSERVATIONS

Observations on location

Conflicts (serious and mild) and potential conflict situations are registered by type at the field studies made by the Technical Research Centre of Finland. In addition, traffic flows are registered to determine conflict exposure.

Situations, where braking or weaving begins 1,5 sec or less before a potential collision, are defined to be conflicts. The definition is based on the experiences gained in Sweden /1/. If braking or weaving is uncontrolled the conflict is defined serious. Potential conflict situations are situations, where the participants adjust

their speeds well enough before the potential collision. All participants don't, however, behave in a way required and the situation nearly ends up in a conflict. Traffic violations are also classified as potential conflicts.

At the field studies the observers take such positions, where they can observe traffic at the studied location without disturbing drivers and pedestrians. Video equipment is usually situated on a roof, bridge of a balcony nearby. In this way people moving on the road very seldom notice the video camera and the camera view isn't obstructed. Sometimes the camera has to be installed on a roof of a van. Traffic radar has also been used at some field studies.

The reliability of the observers is quite good. Only about 15 % of all observations are in error /3/. Still, all observations are checked at laboratory from the video tape afterwards.

Applications

The conflict method is especially suitable when the effects of safety devices and measures are to be investigated quickly. Conflict studies must only be made before the implementation of the device and a couple of months after it. The effects of the device can then be estimated as the observed changes in conflict risks. These changes can be tested i.e. by X^2-test /3/. In all, a conflict study may last 6 to 8 months from planning to reporting. Same amount of data could well require 5 years just waiting for sufficiently large accident material.

The method has also been used in studying "black spots" and junctions. In addition to conflict risks and frequencies the Technical Research Centre of Finland usually reports the results with the help of conflict charts, such as in Fig 3.

Next some applications are presented, where the conflict method was used in evaluating the effects of road safety measures and devices.

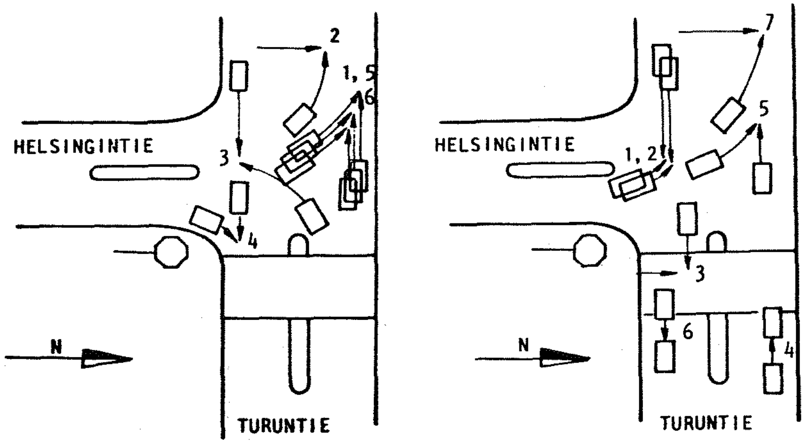

Fig. 3. Conflict chart.

The effects of pedestrian refuges was studied in Helsinki /3/. Pedestrian conflict and potential conflict situation risks before and after the building of refuges are presented in Fig. 4. The exposure E was for all studied pedestrian crossings the square root of the product between pedestrian and vehicle flows.

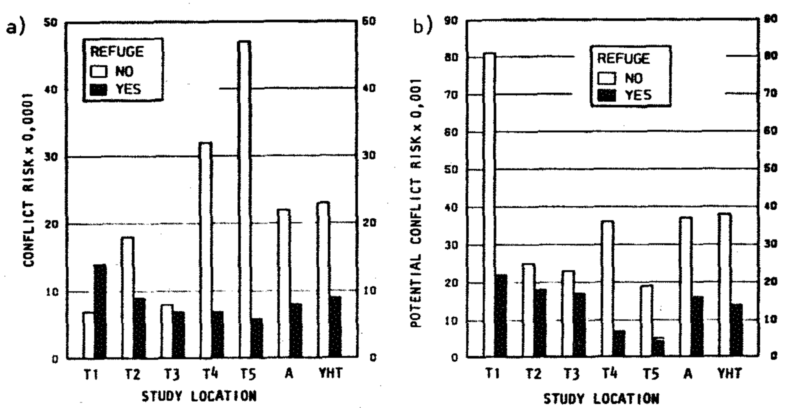

Fig. 4. Pedestrian conflict risks (a) and potential conflict situation risks (b) at different pedestrian crossings (T1-T5,A), and in total (YHT) before and after the building of pedestrian refuges.

The risks for conflicts and potential conflict situations between pedestrians and vehicles were about 60 % lower at the after-studies than at the before-studies on an average. The decrease was statistically significant.

Another study dealt with the effects of different pedestrian crossing arrangements on pedestrian safety /4/. Research material consisted of police reported traffic accidents from 6 years at 16 crossings and 6 hours' conflict observations at 13 of the 16 crossings. Some results are presented in table 1.

Table 1. The risk differences (%) between pedestrian crossing groups that differ from each other in only one crossing arrangement (refuge/junction/signal control).

Differing arrangement	Compared crossing groups	Risk difference between crossing groups (%)			
		All accidents	Non-alcohol accidents	Conflicts	Potential conflicts
Refuge (R)	- R JS - RJS	-30 (-) +111 (-)	+7 (-) +180 (-)	-9 (-) +332 (-)	-77 (xxx) +532 (xxx)
Junction (J)	RS - RJS	+6 (-)	-7 (-)	-28 (-)	-2 (-)
Signal control (S)	R - RS RJ - RJS	-57 (xx) -30 (-)	-53 (-) -22 (-)	+20 (-) -49 (-)	-66 (xxx) -75 (xxx)

The significance of the risk difference:

(-) when the difference is not significant,
(x) when the difference is significant at the 0,05 significance level
(xx) when the difference is significant at the 0,01 significance level
(xxx) when the difference is significant at the 0,001 significance level.

The method has also been applied to highways outside built-up areas. On study dealt with the effects of acceleration lanes on traffic flows at grade-separated intersections on a four-lane divided highway /2/. The study material was obtained at four intersections so that the total observation time was 22 hours. The exposure measure was the square root of the product between vehicle flows entering from the ramp and driving on the right-side lane. Only 4 conflicts were observed during the after-studies, when the number of conflicts during the before-studies was 14. The conflict and potential conflict risks were significantly lower after the building of acceleration lanes than before. The decrease took place at the three busiest intersections and mainly when the pavement was slippery.

In another study the effects of the replacement of crawling lanes by overtaking lanes were investigated /5/. The exposure used was the vehicle flow in the studied direction. The results are presented in Fig 5.

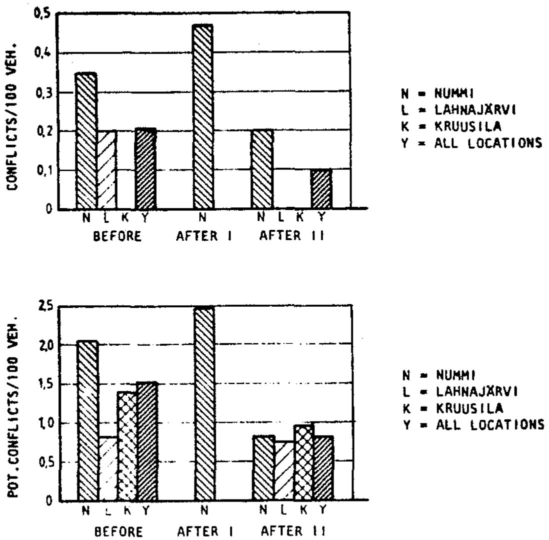

Fig. 5. The risks of conflicts and potential conflict situations before and after the lane change at different study locations.

The risks were lower three months after the change (After II-phase) but not significantly due to too short observation period (12 hours

during before and after phases). As an experiment observations were made at one location, Nummi, just two weeks after the change (After I-phase). The risks were at these studies significantly higher than three months after the change. This was probably due to drivers' unfamiliarity with the new regulation or insufficient information in mass media.

A major conflict study is going on concerning the effects of the total change in Finnish traffic legistlation. The safety effects of different pedestrian-bicycle-way characteristics and arrangements is also under study.

3. CONFLICT SIMULATION

The development of a model for simulating traffic conflicts began at the Technical Research Centre of Finland in 1973. The model was first completed in 1974, but it has been improved continuously.

The input information needed by the model consists of the geometry of the road environment i.e. a map of a junction, the amount of traffic (the number of pedestrians or vehicles in different flows), the speed distribution of different vehicle flows and the phasing scheme of the possible signal control.

The model generates vehicle into the system according to the input information. The moving of the vehicles is based on six different movement rules. Another factor affecting vehicle movements is the behaviour of the driver, which is described in mathematical functions derived in behavioural studies abroad. Because most conflicts are due to some shortage in the ability of the driver to observe everything going on in the traffic system a number of random variables has been used to describe the observation ability. The occurrence on a conflict and also the severity of the conflict are judged by braking decelerations.

The output of the model consists of the number of conflicts in the time given classified by the severity and the type of the conflict in different parts of the road environment studied. The model also gives the types of the vehicles in conflict situations and the platoon length maximums in the in-coming lanes of the junctions and some variables describing the fuel consumption in the road network studied. In addition, the function of the model can be visualisec on a graphic terminal.

The validation of the model after the recent improvements and changes is to be carried out in 1982. Even before these improvements the simulated conflicts correlated highly significantly with the observed accidents and conflicts at the locations tested.

The simulation model can be used both for one junction and also for a part of network. The only practical restriction in the road network size is the capacity of the used computer.

The model is especially useful in evaluating the effects of safety improvement measures and devices already in the planning stage, even for completely new road projects.

4. CONCLUSIONS

The advantages of the traffic conflict method can be summed up as follows:

- effects of safety measures can be evaluated quickly,
- good reliability especially when used with video,
- visual demonstrations of the observed conflicts and potential conflict situations on video tape (or charts) can easily be made and are also interesting and useful for traffic planners and decision makers,
- conflict simulation enables effect evaluation of safety measures even in the planning phase,
- measurements on location give also lots of information about traffic conditions in addition to safety aspects.

The disadvantages are as follows:

- conflict observers must be effectively trained in order to gain sufficient reliability,
- studies with video tend to have larger costs than conventional statistical studies, but the amount of additional information and the savings in accident costs due to shorter research periods compensate well for this disadvantage,
- the connection between conflicts and accidents is not known for all accident types or road environments,
- the connection and the ratio between conflicts and accident varies for different accident types and the reasons behind this variation are not yet known,
- the validity of the conflict simulation model isn't sufficiently thoroughly tested.

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SAFETY EVALUATION OF FLASHING OPERATION AT SIGNALIZED INTERSECTIONS

D. Mahalel * A. Peled ** M. Livneh ***

ABSTRACT

This article focuses on the safety evaluation of stopping traffic signal operations at off-peak traffic hours and substituting a flashing amber for all directions. This control strategy is motivated by the need for energy conservation considerations through reduced amounts of acceleration and idling time of vehicles. Although this policy is intended for those hours when signals are not warranted by the low traffic volumes, there still exists the need to investigate the safety implications of this kind of operation.

In the present study, a conflict was defined as "an event in which a road user was forced to change his path of direction in space and/or in time following the existence of another road user in his vicinity." This broad definition has freed the observer from the need to detect only emergency evasive manoeuvres, and therefore decreased the range of subjective interpretation of the observer. As a result, the reliability and consistency of the data has increased.

The observations were carried out by trained observers at a sample of intersections using two control strategies : full signal operation and flashing amber phase. The observers were stationed at each leg of the intersection using pre-prepared forms, and noted the travel direction of the two vehicles involved in the conflict. The results showed that the most frequent type of conflict under full signal operation were of the rear end type, while during the flashing amber operation crossing and merging manoeuvres were dominant.

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1. INTRODUCTION

Following world-wide increases in the price of energy, there is a need to re-evaluate the justifications and implications behind various control strategies for intersections and road sections. The motivation is to identify those situations in which the level of control can be changed, and as a result, to decrease the number of accelerations and waiting times while idling. Among the operational alternatives available for this purpose are the following : preference of the "give way" sign over the "stop" sign; installation of vehicle actuated traffic signals; a green wave; and computer coordinated signal network. In addition, there are various strategies of systems management adapted to this purpose which include priority for public transport, parking restrictions in city centres, etc.

Within the framework of the current research, the latent energy saving resulting from the stoppage of normal signal operation at off-peak traffic hours is examined. The traffic signal is operated only at a flashing yellow phase for all directions of traffic. Priority is determined according to the traffic signs permanently situated at signalized intersections. The function of these traffic signs are only for those times when the traffic signal is in flashing operation or when the traffic signal is not in operation at all. When the traffic signal is in full operation, drivers are supposed to ignore these traffic signs. A similar approach for traffic signs at signalized intersections also exists in Germany.

Following the change of traffic signals to a flashing operation, we can expect a decreased amount of stops and waits while idling because of the following reasons :

1) There are isolated traffic signals in residential areas or on certain roadways whose operation is only needed at peak traffic hours in the mornings and afternoons. At other hours, these traffic signals are not needed as the traffic volume does not justify their existence.

2) There exist traffic signals which were installed according to planning guidelines. Traffic arrangements existing in the vicinity following their installation created a new reality regarding traffic volumes which no longer justified the existence of these traffic signals. For various reasons (some political), traffic signals are usually not removed once they have been installed.

The specific aim of this research was to determine the range of traffic volumes whereby there would be no significant safety implications for stopping traffic signal operations. This evaluation requires the locating of existing operational problems at the intersection for each range of traffic volume, an analysis of these problems and giving the correct emphasis for the expected safety damage these problems are liable to present.

In the following section, we will describe the methodological problems liable to arise during the safety evaluation of intersections. Section 3 will describe the method of work employed in this research, while Section 4 will analyse the results obtained and will compare these results to road accident data.

The operative conclusion resulting from the use of the conflict technique in the present study was that this technique is very useful for locating operational problems of a safety nature present at intersections. In addition, there is a similarity between the problems defined by conflicts to types of road accidents at intersections with similar control operations.

2. SAFETY EVALUATION OF INTERSECTIONS

In a project evaluating safety levels of intersections, two research methodologies can be used :

1. Retrospective Research - research based on data collection between two periods in the past. This type of research is possible when the effectiveness of control stategies or engineering installations in existence for a number of years is examined. In these instances, data can be collected on accidents occurring in the same places, and either a "before and after" analysis or a comparison to a control group can be made.

2. Prospective Research - research based on data collection between two periods in the future. This methodology is used when evaluating installations existing for only a short period of time or when will be installed in the future and no accident history data exists for them. Data which can be collected for carrying out a prospective research are :

   a) accident data

   b) conflict data

The disadvantage in a prospective research based on accident data is primarily in the length of time needed to carry out the research (a few years). The limitations set by minimal sample size need a data base from existing improvements from relatively large number of intersections. If we take into account that the safety improvement is liable to be found deficient or even dangerous, it is easy to describe the financial loss and the risk involved in this type of research. In order to decrease these risks, it is advisable to collect most of the data before deciding on commencing the improvement. That is to say, only in projects where there exists a firm evaluation that a certain improvement will be effective, is it then worthwhile carrying out this improvement for a significant number of intersections (greater than 10), and to examine the accidents which will take place at these locations.

Figure 1 presents the process involved in the prospective research for evaluating the safety level of engineering improvements. The emphasis in this presentation is that the conflicts technique

is not a methodology to take the place of using accident data, but as an intermediate stage in the evaluation process. This intermediate stage would precede the decision to experiment on a large scale and over a lengthy period of time. This approach does not exactly adapt to the research approach at the beginning of the 1970's where the conflicts technique was thought to replace research based on accident data (Perkins and Harris 1968, Campbell and King 1970, Baker 1972, Hyden 1977).

The consensus was that because of all the problems involved in accident data collection - lack of complete reporting, the need to use lengthy time periods and the lack of detail of definitions in the reporting - all these contributed to the need of searching for a different research tool. The answer to these problems was seen in the conflicts technique, and were partially realized because of the lack in obtaining high correlative factors between accidents and conflicts. In addition, there is the doubt that in part of those researches where there is a high correlation factor between accidents and conflicts, if this is not caused by the existing relationship between accidents and exposure.

The definitions of conflicts as existing in the literature are partially affected by the current approach that a conflict is an event preceding an accident. Therefore, conflicts should be defined as all those situations similar to accident situations. McFarland and Mosely (1954) were among the first to define conflicts as "emergency situations or critical incidents which could easily have led to an accident."

Perkins and Harris (1968) who gave an impetus to the subject at the end of the 1960's, defined conflicts as events similar to those events preceding an accident. They defined a conflict as an evasive action of at least one of two vehicles close by in time and space. An evasive action is defined either as a braking or lane changing manoeuvre. A similar definition was adopted in a comprehensive work by Glauz (1980) which examined the operational levels of a number of methodologies. Spicer took a more radical approach to defining conflicts and graded the different braking levels; at first into two levels, Spicer (1971) and later on to five levels, Spicer (1973). He found that the best correlation exists between severe conflicts to accidents with casualties.

On the other side of the spectrum, there are several works where the behaviour of all vehicles at an intersection was measured in a methodological and objective manner and include Allen et al. (1978), Jorgensen (1977), Hakkert et al. (1977). Allen defined such indicators as gap time, encroachment time, post encroachment time, while Hakkert et al. defined the sum of acceleration and changes of direction. Jorgensen defined such indicators as accepted gap $<$ 4 sec. speed $>$ 80 km/h. and braking ($g > o$). These indicators were measured for all vehicles and not only for that of a sub-group such as in research based on observed behaviour. The major disadvantage of these methods is the need for sophisticated equipment and the length of time needed for data analysis. In these last studies, there is a trend to view conflicts not as accident surrogates but as logical indicators of safety or operational problems.

It appears that the different versions in defining conflicts is especially important for finding a high correlation between conflicts and accidents. However, if our aim is to locate safety operation problems, it appears that the conflicts technique is robust for this definition. For a good example of this, Malaterre and Muhlrad (1975) described a comparative research where conflicts were counted at two intersections through the use of 4 different groups based on various methods. Despite the differences in counts received, the safety analysis of intersection problems was similar for all the groups.

3. RESEARCH METHOD

As stated previously, the aim of the research was to examine the safety implications involved in strategic control operation of flashing signals at off-peak traffic hours. This strategy is accepted practice at most signalized intersections during night-time hours (from midnight till 5 a.m.). According to the Traffic Regulations, an intersection can be in flashing operation if hourly traffic volumes for a continuous four hour period does not exceed 400 vehicles per hour. The application of this regulation during daylight hours is very limited. In addition, there are also disruptions in the normal operation of traffic signals due to some malfunction in the system. In these instances, a flashing signal is put into operation for all directions of traffic.

The experience obtained from programs of night-time flashing operations and from signal operations due to malfunctions during daylight hours could not serve as the single factor in the decision making process. The reason for this limitation is the lack of knowledge for traffic volumes and time factors where the traffic signal was in a flashing operation program.

In order to locate the range of traffic volumes where disruption of traffic signal operations does not create any significant safety problems, it was decided to base the research on a conflicts study. The purpose was to conduct a conflict study for two operational situations - a regular program and a flashing program. A comparison of these two operational situations absolves the need to predict the number of accidents based on knowledge of the conflicts.

To define a conflict, the definition chosen by Discussion Group C of the First Workshop on Traffic Conflicts, Oslo (1977) was used : "A traffic conflict is an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remain unchanged."

Various interpretations of the above definition can cause differences in the operational definition of conflicts. The major differences will be in the level of subjective judgment on the part of the observers. For example, Glauz (1980) states

the need for a clear evasive action so that the driver must react either by a braking or swerving manoeuvre.

In the present study, the interpretation was broadened so that a conflict was defined as an event in which a road user was forced to change his direction of travel and/or his speed because of the existence of another road user. With regard to the terminology "speed change," this does not only imply a braking manoeuvre but also an acceleration manoeuvre as well.

This broadened definition of conflicts and the resulting work rules increases the range of the sample and decreases the sampling errors of estimates. In this way, the two operational situations can be compared on the basis of more reliable data and not on the basis of relatively rare events happening at a low probability.

This approach presents a synthesis between those approaches requiring high levels of subjective decisions on the part of the observer, such as Spicer (1973), Perkins and Harris (1968), or Hyden (1977) to those methods based on specific parameter measurements in a methodological way for all vehicles such as Allen et al. (1978).

In the framework of this study, data was collected for four urban intersections. At each intersection, data was collected for 4 days - 2 days with the flashing operation and 2 days for the normal operation. The observers underwent a training period of 5 hours prior to beginning the measurements. Different conflict types were pointed out to the observers; a collective measurement was taken at one of the intersections and an analysis was made by the group for the different events which occurred.

At each leg of the intersection an observer was stationed at a distance of 20 metres from the stop line. Each observer was asked to report on those conflicts occurring to vehicles approaching the intersection from the leg where the observer was positioned. In order to collect data in a more systematic manner and to facilitate analysis of the results, each observer was given a form (Figure 2). This form was divided according to the directions of traffic in the intersection leg and according to the possible types of conflicts for each direction with other vehicles in the intersection. Conflicts with pedestrians as well as conflicts between vehicles were also counted.

In addition to the observers positioned at each leg, the entire intersection was also filmed using video equipment. The video photography served mainly to analyze the operational parameters of the intersection (waiting times, percentage of vehicles stopping, etc.), and to complement traffic volume data.

4. ANALYSIS OF RESULTS

In the field study, observations were carried out for 34 hours in which the traffic signal was in regular operation and 29.5 hours in which the traffic signal was in the flashing operation. Vehicles observed at each intersection in accordance with the type of signal operation and direction of traffic are presented in Table 1. The distribution of types of conflicts observed for the two traffic signal operations are presented in Table 2.

The most outstanding phenomenon resulting from the flashing operation is the increase in the number of conflicts occurring at the intersection (crossing and merging). In a regular signal operation, conflict of this type accounts for 22.4% of all conflicts occurring at the intersection, while in the flashing operation, they represent 71.4% of all conflicts.

Another phenomenon resulting from the flashing operation is the proportional decrease in those conflicts involving pedestrians and in rear-end conflicts.

The reason for the increase in the number of conflicts of the crossing and merging type is the confusion regarding the priority regime at intersections. In accordance with Traffic Regulations, priorities during the flashing operation of a traffic signal are determined by those traffic signs positioned at the intersection ("stop" and "give way" signs). In the field study, it was found that drivers do not perceive these signs and therefore, there is a relative increase in conflicts related to traffic control.

The relative decrease in those conflicts involving pedestrians stems from the disappearance of the shared phase in the traffic signal for both pedestrians and vehicles. For right turns, pedestrians and vehicles receive the signal to proceed with traffic and to cross the street at the same time. In a flashing operation, pedestrians are able to choose for themselves the crossing gap they need to make a safe crossing.

Table 2 also presents the distribution of types of road accidents with casualties for the two situations of traffic signal operation. These accidents occurred at urban intersections in Israel during the years 1974-1979. As can be seen, those trends which were distinguishable in the analysis of conflicts are also visible in the road accident rates. In the flashing operation, the similarity between conflicts to accidents is greater than for the regular operation. The reason for this is in the differences in a relative portion of rear-end conflicts. For these types of conflicts, a large portion of these instances result in damage only accidents as against other types of conflicts. Given a conflict, the conditional probability for an accident occurring is lower for this type of conflict as compared to others. The opposite effect also occurs for conflicts of the crossing type. Given a crossing conflict in a regular signal operation, the conditional probability for a crossing type accident is relatively greater.

It should be noted that the differences between the types of accident for the two signal operation situations do not cause any significant changes in accident severity. Table 3 presents the distribution of accident severity for the two signal operation

situations. Despite the relative decrease in the percentage of slight accidents during the change from regular to flashing operation (from 89.5% to 86.3%), these differences are not significant at the 10% significance level.

As stated, the research aimed at locating those traffic volume ranges whereby the use of a flashing signal operation will not cause any deterioration of the safety level at intersections. In order to ensure an analysis of time intervals where no changes occur in the traffic volume, the counts were divided into time interval samples of 15 minute periods. The decision rule for a situation where no significant changes in the number of conflicts occurred defined the range in which the average number of conflicts for the regular signal operation was not smaller than one standard deviation from the flashing operation. This decision rule is rather conservative as opposed to tests at the 5% significance level where the accepted practice is to take a distance of 2 standard deviations.

Table 4 presents the numerical results. Each traffic volume contains all the samples for which the traffic volumes did not exceed those stated in each line. As can be seen, for traffic volumes of up to 700 vehicles per hour, the differences in the number of conflicts are within the range of one standard deviation. Since traffic volumes were calculated on the basis of 15 minute time intervals, there is a need to adapt them to existing situations at the intersection for an entire hour period. According to the Highway Capacity Manual 1966, the average peak hour factor for signalized urban intersections is 0.85. Therefore, traffic volumes should be adjusted from 700 vehicles per hour to 600 vehicles per hour. At this traffic volume, there is no significant change in the number of conflicts occurring during the change from regular signal operation to a flashing operation.

The major problem which was found during the flashing operation was one of intersection control; the priorities regime of minor streets is not clear enough to drivers. It is most probable that drivers neither differentiate nor understand the significance of the traffic signs permanently positioned at signalized intersections. In order to resolve this problem, the possibility of dividing the flashing operation for major and minor streets is now being considered. This means that major streets will have a flashing yellow signal while minor streets will have a flashing red signal equal in meaning to a "stop" sign. The assumption is that giving an order to the driver through the use of signal lights is always more effective than the use of traffic signs.

5. SUMMARY AND CONCLUSIONS

In the course of the safety evaluation involved in changing traffic signal operations from a regular operation to a flashing operation, the following conclusions were obtained :

1) The conflicts technique is an effective tool in locating existing safety problems at intersections. This fact was verified by means of comparison between types of

conflicts and types of accidents for the two signal operation situations.

2) There is a need to expand the definition of a conflict so that the subjective judgment of the observer is minimized. Therefore, a conflict should include all those situations whereby one of the road users changes either his speed or direction and not only to rely on emergency or evasive actions.

3) The change from regular signal operation to a flashing operation is accompanied by a relatively partial increase in the number of crossing and merging conflicts. In addition, there was a decrease in the number of conflicts involving pedestrians.

4) In general, no significant changes were found in accident severity. This stems from the low severity level generally existing for urban intersection accidents (about 88% of these types of accidents are reported as slight).

5) For up to 600 vehicles per hour, it is possible to use a flashing signal operation without causing any significant changes in the number of conflicts occurring at a given intersection.

6) There is an indication of the possibility that a signal operation using a flashing red light for minor streets and a flashing yellow light for major streets is preferable to using a flashing yellow for all directions.

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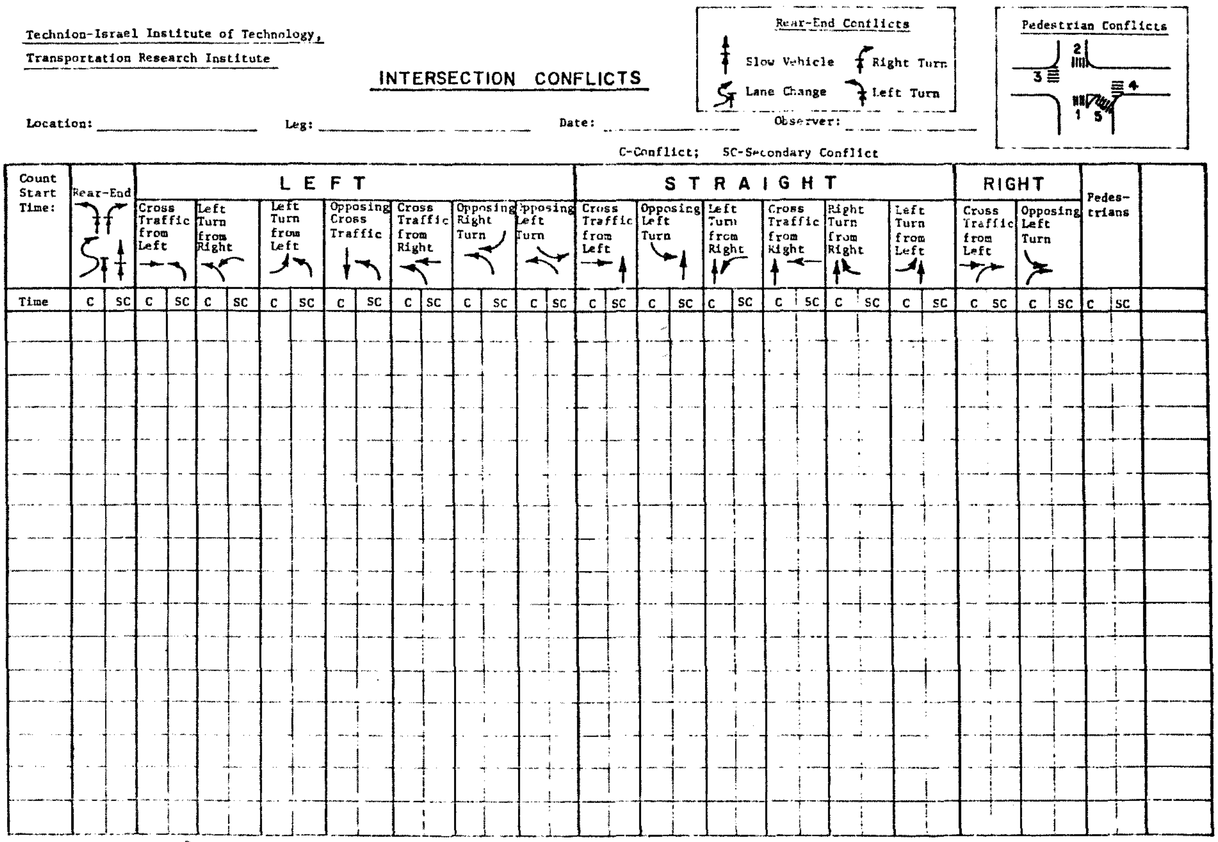

Technion-Israel Institute of Technology,
Transportation Research Institute

INTERSECTION CONFLICTS

Rear-End Conflicts: Slow Vehicle; Right Turn; Lane Change; Left Turn

Pedestrian Conflicts: 1 2 3 4 5

Location: ______ Leg: ______ Date: ______ Observer: ______

C-Conflict; SC-Secondary Conflict

Count Start Time:	Rear-End		LEFT														STRAIGHT												RIGHT				Pedestrians	
			Cross Traffic from Left		Left Turn from Right		Left Turn from Left		Opposing Cross Traffic		Cross Traffic from Right		Opposing Right Turn		Opposing Left Turn		Cross Traffic from Left		Opposing Left Turn		Left Turn from Right		Cross Traffic from Right		Right Turn from Right		Left Turn from Left		Cross Traffic from Left		Opposing Left Turn			
Time	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC	C	SC

Fig. No. 2 Standard form for traffic conflict study.

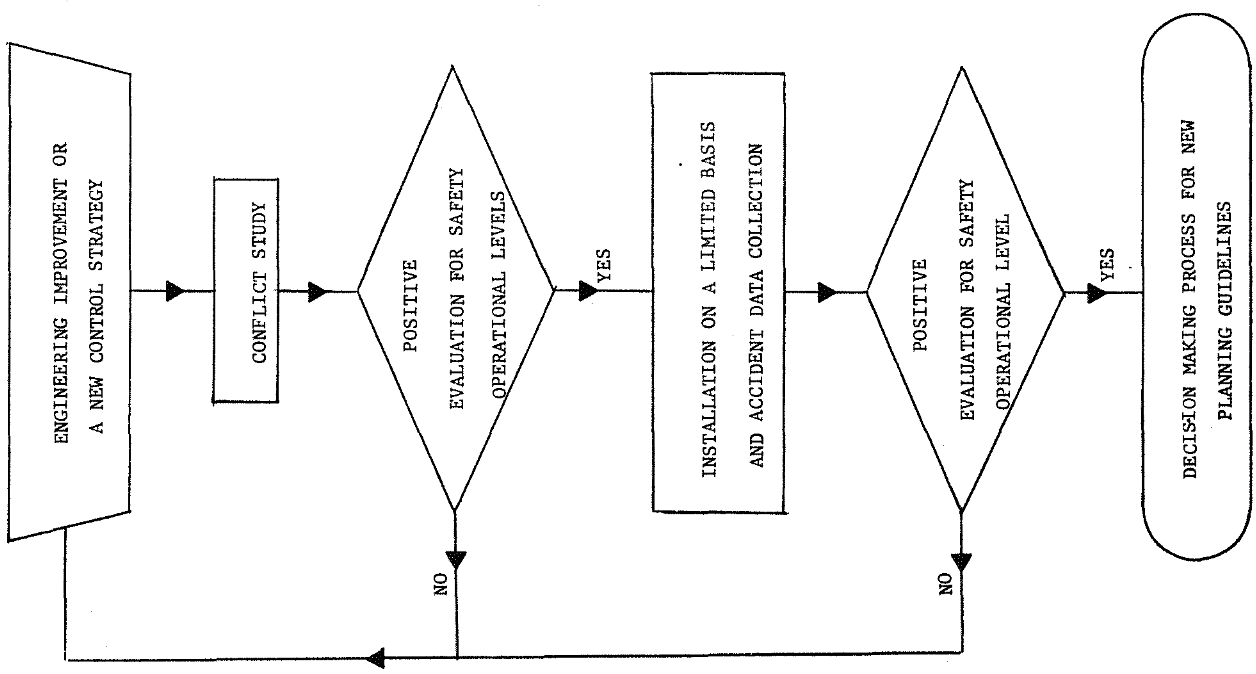

Fig. 1: Schematic Presentation of a Prospective Research Methodology.

Table 1. Number of Vehicles During the Field Study in Each Intersection.

Inter-section	Direction	Regular Operation Major	Regular Operation Minor	Flashing Operation Major	Flashing Operation Minor
A	total	4668	1293	3663	925
	right	516	547	508	371
	straight	2218	340	1676	251
	left	1934	406	1479	303
	Average (veh/h)	582		540	
B	total	2766	1651	2157	2234
	right	1500	445	1280	333
	straight	0	1184	0	941
	left	1266	22	877	960
	Average (veh/h)	883		1098	
C	total	10171	1783	7795	1319
	right	1192	437	951	322
	straight	8230	0	6310	0
	left	749	1346	534	997
	Average (veh/h)	1087		1042	
D	total	5443	1095	5676	1153
	right	488	460	500	526
	straight	4243	0	4533	0
	left	706	635	643	667
	Average (veh/h)	817		808	

Table 2: Distribution of type of conflicts and accidents according to type of operation

Type	Conflicts Regular	Conflicts Flashing	Accidents Regular	Accidents Flashing
Pedestrians	21.9	9.3	19.1	12.2
Rear-end	55.7	19.3	34.4	16.0
Merging	20.4	33.0	46.5	71.8
Crossing	2.0	38.4		
Total (%)	100	100	100	100
(abs)	(636)	(1052)	(7176)	(299)

Table 3: Severity of accidents according to type of control.

Type of operation \ Severity	Slight	Serious	Fatal	Total
Regular	6425	652	99	7176
%	89.5	9.1	1.4	100
Flashing	258	36	5	299
%	86.3	12.0	1.7	100

$\chi^2 = 3.24$ df = 2 $P(\chi^2) = 0.80$

Table 4: Average number of conflicts per sample

Maximum Volume [veh/h]	REGULAR OPERATION			FLASHING OPERATION		
	No. of samples	Average No. of conflicts	Standard deviation	No. of samples	Average No. of conflicts	Standard deviation
500	5	5.2	2.4	13	4.3	2.4
600	29	4.8	2.4	29	5.2	2.8
700	50	4.2	2.5	42	6.6	4.1
800	67	4.1	2.4	58	7.1	4.1
900	83	4.0	2.3	76	7.3	4.4
1000	97	4.1	2.4	93	7.7	4.7
1100	116	4.3	2.7	107	8.2	5.2
1200	125	4.3	2.6	113	8.5	5.3
1300	132	4.5	2.8	118	8.8	5.6
1400	136	4.7	3.0			

SESSIONS 6+7:
Process evaluation: behavioural studies

SESSION 6 AND SESSION 7

Chairman: Mr. B. Horn (OECD)

Theme: process evaluation: behavioural studies

A. R. van der Horst: The analysis of traffic behaviour by video
(the Netherlands)

P.W. van der Kroon : Road humps: the remedy for each and every traffic safety problem?
(The Netherlands)

S. Lundebye and : Measures for reducing vehicle speed on residential roads
F.H. Amundsen (Norway)

W. Molt and : An adaptive theory of road safety
H. Beyrle (Germany)

J.A. Rothengatter : Evaluation of a pedestrian training programme for preschool children
and H.H. van der Molen (the Netherlands)

THE ANALYSIS OF TRAFFIC BEHAVIOUR BY VIDEO

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Soesterberg, The Netherlands

1. INTRODUCTION

At the Institute for Perception TNO, the study of human information processing is a main research area including the study of perception, decision making, and action. Road-user behaviour in particular is studied by using various methods ranging from mere observations in real traffic situations to highly controlled laboratory experiments, sometimes using advanced simulation techniques. The choice of methods depends on the questions to which the research is addressed.
In what follows an objective method, based on video, for observation and analysis of the behaviour of road-users in real traffic will be discussed. As an example a study will be reported in which new road design elements were evaluated in a demonstration project on cycleroutes through The Hague and Tilburg, two cities in The Netherlands. The study was carried out under contract with the Ministry of Transport. The questions were a.o. how the new elements are functioning, whether they are leading to the desired traffic behaviour and whether they have an effect on road safety. With respect to the last aspect accident figures do not form an efficient basis for studying the effects of road design elements on single spots. In this kind of situations serious interactions between road-users (conflicts) are thought to be an alternative to accidents as a criterion measure. A substitute measure as conflict counts might overcome some limitations in the use of accident figures; accident frequencies are unstable, necessary observation periods are too long in particular in evaluation studies and only a fraction of all accidents are reported with also differences with regard to types of accidents. These three limitations are the more severe, if the theoretical accident frequencies are already small, as is the case in studies at particular locations of the road network like neighbourhoods and intersections.
In the past various conflict-observation methods have been developed, mostly using individual observers. Although they may be highly trained and experienced, large differences between individual observers remain, sometimes due to inadequate definition of conflict, sometimes due to, for example, inaccurate time estimation in case of an interaction between road users. To reduce observer subjectivity, it was considered necessary to develop an observation technique which enables objective quantification of the severity of interactions between road users.

2. TRAFFIC CONFLICT METHODS

The Traffic-Conflicts Technique (TCT) was adopted as an operational tool in road safety research by a publication of Perkins and Harris (1967). They define a traffic conflict as any potential accident situation, leading to the occurrence of evasive actions like braking or swerving. Over twenty criteria for traffic-conflict situations are given. Evasive actions are counted simply by scoring brakelight indications or lane changes. During three 12 hour observation sessions an intersection can be evaluated completely. The observation team consists of two observers, one counting traffic conflicts and one counting traffic volumes. A detailed procedures manual has been published by Perkins (1969).

The strength of the General Motors TCT lies in its simplicity of application. Although the method was taken up enthousistically, later studies showed some deficiencies of this method. The set of conflicts, as defined by Perkins, appears to be too large to have a close relationship with accidents or with collisions. Campbell and King (1970) used the General Motors TCT to measure the accident potential of two rural intersections. They found no significant association between conflicts and reported accidents. Omitting rear-end conflicts and rear-end accidents they observed a much higher degree of association. The reason for doing so was that while collecting the data it was noted that, although a large number of rear-end conflicts occurred, it appeared that some drivers were braking only for personal comfort or by way of precaution.

Furthermore, a need existed to classify the degree of severity of the evasive action. This was done by Older and Spicer (1976), who developed a severity grading in five categories, ranging from precautionary braking or lane change to an emergency action followed by a collision. In these conflict studies individual observers were used, complemented by time lapse film recordings (two frames per second). According to Older and Spicer, a combined observer and film study is necessary for research purposes. For a rapid assessment of number and location of conflicts, they conclude that the use of individual observers only is sufficient. This conclusion, however, is criticized by Hauer (1977) and Allen et al. (1977). Firstly, collisions may occur without evasive actions being taken. Therefore, a definition of conflicts including the occurrence of a collision, not preceded by evasive actions, is desirable. Secondly, the grading of severity of the evasive action by observers introduces a rather subjective aspect. This may be reduced by an intensive training programme. Older and Spicer (1976) found an agreement of 80% between gradings of the same traffic event by two groups of observers. However, effects over a longer time period were not investigated.

The time-to-collision concept (TTC)

To describe the danger of a conflict situation objectively, Hayward (1971, 1972) defined the *time-measured-to-collision* (TMTC or TTC). This measure is the time required for two vehicles to collide if they continue at their momentaneous speeds and on the same path. The measure is continuous with time. The theoretical shape of a TTC curve as a function of time is given in Fig. 1. If the vehicles are not on a collision course the value of TTC is infinite. However, a change in speed or path of one of the vehicles may lead to a collision course, implying that TTC is finite and will decrease with time. This will be linear as long as the speed and course of both vehicles are constant. If neither one would take action, it will result in a collision (TTC = 0). An evasive action (decelerating, swerving) may lead to a minimum value for TTC, which then increases to infinity again. It often happens that roadusers are on a collision course, but very rarely it will result in a real collision, because drivers are making continuously the necessary speed and heading changes. The minimum TTC value is a critical measure for the risk involved in an interaction between roadusers. Hayward (1972) suggests to use a minimum TTC value of 1.0 s as a good threshold. Interactions with a minimum TTC below this value would be defined as serious conflicts. The definition of a conflict then becomes: a conflict is each traffic situation with a minimum TTC less than 1.0 s. Hayward calculated TTC-curves by analysing film pictures quantitatively. Hyden (1975, 1977) tried to simplify this method with a lightly different definition. He proposes a larger critical value, namely 1.5 s instead of 1.0 s. Hyden had individual observers estimate minimal TTC values after an intensive training with help of video recordings of traffic situations with known TTC values. However, in doing so Hyden introduced again observers' subjectivity.

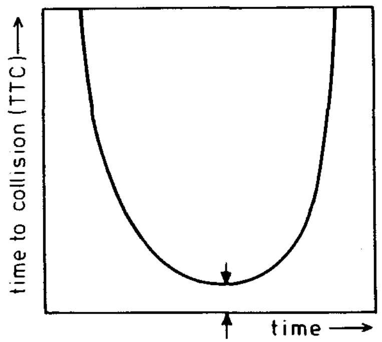

Fig. 1. Theoretical TTC curve as a function of time (Hayward, 1972).

3. RECORDING AND ANALYSIS METHOD

In order to measure motion and positional parameters involved in an interaction between road users, the use of film or video appears to be still necessary. Both techniques have their specific advantages and disadvantages, but with respect to costs and practical aspects the use of video is preferred (Van der Horst and Sijmonsma, 1978). In the near future the potential for automatic analysis of video seems to be rather high. At the Institute for Perception TNO a method has been developed for the quantitative analysis of video recordings in a semi-automatic way. A short description of this method will be given in this chapter.

Recordings

The behaviour of roadusers is recorded by means of video. A suitable place for mounting the camera has to be found in the neighbourhood of the location, preferably at a height of more than 4 m above the road surface, of course as unobtrusively as possible. In a study at 20 intersections on cycleroutes in an urban area (chapter 4) a good camera position could be found rather easily in adjacent buildings or in lampposts.

A block-diagram of the video recording equipment is shown in Fig. 2 up to now only one camera has been used. When the outlook over the location is too limited, the use of a second camera in combination with a video mixer is optional. The timer superimposes a numerical display of month, day, hour, minutes, seconds and 1/100 s onto the video picture. This is very helpful in selecting traf-

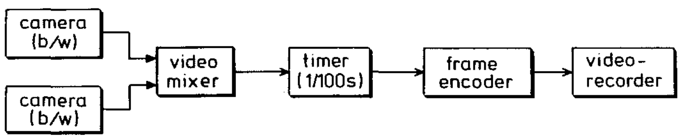

Fig. 2. Video recording equipment.

fic situations and relating these with other parameters like traffic volumes, densities, etc. Each frame is labeled uniquely by superimposing digital information at the beginning of each video line by the frame encoder, in order to search a particular video frame automatically, see Fig. 3. The digital label (24 bit) is repeated four times in each frame. So the information is always available independent of the position of the "noise bar" (the separation between two successive frames on stills). The video signal is recorded by a Sony Umatic video cassette-recorder (type VO2850).

Fig. 3. Video still with digital label at the left, electronic cross-hairs, time and noise bar (at the bottom).

Analysis

The vehicle movements, recorded on video-cassette, are analysed quantitatively to describe their behaviour in terms of course, course changes, speed, speed changes and measures for the interaction with other roadusers, for example time-to-collision (TTC). The quantitative analysis consists of selecting the positions of some points of the vehicle on a video still. By means of transformation rules, positions in the plane of the picture can be translated to positions in the plane of the street. By differentiating successive positions in time, the speed of the vehicle can be obtained. The selection of one picture from every twelve (one picture/0.24 s) appeared to be a reasonable compromise between accuracy and length of analysis time.

Video analysis equipment

To ensure a flexible use of the analysis equipment a great part of the system has been realised in software. The central part of the system consists of a small minicomputer (a PDP 11/03 with 28K memory), see Fig. 4. A 8-channel digital interface (24 bits per channel) interconnects the computer with the other elements. A small modification of a standard joy-stick remote control unit makes computer control of the video recorder possible (operational control and control of the tape speed). The tape speed can be adjusted continuously from zero to plus and minus three times the normal video tape speed. The digital labels

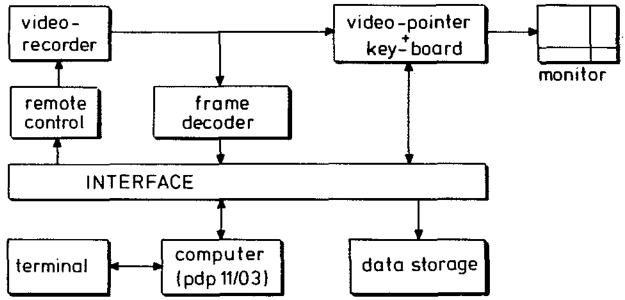

Fig. 4. Block-diagram of the video-analysis equipment.

(stored in each frame four times) are read by the frame decoder continuously and passed at a command of the computer. This enables the computer to search the desired frame and then to shift down the noise bar to the bottom of the monitorscreen.
The operator is communicating with the system in two ways, by means of a terminal for normal input and output of the programme and by means of a special keyboard (Fig. 5) consisting a.o. of 16 push buttons, to which a function may be related in software, for example "point ready", "picture ready", "manoeuvre ready", "other point", etc. The operator is indicating a point on the screen of the video monitor by positioning two crosshairs, continuously by a joystick or step-by-step by four push buttons. The crosshairs are mixed electronically

Fig. 5. Monitor, remote-control of the video recorder (at the right) and the special keyboard (black) with 16 programmable push buttons and the control of the electronic crosshairs: a joystick and at the left four pushbuttons.

in the video, so parallax errors have been avoided. On command of the operator, the computer reads out the x- and y-coordinates, and then positions the crosshairs on predicted x- and y-coordinates of the next point to be measured. The prediction is based on previous selected positions of the point. In this way the operator has only to correct these coordinates with a few steps. After finishing the manoeuvre a datafile is submitted to a data storage device for further analysis, in the current system to a disc of a PDP 11/40 computer.

Transformation from video coordinates to street coordinates

The known coordinates (X_V, Y_V) of a given point in the video plane have to be transformed to coordinates (X_S, Y_S) in the plane of the street; see Fig. 6. Assuming that all points of the street are lying in one flat plane and that no reproduction errors occur (neither by the camera nor the monitor) the following transformation rules can be derived (Hallert, 1960):

$$\left.\begin{aligned} X_s &= \frac{C_1 X_v + C_2 Y_v + C_3}{C_4 X_v + C_5 Y_v + 1} \\ Y_s &= \frac{C_6 X_v + C_7 Y_v + C_8}{C_4 X_v + C_5 Y_v + 1} \end{aligned}\right\} \qquad (1)$$

The coefficients C_1 to C_8 can be calculated from (1) if the coordinates of at least four points are known in both planes. Substituting the X_V, Y_V, X_S and Y_S of four points in (1) gives a system of eight linear equations with C_1 to C_8 as the unknown elements. This system can be resolved if none combination of three points in both planes is lying on a straight line.
This transformation offers the great practical advantage that nothing has to be known about the position and orientation of the camera. All information is in-

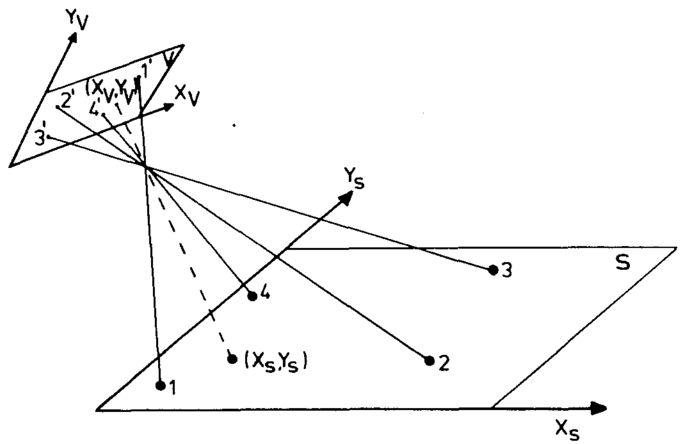

Fig. 6. Schematic representation of the projection of points in the plane of the street (plane S) on the video plane (plane V).

cluded in the way in which the four points on the street are projected on the video plane. On the street, only the distances between the points have to be measured. The accuracy of the transformation depends strongly on the selection of the four reference points. So it is advisable to measure some more points to have a check on the transformation and to make an optimization possible.

Data analysis

A datafile, generated by the video-analysis equipment, contains the x- and y-coordinates in the video plane of successive positions of points of the vehicle involved. This datafile is stored on a disc of a PDP 11/40 computer. Software has been developed for further analysis, namely for the transformation to street coordinates, a smoothing routine to minimize sampling inaccuracies, the calculation of motion parameters like speed and acceleration and the computation of interaction measures (like time-to-collision (TTC) curves and minimum passing distances). For the last measures accurate vehicle dimensions are required, for which a data base of current types of motorcars is available. For the calculation of the TTC measure, see the Appendix. The outcome of the procedure is illustrated in the example of Fig. 7. In a situational map of an intersection the courses of a car coming from the minor road and two cyclists on a cycle track are plotted. Each point gives the position of a given point of a vehicle at successive time intervals, here 0.24 s. The car driver did not give right of way to the cyclists. Cyclist 1 had to stop (points close together), while cyclist 2 rode behind the car. The plot in the bottom corner gives the time-to-collision (TTC) curve for the interaction between the car and cyclist 1.

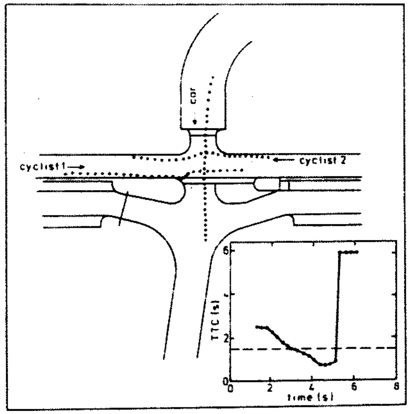

Fig. 7. Example of a serious conflict between a car from the minor road and cyclist 1. Bottom right: time-to-collision (TTC) curve.

4. BEHAVIOURAL STUDY CONCERNING PRIORITY INTERSECTIONS OF THE DEMONSTRATION CYCLEROUTES AT THE HAGUE AND TILBURG

Background

The increasing number of cars on the road leads to an increasing demand on the available space. Therefore, the government's policy aims at a restricted car use, especially in urban areas and during peak hours, and to promote the use of the bicycle and/or public transport instead. A safe and highly comfortable system of cycletracks might promote the use of the bicycle. To stimulate the construction of cycleroutes in urban areas, the national government had designed and constructed the two aforementioned demonstration cycleroutes in The Hague and in Tilburg.
These cycleroutes have their own tracks on the road, separated from motorised traffic, traced through areas with rather low traffic volumes, crossing other traffic streams as less as possible, giving right-of-way to bicyclists at non-signalised intersections, special priority measures at signalised intersections and, if necessary, even a viaduct or tunnel over/under heavy traffic streams.

Especially at non-signalised intersections, where the cyclists on the cycletrack have the right-of-way over crossing traffic, the road design elements play an important part in supporting the traffic behaviour, as intended by the designers. The experimental character of the project made it possible to try out some different solutions for the same kind of problems at a priority intersection.

Procedure

The evaluation of the functioning of new road design elements at a number of priority intersections, with respect to roaduser behaviour, consisted a.o. of:

a. A comparison between the actual behaviour and the behaviour as intended by the designers for each aspect and location,
b. a comparison of the actual behaviour between experimental locations and
c. as far as possible, a comparison between the actual behaviour at the experimental locations and the behaviour at some control locations, without special provisions.

At fifteen locations of the cycleroutes and at five separate control locations video recordings were made, at each location for six hours during one day. The video recorder was started by hand when a vehicle arrived and stopped when the manoeuvre had occurred. For each location the relevant road-user behaviour to be recorded had been discussed with municipal authorities.
From the video recordings a number of behavioural aspects, including path chosen, speed, speed changes, place of stopping and, of course, interactions with cyclists on the cycletracks (conflicts), were studied in detail, as influenced by specific design elements (humps, hobbles, constrictions, curves, etc.), in particular for crossing traffic. Whenever clear behavioural alternatives could be distinguished, registrations were done by individual observers directly from the video recordings. Otherwise a quantitative analysis was carried out with the video analysis equipment, as described in chapter 3.

Results

In this session only some aspects of speed control and the interactions with cyclists will be discussed, just for demonstrating the usefulness of the observation- and analysis method. For more detailed information it is referred to Van der Horst (1980).

Speed curves

A number of the road design elements has the function of reducing the speed of crossing cars. By analysing the video recordings quantitatively, speed curves were determined for cars, crossing the cycletrack without the presence of other traffic. For four locations Fig. 8 gives an example of speed profiles of crossing cars as a function of the distance to the cycle track. Each point gives

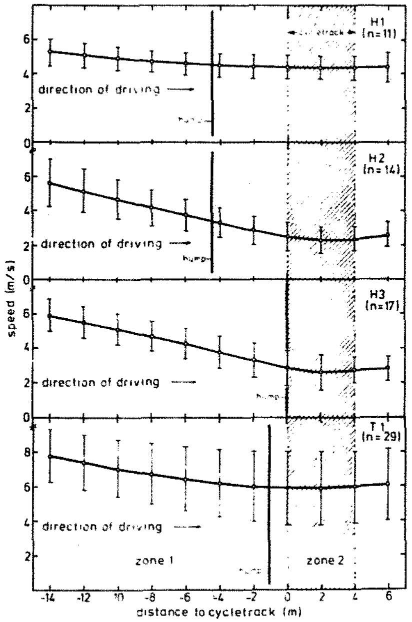

Fig. 8. Speed profiles of freeriding cars from the minor street at four locations (H1, H2, H3 en T1).

the mean value of n vehicles, together with the standard deviation. The most important characteristics of such profiles are a.o., the speed on the boundary of the cycletrack ($\bar{v}$), the minimum speed ($\bar{v}_{min}$) and the place where this minimum is reached ($\bar{d}_{min}$). The front axis of the vehicles is taken as the measuring point. In Table I these characteristics are given as a mean for each group of locations. d_{min} Gives an indication of the place where car drivers have taken the decision to go through. Although the speed curves differ between locations,

Table I. Mean speed on the boundary of the cycletrack ($\bar{v}$), mean minimum speed ($\bar{v}_{min}$) and the mean distance to the cycletrack where this minimum is reached ($\bar{d}_{min}$), for freeriding cars from the minor street; n is the number of locations in each group.

group of locations	n	$\bar{v}$ (m/s)	$\bar{v}_{min}$ (m/s)	$\bar{d}_{min}$ (m)
The Hague	8	2.7	2.5	-0.5
Tilburg	6	3.6	3.4	0
control	5	4.3	3.7	+4

in general the speed control elements (humps for instance) at the experimental locations are functioning according to the expectations. The speeds are lower than at the control locations and the place where the minimum speed is reached (d_{min}) appears to be prior to or on the cycletracks instead of a few metres after the cycletrack for the control locations. With the special elements more attention is paid by car drivers to the cycletrack.

In case of interactions with cyclists, the minimum speed was reached on or after the cycletrack for control locations, while for the experimental locations it was reached a few metres prior to the cycletrack, an example of which is given in Fig. 9.

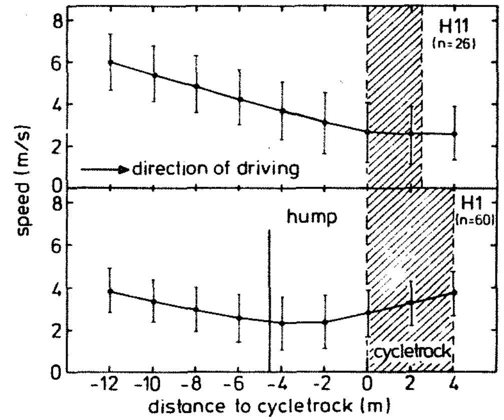

Fig. 9. Example of two speed profiles of crossing cars with cyclists on the cycletrack, H1 is an experimental location with a speed control hump at a distance of 4.5 m from the cycletrack, H11 is a control location without hump in front of the cycletrack.

An experimental parameter in applying a speed control hump is the distance between the hump and the element it is intended for (here the cycletrack). A comparison of locations where this distance was different (between 0 and 5 m), resulted in a preference for a hump as the beginning of a plateau at a distance of about 4.5 m from the cycletrack.

A raised intersection plane, consisting of humps + plateau of brick pavement, reduced the speed of through-going cars on the main road significantly with 4 m/s, a reduction of about 40%.

Interactions between crossing cars and cyclists at the cycletrack

An important aspect in evaluating intersections is road safety, in this study, especially in relation to cyclists. The number of accidents at a single location cannot be used as a evaluation criterion for reasons given before. Conflicts seem to have an alternative to accidents as a criterion measure for road safety. In the following the time-to-collision (TTC) will be given as a possible measure for describing serious interactions between road users.

By means of the video-analysis equipment a large number of manoeuvre combinations were analysed. On the basis of the x and y positions of the vehicles at successive moments TTC curves can be calculated with the help of a computer programme. Fig. 7 illustrated already the output of a given manoeuvre combination: a serious conflict between a crossing motorist and two cyclists on the cycletrack.

The number of conflicts (for example defined as the number of interactions with a minimum TTC less than 1.5 s), related to an exposure measure E might give a risk index (RI) for two intersecting traffic streams. On the basis of these risk indices, intersections might be compared relatively. From the literature it is not quite clear which kind of exposure measure has to be used. Often the exposure E of two traffic streams i and j has been defined as:

$$E = \sqrt{I_i * I_j}$$

where I_i and I_j are the number of vehicles in stream i and j during a given period. In the following this E will be used.

In Fig. 10 the number of conflicts is given as a function of the exposure E for two types of manoeuvre combinations at the intersections under study. In Fig. 10a it concerns the conflicts between car drivers from the minor street (car_1) and cyclists coming from the left (the first bicycle stream B1), while in Fig. 10b between stream car_1 and cyclists coming from the right (the second stream B2). Each point represents the relevant type of manoeuvre at the intersection. The quotient of the number of conflicts and E gives the risk index RI. The solid line in both figures represents RI, averaged over all points (car_1 - B1 and car_1 - B2 combined). Interactions between car_1 and B1 at an average are scoring above this line, while those between car_1 and B2 are below. Cyclists B1 are involved more frequently in a serious conflict with cars from car_1 than cyclists from B2. The width of the cycletrack gives some extra space between a car from car_1 and a cyclist from B2. The reversed situation

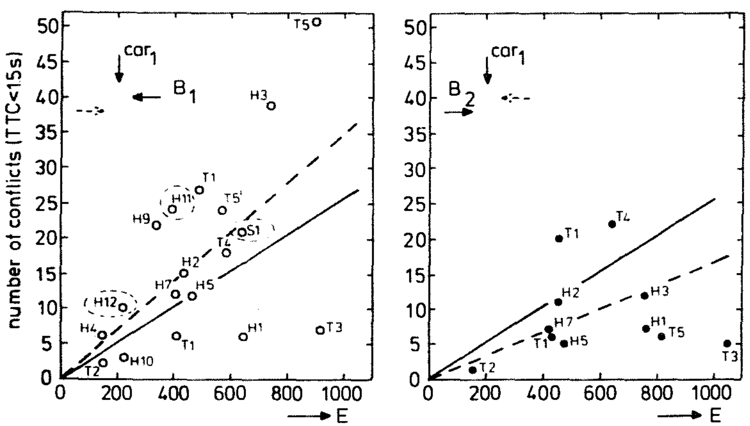

Fig. 10. The number of conflicts (TTC < 1.5 s) as a function of exposure E ($E = \sqrt{car_1 . B_i}$) for two types of manoeuvre combinations. The control locations are marked with ( ).

holds for cyclists from B2 and cars coming from the opposite direction (data not presented here). The mean RI per type of manoeuvre combination in Fig. 10 is given by the dashed lines. Intersections above this line are relatively more unsafe (in terms of conflicts) than intersections below the line, that is for the particular type of manoeuvre combination.

Initially, it was not obvious which minimum TTC value has to be used. However, it appears from this study that interactions with a minimum TTC value greater than 1.5 s do not contribute an essential part to figures based on TTC < 1.5 s. So 1.5 s is used as an upper limit. In Fig. 11 a distinction has been made for pairs of locations which are comparable for a number of aspects. Three different types of riskindices are given, based on interactions with a minimum TTC of less than 1.5, 1.25 and 1.0 s, respectively. For example at the cycleroute location H3 the number of serious interactions between cars from the minor road (car_1) and cyclists on the cycletrack was higher than at cycleroute location H1, independent on the type of riskindex that is used (left topfigure). In this case the distance from hump to cycletrack was largely responsible for the difference; at location H1 this distance amounts 5 m and at location H3 it is 0 m. Another indication that humps at a distance of about 5 m are functioning better than humps bordering the cycletrack.

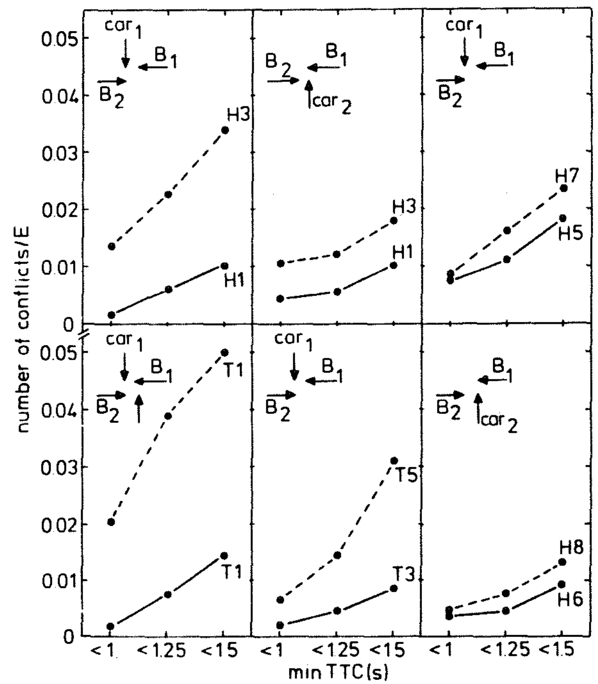

Fig. 11. Riskindices (number of conflicts/E) based on different minimum TTC values (< 1., < 1.25 and < 1.5 s) for pairs of comparable intersections. The type of manoeuvre-combinations is given in the left top corner.

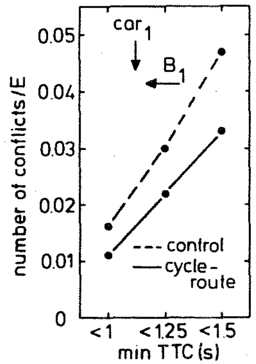

Fig. 12. Riskindices of the control locations (H11, H12 and S1) in comparison with the cycleroute locations, for the manoeuvre-combination car$_1$ - B1, i.e. cars from the minor road and the bicycle flow, which is intersected firstly.

In general the three control locations (H11, H12 and S1) produce more conflicts, than locations at the cycleroutes, for one type of manoeuvre combinations see Fig. 12.

5. CONCLUSIONS

- Recording and analysing the traffic behaviour in detail may give a lot of information about the functioning of several road design elements.
- The method as described in chapter 3, based on video, enables a process oriented analysis of interacting behaviour between roadusers, not necessarily restricted only to the time-to-collision concept.
- However, in spite of a semi-automatic analysis procedure by the use of a minicomputer, the quantitative analysis remains time consuming. Further automation of the procedure seems necessary.

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APPENDIX

The computation of the time-to-collision measure (TTC)

Let Fig. A give the simplified situation at time t. Vehicle 1 and vehicle 2 are approaching each other. Assuming that from the moment t no changes in speed and heading occur, for each vehicle a straight line is estimated through the current point (P) and three preceding points. The intersection of the two lines, point S, is determined. Then, the decision is made whether the vehicles are on a col-

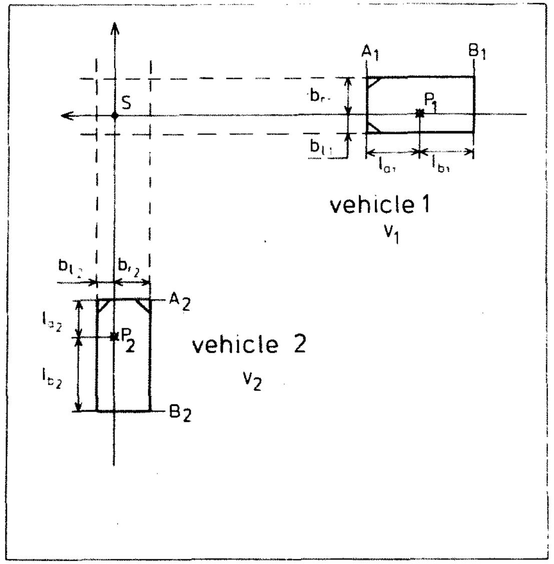

Fig. A. Some vehicle characteristics used in calculating TTC curves.

lision course or not, taking into account the dimensions and speeds of both vehicles. They are in fact on a collision course at time t if either of the following two conditions is satisfied:

$$t_{A1} < t_{A2} < t_{B1} \tag{A1}$$

$$t_{A2} < t_{A1} < t_{B2} \tag{A2}$$

in which:

$$t_{A1} = t_{P1} - \frac{l_{a1} + b_{r2}}{V_1} \tag{A3}$$

(time vehicle 1 reaches the intersection plane)

$$t_{B1} = t_{P1} + \frac{l_{b1} + b_{12}}{V_1} \tag{A4}$$

(time vehicle 1 has left the intersection plane)

$$t_{A2} = t_{P2} - \frac{l_{a2} + b_{l1}}{V_2} \tag{A5}$$

(time vehicle 2 reaches the intersection plane)

$$t_{B2} = t_{P2} + \frac{l_{b2} + b_{r1}}{V_2} \tag{A6}$$

(time vehicle 2 has left the intersection plane)

t_{P1} = moment point P1 passes intersection point S;
t_{P2} = moment point P2 passes intersection point S;
V_1 = speed of vehicle 1 at moment t;
V_2 = speed of vehicle 2 at moment t.

Then, TTC will be for (A1): $\quad TTC = t_{A2} - t \quad$ (A7)

and for (A2): $\quad TTC = t_{A1} - t \quad$ (A8)

Determination of the TTC for successive times (e.g. each 0.24 s) allows it to be plotted as a function of time, but only if (A1) or (A2) is satisfied.

The above applies to a 90^o angle of intersection. Adjustments can be made for other angles. Special computations have to be done if one of the vehicles has a speed of 0 km/h (V_1 or V_s = 0). The continuation of movement is based on a constant speed in one direction at moment t. In the next step, let us say after Δt s, the computation of TTC is made with the speeds and courses at moment t + Δt, which of course may be different from those at the previous moment t. Balasha et al. (1978) suggest that other assumptions for the continuation of movements, like a constant angular velocity and a constant acceleration or deceleration might give improvements for the computation of TTC values.

Road humps. the remedy for each and every traffic safety problem?

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The sixties and seventies:
In the sixties, ownership and use of motor-cars showed a great increase in the Netherlands. Many kilometres of motorway were added to the existing network. In and near the cities, too, more and more facilities for the motor-car came into being.

But nothing was done where this growing stream of cars came from, where they returned to, and where they stood: the residential area. The street design of the fifties was the street design of the sixties and seventies. The increased automobile traffic and the number of parked cars started to cause problems. The residential area was felt to be unsafe.

Ideas on how to cope with these problems took shape in the seventies. The restricted traffic residential area was born, along with a succession of technical solutions to traffic regulation, in order to create a traffic environment sympathetic to pedestrians in residential areas. It soon became apparent that a residential area with restricted traffic could only be used when there was ample space. And among the technical solutions to traffic control, road humps became the best known.

The road hump
Not only did it dawn on the professional world, but also on the residents themselves that this might just well be a solution to their traffic safety problems. People began to clamour for road humps; the residents put pressure on the city of Amsterdam for their construction.

In 1978 the city conducted a trial with road humps. As a start, 15 humps were constructed. The trial showed that road humps were effective in lowering the speed of cars, that there was no noticeable rise in the noise level, and that vibrations underground and in the nearby buildings played no significant role.

Studies in other countries had shown that the number of accidents diminishes in streets where road humps have been constructed. Although insufficient data was available on Amsterdam, it seemed defensible that the effect here would not be in the opposite direction.

The trial was viewed as successful, and after comparison with

experiences elsewhere, it was decided to apply road humps on a larger scale in Amsterdam.

The use:
Amsterdam set up several conditions and stipulations which any request for a road humps must meet if it is to be granted. The road humps used were convex, and until mid-1980 they were built with a pavement extension. After that time, the loss of 4 parking spaces through pavement extensions was no longer considered acceptable.

In principle, no road humps are laid on main traffic arteries as designated by the city's traffic circulation plan, on bus routes, on routes connecting emergency services to main traffic arteries, and on the canal belt.

The local community centre in the area a road hump request comes from is involved in the decision making on its construction.

All this has resulted in an annual expenditure of hundreds of thousands of guilders on laying road humps, and there are an estimated 140 road humps in Amsterdam today.

The policy issues:
There is still a great demand for road humps, but doubt is beginning to creep into the minds of the policy-makers. "Is it really a good thing to cover the city with road humps." and "What are the reactions of residents to this 'miraculous' cure for the unsafe traffic situation in the neighbourhood" are questions which are raised. Besides, nowadays money and other means are scarce and must be used with great care. More detailed criteria and a more detailed selection pattern are felt to be desirable.

In 1980, these questions gave rise to a study of the effectiveness of road humps and the attitude towards them of residents of the streets involved.

The study:
The study, in the form of a poll, was held in four streets both before and after road humps had been laid.

The streets were:
- Jennerstraat;
- Newtonstraat;
- Gerard Terborgstraat;
- James Wattstraat.

The first inquiry was held in March 1980, the second one in November 1980. The humps referred to in this study are convex with pavement extensions (narrowing the street profile).

The residents:
It is also important how the users, the residents, experience their street. Do they feel safe, do they think their children

can play safely, do they see their street as a car park? Such questions relate to what can be described in terms such as subjective traffic safety and livability . Little is known on this topic at present. The methods of study have not yet been worked out. For the local government, the city, it is also a learning process; this type of research is highly problematic. We therefore suffice here with a general description; detailed study data are available.

<u>The inquiry:</u>
In residential streets where road humps . were planned, an oral poll was held among the people living there of their opinions on road humps and their expectations of their effects. Some time after the road humps were laid, the poll was repeated and the residents were now asked about their experiences with them.

The study was intended to give an idea of the opinions of a few categories of directly involved residents and not of the population of Amsterdam in general. So the goal was not to obtain a representative sample; since the inquiry was held in streets where road humps were to be built, this would not have been possible either. The study cited here is a population study.

<u>The questions:</u>
It was thought that the frequent user groups from the residential environs (children, elderly persons, etc.) might react differently than residents on the whole. Questions were included on sex, age, job, car ownership, and family composition.

The study questions focus on aspects which are most closely connected to the relationship of car traffic and residential environs: "crossability", safety, speed, and "livability". In the first inquiry a question was included on attitude towards road humps . In both inquiries more detailed responses were possible in the "open question".

Since the community centres had been informed of the plans to lay road humps , the first inquiry also contained a question to find out in how far this information was known to the residents.

<u>The response:</u>

A total of 250 residents were queried in each poll. In both cases the response was around 80%. The number of respondents per street varied from 27 to 93.

<u>The answers to the questions:</u>
Before the road humps were laid, almost three-quarters of the respondents had positive expectations from road humps ; only a very small minority saw nothing in them. In the second inquiry this question was not asked.

The respondents' expectations on "crossability" expressed in the first inquiry were not entirely fulfilled; in the second inquiry more people were of the opinion that there was no difference in the "crossability" of the street.

Compared to the first inquiry, fewer respondents to the second one had a positive opinion of the safety-promoting effect of road

Expectations of speed moderation were very high in the first inquiry. In the second inquiry, only a small majority of the respondents felt that driving speed had decreased, and over a third indicated they had noticed no difference.

In the first poll, respondents already had some doubts of whether the street would become more livable due to the road humps Nearly half of the respondents thought that their street would become more livable; however, an almost equally large number expected no such positive effect. In the second inquiry, less than a third of the respondents felt that it had become more livable. Almost half of those questioned in the second poll , thought there was no difference.

<u>More detailed analysis:</u>
Although there were differences between the streets studied, they are not large enough to justify treating each street separately.

Different societal groups make different uses of the residential environs. The results were studied for differences in expectations of or experiences with the effects of road humps between these various groups.

From both inquiries it appeared that frequent users of the residential environs do not differ unequivocally in their opinions on and experiences with road humps from other groups questioned.

<u>Other results:</u>
Much use was made of the "open question" in the second inquiry. It came across clearly that the loss of parking space was not very much appreciated.

The community centres were not entirely successful in informing residents: not even one-quarter of those questioned had any knowledge of the planned road humps

<u>To summarise:</u>

Remarkably, there is a clear decrease in the positive opinion on aspects such as "crossability", safety, speed, and "livability".

A small majority still holds a positive opinion. The idea that frequent users would have a different, more positive opinion of the effects of road humps was not confirmed by this study.

It may be stated that road humps are not a cure-all, a definitive yet simple solution to the range of problems which can be described by the terms subjective traffic safety and livability .

<u>What now:</u>
Up till now, Amsterdam's usual policy has been to grant requests for road humps after consulting the community centre, provided

that they are not for a street where it has been agreed no road humps will be laid.

In the future it must be considered that the person or body making the request may have too high expectations of the effects of road humps on subjective traffic unsafeness and "livability".

The information supply by community centres to the residents would seem to be not intensive enough. The existing procedure deserves to be reconsidered. An inquiry amont residents on this topic could prove useful.

Considering the fact that the construction of a road hump requires a comparatively high investment - depending on the situation Hfl.6,000.00 - Hfl.10,000.00 - and that the effects of a road hump are noticeable only in a limited area (earlier research shows they have an area of influence between 30 and 50 metres), much reservation should be practised before covering a street with roadhumps.

Surely now, when the city budget is faced with considerable restrictions, it is necessary to reconsider the conditions under which requests for road humps are granted.

MEASURES FOR REDUCING VEHICLE SPEED ON RESIDENTIAL ROADS

by

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STEIN LUNDEBYE

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OSLO - NORWAY

1. INTRODUCTION

Frequent discussions have taken place in Norway, as well as in several other European countries, regarding responsible driving speed through residential areas. The residents claim that the vehicle speed is too high and that physical countermeasures must be implementet in order to reduce the speed of the vehicles passing through these areas. The speed is often so high because the residential roads have been constructed with such a good geometrical standard which results in fast driving.
The highway authorities have been trying to find suitable countermeasures which would result in a reduction of the vehicle speed and, at the same time, would be economic feasible to implement.

Since 1975, the Institute of Transport Economics (TØI) has been commissioned by the Norwegian Public Roads Administration to carry out the research work in the following three stages:

1) Analyse the vehicle speed on residential roads and to carry out interviews of road users and residents.

2) Carry out experiments with possible countermeasures in several cities in Norway and to evaluate these.

3) Recommend geometrical road design standards, guidelines and handbooks on speed reducing countermeasures for residential roads.

2. VEHICLE SPEED IN RESIDENTIAL AREAS

The first part of the study was to carry out speed measurements and roadside interviews on some residential roads. The speed measurements and the interviews were carried out on 21 residential roads in Norway during the autumn 1976.
It was found from the roadside interviews that about 45% of the persons interviewed were satisfied with the traffic situation. About 40% of the parents with small children playing near these roads were not feeling that it was unsafe traffic environment for their children.

As far as physical countermeasures are concerned, 30% preferred special speed limits. About 15% would like to see "no through road" signs erected and more footpaths constructed. About 40% would like a speed limit of 30 kph or lower. Road users, who did not live in the area surveyed, asked for more "playing areas" for the children.

Motor vehicle drivers were then asked which factors that caused them to reduce their own driving speed, and about 54% mentioned that "children playing in the area" was the most important factor. Then "concealed accesses to properties" and "respect for the traffic rules" were other important factors. The chance of being caught by the traffic police for not obeying the traffic laws was mentioned by less than 1% of the persons interviewed.

Speed measurements showed that it was a close correlation between road width and driving speed. Figure 1 below shows that while only about 5% of motorists drive faster than 50 kph when the road width is 4 metres, about 20% drive faster than 50 kph when the road width is 10 metres. This means that if the road width is 6 metres or more, a speed reduction could be achieved if the road width is reduced to 4 metres or less.

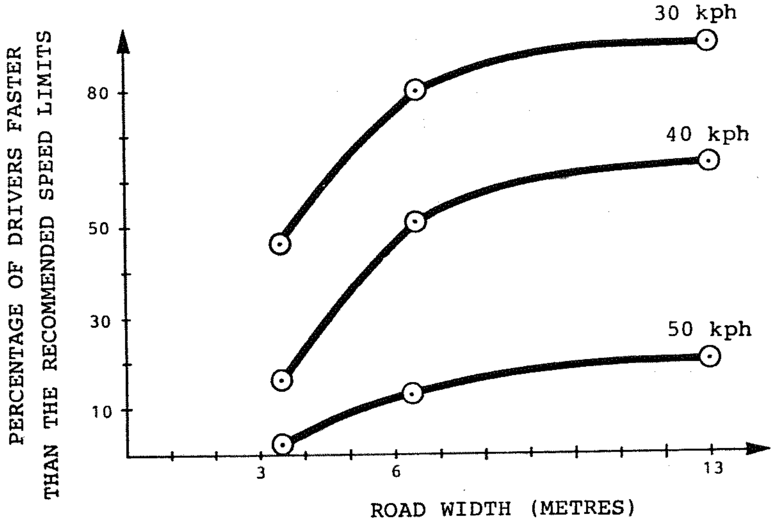


Figure 1: Correlation between road width and vehicle speed

There are several methods which could be applied to reduce the vehicle speed, and these methods could be grouped into the following 3 categories:

1) Geometric design:
   - road curvature
   - road width
   - length of the road

2) Physical measures:
   - road humps
   - refuges or road narrowing
   - diagonal diverters
   - roundabouts

3) Traffic management:
   - speed limit
   - limited access
   - traffic signals
   - give way/stop signs

The second part of this paper will concentrate on the experiments carried out with 30 kph speed limits, humps and road narrowing.

3. TRAFFIC CONTROL DEVICES FOR RESIDENTIAL AREAS

a) Speed Limit 30 kph

One of the countermeasures which was most popular with the persons interviewed was the 30 kph speed limit. During the study both ordinary speed limit signs (for road sections) and special "speed limit zone" signs (for smaller residential areas) were tested.

Seven local authorities in Norway were contacted, who had already themselves expressed an interest to participate in the experiments. Since the actual numbers of traffic accidents were small, it was decided to use driving speed as a measure of the effect. The reason for this is based upon the general knowledge that it is a close correlation between vehicle speed and the number of and the severity of road accidents.

Speed measurements were carried out before the speed limit signs were erected, and about one year later. The measurements were, in 6 of the local authorities, carried out during a 24 hour period by using a radar hidden in a small trailer.

The results of the speed measurements are shown in the following table:

Table 1: Before - and After Measurements of 30 kph speed limit

Location	Average Driving Speed (kph)			% Driving Faster Than 30 kph		40 kph		50 kph		No of Vehicles	
	B	A	Diff	B	A	B	A	B	A	B	A
KRISTIANSAND	28,5	26,5	- 2,0	36%	34%	13%	9%	3%	1%	824	927
HAMAR	38,8	30,0	- 8,8	80%	48%	47%	15%	12%	3%	3 770	2 380
TRONDHEIM	43,6	34,6	- 9,0	85%	69%	68%	25%	33%	5%	6 582	4 514
KONGSBERG	31,1	31,6	+ 0,5	46%	47%	-	-	2%	2%	299	318
SØR-TRØNDELAG	32,1	28,2	- 3,9	54%	38%	21%	9%	4%	1%	1 454	1 429
LILLESTRØM	25,8	22,4	- 3,4	43%	29%	14%	6%	1%	1%	187	437

B = Speed Limit before (50 kph)
A = Reduced Speed Limit afterwards (30 kph)

The measurements were carried out during 1977 - 1979.

The results in table 1 show that the vehicle speed on most of the residential roads were reduced, and the speed measurements indicated that Hamar and Trondheim had the largest speed reductions. The preliminary results from these experiments showed that signing of reduced speed limits gave a reduction of the vehicle speed. By using frequent police enforcement a speed reduction of 10 kph can be achieved, depending upon the level of speed before the studies commence. Without police enforcement, it is rare that the speed reductions exceed 5 kph. In Trondheim there was police enforcement at two of the five sites studied.

The results from Trondheim and Kristiansand were classified into time intervals of one hour periods. The analysis of the results indicated that the speed reductions were greater during the day than during the night.

The percentage of motorists driving faster than 30, 40 and 50 kph indicated that an unacceptable number of drivers exceeded the recommended speed limit (30-70%).

The people living in the residential areas surveyed were also asked questions regarding the traffic and road safety situation. The answers given to three of the most important issues are shown in table 2 below.

Table 2: Answers given by the residents regarding the traffic situation in their neighbourhood

Question no 1: Has the traffic situation changed?		
Improved	=	69%
Not changed	=	17%
Worsened	=	1%
Do not know	=	3%
Question no 2: Do you prefer other countermeasures?		
Traffic sign ("Children playing")	=	33%
Road humps	=	21%
Footpaths or road closures	=	12%
Children play grounds	=	8%
Separate pedestrian ways	=	7%
Question no 3: How can we improve the respect for traffic signs?		
Increase police enforcement	=	47%
Information	=	44%
More traffic signs	=	9%

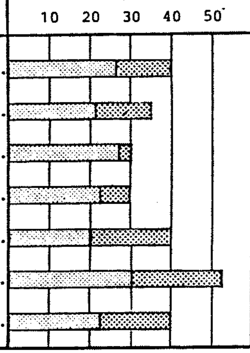
Generally speaking, there seemed to be a good agreement between the answers given and the results of the speed measurements.

b) Road Humps

Speed reducing humps on the road have been commonly used in several countries and the good effect of these has been described in many publications. The main aim of these experiments has been therefore to study the possible problems with respect to winter-maintenance, e g snow clearing and grading.

Humps on residential roads in Norway have been designed as segment of a circle, 4 m long and with a height of 10 centimetres. On roads with public bus routes, the humps have normally been 5 m long.

The results of the speed measurements on 8 residential roads with humps in Norway are shown in figure 2 below.



Location	Average Vehicle Speed (kph)	Percentage Driving Faster Than 30 kph B	30 kph A	50 kph B	50 kph A	85th Percentage Speed B	85th Percentage Speed A	Distance between humps (m)
OSLO		-	25%	14%	0	50%	31%	75 m
BÆRUM		65%	6%	4%	0	48%	35%	-
STAVANGER I .		35%	24%	0	0	36%	32%	75 m
STAVANGER II.		49%	14%	0	0	37%	29%	50 m
VERKET		93%	5%	15%	0	50%	26%	50 m
SEM		94%	50%	54%	2%	61%	40%	60 m
ASKER		89%	10%	6%	0	46%	29%	-

Key: B = "Before"-measurements
A = "After"-measurements
= Speed before countermeasure
= Speed after the construction of humps

Figure 2: Before- and After- Studies of Vehicle Speed on Residential Roads with Humps

The variation of the speed measurements taken after the humps were constructed could partly be due to the distance from the radar to the hump (the speed on the hump could be somewhat lower) and the variations of the shape and height of the hump. The results show that with a correct geometric design of the hump and distance between humps, an average speed of 25 kph could be expected, independent of the initial level of speed. Over the hump the vehicle speed will be below 20 kph.

Part of the speeding problem in residential areas is a small group of motorists, who drive fast, i e more than 40-50 kph, and who create a lot of unsecure feelings for parents due to the traffic, especially for the families with small children. It can be seen from figure 2 that this problem is eliminated at the places where road humps have been constructed. However, this is not the case where only speed limit signs (30 kph) have been installed (see Table 1).

Steady vehicle speed and less discomfort can be achieved by placing the humps closer to each other, e g 50-75 metres. Motorists would then not gain anything by accelerating between each hump and would be more prepared for driving at a lower speed. Then he would not have to think so much about where the road humps are situated and concentrate more on the traffic environment along the the road, e g other road users, children playing etc.

A distance of less than 50 metres between each road hump is not recommended as one has to consider the speed reduction on one side, the vehicle comfort and the road maintenance problems (snow clearing) on the other side.

Interviews have been carried out at some of the places where road humps have been constructed. The results of the interviews are shown in the following tables:

Table 3: Result of Interviews on 2 Roads with Humps (Stavanger 1979)

Question: "Is the traffic situation improved after the road humps were constructed?"	Much Better	Better	Not Changed	Worse	Do not know
	42%	34%	13%	3%	8%
	(76%)				

Question: "Is the Vehicle Speed Reduced after Humps were Constructed?"	Considerable Reduction	Reduced	Increased	Do not know
	48%	41%	0%	11%
	(89%)			

Question: "How are You Affected by the Road Hump?"	Road User Group	No Change, did not notice Hump	Annoying	More Difficult to travel	Do not know
	Car Driver	43%	21%	5%	31%
	Cyclist	44%	4%	0%	52%
	Pedestrian	65%	3%	0%	32%

Table 4: Results of Interviews regarding the Opinion on Road Humps

Location	Should the Humps Still Remain?			Are the Children Safer after the Construction of the Humps?			Comments
	Yes	No	Do not know	Yes	No	Do not know	
SEM	76%	19%*	5%	53%	16%	31%	* 83% of the persons answering "No" had no children.
VALE	69%	27%*	4%	53%	14%	33%	* 85% replies. 71% of the people interviewed had no children.
OSLO	79%	19%	2%	78%	15%	7%	33% replies

The experiments showed that pedestrians and cyclists clearly were not conscious of the humps. The majority of the motorists did not feel any disadvantage or discomfort because of the road humps.

The studies indicated that 75% of the residents wanted to keep the road humps. Those, who were negative to the humps, were mainly persons without children. These people do not experience the unsafe feeling of having children playing near a road, and the advantages which reduced speed gives due to the humps. However, almost 50% of the persons interviewed wanted further measures, e g "Children playing"-signs. The disadvantages with road humps are considered less than expected by the drivers. Only 25% of the people interviewed were conscious of the humps or felt that it was more difficult to drive because of the humps.

An other question, which was asked during the survey in Stavanger was if children were playing more in the streets now than before? Only 11% of the persons answered "Yes" to this question.

The winter maintenance problems with road humps have been studied systematically in several places in Norway during the last 2 - 3 years. The following snow clearing equipment has been used: pointed snow plough, diagonal snow plough, snow blower and grader. Experience has shown that the roads generally speaking can be maintained just as well after the construction of road humps as before.

It is measured an even layer of snow (1 - 2 cm thick) along the whole road. The main problem is that the effect of the hump can be somewhat reduced because snow remains in the transition between the hump and the road. The result is that the hump is extended and the transition becomes more gentle. If one wishes to maintain the normal effect of the hump, it is important to remove this snow quickly. Otherwise, the traffic will wear out this snow after a period of time - especially in the wheel tracks.

If one wants to carry out a satisfactory winter maintenance work with snow clearing equipment, it is important to drive the snow plough with reduced speed (15 - 20 kph) over the humps and to be very careful during this operation. In order to shift the snow away from the road, it could be necessary, if the snow is high, to drive several times over the humps. It could be difficult to estimate the total loss of time to carry out this work, but if there are not constructed too many humps, the time loss would be negligible.

Experience shows also that it is important to inform and motivate the winter maintenance crew, who carry out this type of work.

c) Road Narrowing

Road narrowing can, in principle, be constructed in the following 3 ways, as shown in figure 3. They can be on opposite sides (Type a), they can be lateral displaced (Type b) or they can be constructed as a traffic island in the middle of the road (Type c).

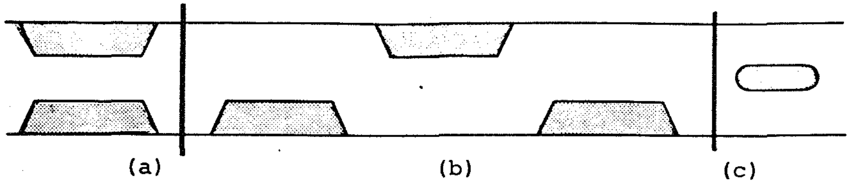
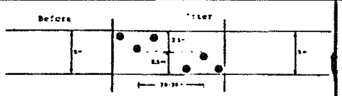
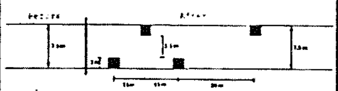
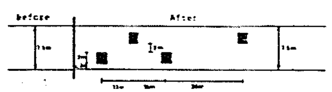
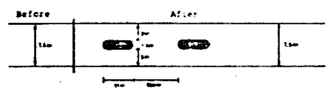
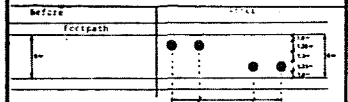
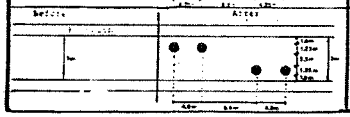


Figure 3: Various Types of Road Narrowing

Each of these types has its advantages and disadvantages, and they must be constructed to suit a particular location. Hence, types a) and c) could easily be combined with pedestrian crossings. It is also important to design the obstacles (road narrowings) in such a way that the road users have to turn in order to pass. For types a) and c) it would only be possible to carry out small changes in the direction of travel. The effect of the road narrowing would also be dependent upon the traffic volume.
Only road narrowing with types b) and c) have been tested. The results from 5 experiments are shown in table 5.
The results in table 5 show that road narrowing gives reduced vehicle speed. The smaller the opening between the obstacles, the

Table 5: Results from Experiments with Road Narrowing

Type of Layout	Before/ After	Average Speed (kph)	Standard Deviation	Percentage of Drivers Faster Than 30 kph	50 kph
	Before	33,0	15,3	62	10
	After	30,8	14,5	53	8
	Before	41,8	8,4	92	16
	After	35,1	7,4	75	3
	Before	41,8	8,4	[illegible]	16
	After	32,6	7,0	[illegible]	1
	Before	39,8	9,6	[illegible]	13
	After	35,1	8,6	73	5
	Before	35,3	8,5	75	5
	After	27,0	-	28	0
	Before	34,4	8,0	72	5
	After	32,0	7,6	63	2

smaller the vehicle speed. Roadside interviews of drivers in the streets where these experiments were carried out, indicated that the people wanted these obstacles removed more than with the experiments with other speed reducing measures.

4. CONCLUSIONS AND RECOMMENDATIONS

The results of the experiments which have been described in this paper have now been well known in Norway. One of the most important results has been the use of reduced speed limits. Previously, technical officers had been very sceptical and tried to avoid erection of these traffic signs. However, today these signs are frequently used within the framework of those policy guidelines given in the new traffic sign manual (1981). The following criteria have been issued by the road authorities for the use of 30 kph speed limit zone signs:

1) The straight sections of the residential roads must not exceed 50 metres.
2) The amount of through-traffic must be small.
3) The speed level must be less than 10 kph over the preferred speed limit.

These criteria can be deviated from if, in addition, the following speed reducing countermeasures are constructed, e g humps, road narrowing etc.
Road humps have now been constructed in several local authorities in Norway, and these humps have often been built in addition to the erection of speed limit signs.
Road narrowing is still a new countermeasure in Norway, so it is not used much yet. How these measures should be used, however, has been extensively discussed.
Our opinion is that it must be possible to make more use of 30 kph speed limit zone signs in residential areas. On certain collector. and main roads it will be necessary to increase the speed limit to 50 - 60 kph. On certain roads in residential areas, where the speed level is too high, there will be demand and a need for road humps, road narrowing, road closures etc.

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An Adaptive Theory of Road safety

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1. Introduction of Issues

In 1979 an approximately 800 Meter portion of road in Unterhaching near Munich was rebuilt, following the Dutch model of Woonerf to be a "verkehrsberuhigte Straße" (a traffic quited street). The main element in the design of the "verkehrsberuhigten Straße" was the creation of a mixed surface (Mischfläche). This means that the segregation of traffic types (seperation principle) is eliminated so that one surface which is at the equal disposal of all traffic participants, is created.

For this mixture to operate safely, driving speed should be drastically reduced. Reduction of driving speed should be achieved through curves, narrow areas, percieved irregularities, elimination of acceleration inducing parallel lines and intersecting elements. At the same time the inconvenience of driving on "verkehrsberuhigten Straßen" should have the result that, depending on location in the network, through-traffic avoids these streets. Frequent meetings of the remaining traffic participants is desirable. "The mutual experiencing of residents on the street should improve the social responsibility in the area concerned" (EICHENAUER et al. 1980 a, S. 9).

Planners emphasize that traffic safety in "verkehrsberuhigten Straßen" no longer chiefly depends on institutionalized rules. Rather traffic safety depends on the timely recognition of the intentions of others.Adaptive behavior should not be forced through restrictions (for example curbs).
"Rather the street design should make the social function (childres playing, taking walks etc.) so perceptually clear that the resulting motivation produces voluntary adaptive behavior" (EICHENAUER et al. 1980 a, S. 11).

Underlying this planning concept is the hypothesis that through changes in the built environment, behavior of traffic partici-

pants can be influenced and traffic safety can be improved.

For the "Bundesanstalt für Straßenwesen" (BAST, 1980) these questions were essential:

a) do new traffic risks arise if this design concept is realized and
b) which methods are suitable for short term measuring of the effects of the rebuilding on traffic safety.

These questions seem to be answerable only if one knows something about how street form influences traffic behavior and how the resulting traffic occurrences are to be evaluated in regard to traffic safety.
Thus sought after is a (social science) theory, which will give a plausible representation of how street form, behavior of street users and traffic safety are related. This theory would then indicate, what risks are to be expected, what conditions the risks influence and whith what methods a short term measurement of safety is to be approached.

2. An Adaptive Theory of Road Safety

The idea of using a relevant accident count (accident density, accident rate etc.) suggests itsself, but has to be rejected because the accident criterium is useless for quick judgement of the safety of a limited stretch of street. Because of the relative rarity of accidents,several years of data gathering would be necessary. Also KLEBELSBERG (1977) emphasizes, too many chance factors influence an accident. It would hardly be possible to isolate the part the structure of the built environment plays in the occurence of accidents from other factors. Because of this some researchers are turning away from using the accident as criterium and are instead focusing more on the antecendent stages of accidents, namely almost-accidents, traffic conflicts, traffic offences and inappropriate behavior. The fundamental idea consists of registering behavior and interaction processes which are related to accidents but occure more often and are thus more easily observeable. Also an attempt is sometimes made to do justice to the complexity of occurrences on the street through use of multi-dimensional observation (for example temporal and spatial proximity of traffic participants, suddenness of reactions etc.). The frequency of events which can be conceived of as antecedent stages are used as indicators of safety. This process therefore will be termed indicator approach. It implies a mechanistic theory of safety as it is, for example, perfectionized in the operation system of the "Bundesbahn": the signal and switch changes should be blocked so that two trains can never move into the same track stretch. Signales ensue in time, and in case of emergency forced braking occures. Intervention of the engineer after visiual contact should not occure, it would be an indication of a grave defect in the security system.

The safety conception of traffic planners was - as it is still largely today - mechanistic. Seperation of traffic types, the lanes, the intersections on several levels and traffic light changes result from this concept. Since it is not possible to implement it with the same perfection as for a rail system and also neither the space nor the funds are present to implement it i. urban areas, there are de facto many intersecting traffic movements.
Because of this the introduced planning and design concept Unterhaching purposefully focuses on the encounters and interactions of traffic participants, since these can not be completely avoided. Through the redesign conditions should be created such that interactions and encounter constellations can occure safely and not be unexpected as in the mechanistic model, where they necessarily do occure and therefore often lead to accidents.

The model contrasting with the mechanistic model will be termed adaptive theory of road safety. The planning and design concepts described above are implicitly based on this theory.

The initial consideration is that a traffic system owes its functionality to the control of humans. The traffic system functions safely, if the traffic participant is able to adequately adapt to the demands of the situation. The behavior of traffic participants and adjustment to the demands of the situation is

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termed achievement behavior.
Analogous to achievement behavior, the adjustment behavior of traffic participants is definied as function of ability and desire.
Thus adaptive behavior depends on the adjustment capabilities and adjustment readiness of traffic participants.

The degree of controllibility of a system will be termed reagibility. The better adjusted the behavior of single traffic participants is, the more reagible is the total street system and the slighter is the probability of accidents.

1. Adaptive Capabilities

What factors influence the adaptive capabilities of a traffic participant?
We destinguish two groups of variables.

a) personal abilities and skills, experience of traffic participants (for example driving ability)

b) variables of the traffic situation (adaptive possibilities)

ad a) personal factors

In traffic psychology it is a wide spread hypothesis that the "endowment" of the driver with certain motor skills, his reaction ability, his intelligence etc. is related to the accident proneness of the driver. It was thought, that "bad" drivers have a greater accident proneness. This hypothesis has not been verified in studies of "accident prone personality" however. Apparently driving ability does not play the decisive role in avoidance of accidents (HOYOS, 1980).

ad b) variables of the traffic situation

The adaptive capability of the acting individual is also influenced by variables of the traffic situation.
The demands of a traffic situation can present various difficulties for a traffic participant and thus make adaptation more difficult. Precisely stated: the traffic situation, to which the traffic participant should adapt, can

be structured so that it is impossible for the driver, in spite of excellent personal abilities and skills, to properly reakt to the demands of the traffic situation (discrepancy between driver fitness and workload, s. GERBERT, 1981). We have termed the influence which the objective situation exerts on the adaptive capabilities of the driver adaptive possibilities.

This reflection is derived from pedestrian movements: people collide very seldom even in the densest crowds. They skillfully move past one another. If there is contact it is, as a rule, without consequences. The pedestrian-pedestrian interaction works not only because, as is often claimed, pedestrians have much room for evasive manoeuvers, but because the demands which are made of the pedestrian in this situation correspond with the pedestrian motor, sensory and cognitive capabilities. The reaction time resulting from the situational possibilities is greater then personal reaction time, so that the pedestrians generally can react opportunely and safely.

2. Adaptation Readiness

Actually one should proceed from the assumption that every traffic participant has the long term motive of avoiding accidents and is willing, in order to prevent damage to him/herself and others, to adjust to the traffic situation because of this safety motive.

In the newer motivation research one finds indications that there is an assortement competing motives (desire for power, agression, risk needs etc.) during participation in traffic, which influence traffic behavior. Need for risk and risk taking behavior have a special position within traffic psychology (for example KLEBELSBERG 1969, WILDE 1974, HOYOS 1964, 1969).

In WILDES (1974) "Theory of Risk Compensation" it emerges as risk taking willingness. It is defined as an intraindividual, relatively constant quantity (trait).

WILDES theory of risk compensation states: "The contribution that

danger percieved in the environment divided by the amount of personal caution, results in a constant, or in other words, the accepted risk. The greater an objective danger seems to a driver and the lower the risk that he is willing to accept, the more careful he will be" (S. 230, 1974).

Thus a traffic participants cautious behavior depends on risk readiness and risk perception. WILDE derives two intervention strategees from this.

1) Lowering of risk readiness
2) Increasing danger awarness

ad 1) Lowering of risk readiness is attempted through pedagogic measures in traffic education. It should be pointed out that risk willingness is related to age. Risk taking readiness seems to be especially high among youthfull traffic participants. Generally however the question arises whether it is desirable to change the risk readiness in an achievment oriented society, where risk readiness, exploration behavior, curiosity etc. are seen as motivational forces in achievement behavior and enterprise. Here there is a value conflict in society.

ad 2) The awarness of danger may be influenced in two ways:
   a) Enlightenment about what risks are related to which behaviors.
   b) Influencing risk perception and interpretation of the situation.

WILDE shows that certain measures, which are supposed to increase safety, are not effective because the traffic participants compensate for the increase in safety, which would have occured if traffic participants had acted as expected, through their behavior.

Thus traffic participants perceive the safety improvements and compensate for them through their behavior. The assumption that objectively safe situations can be percieved as such and vice versa is implicit in this thesis (congruence between objective and subjective danger). From this it may be concluded

that risk perception can be influenced by changing situations. Thus a situation should be objectively safe, but elicit a certain subjective impression of danger.
Exaggerating, Dietrich (1976) formulated "The safe street is the homogeneously dangerous street.... " (Pg. 11).

We are not of the opinion that the purpose of a structural change should be to make traffic participants constantly insecure. Permanent feelings of insecurity could also lead to insecure behavior, which is detrimental for traffic safety.
MAUKISCH und PFEIF (1976) energetically protest against the belief that the traffic participant voluntarily accepts risk. "From the viewpoint of the driver it is important to reach a destination and at the same time to decidedly keep the (subjective) risk at null. Objectively this safety can be reached at no time, but vehicle use would certainly not be so wide spread if there were not the general belief that the subjective risk can constantly be kept meaningless .... through appropriate actions" (Pg. 19).
Indepent of whether a driver is willing to accept a certain amount of risk or he/she wants to keep the risk at null, the question of through what driving style he reaches his "individual norm" arises. Congruently the authors see this norm as a relatively constant trait. From this it follows that - if the norm is constant, driving style nevertheless differs so that the norm is reached in different situations - an explanation is necessary for the differing behavior.
TAYLOR (1964) has shown that the activation level of motorists measured by galvanic skin response, remained constant in spite of differing traffic conditions - this is also support for a constant norm, which however points toward another state of affairs. Humans are not just stimulus neutralizers, but also stimulus seekers, thus humans have a basic need of a variety of experience and information (BERLYNE 1965, BRODY 1971). The result is that humans avoid situations that elicit boredom as well as situations that elicit tension but seeks optimal stimulation, which is experienced as pleasant (LEUBA 1955).

While driving the motorist is constantely bombarded with information from the environment. The driver can then, to a certain extend, influence the offering of information which results from the situation and which effects his stimulation level, through his own driving style.
If the information load is too great, the driver can for example reduce speed and thus reduce the amount of information per time element, to avoid overload and stress. On boring monotonous streets which cary little information, the driver can increase speed, so that his/her optimal stimulation level is reached, without feeling insecure or overload.

From the vantage point of this theory it may be concluded that a driver being dependent on the quantity of information in the situation chooses a style of driving such that he/she is neither over- or underloaded in the long run and at the same time feels safe, so that his/her subjectively experiences risk is kept around null.
Reports of drivers on this topic support this (HELD 1980). Thus drivers strive to realize an internal state of balance with their style of driving, even though the driving style may be classified objectively as being risky.
In our opinion one of the main problems of traffic safety is here. A normal driver is, as a rule, neither a"suicidal driver" nor a "race driver", who always drives at the limits of his/her capacity and stress tolerance. Rather the problem is that the driver does not adequately assess the results of driving style (for example effect on reaction time, braking distance, centrifugal fores etc.), which the driver experiences as pleasant. Humans are by nature pedestrians and control the physical requirements of walking. Humans obviously lack the ability to appropriately depict the physical forces of an automobile.
Situations in which the driver already reaches his/her "individual norm", be it a certain quantity of risk, or his/her optimal stimulation level, through a driving style (for example low speed) which objectively gives him/her sufficient reaction time, are beneficial for traffic safety (sufficient reaction time is present when

the reaction time resulting from ones own speed and ones own momentary dispositions is less then the reaction time resulting from situational possibilities).
In general highly informative situations would be beneficial in places where, for example, low speeds are necessary for traffic safety (for example residential streets).

The content of information from the environment is also essential for traffic safety. The information should induce the driver to adapt anticipatively and predictively. This means that the driver not only orients him/herself by actual events but can also understand environmental cues which indicate potential, not immediately perceivable interferences and events. Thus besides the information quantity, the information content termed demand character of situations (valenz) is also covered.

In addition to the previously discussed motives of safety/risk and the information motive, there are a number of further competing motives which are important.
Now the pivotal and pressing issue for traffic behavior and traffic safety is which motives come through under what conditions. It is to be assumed that in situations which are experienced as competitive situations the norm "leave the other driver behind" is activated and then results in the corresponding behavior - undesirable for traffic safety, but an "appropriate" reaction to the demand character of the situation.
Another example, which directly concerns the issues covered here, is the designing of a street such that it is inequivocally experienced as belonging to pedestrians. Thus we assume that resulting is an activation of the rules of social conduct (being considerate etc.) of the motorist, while competition motives and risk motives fade into the background. If the demand of the situation activate the rules of conduct, then the question of what information the designer should "write into" the situation through design elements to achieve an anticipatory adaptation, arises.

Adaptation theory holds that humans are, in principle, willing to adapt to the demands of the situation. It is decisive how a person interprets a situation, his or her subjective situation. The subjective situation of the driver may be influenced through

the objective design of the street. It was attempted to support this through theory of optimal stimulation and demand characteristics.

Summary of the most important tenets of adaptation theory:

The safety of the street traffic system can be increased if adjustment to the traffic situation is made possible for traffic participants. Analogous to achievement behavior this bahavior of traffic participants is defined as a function of ability and willingness.
Adaptation theory holds that both components, that is adjustment capabilities (through adjustment possibilities) as well as adjustment readiness (through information load and demand characteristics of the situation), may be influenced through the built environment of the street.
A change in the built environment increases safety if it positively influences adjustment capability and adjustment readiness and thus increases the reagibility of the system.

3. Applications of the Adaptation theory in Safety Measurement.

Adaptation theory holds that traffic safety may be increased through the changes in built environment if the changes positively influence adjustment capabilities as well as adjustment readiness.
From this two steps follow for the analysis of the research hypothesis that traffic safety is improved through structural change.

1. Designation of relevant variables, which are altered through the structural change and assignment of the variables to the constructs of adjustment capabilities and adjustment readiness.
2. Analysis of how the relevant variables change and assessment of the change in light of adaptation theory.

ad 1) Adjustment capability is derived from the component driving skills and the reaction possibilities for the traffic participants that results from the situation. It may be assumed that driving skills of a motorist, his/her abilities etc. do not substantially change, since first of all the same driver uses the street before and after a structural change and secondly because there is only slight time period before and after the structural change.

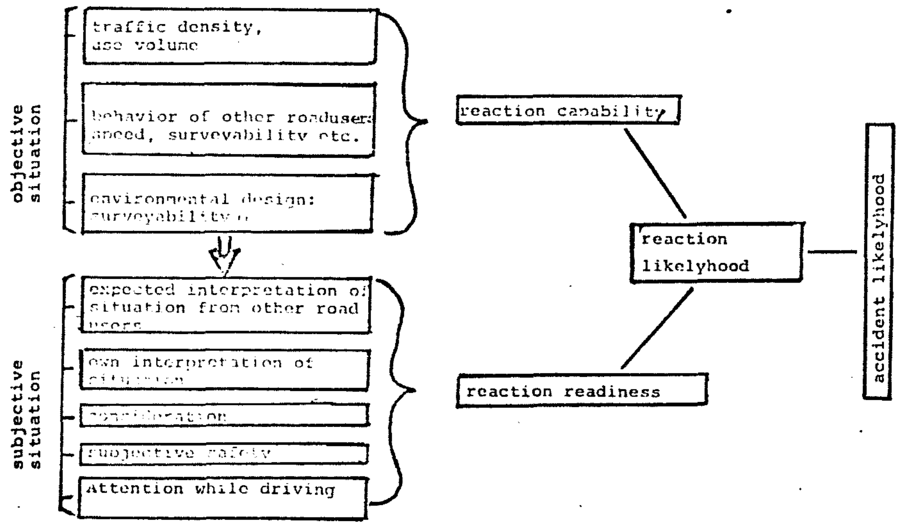
Changes in reaction possibilities are expected as a result of the structural change. The shorter the braking distance is and the better evasion possibilities are, the better the reaction possibilities are for the acting individual in a street situation. This physically mainly depends, aside from certain vehicle qualities, on speed and traffic density. The surveyability of the street area also plays a role since the driver can only react to the situation which is encompassed by his field of vision. Decisive is not only the drivers own speed but also that of other traffic participants. These conditions will be termed objective situation. They influence the reaction possibilities of the acting person.

The second condition for reagibility of the system is reaction readiness of a traffic participant. The theory of adaption holds that a traffic participants is, in principle, ready to adjust to the situation. However his or her adaptive behavior is dependent an his or her subjective situation. Transfered to the concrete issue the question of whether the driver actually interprets the situation a "pedestrian street" and gives the pedestrian priority arises. Furthermore, what behavior and what interpretation of the situation does a traffic participant expects from the other participants? The assessment of subjective safety is also essential in determining the driver's behavior. If he/she does not reckon with other traffic participants being on the street and fells to safe, this is detrimental for his reaction readiness. In addition it is important that the driver accepts the street design of a traffic quieted street and does not experience it as an obstical, because otherwise

aggressiveness rather than consideration would result.

Finally intense attention on the part of the driver is beneficial, when coping with critical situations. These conditions will be termed subjective situation of a driver. They determine the reaction readiness of the acting individual.

These aspects are summarized in the analytical model of road safety:



ad 2) According to adaptation theory, road safety is increased if reaction capabilities and reaction readiness are improved: reaction capability is improved through

- reduction of driving speed
- reduction of traffic density
- increasing the surveyability of the street area

It is beneficial for reaction readiness if

- the street is experienced as a pedestrian street after the structural change
- consideration of traffic participants increases
- the subjective safety increased less strongly than the objective safety increased
- the attention of the driver is increased while driving on the traffic quieted street
- traffic participants accept the traffic quieted street.

4. Research Results

Results are from EICHENAUER et al. (1980), MOLT and BEYRLE (1982), BEYRLE and MOLT (1982).

a) about reaction capability

- Speed

Measurement Location	before	after $\bar{V}$	Diff. absol.	before	after V 85	Diff. absol.
Friedens-platz only in day	42,6	19,0	- 23,6	48,6	22,7	- 25,9
only in night	45,6	20,3	- 25,3	x	x	x
Haus Mager	42,3	27,2	- 15,1	48,6	33,4	- 15,4
Gerade Süd	45,2	33,6	- 11,6	52,6	41,1	- 11,5

x = not measured

Through the re-design driving speeds were reduced to an average of 23 km/h (before 43 km/h). Even greater reductions occured in the especially safety relevant maximum speeds.

The results of another study, in which the authors also participated, confirms these speed results (EICHENAUER et al. 1981).

Six conventional residential streets were compared to six traffic quieted streets. On the average there was a speed of 23 km/h in the traffic quieted streets and a speed of 36 km/h in the conventional streets. It should also be mentioned here that different driving styles have an enormous effect on the noise emissions of a vehicle. This study showed that in "verkehrsberuhigten Straßen" driving was up to 10 dB(A) and on the average 5 dB(A) quieter. Noise relevant design elements were shown to be: segmentation of the street width (mixed surface), amount of visual lines and width of the usable driving space.

- traffic density

  The amount of individual motorized traffic was reduced by almost half during the middle of the day as well as during peak hours (after the re-design : peak hour 120 automobiles). The number of pedestrians and bicyclists increased by about 15 percent.

- surveyability

  through the re-design almost all blind corners in the street were removed. Sufficient surveyability is possible from even location on the street without the result of a "optischer Durchschuß" (long range visual permeability).

As the results of the study show, the measured variables have changed for the better from the vantage point of adaptation theory. Reaction possibilities have improved for the traffic participants.

On Reaction Readiness

- Interpretation of the situation: after the redesign the road users interpret the situation as being traffic quieted street, where pedestrians and bicyclists have priority.
- Consideration: a change in consideration can be registered only for motorists, whose consideration is reduced. This may be traced back to a group of drivers who were anoyed with the behavior of pedestrians after the redesign.

- Subjective safety: the subjective feeling of safety of traffic participants essentially did not change. Because of the improvement of the objective conditions this state of affairs is evaluated as beneficial for reaction readiness.
- Attention while driving: the drivers claim that their driving is relaxed and attentive after the design. (1)
- Acceptance of the street: the new street is accepted by most of the street users. This is expressed in the positive expectations of the street users before the redesign and in the fullfilled expectations after redesign. Altogether the street is an aesthetic improvement. The subjective noise experience is also improved more than corresponds to the objective noise improvement (see EICHENAUER et al. 1980 b).

The results for the subjective situation of the traffic participants are not so clear as the results for the objective situation. At least in one case, in which measurement problems can not be excluded as causes, a deterioration of the indicator resulted.
Generally, however, it can be concluded that the subjective situation of street users beneficially influences their adaptation readiness.

Congruent with this results is that after redesign no "dangerous situation" in terms of the indicatior approach arose, compared to nine before redesign. Observed conflicts, three before and three after, remained constant. After the redesign two accidents with slight material damage occured within three years, compared to 16 accidents within seven years prior to the redesign.

(1) Contrary to previous interpretations (vgl. HOLT et al. 1982) this is evaluated as being beneficial for reaction readiness.

5. Conclusions

From the development of adaptation theory and its application two conclusions are drawn with regard to road safety:

1) From the vantage point of traffic safety new design concepts for installation of city streets should be demanded.

2) Streets can be evaluated in an uncomplicated process from the vantage point of road safety, which makes a short-term assessment possible.

ad 1) In city streets meetings and interactions between traffic types are not avoidable because of various reasons. In many cases the customary street designs do not provide the prerequisits for a safe and oportune adjustment to the demands of traffic happenings. Design concepts, such as the ones realized in Unterhaching, are appropriate for creating traffic conditions to which traffic participants can adjust and which increase road safety.

ad 2) Accidents and traffic conflicts are unsuitable for a short term assessment of traffic safety of a large street segment. Indicators, such as those suggested in the analytical model of road safety, are easy to gather and prove to be sensitive indicators of changes.

For further developement of these indicators we suggest two measures for the short-term assessment of safety (reagibility) of a large street area:

a) variability of speed: as SALUSJÄRVI (1980) was able to show, the homogeneity of driving speed plays an important part in the traffic safety of a street.

b) reagibility measure: $\left(\frac{\text{potential braking distance}}{\text{actual braking distance}} \right)$
This measure will be defined as quotient of the potential braking distance, which results from the existing surveyable space, and the actual braking distance, which results from driving speed and individual reaction time. If for example the surveyable

area (to the front and to the side) is greater than 30 meters from every location on the road and the braking distance needed to stop is less than 30 meters, then the quotient is greater than 1, which is favourable for the avoidance of accidents. If the reagibility measure ist greater than 1, then the likelihood of accidents should be slight. If it is less then 1, then the likelihood of accidents increases.

It seems to us that measurement of accidents and (serious) conflicts are vital for the validation of these indicators. It should be noted that not all accidents are appropriate for this (not appropriate are for example, accidents that induced by alcohol). Reactions, which are already assessed as being slight conflicts, are direct indications of the reagibility of a system and thus not suitable for validation.

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Evaluation of a pedestrian training programme for preschool children*

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Introduction

Traffic accidents form for children a most serious threat to the life and health. The extent of the child traffic accident problem in the Netherlands, both in the absolute and in the relative sense, has been described by Van der Molen (1978). Some conclusions of that study are presented here.

In 1972 one third of the Dutch child mortality between 5 and 14 years of age was caused by traffic. In that year 3 out of every 1000 children in this age category was registered as being wounded in a traffic accident. Interpreting this figure we have to consider that the accident registration system is far from complete. If one doesn't correct for the (low) degree of traffic participation (exposure), then accident statistics give a gross underestimation of the risk children run in traffic. That children cope badly with the traffic system appears from the fact that, despite a relatively low exposure, children get more pedestrian and bicycle accidents than adults. Until 9 years of age Dutch children are mostly wounded in traffic as pedestrians, above this age mostly as bicyclists. The accident peak for wounded pedestrians lies around 6 years of age and for wounded bicyclists around 12-15 years of age.

The exact circumstances under which child traffic accidents occur, i.e. types of environments, manoeuvres, behaviour and predisposing factors, have been studies in many countries. A detailed review of some 50 studies of this kind was provided by Van der Molen and Tutert (1980, 1981). These data have been re-ordered in the framework of a pedestrian task analysis, together with data on children's traffic behaviour and exposure. In another study (Van der Molen, 1980), it is outlined how these types of data on "pedestrian performance" can serve the process of selection of important educational objectives for particular age groups. That study led to the conclusion that it is important to try to train preschool children in the task "crossing from between parked cars", despite the fact that this is a task which is conceptually hard to grasp for this age group. The reason for this was that preschool children in the Netherlands are mostly involved in this type of accident, and that it would generally not be feasible to make them cross away from parked cars.
It was further concluded that preschool children were next to be trained in crossing at intersections, a type of accident with a peak around the age of six, around the time Dutch children change from Kindergarten to primary school.

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Objectives of educational programme

Countermeasures to improve the safety of young children in traffic can involve legal measures (e.g. reduction of the speed limits for motorized traffic in residential areas), engineering (e.g. redesign of residential areas , introduction of ramps to reduce speed) or involve educational programmes in order to alter the traffic behaviour of children. An essential first step in the design of any countermeasure, be it educational, legal or engineering, is an analysis of the tasks involved in traffic participation, in this case, as pedestrian. This is essential for two reasons: Firstly, such an analysis tracks down which behaviour is most problematic and which situations are most hazardous, and consequently directs the focus of the countermeasure activities. Secondly, it clarifies the relevant factors that have to be taken into account in the evaluation.

A full-scale task-analysis can entail a behaviour requirement analysis, that specifies in detail the traffic environment and the behaviour required in those situations (i.e. a description of "ideal" behaviour), and secondly, a behaviour description analysis, which consists of empirical data from behaviour observation, traffic exposure and accidents studies (i.e. a description of "actual" behaviour), and thirdly, an ability requirement analysis, comprising an inventory of the psychological functions and abilities presumably required for task performance.

Dependent on the type of countermeasure and the particular age-group any of these approaches may receive particular emphasis. In the design of engineering countermeasures, for example, it is particularly important to ensure that the traffic situation does not set unrealistic demands on the psychological functions or abilities of the road user, hence an abilities requirement analysis would be essential. In the design of educational countermeasures it is important to compare "ideal" and "actual" behaviour, to identify the behaviour that falls short of the requirements and is critical to the safety of the target group. The performance of a task-analysis for pedestrian behaviour of young children has in fact been carried out and has pinpointed three behavioural sets which are notably critical to the safety of young children; crossing in quiet streets, crossing near parked cars and crossing at junctions (see Van der Molen, Rothengatter, Vinjé, 1981). These three behavioural sets have been formulated in terms of educationsl objectives, specifying how the child should behave after the educational programme has been implemented. Although these specified, concrete objectives form an explicit and quantitative basis for the process of evaluation, it should be stressed that they are by definition partly based on theoretical considerations. For example, the abovementioned task analysis demonstrated that crossing near parked cars gives cause to the majority of accidents with young children (see Van der Molen, 1980). Consequently, an ideal performance strategy for this situation was formulated, and included in the educational programme. Whether this ideal performance strategy does indeed prove to be safer than the actual performance cannot be demonstrated empirically unless an educational programme which is successful in terms of implementing this "ideal" strategy is carried out on a large scale.

This problem, which is termed "external validity" by Cook and Campbell (1979) is essentially a validity problem in the selection of the educational objectives and not a validity problem in terms of selection of evaluation criteria. Wilde (1978) uses the term "intermediate criteria" for the assessment of behavioural change in the target group, suggesting that traffic accident reduction is the primary objective of countermeasures. However, the effectiveness of an educational programme should primarily be measured in terms of the formulated objectives of the programme. In other words effectiveness measurement should assess to what degree the programme is successful in attaining its' objectives, which in the case of educational programmes should be expressed in terms of behaviour changes in the target group. Whether these behaviour changes do indeed result in a traffic accident reduction depends on the validity of the formulated educational objectives. Only after it has been ascertained that the educational programme is effective in terms of attaining its' educational objective, it becomes feasible to evaluate the validity of these objectives in terms of accident reduction in the target group.

Development and application of educational programmes

Once the programme objectives are defined, it is relatively easy to specify the content of the programme since this is directly deduced from the objectives. However, the methods of achieving the formulated objectives cannot be derived from the objectives. Methods of traffic education have been subject to extensive research which is reported in detail elsewhere (Rothengatter, 1981). Review of the experiments testing different methods of traffic education revealed that most methods are not successful. This can be attributed to the lack of a theoretical basis for these methods, which are mostly cognitive instructions, whereas theoretical considerations would advocate a behavioural approach in which the required behaviour is directly trained in the actual traffic environment. In a pilot study this approach was tested by designing a training programme for crossing near parked cars. Using behaviour modification principles such as positive reinforcements, the required behaviour elements were trained with four year-old children by experienced assistants. The effects of the training, which lasted for only twenty minutes, were assessed through a traffic knowledge test and a behaviour test. Multivariate analysis demonstrated significant effects of some of the training principles (Rothengatter & Brakenhoff-Splinter, 1979), which suggested possibilities of behaviour change through training even in very young children.
The results of this and other pilot experiments led to an extensive modification of the programme to include all three basic crossing strategies, i.e. crossing in quiet streets, crossing near parked cars and crossing at junctions. For each of these strategies the complete behaviour sequence was specified for training and for evaluation purposes. The complete programme involved both parents and preschools, and consisted of two weeks of training with one session a day. In a quasi-experimental application of the programme, the target group population of a small town in the Netherlands was divided into three groups. In one group the programme was applied as intended in large scale implementation, which involved the parents as well as the preschools. In this "parents" group, the parents were informed about the programme and motivated to participate through a parents discussion evening at the school, a 20-minute film demonstrating the training methods and an information booklet, which they could use as reference during the training. They were also presented behaviour observation scoring forms to be used as checklist after each training session. In addition, the schools in this "parents" group carried out an instructional programme, using audio-visual material, which was in line with the parents' activities.

Since the parents' motivation and ability to carry out the programme as intended was an unknown factor, a second experimental group was introduced, in which the training programme was carried out by experienced assistants instead of the parents. This "assistants" group received an otherwise similar treatment as the "parents" group. A third group received a delayed treatment and served as controls. In all 315 children between four and six years old received the training programme.

Evaluation measures

Since the programme application required a massive research effort (up to forty people were full-time involved in the programme application) and was considered to be an essential step between small-scale pilot experiments and nation-wide implementation of the programme, the programme was extensively evaluated following several strategies.

The first strategy is termed process evaluation, since this evaluation strategy was designed to obtain as much information as possible about the process of the training carried out by the parents and the instruction carried out by the preschool staff. The second evaluation strategy is termed product evaluation, which was designed to obtain information about the effects of the training programme. For these two evaluation strategies the following procedures were developed.

Process evaluation

- parents' evaluation interview and questionnaire about programme application
- preschool staff interview about programme classroom processes.

Product evaluation

- children's traffic knowledge test
- children's test of behaviour repertoire in the real traffic environment
- children's spontane ous behaviour unobtrusive observation on the way to and from school
- unobtrusive observation of mothers' and children's traffic behaviour in each other's company.

The programme set-up and evaluation procedures are schematically represented in figure 1.

In the following sections the procedures and results of each of these evaluation measures will be discussed in more detail.

Parents' evaluation interview and questionnaire about programme application

Earlier studies (Rothengatter, 1980) which involved a survey amongst mothers with small children, have demonstrated that parents report to be very concerned about the traffic safety of their children, and virtually all parents report themselves to be involved in some sort of traffic education. This does not imply that they are necessarily very successful; the topics they chose to teach their children mostly do not include those which are known to be critical to safety of the children (most parents devote for example much attention to crossing at regulated crossings) and the methods parents use in educating their child in traffic are not particularly

parents group	assistant group	control group
knowledge test behaviour tests parent behaviour observation children's behaviour observation	knowledge test behaviour tests parent behaviour observation children's behaviour observation	knowledge test behaviour tests parent behaviour observation children's behaviour observation
PROGRAMME APPLICATION		
parents scoring forms	assistants scoring forms	
knowledge test behaviour tests children's behaviour observations	knowledge test behaviour tests children's behaviour observations	knowledge test behaviour tests children's behaviour observations
parents evaluation interview		
preschool staff interview	preschool staff interview	
parents' behaviour observation	parents' behaviour observation	

figure 1: experimental design and evaluation measures

effective (e.g. general warnings about the dangers of traffic or emphasizing incorrect behaviour). As a result, parents do not have very high expectations of the effects of traffic education.

In the evaluation questionnaire particularly attention was therefore devoted to questions related to the training methods followed in the programme, the training circumstances and the behaviour of the child during the training. As none of the parents explicitly refused to take part in the programme, every parent was considered as participant, even though they may not have carried out the complete programme or have dropped out during the programme. In fact, the return of the scoring forms which had to be completed by the parents after each training session was 88%, from this we can conclude that the majority of parents indeed carried out the programme as intended.

About half of the parents reported that they followed the training methods exactly. Virtually all of them found them easy to carry out. The most difficult for the parents appeared to be refraining from commenting on incorrect behaviour, which was strongly advocated in the programme. Crossing in quiet streets appeared to be somewhat easier to train than the other crossing strategies, but most parents felt that their child benefitted most from the part of the training related to crossing near parked cars. Stopping and looking for traffic are the children's behaviour elements that are most often reported as changed (about 60%). Some 57% of the parents felt the programme has helped their child to behave more safely; only 7% was positive that the programme did not make any difference.
The results of this questionnaire enable considerable programme improvements on the level of presentation (e.g. inclusion of tips for situations in which the child does not want to cooperate or how to cope with incorrect behaviour) and on the level of presentation (e.g. clear distinction between the different parts of the programme). In addition, the questionnaire data could be used as predictor variables in a regression analysis in which the behaviour posttert scores of the children (see below) served as criterion variable. This enabled assesment of the robustness of the programme and could also be used to identify those programme training methods which contributed most significantly to the programme effects. The behavioural pretest score was added as a fixed predictor variable to compensate for possible ceiling effects. The total amount of explained variance is about 55% if 9 variables are included (Multiple $R = .74$). Variables which contributed significantly to the prediction of the behaviour test-scores included: the fact that the child liked the programme, that the parents regard the use of positive reinforcers as effective and attractive and that the parents were able to refrain from negative comments on incorrect behaviour. These results could not only be used to make further improvements to the programme, but more importantly, could be interpreted as strong support for the approval of the programme, based on learning theoretical considerations concerning the importance of attractive practical training and the use of positive reinforcers in the programme.

Preschool staff interview about programme classroom processes

This evaluation procedure was included in the total programme evaluation, based on the consideration that the preschool staff has an important role in disseminating the programme and motivating the parents to participate. In order to obtain full cooperation of the staff it is of crucial importance that the programme is adapted to the existing classroom routines . Earlier studies (Rothengatter, 1981) had already ascertained that the most effective traffic education activity that can be displayed in the classroom involves presentation through audio-visual media of the traffic behaviour to be learned. However, the present process evaluation amongst preschool-staff revealed that such presentations were regarded as impractical, if they were not accompanied by other materials which enabled preschool staff to elaborate further on the subject. Thus the conclusion of these evaluation interviews was that the audio-visual material should be amended with other printed materials, because even though these printed materials would as such not be an effective ingredient in the programme, they would fascilitate acceptance by the preschool staff of those materials which have an proven effectiveness.

Children's traffic knowledge test

Increases in traffic knowledge are frequently reported as effects of the application of traffic education programmes (e.g. Jones, 1979) and by some authors considered as a necessary prerequisite for behavioural change. Indeed, many evaluation studies of traffic education programmes employ traffic knowledge as sole criterion for evaluation, without explicitating why or how improvements in traffic knowledge are related to changes in traffic behaviour (e.g. Singh, 1978). In order to test the knowledge behaviour relationship and to investigate whether knowledge improvements are necessary for behaviour improvements a traffic knowledge test was administered to all subjects before and after the programme application. The test consisted of 40 dichotomous items, presented on videotape. Each item displayed a child in a particular traffic situation and the subject had to indicate whether the child's behaviour is correct. The traffic situations displayed in the test corresponded to the traffic situations in which the programme training took place. In the construction of this test, the test was subjected to an item analysis based on item test/rest correlations. The results of this item analysis led to a subsequent factor analysis that resulted in a three factor structure. The reliability of the test and the three subtests was estimated by determining the internal consistency. The coefficient α amounted to .77 for the total test, and .82, .94 and .79 for the three subtests (Rothengatter, 1977). The pretest scores of the traffic knowledge test in the present experiment were used as a replication for the calculation of the coefficient estimate of internal consistency for the three subtests, which amounted to $\alpha = .89$, $\alpha = .84$ and $\alpha = .73$ respectively. Alpha stratified was calculated for the total test at .74. These figures correspond quite closely to those found in the test construction. A replication of the factor analysis on these data confirmed the three factor structure of the test. Not withstanding the satisfactory psychometric characteristics of the traffic knowledge test, the test failed to demonstrate any consistent improvements in traffic knowledge as measured with the test or with one of the subtests. This strongly suggests the conclusion that the programme does not have any demonstrable effects on traffic knowledge. In fact, considering the high average pretest scores, it can be concluded that the relevant traffic knowledge is already present in children even at a very early age.

Children's traffic behaviour repertoire test in the real traffic environment

Standardized behaviour assessment procedures for traffic education programmes concerning pedestrian behaviour are not available. The most widely accepted routine consists of bringing the pupil into a situation in which the target behaviour can be displayed and requesting or prompting the child to exhibit this behaviour. The designed behaviour tests concern the three crossing procedures of the programme. The items of these tests consist of the behaviour elements described in the concrete behaviour objectives. The tests have therefore 6, 9 and 8 items (e.g. stop, look left, look right, cross at right angles, etc.). The test procedure was carried out in normal traffic situation representative for the situations of the programme (quiet streets, parked cars, junctions). The subject would be brought into situations requiring the relevant crossing procedure in a naturalistic manner; for example through a walk in the direct neighbourhood of the school. The child's behaviour was not commended upon, and observation forms were used to score the child's performance. Although the items of the tests are directly deduced from the formulated concrete objectives and therefore cannot be considerd homogeneous, coefficient α was calculated for each of the tests to obtain an estimate of internal consistency. The resulting coefficient α was .63 for crossing in quiet streets, $\alpha = .55$ for crossing near parked cars and $\alpha = .62$ for crossing at junctions. Test-retest reliability estimates were calculated for the pretest-posttest scores of the control groups resulting in $r = .32$, $r = .58$ and $r = .48$ respectively. The limited reliability of the tests can be at least partly attributed to extreme high p-values of some of the test items.

On the data obtained from the test procedures a multivariate analysis of variance (Finn and Mattson, 1974) has been performed to assess the overall effect of the programme application. The data obtained from the younger group of children (younger than 5 years) have been treated seperately from the older group of children (5 years and over) to control for age effects. In both age-groups a significant pretest/posttest effect ($MF = 1948$, $p < .01$) and a significant interaction effect ($MF = 9.59$, $p < .01$) was found for the MANOVA. In the younger age-group an univariate analysis of variance was performed on the test data for crossing in quiet streets and for crossing near parked cars. The ANOVA for crossing in quiet streets revealed a groups effect and a pretest/posttest effect but no significant interaction (see for full details on the results of the MANOVA's and ANOVA's, Rothengatter, 1980). Figure 2 illustrates that the absence of interaction must be contributed to the high pretest

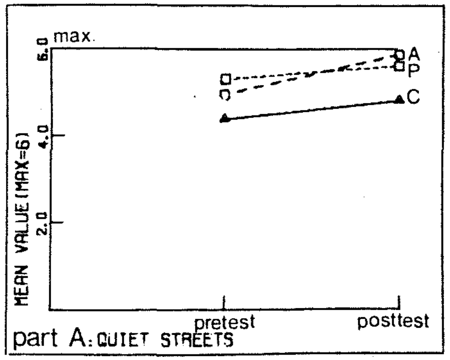

Figure [illegible] Mean values of pretest and posttest scores of the behaviour test A (crossing quiet streets) for children under five years.

values, which limit the possible improvements that can be reached in the experimental groups (In all figures A denotes assistants group, P parent group and C control group) The results of the tests were therefore also considered in terms of minimal crossing strategy. The performance of a safe crossing minimally requires children in the test situation to stop at a place from which they can detect all oncoming traffic and look in those directions from which traffic can approach. Scoring on this minimal strategy is dichotomous., either a safe strategy is followed or not Hence, it is possible to calculate the percentage of children following the minimal strategy before and after the programme. As illustrated in figure 3 this approach presents much clearer effects; while the assistants group reaches 100% correct and the parents group about 80% correct, the control group does not reach the 50% correct level.

The results of the NOVA on the test data related to crossing near parked cars are much clearer. significant pretest/posttest effect is found and a significant interaction effect. These results are illustrated in figure 4, presenting the mean values of the pretests and posttests scores. Both experimental groups show a substantial increase, whereas this increase is absent in the control group. This leads to the conclusion that the found effects can be interpreted as true treatment effects, which is confirmed by the analysis of separate contrasts. Presentation of the data in terms of percentages of children performing the minimal crossing strategy gives very much the same picture. Considering all ANOVA effects, it can be concluded

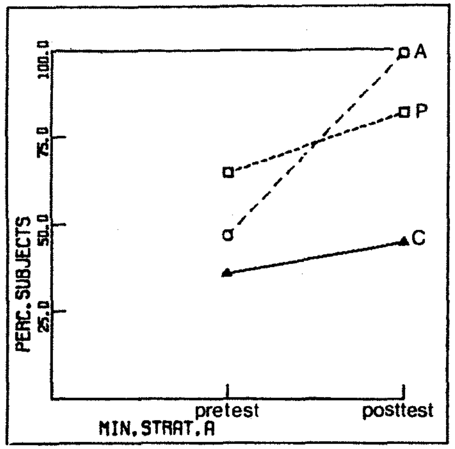

Figure 3 Percentage of subjects under five years performing the minimal strategy of part A (N = 181)

that for children under five years of age the application of the programme has demonstrable effects on the behaviour tests. These effects are more pronounced in the more complicated crossing situation (near parked cars) and are more pronounced in the assistants group than in the parents group. For the older age group the results of the pretest and the posttests on crossing near parked cars and at junctions are considered separately. As in the younger age group the MANOVA performed to assess the overall effects of the programme application resulted in a pretest/posttest effect (MF = 10.42

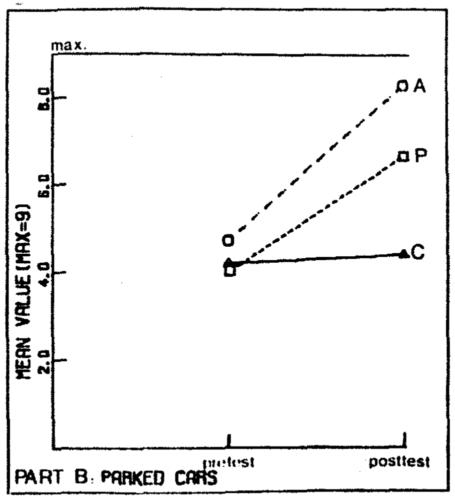

Figure 4 Mean values of pretest and posttest scores of the behaviour test B (crossing near parked cars) for children under five.

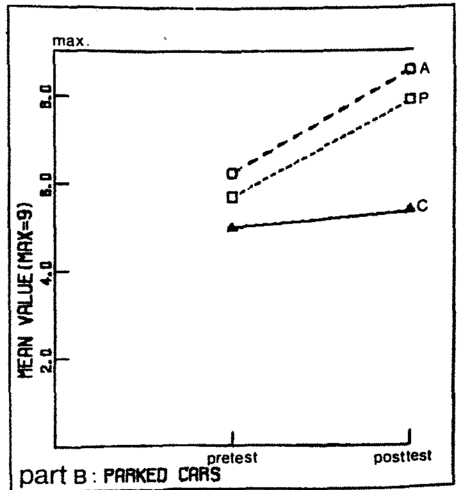

Figure 5 Mean values of pretest and posttest scores of the behaviour test B (crossing near parked cars) for children aged five years and over.

p .01) and an interaction effect (MF = 3.66,p .01). Univariate analysis performed on the data of the tests related to crossing near parked cars reveals again significant pretest/posttest effects and significant interaction effects. The mean scores on this test are presented in figure 5. Both experimental groups appear to gain substantially between pretest and posttest, whereas this gain is absent in the control group. A test for separate contrasts reveals significant differences between both experimental groups and the control group on the posttest. Figure 6 presents the same data in terms of percentages of subjects performing the minimal

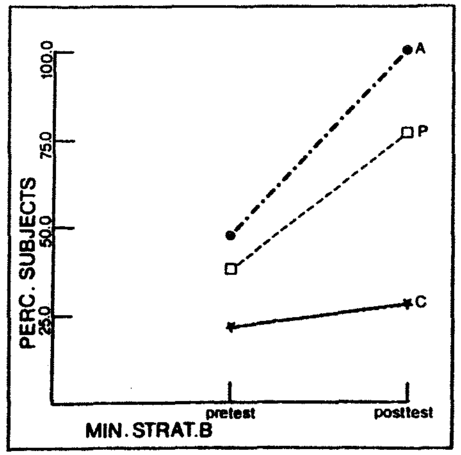

Figure 6 Percentage of subjects aged five years and over performing the minimal strategy of part B

strategy for crossing near parked cars. This figure demonstrates that after training all subjects in the assistants group and over 80% of the subjects in the parents group perform this strategy correctly. Finally, the results

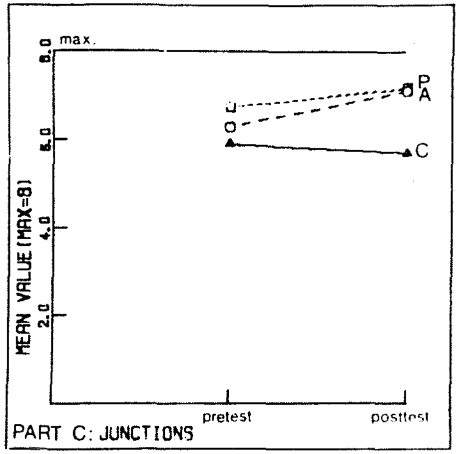

Figure 7 Mean values of pretest and posttest scores of the behaviou test C (crossing at junctions) for children aged five year and over.

of the tests on crossing at junctions are considered for this age group. Figure 7. presents the mean values of pretest and posttest and illustrates the increases in both experimental groups and a slight decrease in the control group. A univariate analysis of variance on the test data does not demonstrate a significant pretest/posttest effect, but does reveal a significant interaction (F = 3.18, .05). A test for separate contrasts demonstrates that this effect reflects a significant difference between the assistant and the control group (t = - 2.34, p .05); the difference between the parents and the control group does not reach a significant level. Expressed in terms of minimal crossing strategy a very similar picture emerges; both experimental groups show increases against a slight decrease in the control group.
Altogether, the results of these test procedures offer very strong support for the training programme. The MANOVA's reveal significant before/after effects and significant interaction effects and subsequent ANOVA's and analysis of separate contrast reveal that these interaction effects reflect a general increase in scores in the experimental groups between pretest and posttest which is absent in the control group and a consistent difference between experimental groups and the control group on the posttest scores. Although no significant differences could be demonstrated, it is clear from all presented figures that the assistants group scored generally higher on

Figures 2 to 7 are adapted from Rothengatter,J.A., traffic safety education for young children, Lisse:Swets and Zeitlinger, 1981 and are reproduced with permission. In these figures P denotes parents group, A denotes assistants group and C denotes control group.

the posttest than the parents group. This suggests that parents are indeed not as proficient as experienced trainers in eliciting behavioural change in children, which could be expected on the basis of earlier parents' surveys.
A substantial emount of additional data has been collected in the course of the programme application. For a discussion of these data and their analysis we refer to Rothengatter(1981). However, one point needs consideration here. A follow-up test was performed three months after the programme application had been completed. Comparison of the posttest scores and the follow-up scores revealed in none of the tests a significant detriment. Thus it can be concluded that the test results reflect a lasting change in the behavioural reportoire of the preschool aged children.

Spontaneous behaviour of children during school journeys

During six-week periods before and after the application of the training program the children were followed and observed unobtrusively on their way to and from school. Only those children were observed who walked without adult supervision. The procedure of training observers to score behaviour with a high degree of reliability is described in detail by Van der Molen, Kerkhof and Jong (1981). The detailed results of the evaluation study are to be reported this year (Van der Molen, in preparation) but some preliminary results are presented here.

The numbers of children observed in the three tasks were rather limited when split up for Assistent-, Parent and Control groups respectively and for the three tasks crossing in quiet streets (task A), crossing from between parked cars (B) and at intersections (C). Therefore we shall firstly present data of the trained children (A and P groups) taking together all 87 crossings at the three tasks together (involving 25 repeated measures of children observed in two tasks). Then we shall present data of A and P groups taken together at each task. We will only discuss any differential effects of A- and P-groups. In order to obtain reasonable testing power despite the small sample sizes we decided to test one sidedly with an α -risk of .10 in the N=87 sample (pooled tasks) and with an α -risk of .20 in the analysis of each task separately. This practice is dealt with in more detail in the next section. We tested with the McNemar test for the significance of changes.

Table 1: behaviour of trained children (A + P groups) on all three tasks taken together both before and after the program (N=87). For the task around parked cars only stopping and head movements at the line of vision were scored as correctly.

behaviour	% before	% after	relative % increase	significant (α = .10) p values
stop	18	36	100	< .01
L + R	18	26	44	.12 *
minimal	9	23	156	.01

* the closest possible p-value to α = .10 given the discreteness of the distribution

From table 1 it appears that the program was on the whole rather effective in increasing the percentages of children stopping at the kerb, making head movements both ways at the kerb or using a minimal "safe" strategy (stopping and head movements both ways at the kerb), but that the percentages were still rather low after the program. The control group children (N=79) showed no increase but a 27% relative decrease in the use of the minimal strategy. Checks were carried out from which we may conclude that these program effects could not be attributed to an increase in momentary traffic when the children were about to cross.

From table 2 it appears that stopping improved considerably and significantly in all three tasks. Making head movements both ways and use of the minimal strategy improved considerably and significantly in task A and C, but not in task B, crossing from between parked cars. However when giving a child on this task one point for each correct item at the line of vision (i.e. one for stopping, HM left and one for HM right) then the mean increased from .45 to .77 which was significant (p=.09) with a paired t-test. However it is clear that performance levels on this task remained very low indeed.

Table 2: behaviour of trained children (A + P groups) on three tasks before and after the programme

behaviour	% before	% after	relative % increase	significant (α=.20) p-values
Task A (N=25)				
stop at kerb	16	40	150	.04
L+R stop at kerb	16	40	150	.04
minimal	16	40	150	.04
Task B (N=31)				
stop at line of vision	3	16	433	.11
L+R at line of vision	10	10	0	
minimal	3	7	133	
Task C (N=31)				
stop at kerb	36	52	44	.15
L+R at kerb	10	26	160	.11
minimal	10	26	160	.11

The control groups in these tasks (N=31, 12 and 36 respectively showed no improvements in the use of the minimal strategy but relative decreases of 19%, 53% and 21% on tasks A, B and C respectively, decreases which were not statistically significant when tested two sided.

Contrary to the evaluation findings in the previous section it appeared that overall improvements were larger in the parents group than in the assistents group, which scored relative percentages increase in use of the minimal strategy of about 100% and over 200% respectively. Summarizing the results of this section and the prevous one we conclude that the program appeared not only to be effective in providing the children with adequate behaviour repertoires, but that they were also using these skills more frequently when they crossed spontaneously on their way to and from school when they felt unobserved. Although these improvements were considerable, performance levels were still rather low.

Behaviour of mothers and children in each other's company

The results presented in the three previous sections can be considered as product evaluations of the program, i.e. they measured the effects of the program in terms of attainment of its objectives. The evaluation study reported in the present section (see Van der Molen, van der Herik and van der Klaauw (1981) for more details) is also concerned with process evaluation of the program, i.e. it provides information on the way in which mediators (i.e. parents) applied the program and how their children reacted to this. We studied the behaviour examples adults gave to the children and whether these examples correlated with that of the children. Further we assessed the degree to which parents gave verbal instructions to which the children reacted with making head movements. Although parents were instructed to train their children in the street and were advised to repeat this regularly, they had never been instructed explicitly to do this on the way to or from kindergarten. However, if the ideas behind the program did come across to the parents, we would expect them te become better educational models and instructors after the program and to show this on the way to or from kindergarten. Similarly one would expect the children to behave more according to what they had learned during the educational program. The latter we may consider to be product evaluation under specific social circumstances.
Before and after application of the programme video observations were made unobtrusively just before and after school time at 18 different locations, mostly at junctions with pedestrian crossings but without traffic lights. We intended to observe the same couples in both the pre- and post-observation, but we managed to do this for 15 couples only. For the statistical analysis of program effects we therefore divided our total number of observations in two independent samples (N = 2 x 48 = 96) in which the 48 couples before and after the education program are different ones, and a dependent sample (N = 15) in which the 15 couples are the same ones in both observations. This small dependent sample size gave serious problems with testing power when employing the usual levels of α-risk, a problem which is frequently overlooked in educational research (Brewer and Owen, 1973). Rather than focussing blindly on the convention to set α at . 05 or less we tried to find a well argumented balance between α - and β -riks and set α at .20 (see also Elstrodt and Mellenbergh for a discussion of this matter). However even now we obtained reasonable (i.e. $\geq$ .66) to good (i.e. $\geq$ .80) power (see Cohen, 1977) only for large population effects. So in the dependent sample any small program effects could hardly be expected to show up.

The data of the pre-observation summarized in table 3, show that adults stopped as often at the kerb as children, a greater percentage of adults made head movements in all directions and more adults crossed in a normal tempo. These findings are completely in line with earlier studies (Van der Molen, 1981).The differences are somewhat smaller in the post-observation due to the fact that child behaviour improved more after the training program.

Table 3: percentages of adults and children displaying specific behaviours in the pre- and post-observation.

behaviour	pre-observations N = 63	N = 63		post-observations N = 63	N = 63	
	adults	children	p-values	adults	children	p-values
stopping	43	46		60	64	
HM left	67	35	$\leq .01$	84	46	$\leq .01$
HM right	71	41	$\leq .01$	70	60	
HM backward	10	3	x	18	18	
normal tempo	98	78	$\leq .01$	98	79	$\leq .01$

x = the p- value is .14; the p-value of the next table is $\leq .05$
HM = head movement
blanks = not significant with a one sided Fisher exact test with $\alpha = .05$

Table 4: φ -correlations between child and adult behaviour during pre- and post-observations

behaviour	pre-observation N=63	N=43	N=20	post-observation N=63	N=34	N=29
	traffic and no traffic combined	traffic only	no traffic only	traffic or no traffic	traffic only	no traffic only
stopping 1)	.71xx	.71	.66	.89xx	1.00	.82
HM left	.16	.19	.09	.14	.16	.03
HM right	.10	.16	.04	.31xx	.31	.25
HM backwards	.06	.06	.05	.45xx	.35	.63
normal tempo 1)	-	-	-	-	-	1.00

1) N=23 both in pre- and post-observations , in stead of 63, as the correlations were calculated only for those pairs that were not holding hands.
xx = significant with $\alpha_1 \leq .01$ with the one sided Fisher exact test.

Indications for significance are only given in the first columns (N=63).
- Correlations are undefined due to the fact that either children of adults showed no variation in thier behaviour.

In table 4 it is shown that especially stopping behaviours of adults and children correlated strongly (regarding only those couples not holding hands) and that this was no artefact of momentary traffic conditions. That the head movements correlations in the post-observations were larger may be due to the fact that during the pre-observations only 2 out of 63 three mothers gave verbal instruction to which the child reacted with making head movements against 11 mothers in the post-observations ($p \leq .01$).

From the data in table 5 it appears that the behaviours trained did improve considerably and often significantly both with children and (to a lesser degree) with adults except those behaviours with high initial percentages. With children the results of the independant and dependent sample were more alike than with adults. However, the significant findings in the adult N=48 sample were always clearly reflected in the N=63 sample, despite opposite trends in the N=15 sample, which might be due to small error fluctuations.

Table 5: improvements in road crossing behaviour of adults and children for the two samples together (N = 2 x 63), the independent samples (N= 2 x 48) an the dependent sample (N=15)

Behaviour	percentages or numbers of adults and children displaying behaviour in pre- and post-observations								
	% pre N=63	% post N=63	% pre N=48	% post N=48	significance at α=.05	number and directoins of changes xx N=15 N_D	+	-	significance at α=.20
Adults									
stopping	43	60	40	63	.02	4	2	2	
HM left	67	84	63	88	$\leq .01$	5	2	3	
HM right	71	70	69	75		8	2	6	
HM backwards	10	18	8	19	x	0	0	0	
normal tempo	98	98	98	100		1	0	1	
crossing at right angles	95	89	94	92		3	0	3	
Children									
stopping	46	64	44	67	.02	4	2	2	
HM left	35	46	35	42		10	7	3	.17
HM right	41	60	42	60	.05	5	4	1	.19
HM backwards	3	18	2	13	.06xxx	6	5	1	.11
normal tempo	78	79	81	83		6	3	3	
crossing at right angles	95	89	94	92		3	0	3	

blanks = not significant with one sided Fisher exact test with $\alpha = .05$ (N=48) or with one sided McNemar test with $\alpha = .20$ (N=15)
x = p-value .12; for the next extreme table $< .05$
xx = with adults no changes occurred in the predicted and tested direction
xxx = the value of p as close as possible to α

The presence of bicycles or motorized vehicles correlated almost .40 with stopping of adults, both in the pre and post observations. The program was effective however in changing to some extent the adult habit to stop rarely in the absence of momentary traffic (15% in pre and 41% in the post observations). The positive effects reported are underestimates for two reasons. During the post observations there was less momentary traffic (54% in stead of 68%). Another reason is that we estimate that only 50% of the parents and 70% of the children observed had actively participated in the program for various reasons described in our extended report. From an analysis of program effects at locations with less then 75veh/h, 75-200 veh./h and more than 200 veh/h it appeared that as far as stopping was concerned improvements occurred especially at locations with the lowest intensities, i.e. where stopping was not already elicited by traffic during the pre-observations. At these low intensity locations the percentage of adults stopping increased from 8 to 42% and children from 8 to 62%. When considering head movement totals in all directions a similar but less strong trend was found that program effects were strongest in the most quiet environments. However, this evaluation study demonstrates that program effects were not only apparent in the quiet locations in which training took place, but also in more busy traffic circumstances.

Evaluation of the traffic education programme in experimental implementation

The evaluation described in the previous paragraphs was designed to measure the behavioural effects of the developed educational programme in a quasi-experimental study. The quasi-experimental nature of the study offered the advantage of identification of the individual subjects, necessary for the pretest-posttest design and the regression analysis and the advantage of the programme's optimal effectiveness and the programme's effectiveness with non-experimental mediators. The differences found between the results obtained by the assistants' training and those obtained by the parents' training indicate that in evaluation studies of educational programmes it is important to make this distinction in the development stage. If in the present study the parents had not been able to obtain significant effects, it would have been dependent on the effects obtained by the assistants whether the results should have been attributed to an ineffective educational method or to an ineffective approach of the parents. As both groups obtained demonstrable effects, this problem did not arise in the present study, but it was possible through regression analyses to determine the most active ingredients of the programme training. This enables further emphasis of the parts of the training that are most crucial in the approach to the parents. If quasi-experimental studies have advantages in terms of diagnostic power of evaluation, they have also disadvantages in terms of validity and reliability of the effects found. Cook and Campbell (1979) have discussed these problems in detail. The design used in this study (pretest-posttest and experimental-control group design) and the many additional evaluation measures that were used counteracted most problems related to the statistical conclusion validity and the internal validity. The problem of construct validity has been partly counteracted by the direct relationship between the items of the behaviour tests and observations and the formulated validity concerns the not-intended effects of the programme application. In the presented study some not-intended effects can be identified that are due to the quasi-experimental nature of the study. In particular the parents and the preschool staff taking part in the programme were aware that the programme application was also an experiment. This may have enhanced their motivation to carry out the programme. An evaluation apprehension effect, due to the fact that they were aware that evaluation measures were carried out, would influence their motivation in the same direction. Thus, it is impossible to exclude the possibility that parents and preschool staff would have made a smaller effort if the programme application would not have been accompanied by intensive evaluation.

Problems of external validity could also not be completely counteracted in this study. Generalization across subjects within the sample is particularly important with regard to age. Since the data have been analysed for two different agegroups, and the effects appeared to be independent of age, the programme effects can be generalized across the age of the target group. Generalization to populations is more problematic because this study cannot demonstrate that the results would have been the same if the programme had been applied to a different sample. Small town versus city differences exist for example, especially with regard to the traffic environment. Traffic intensities are generally higher in cities larger than the town in the study, but on the other hand, children in towns of the size of our experimental area have a far higher exposure rate than children in large cities (Winterfeld, 1977). The differences in the traffic environment within the population may implicate differential effects of the programme implementation due to differences in traffic exposure in the target group. The directions of such influences are not predictable. A large scale implementation study has been carried out to investigate the problems of construct and external validity resulting from experimentation and area selection effect. For the purpose of this study one city and one town was selected which had known demographic characteristics and which are together representative for about half of the Dutch agglomerations. In each agglomeration two areas were selected which consisted of modern housing estates and two inner-city areas. One of each of the areas was assigned control area and one experimental area.

The programme received extensive modification. The content and methods of the programme remained unchanged, but the manner of presentation was adapted to the operational conditions. For the preschool classroom teaching activities various materials were produced in accord with the suggestions of the preschool staff participating in the previous experiment. Information booklets for preschool staff were produced so that they could use the programme materials without external support. In addition professionally produced information and instruction material was made for the parents on such a level that no need for further guidance was anticipated. Finally, material directed at the children was produced for motivational purposes. These materials were put at the disposal of the preschools in the experimental groups at the start of the experiment. The programme lasted six weeks, in these six weeks the research staff did not interfere in any way with the teaching activities of the preschool staff or the training activities of the parents.

Evaluation took place on several levels. The motivation of the parents and preschool staff to take part in the programme and the attitudes of the parents was studied through questionnaires in accord with the attitude-behaviour model as outlined by Fishbein & Ajzen (1975), which distinguishes attitudes, intentions, motivations to comply, social norms, behavioural beliefs and outcome evaluations. The use of this model in a pretest-posttest and experimental-control group design study is expected to obtain important information with respect to the attitude-intentions and behaviour relationships in the target groups. In addition a second questionnaire was sent to the experimental group enquiring about the training behaviour the parents and preschool staff had undertaken as a result of the programme dissemination. Finally, parents were requested to return the observation forms they had scored as part of the programme application. The results are in the data analysis stage. Overall response rates to the questionnaires are about 50%. Preliminary results suggest that there is indeed a difference in attitudes, behaviour and training results between the housing state and inner city areas. Differences between small town and large city samples are not apparent. So far, the results do not suggest large differences in response to the programme as a result of the absence of an unintended experimentation effect, which is in support of the construct validity of the measurements in the previous study.

Following further extension and modification of the programme the last stage which is necessary before nation-wide implementation can be considered will entail evaluation in terms of measures representing the accident risk of the target group. Such an evaluation requires an implementation of sufficient large scale; fortunately the total numbers of accidents involving small children are not of such a magnitude that programme effects could be detected in small samples. It would also require implementation of a longer period of time, to ensure that all children in the target group age would have received the programme. Evaluation in terms of accident is however problematic in more respects than requiring large samples. Accidents are multicausal events, and not all of them can be prevented by educational programmes, even not by ideal ones. In order to prevent unnecessary noise in the data collection, accident data need detailed descriptions of the situations in which the accidents took place and the behaviour preceding the accident. Such a procedure would reveal the necessary information that could validate the presently hypothetical accident-behaviour relationships and with that validate the educational objectives formulated for the programme. Unfortunately, it is generally accepted that such information is extremely hard to obtain through present methods of accident data collection.

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SESSION 8

Chairman: Mr. Gressier (France)

Theme: Product and process evaluation

N.R. Ashton and R.E. Brindle (Australia)	: An attempt at evaluating local area safety improvements in an Australian study
C.J. Baguley (U.K.)	: Evaluation of safety of speed control humps
U.Engel (Denmark)	: "Short term" and area wide evaluation of safety measures implemented in a residential area named Osterbro. A case study.
G. Nilsson and H. Thulin (Sweden)	: Measurements of degree of separation between vehicles and pedestrians in urban areas
G.O. Riediger and G. Zimmerman (Germany)	: On the methodology underlying the short-term evaluation of traffic engineering measures e.g., solutions to left turns in the City of Hamburg

SESSION 8:
Product and process evaluation

AN ATTEMPT AT EVALUATING LOCAL AREA SAFETY IMPROVEMENTS IN AN AUSTRALIAN STUDY

by

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The observations and opinions contained in this report are the Authors', and are not necessarily those of their respective organisations. The authors are grateful to Loder and Bayly, Melbourne, for permission to use illustrations from their reports. These illustrations may be freely used if the original authors are acknowledged.

INTRODUCTION

This paper breaks no new ground. In the spirit of the specification prepared by the organisers of this Seminar, it attempts to record the discussions which took place on monitoring and evaluation of local street programmes as part of a specific study in Melbourne, Australia. Although probably unknown to many others around the world, Australian practice in local area traffic management (LATM) is nevertheless extensive. Many of these programmes have aimed at general improvements to amenity, but local street safety is also a common problem. The potential for the application of meaningful evaluation procedures is therefore great. The paper firstly outlines Australian LATM practice and its broad findings, then makes some general observations on the extent to which this practice has been assessed, especially with respect to safety impacts. The Local Traffic Area concept recently adopted in Melbourne is then introduced as background to a description of a study which included a specific intention to examine evaluation procedures. Some of the considerations of that phase of the study are outlined, including the scope of discussions during an expert group meeting on the subject.

AUSTRALIAN LOCAL AREA TRAFFIC MANAGEMENT EXPERIENCE

There are about 350 local government authorities in Australia who are responsible for urban areas, or parts of urban areas, above 5000 population. Data collected in 1978-79 by the Australian Road Research Board (ARRB) showed that 99 (71 per cent) out of 139 local authorities in the six State capital cities had installed at least one street closure, and smaller numbers had experience with midblock and diagonal closures (Table I).

TABLE I

AUSTRALIAN LOCAL GOVERNMENT EXPERIENCE WITH TECHNIQUES TO ALTER THE LOCAL STREET NETWORK

	% of L.G.A.s *		
	Metro n=139	Other Urban n=134	Total Urban n=273
Street closure			
- at intersection	71	43	57
- midblock	24	8	16
- Diagonal	13	4	8

* = Local Government Authority

Australia also has a wealth of experience with alternatives to street closures, which can aim more directly at traffic behaviour. The need for such alternatives was partly created by the controversy which often surrounded extensive street closure programmes. Table II shows that about one in every eight metropolitan local government authorities has had experience with various forms of two-way pavement constrictions, which range from mild to severe, and about one quarter have examples of 'wandering pavements' (pavement deviations to direct vehicles from a straight path, generally too gently to be really effective).

Table III summarises Australian application of three other selected techniques aimed at modifying driver behaviour. One in three metropolitan councils have experience with local street roundabouts, 11 per cent with tactile speed control devices on public roads, and seven per cent with various threshold techniques to emphasis the transition from a traffic route to an access street.

TABLE II

AUSTRALIAN LOCAL GOVERNMENT EXPERIENCE WITH TECHNIQUES TO ALTER THE LOCAL STREET CARRIAGEWAY

	% of L.G.A.s		
	Metro n=139	Other Urban n=134	Total Urban n=273
2-way constriction	12	10	11
1-way constriction	6	1	4
midblock islands	14	10	12
'wandering pavement'	24	18	21

TABLE III

AUSTRALIAN LOCAL GOVERNMENT EXPERIENCE WITH THREE OTHER TECHNIQUES TO MODIFY DRIVER BEHAVIOUR

	% of L.G.A.s		
	Metro n=139	Other urban n=134	Total Urban n=273
Minor street roundabouts	35	19	27
Tactile speed control devices	11	7	9
'Threshold' techniques	7	2	5

The results of this Australian experience could be summarised as follows.

(a) Experience in Victoria has shown that long-profile road humps are an effective speed-control device when used in a properly designed installation, and are suitable for use on public roads when the available guidelines are observed. (This principle has now been accepted by the Victorian Road Safety and Traffic Authority). Anticipated legal problems are not insurmountable.

(b) Street closures are widely used and undoubtedly improve spot safety when applied at an intersection. Closures themselves warrant no traffic-related research, but their effects on area circulation patterns, community response to route change, network characteristics and so on certainly demand far more attention than they have so far received. The absolute success of road closures in forcing a change of route is directly responsible for the strong pressure against them.

(c) Small roundabouts are feasible and successful in residential streets, as the extensive experience in South Australia and Victoria shows. This experience points to the need for standard rules of priority and other driver behaviour, clear approach visibility and careful attention to lighting. The value of excessive design is questionable in low-volume situations, vehicle swept paths proving to be a stronger design parameter than capacity. Practice appears to favour mountable, if not fully crossable islands. Apart from basic guidelines governing these aspects, current practice appears to favour non-prescription of design and detailing.

(d) Experience with streetscaping, kerb extensions to form parking bays and pavement constrictions, wandering pavements and so on is far less standard and is not well-documented. Although current examples (found in every State) are useful as a visual source of design ideas, traffic and community impacts of specific treatments cannot be predicted on the basis of present information.

(e) Attempts to control vehicle speeds using constrictions, islands, etc., have been made in several isolated locations around Australia. Conclusions about their effectiveness and feasibility cannot be drawn from available information. Investigations by the Victorian Road Safety and Traffic Authority over recent years, including several field trials around Melbourne, will hopefully produce quantitative conclusions (Ashton 1981).

EVALUATION IN AUSTRALIAN LATM PRACTICE

With this extensive experience, it might be expected that there is ample formal evaluation data which supports or questions the use of the various techniques of local street improvement.

This is in fact not so. Of the 169 local authorities throughout Australia who reported application of one or more of the techniques, 57 are reported to have conducted area-wide programmes (as distinct from remedial actions at black spots). None of these programmes are known to have involved a formal evaluation of the safety benefits, although in several cases before- and-after accident data is reported.

The reasons for this lack of evaluation may be unique to Australia, with its generally apolitical, unpaid and part-time elected local councillors served by relatively few technical officers skilled in this area.

(a) Improved safety has not generally been an explicit objective of the street improvement programmes. The incidence of casualties in minor streets is not commonly acknowledged, although data compiled by ARRB verifies overseas observations that non-arterial accidents comprise a substantial minority of urban accidents. The accident rate per vehicle-kilometre of travel on the more important streets within housing areas ('collectors' or 'local distributors') in fact appears to be substantially higher than that for arterials and other higher-order distributors.

(b) Whether or not a formal evaluation demonstrates benefits, the principal test of acceptability is the public reaction which a device or programme excites. Even so, this public reaction can be swayed to support a programme if convincing proof of improved safety could be found and promoted. Otherwise, daily experiences (extra inconvenience, forced change of route etc.) will dominate the public's reaction.

(c) Once a project is implemented, the pressures on local authority staff are such that they rarely have time to stop and consider what they have done.

(d) If awareness of safety impacts is exercised at all, it focusses on ensuring that the physical measures adopted are not themselves hazardous. It is ironic that (usually unfounded) fears that the devices are hazardous are often expressed in objections to schemes which could be shown to improve safety in an area.

This last comment pertains particularly to small roundabouts, road humps and various forms of 'slow points'. The latter will be described in the case study later in this paper. The roundabouts which have proliferated in Melbourne's local streets in recent years have clearly produced dramatic reductions in accidents. Daley (1981) reported that accidents (casualty plus reported damage) occurring at 51 intersections on all levels of road dropped from 140 per year to 74 per year after the installation of roundabouts (significant at one per cent level). Unpublished data on 16 roundabouts at minor intersections in Melbourne reveals an even greater decline (from 0.54 to 0.03 casualty accidents per intersection per year).

The research at ARRB on road humps reported by Jarvis (1980, 1981) neatly complements that in the UK (Sumner and Baguley 1979) and the USA (Smith and Appleyard 1981). The streets where humps have so far been installed (in Stirling WA., Corio, Hawthorn and Sandringham Vic.) did not have high prior accident rates. Their safety evaluation therefore typifies the problem to which this Seminar pays attention. Assessment of these installations has relied merely on demonstrating a clear reduction in speeds and an absence of any accidents in association with them.

While there have been no systematic assessments of the many Australian area-wide local traffic management schemes, some incidental information on South Australian examples can be quoted. The Woodville (SA) schemes were described in terms of elimination of through traffic (Department of Transport 1978), and observed accident reductions were attributed to this. In the first area to be treated (Woodville South in 1971), internal accidents, both casualty and damage, reduced by 48 per cent. Within a second area (Flinders Park) the reduction was 33 per cent. It was reported that the perimeter road rate was unchanged.

In Unley, the first two months of experience produced a 60 per cent reduction in accidents internally and a 36 per cent reduction on peripheral roads (Road Traffic Board 1975). Perhaps more meaningfully, after 12 months experience there had been 56 per cent fewer injury accidents and 42 per cent (about 50) fewer total accidents internally than were expected. Peripheral road accidents were slightly higher than expected but injury accidents were 32 per cent less (both observations not significant at five per cent level). Within Burnside, internal accidents over one year decreased from 50 to 29. Meanwhile, peripheral road accidents between major intersections also dropped (from 145 to 127). The major intersection rate remained about the same. Cairney and Brebner (1980) noted that 61 per cent of Unley respondents spontaneously mentioned improved safety or a reduction in noise following road closures there, a belief which is borne out by the data.

These cases are quoted to illustrate the assertion that, if the area is big enough and/or the accident rate is high enough, statistically reliable numbers of accidents *can* be obtained without waiting for many years. In Australian cases, typified by the example described in what follows, the study areas are usually large enough to embrace significant numbers of annual accidents. Daff and Hua (1981) found that there was about 2.5 million vehicle-km of travel per square kilometre of residential area in suburban Melbourne. Using Harper's (1970) rate of 1.37 casualties per 100 million vehicle-km for minor Australian streets, this produces an expected value of about 3.5 casualties per square kilometre per annum. On that basis, recognising that study areas typically range above 1 km² in area, and assuming areas of greatest need will experience a greater rate, it can be seen that 'before' casualty numbers in a study area could be well above five per annum. Therefore, if an *area* approach is taken, the problem is not one of having enough accidents to perform statistically valid analyses, but rather is a question of having sufficient historical data to establish variability in the yearly casualty numbers.

The need for substantial data is of course not the principal reason for adopting an area-wide approach to local area traffic management. The Victorian approach, based on 'local traffic areas', recognises the need to study traffic impacts and changes over a wider scope than the immediate group of streets. The consequences for evaluation are noted in the following discussion of some Melbourne cases.

CASE STUDIES FROM VICTORIA

In order that the municipal engineer can undertake road planning on a rational basis, a road hierarchy system has been introduced in the

State of Victoria (Road Safety and Traffic Authority 1980). Each municipality is encouraged to produce a road classification plan for existing roads in their area. Emerging from such plans is the concept of Local Traffic Areas as depicted in Figure 1.

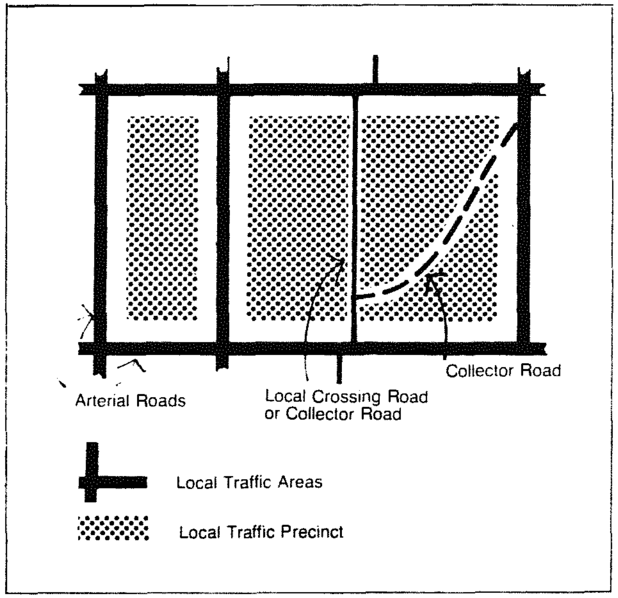


Fig. 1: Definitions adopted for Victorian studies.

Typically in an Australian situation the Local Traffic Area could be up to 2½ square kilometres in size and contain 2,500 dwellings. Within these areas there are local streets of varying network importance. Areas bound by Collector or Local Crossing Roads and the arterial roads are termed Local Traffic Precincts. It is in these areas that the opportunity for radical changes to the road system occur.

The prinicpal function of a Collector Road is to distribute traffic between the arterial roads and local streets. It 'collects' traffic from a catchment of local streets branching off it and connects to a Local Crossing Road or Arterial Road.

Local Crossing Roads, on the other hand, are those roads which fulfil a need to directly cross a Local Traffic Area because in one dimension at least, the area is too large to be reasonably circumnavigated by intra-suburban traffic.

A number of studies and experiments have commenced in Melbourne and provincial cities to study and improve the safety and amenity of Local Traffic Areas. To a large degree, the introduction of 'Woonerven' in Holland has provided the incentive to adapt this concept to Australian cities. However, Australian suburbs are vastly different to Dutch cities and densities of ten dwellings/ha are the norm. Right of way widths and house allotment frontages are typically 15 metres and most vehicles are parked within the house property. This created long, straight and comparatively wide residential streets where speeds of 60-80 km/h are common. The street became an asphalt strip completely dominated by the motor vehicle.

Because it is too costly to remove the kerbs, gutters, asphalt, etc and redesign the street to be more compatible with the residential function, devices have been suggested to be incorporated into the existing road system to slow vehicles (Figures 2a and 2f) (Loder and Bayly 1981a, b, c, d). It is of interest to note that the devices suggested are coincidentally not dissimilar to those recently installed in Danish cities (Denmark-Justitsministeriet 1978).

Three separate, but similar studies on the application of such techniques have been undertaken in Victoria. Two of these are in Sandringham and St. Kilda, both suburbs of Melbourne, and the third is in Geelong, a provincial city in Victoria. The Sandringham study was run by a steering committee representing the Victorian (State) Road Safety and Traffic Authority (RoSTA), the Australian Department of Transport's Office Road Safety, and the City of Sandringham.

The interests of the three participants were primarily:

(a) RoSTA's interest in a demonstration of an area-wide approach to local street management and safety gains.

(b) Sandringham Council's concern for the improvement of its local streets both visually and in safety.

(c) The Office of Road Safety's particular interest in the process of the study and its applicability elsewhere.

The study was undertaken by a firm of consultants, Loder and Bayly, in conjunction with three local area committees. All meetings of these committees were open to the public. All the ideas for treatment was discussed by the Consultants with the Committee prior to being presented to the Steering Committee.

Four meetings were held with each of the three local area committees and the main issue at each meeting was in turn:

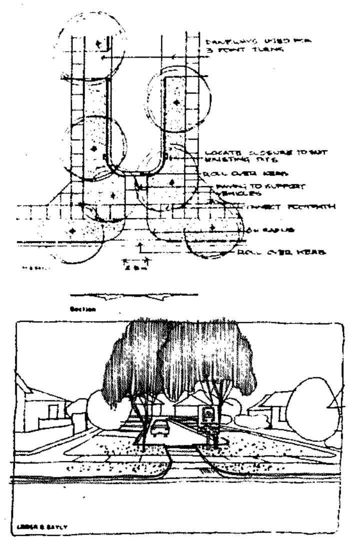
(a) problem identification

(b) alternative solutions, device trials

(c) general plans and device evaluation

(d) draft final plan and extent of solutions.

Meeting times and dates were advised by letterboxing the community. The meetings usually lasted for two and a half hours. A thirteenth and final meeting was held for all committees and areas combined.



Driveway Entry

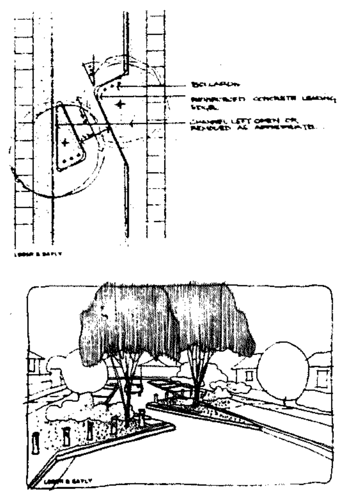
Driveway Entry (E)

Treatments at the intersections of arterial roads and local streets.

Designed to emphasise the different nature of local street to the arterial street.

Discourages inappropriate traffic.

(a)



Single Centre Lane Angled

Slow Point (S)

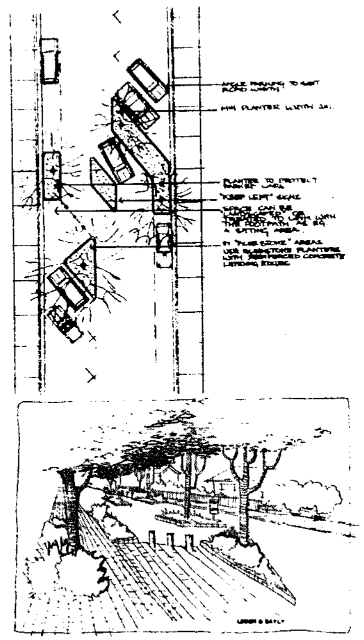
Located at midblock location to reduce vehicle speed.

Helps to break down visually the linear look of the street.

Can incorporate a road hump in certain circumstances.

(b)

Figure 2: Local street treatments proposed in Melbourne



Split Single Lane Angled

Slow Point (S)

For use in wider streets where parking space is at a premium.

Opportunity to create effective landscaping to improve streetscape.

Encourages lower speeds in the street.

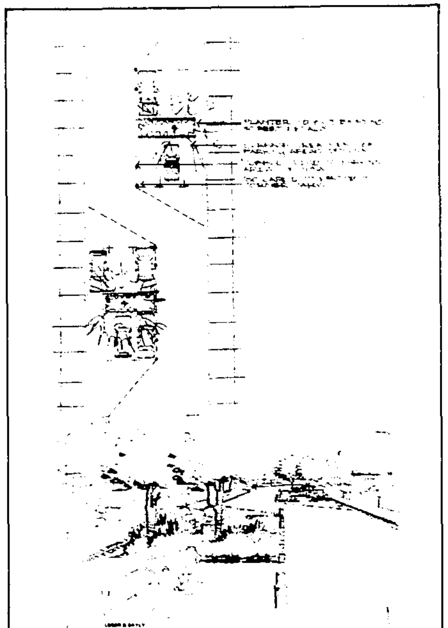
(c)

The process generally worked well. In addition to the more obvious benefits, it allowed Councillors to obtain an informed opinion about the way many concerned residents felt about the proposals. This was considered important for the Councillors to maintain a balanced perspective, since they would almost certainly be subjected to stronger representations from those opposed to the plan than by those in favour of it, if it is initially supported by Council.

Early in the study, the required solutions divided into two distinctly different categories, which precisely matched the equally distinct nature of the problems perceived. Spot accident locations could be treated, by and large, independently. Problem streets, on the other hand, needed an area-wide approach, in order to preclude the transfer of problems from one local street to another.

In most locations in the study area, though, speed was perceived to be the major problem rather than accidents which were only perceived when they occurred in the 'black spot' type locations. It was necessary, therefore, to provide measures that reduced the speed of vehicles in these streets. In order to fulfil this objective it was vital that any changes designed to reduce speed were themselves safe, and added to rather than reduced the visual character of the street.

The devices shown in Figures 2a-2f were among those which evolved out of this group of studies. Trials of some of these 'slow points' were undertaken as part of the Sandringham study and it was found that



S4
Effective Angle Parking Stack

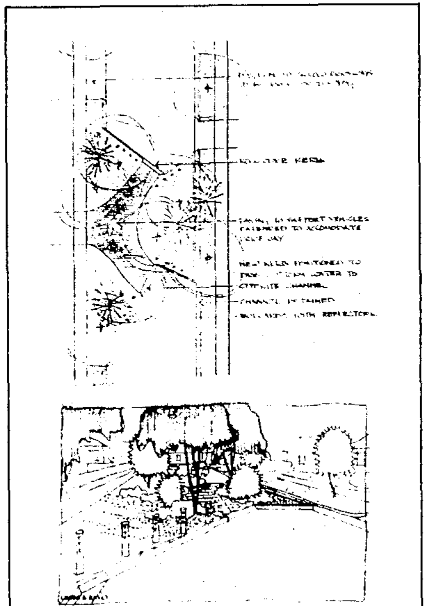
Slow Point (S)

A variation of the above design which is relatively inexpensive.

Encourages low speeds in vicinity of device.

Effective in areas of high parking demand.

(d)



Driveway Link

Driveway Link (M1)

Short section of street is reconstructed to level of footpaths.

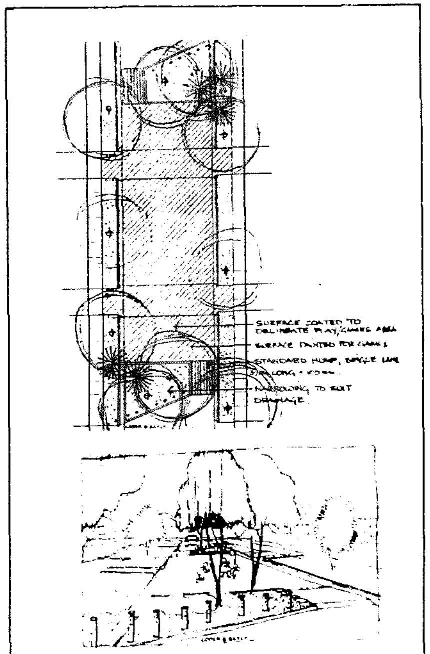
Similar to Road Closure but vehicles can pass through the link.

Requires complete reconstruction and alteration to drainage.

Enables additional landscapes and open space areas to be provided.

(e)

Figure 2 (ctd)



Play Space
Humps and Coloured Surfaces

Play Space (S7)

Place where 'Woonerf' principles can be applied over specified section of carriageway.

Area to be designed as an entity to be completely safe.

Speeds through space should not be able to exceed 10km/h.

Parking should be prohibited in area.

(f)

speeds were dramatically reduced. For instance, at the one lane angled device median speeds were reduced from 60 km/h to 35 km/h after the device was installed.

Implementation

It was considered necessary to prepare a plan showing the area with the recommended devices located on it. Figure 3 illustrates the recommended plan for the area in St. Kilda.

The implementation process is necessarily staged on a yearly basis and could take up to ten years to complete. Residents directly affected by the coming year's proposals should be given a plan and explanation describing the works in their area. It was recommended that the plan only proceed if less than one third of residents lodge an objection. A street could be brought into the scheme at a later date if there is a change in attitude.

EVALUATION IN THE SANDRINGHAM STUDY

Although the treatments actually carried out in the Sandringham study were few in number (only two streets being treated as demonstrations of the types of devices which could be used elsewhere), the consultants were also required to explore the methodology for monitoring and

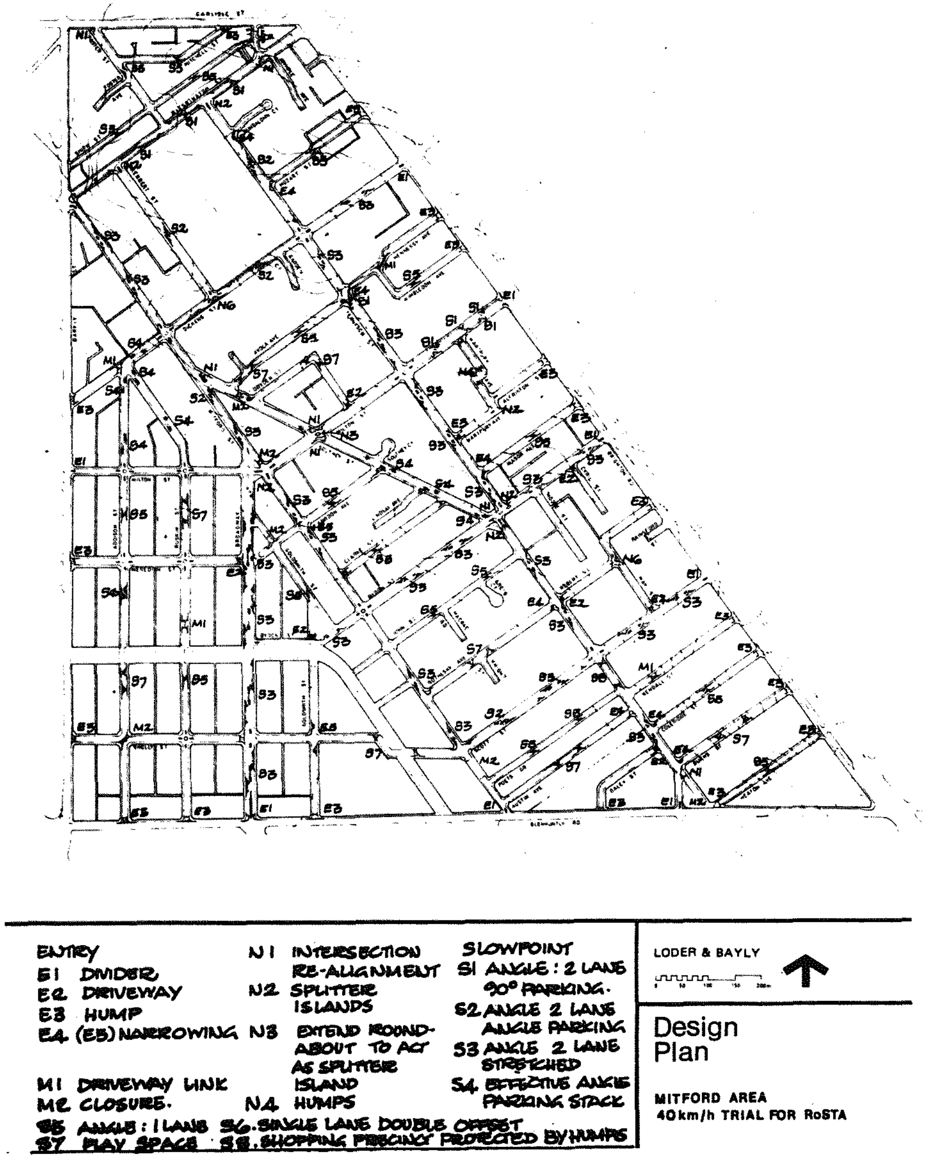


Fig. 3: The Mitford (St. Kilda) Area, showing proposed locations of treatments.

(Source: Loder and Bayly 1981c)

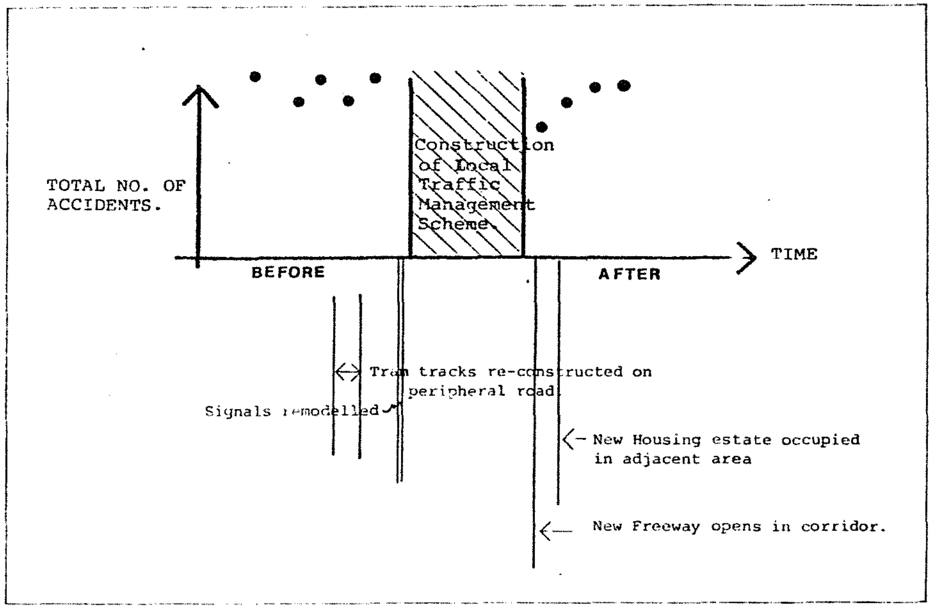


Fig. 4: Hypothetical accident data, illustrating extraneous influences on accident changes. (Source: Loder and Bayly 1981d)

evaluating future area-wide installations. In their response (Loder and Bayly 1981d), the consultants noted several of the problems which were also raised preparatory to this Seminar, especially the problem of the unstable environment in which before-and-after studies have to take place. (Very little can usefully be deduced from data like that in Figure 4, for example).

A procedure was recommended which relied on *monitoring* of certain parameters as a basis for short-term progressive assessment of a scheme, and as a source of the information for longer-term *evaluation*. Some of the possible parameters for monitoring are listed in Table IV. To these could be added indicators of residents' perception of changed levels of safety (which may or may not accord with measured changes), and other such measures which, being related to feelings rather than necessarily to facts, often are better indicators of likely community reaction. This also highlights the multi-objective nature of local street evaluation, safety being only one of several issues requiring attention.

Parameters for monitoring

Some brief comments should be made about some of the parameters listed in Table IV. About 20 per cent of all collisions were estimated by the consultant (without detailed research) to be reported to police. Only about half of those appear in published accident records. Other sources of collisions data, largely on unreported property damage collisions, are illustrated in Figure 5.

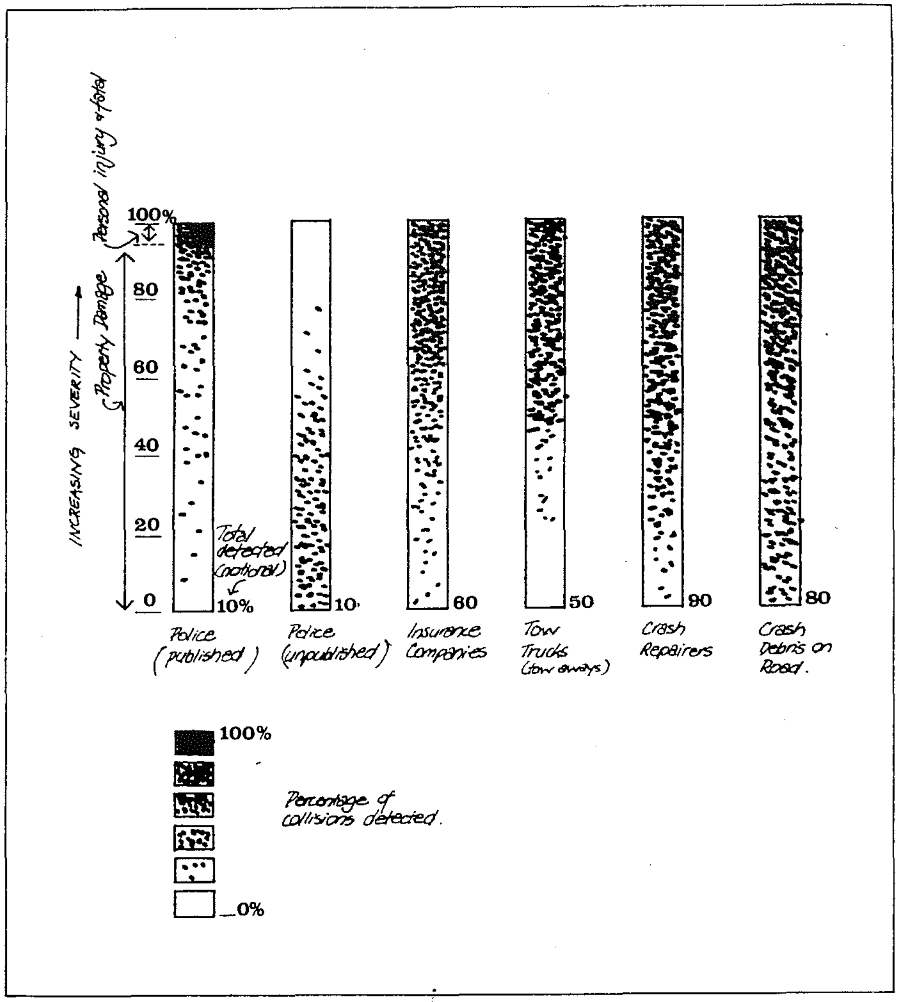


Fig. 5: Potential sources of collision data (Source: Loder and Bayly 1981d)

Conflict analysis is not among the tools adopted for assessment of accident potential in Australia. There are some reservations about the survey requirements and scepticism, voiced by Williams (1980), about the actual relationships between observed conflicts and actual accident occurrence.

The use of operational parameters (speed, visibility, volume, etc) as proxies for accident potential is fairly common, although it is acknowledged that we still lack information about causal relationships between such variables and accident occurrence.

Short-term changes in traffic volumes imply a diversion of traffic to other routes as a result of a scheme. The consultant argued that, where this diversion was from local streets to arterial roads, a reduction in exposure followed (on the basis of the rates developed by Daff and Hua 1981). If this logic is to have useful application, better estimates of vehicle-kilometres of travel are required, and firmer relationships between travel-based exposure measures and accidents must be established.

TABLE IV

POSSIBLE PARAMETERS TO INDICATE SAFETY LEVELS DURING MONITORING

These relate to incidents involving collisions	Reported accidents (to police)
	Reported accidents (to crash repairers)
	Reported accidents (to tow truck operators)
	Reported accidents (to insurance companies)
	Reported accidents (to ambulance services)
	Crash debris on road
	Resident views and perceptions
These relate to 'near miss' incidents	Skid marks
	'Conflict analysis' - braking and swerving
	In-vehicle observers
General operational parameters	Vehicle speeds
	Vehicle lateral displacements
	Visibility
	On street parking
	- many more possible measures
'Exposure' parameters	Vehicle kilometres of travel on local streets
	Vehicle kilometres of travel on arterial roads
	No. of vehicles entering intersections of different types.

Source: Loder and Bayly (1981d).

Basis for evaluation proposed in the Sandringham study

The recommended procedure for evaluation of schemes creating significant diversion of traffic to arterials involved the use of easily-measurable traffic flow data and calculated average accident rates on different types of street. Assumptions about the independence of rates per unit travel and traffic flow levels are implied in this approach.

Where little diversion of traffic is expected, Loder and Bayly recommended collation of reported accident data (published and unpublished). In most Australian cases, as noted earlier, the number of accidents in reasonably brief 'after' periods should be large enough to permit statistical analysis. (This implies reasonable constancy in the percentage of total accidents which come to the attention of the police). In addition, until speed/accident and other such relationships can be firmly established, an inventory of measurable and non-measurable factors likely to be related to accidents was recommended so that at least a subjective assessment could be made of the correspondence between changes in these factors and changes in accident numbers and locations.

The consultants recommended *against* using the following, which have been suggested elsewhere:

(a) control areas - because area characteristics are hard to pair adequately, and reliable estimates of general trends are more likely to be obtained from Melbourne-wide data;

(b) conflict analysis - because of the large survey resources that were expected to be required, and doubts about conflicts-accidents relationships; and

(c) use of insurance and other records - because, even accepting the time and the other difficulties involved in extracting the data, precise locational data is not usually obtainable from such sources.

Group discussion on evaluation methods

After the foregoing propositions were made by the consultant, about 20 experts on traffic, statistics and the implementation of traffic management were brought together to discuss the problems of monitoring and evaluation. As often happens at such gatherings, the discussion was somewhat free-ranging and inconclusive. However, in addition to confirming some of the points made earlier in this paper, the following matters were raised:

(a) Is the number of actual collisions or the level of safety perceived by residents a more critcial variable? Should we be observing changes in the way residents use their local streets (i.e. playing, walking, parking) as proxies of their perceived safety? Residents who have a 'siege mentality' (i.e. with high perceived threat) with respect to their streets are unlikely to expose themselves to as much danger as those who live on quieter streets. How much can we rely on local residents to give an accurate picture of hazards in an area? Perceived safety may be unreliable for before and after studies because residents will have a preset bias due to having supported or opposed the traffic management treatments before their installation. Should we try to correlate perceived values with easily measured quantities such as traffic speed and volume?

(b) Accidents are presently too dispersed on the local street system to form 'black spots'. Their transfer from the local street system to the arterials is beneficial because they could then be 'treatable'.

(c) Is cost/benefit analysis appropriate? (Probably too ambitious given our lack of knowledge). The money spent on accident countermeasures is not from a fixed sum. It can go up and down at the expense of non-safety, non-transport expenditure such as libraries, especially at the local government level. Safety benefits of local area traffic management changes are generally only given lip service ('we are studying safety, of course'); the real decisions and recommendations are based on other issues such as amenity. In the final analysis, the cost of accidents will be the extent to which the community is willing to pay. This presents problems because the road death of a notable footballer ranks far more highly than that of a motor cyclist, as judged by community response.

(d) Use of the exposure measure of vehicle-km is likely to bias against bikes and pedestrians in local areas. Is exposure a good indicator of likely numbers of any accidents? (There were differing views, dependant on type of accident). Observing crash debris will bias against pedestrian and bike accidents.

(e) Some sources of data are available for accident analysis but records are not collated by geographic area e.g. Motor Accident Board records in Victoria, tow-a-way reporting forms and household survey interviews. If our reporting system for accidents is inadequate do we collect more data in particular geographic areas (e.g. hire people to liaise with tow truck companies and audit their work)? A lot of data could be obtained by hiring one person for a year. We could increase reporting by asking residents to report incidents and near misses in which they have personally been involved (but expect large biases, double counting, staleness of data etc).

CONCLUSIONS

Although the process described in this paper may get us closer to a practical monitoring procedure for Australian projects, none of the extensive experience so far in Australia sheds much light on the theory of evaluation procedures. Since local authority action (and reaction) is the principal determinant of changes in Australian local streets, measurements of perceived safety and obvious characteristics of street operation (especially speed) are likely to prove to be most useful in practice. Such things can be measured reasonably easily and are factors which laymen and elected representatives can appreciate.

Nevertheless, specific measures of changes in safety are required by those involved in promoting new design concepts and in funding their application. Short-term assessment is not as necessary at this level, and perhaps improvements in accident data recording and retrieval will largely meet such needs outside the municipal arena.

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EVALUATION OF THE SAFETY OF SPEED CONTROL HUMPS

by C J BAGULEY

ABSTRACT

To illustrate various problems which arise in the evaluation of accident counter-measures this paper presents a case study of the public road trials of a design of speed control hump developed at TRRL. The objectives of the study are outlined together with details of the legal and practical constraints affecting its design and the various evaluation measures used.

The effectiveness and acceptability of humps as a means of improving safety and amenity on residential roads was investigated. The period for which the experimental humps could remain in position was restricted by law to one year which thus also restricted the length of evaluation period. The way in which suitable sites were selected for study is discussed.

The study took various measures of the effect of the humps on vehicle speeds on the roads concerned (ie a 'process' evaluation), on the previously untested assumption that a reduction in speed would reduce accidents on such roads. There was also a resultant indirect effect on accidents via changes in vehicle flows. The ultimate evaluation, made in terms of accident changes (the 'product' evaluation) is also discussed. A survey of public opinion at the experimental sites was carried out and the importance of this (as a possible further 'process') is considered. The paper also outlines the problems associated with selecting appropriate control data.

Both types of evaluation techniques demonstrate the need for area-wide studies and the value of monitoring as many variables as possible to enable all the advantages and disadvantages of the measure to be assessed.

BACKGROUND

In Great Britain, 32 per cent of road accidents involving injury or death occur on minor roads in built-up areas and at least 30 per cent of those killed or injured are pedestrians. It has been assumed that a major contributory factor to the incidence and severity of these accidents is excessive traffic speed and it has been argued that the maximum permitted speed of 30 miles/h (48 km/h) is too high for many of these roads in built-up areas. Most of these minor roads are residential roads and many, in addition, contain schools or play-areas and have a high proportion of pedestrian movements particularly of children. It is commonly believed, however, that the introduction of lower speed limits would be impractical as they would be virtually impossible to enforce adequately. The concept of a device which could be easily installed on existing roads and which would efficiently slow down drivers without the need for enforcement or restriction of access is obviously an attractive one.

Watts[1] had tested different sizes of road humps which were the segment of a circle in cross-section using different subjects and vehicles driven at a range of speeds over the humps on a test-track. He concluded that a particular design (3.7 m long and 102 mm high at its centre) could be crossed with reasonable comfort in all test vehicles at 5 mile/h (8 km/h) and would produce an uncomfortable ride in excess of 20 mile/h (32 km/h). It was predicted that a series of these humps along a road should therefore produce an average speed of light vehicles of between 15-20 mile/h (24-32 km/h).

OBJECTIVES OF THE EVALUATION

An evaluation of this design of hump on urban residential roads was thus planned to test (i) whether traffic speed could be reduced to the above levels in practice, (ii) how effective humps would be in improving safety and amenity, and (iii) whether or not the measure would be acceptable to the general public. It was felt important to study public opinion as permanent introduction of humps on public roads would ultimately mean changes in legislation and excessive opposition to the measure would inevitably render these changes unlikely to be introduced.

SITE SELECTION

Road traffic law had been enacted which permitted TRRL as agents of the Secretary of State to install speed control humps for an experimental period of one year only at any one site. It was expected that due to this rather short evaluation period difficulties might arise in assessing the effects of humps on accidents particularly as the number of sites at which the assessment was to be made was restricted by the research resources available at the time.

A further constraint on the selection of roads for study arose from the need to rely on local highway authorities to indicate available sites. This procedure, however, did perhaps help to alleviate some of the 'bias by selection' or 'regression-to-mean' effect. The highway authorities tended to suggest those sites where some residents had already requested something be done about the excessive speed of traffic, and although the roads were considered dangerous by these residents this was not, in many cases, borne out by the injury accident records. Only about three of the nine sites finally chosen for treatment had particularly poor accident histories.

The two major factors used in selecting sites from those available were whether the roads were less than ½ mile in length and already had slow entry

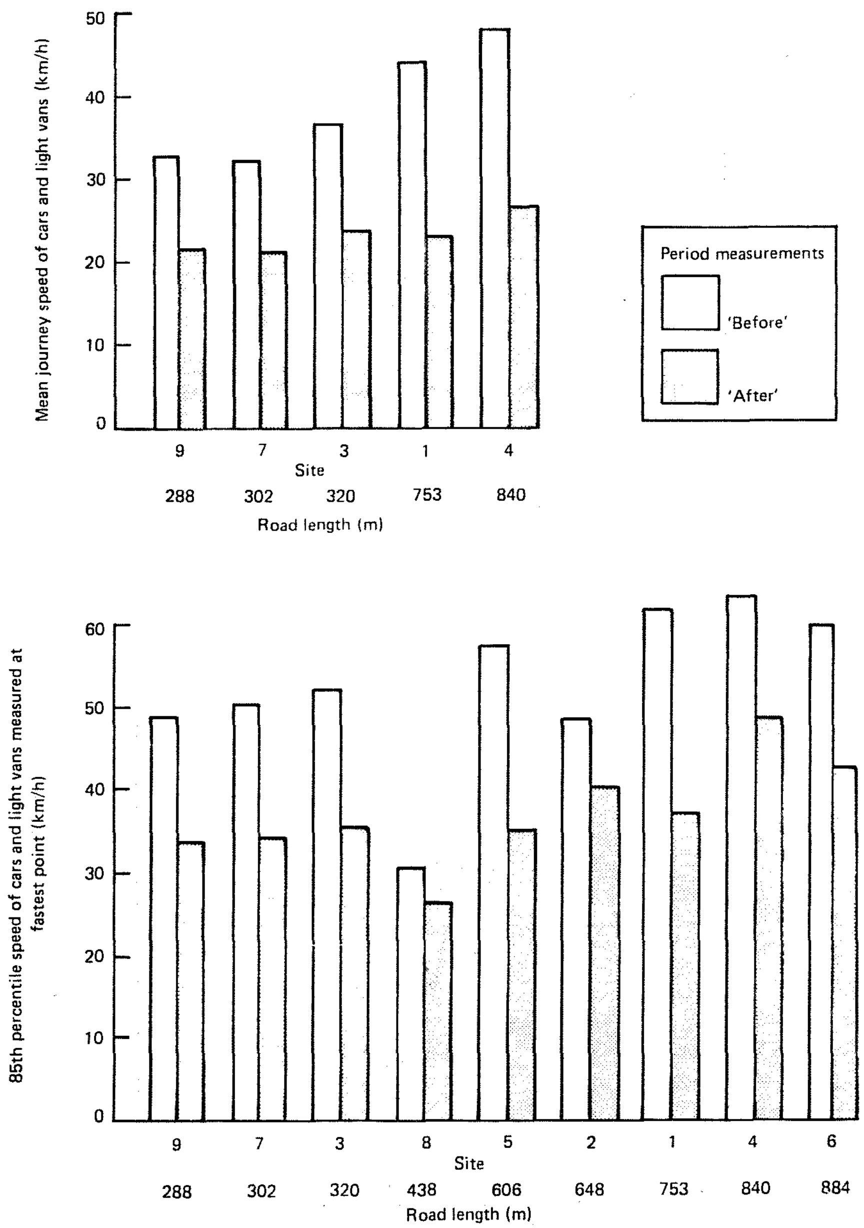

Fig. 1 Vehicle speed changes

speeds where the first hump of the series could be located. These criteria were set as means of avoiding excessive delay to traffic and minimising the possibly hazardous incidence of drivers encountering the first hump of the series at high speed. A drawback of using such selection criteria is that final conclusions about the effectiveness of the measure should only be applied to roads having similar features and it will not be known how important these site restrictions were.

As wide a geographic spread of sites as possible was used to avoid any effects peculiar to one particular region. Also, to reduce the likelihood of any one social class or class of driver biasing the results, a variety of types of area were chosen ranging from a road bordered by local authority tenement blocks in Glasgow to private residential houses at a site in Kensington (an inner suburb of London).

The first five sites used in the study[2] were all residential roads containing dwellings distributed fairly evenly along their length and carrying, almost exclusively, light vehicle traffic (ie very few heavy goods vehicles and no regular bus services). The later four sites[3] each had other features, for example, one had a scheduled bus service along it and another was a seafront esplanade bordered by shops and hotels. It was not expected that firm conclusions about the particular effects of humps at each of these new types of site would be established (having only one site of each type) but it was hoped that they would augment the findings from the earlier sites and at least indicate any extreme effects due to these other features.

EVALUATION MEASURES

A. Changes in behaviour and public opinion (process evaluations)

1. Of prime interest in this study was the effect of humps on traffic speed, on the previously untested assumption that a reduction in speed would reduce accidents on residential roads. There was, however, no one measure of vehicle speed that appeared the most appropriate to take in all circumstances. As accidents can occur anywhere along a road, one relevant measure was considered to be the average journey speed along the length of humped roads. These measurements were, however, found to be impractical at some sites which had very low flows as most vehicles did not travel the full length of the road.

It was considered that a more appropriate measure relating to accident frequency might be the maximum speed attained by vehicles. This is not necessarily reflected in journey speed measurements as some parts of the road could be considerably slower than others due to factors such as changing widths, bends, parked cars or number of side roads. In the 'before' study it was found that there was usually one short section on a road where most drivers were travelling at their fastest and its approximate position, where measurements were to be made, could be found by following a relatively small sample of drivers along the road. In most cases this point of maximum speed was shifted to a completely different position after the humps had been installed, and for comparison with 'before' measurements this point was taken to be midway between the two most widely-spaced humps on the road. It is clear from the results shown in Fig 1 that humps can reduce speeds substantially.

Speed measurements were also made between humps with a range of spacings and on the humps themselves at each site. Fig 2 shows the mean mid-point speeds against hump separation and some of the scatter from the regression

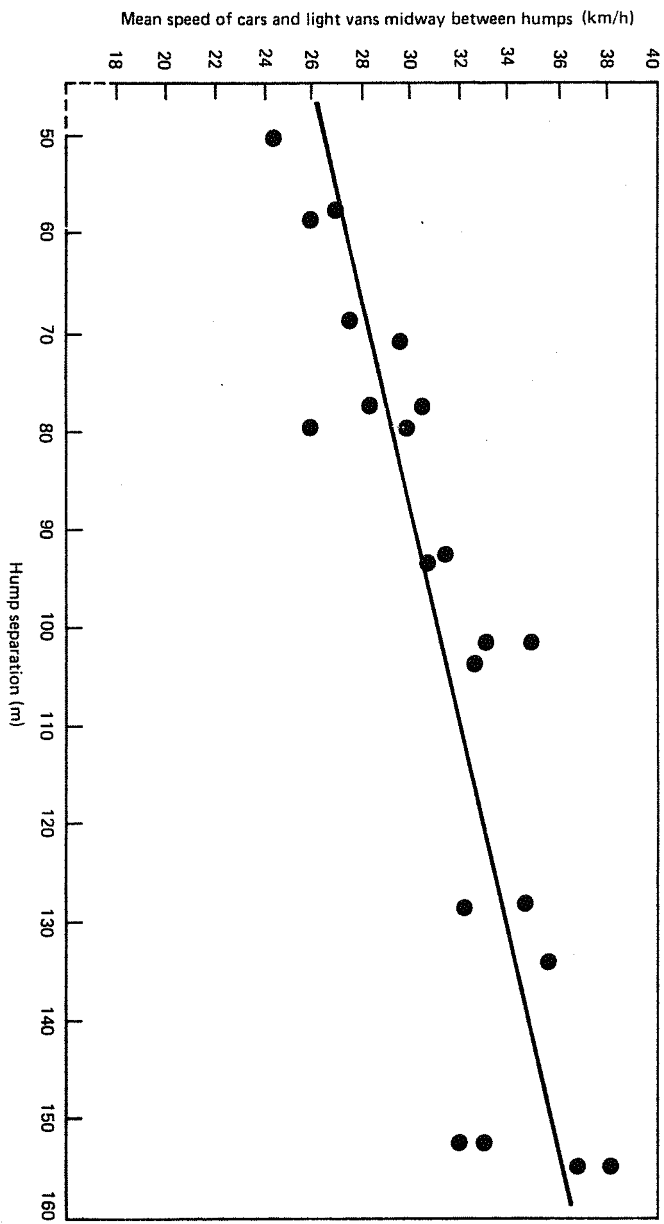

Fig. 2 Relation between mean speed and hump spacing

line drawn may be due to the fact that maximum speed attained is dependent on other factors such as road width and proportion of through-traffic. However, the results demonstrate that some control of the maximum speeds and hence average speed along the road can be achieved by choice of hump spacings.

2. A secondary expected effect of introducing speed control humps particularly on a road that is used as a short-cut is that some drivers would be discouraged from using the road altogether. It was therefore most important to consider the road as part of a wider area (usually a complete housing estate) and monitor traffic flow on as many routes as possible in an attempt to find out to which roads traffic had been diverted. Wherever possible, average 16-hour weekday counts over the same period of year in the 'before' and 'after' periods were compared to avoid bias due to seasonal variations.

Ideally, traffic using the humped roads as a short-cut would be diverted onto distributor roads designed to accommodate much larger flows but in practice part of this diverted traffic appeared to use other roads in the estate. The proportion of the original vehicles that no longer used the humped road varied considerably between sites. Prediction of this quantity would obviously be very difficult but detailed journey time measurements at one site indicated that the additional time necessary to travel the alternative routes was an important factor.

3. It was hoped that humps would provide considerable improvement in safety for pedestrians and so crossing manoeuvre studies were made at two of the sites[3,4] where pedestrian activity was sufficiently high to make this feasible. Using time-lapse film, pedestrians' safety gaps and time delays at the kerb were measured and preferred crossing areas in the 'before' and 'after' periods noted. Unfortunately, agreement of results from the two sites was poor due to differences between the sites themselves eg road widths, parked cars, traffic conditions, pavements. At the first site where mean journey speed was changed from 44 to 23 km/h and flow reduced by about 57 per cent, both pedestrians' safety gaps and kerb delays were markedly improved. The second site already had low speeds (reduced from 17 to 14 km/h) and humps did not affect traffic flow: thus a slight improvement in kerb delays only was observed.

The first site also indicated that pedestrians tended to choose humps as places to cross the road at footpath level and, although unexpected, this was regarded as an advantageous effect since these locations were now the areas on the road where traffic was travelling at its slowest. However, at the second site no change in the positions where pedestrains crossed the road could be detected.

4. Other measurements made at the experimental sites were of noise and vibration since complaints of these being due to traffic using the road were often made by residents. Noise measurements (18-hour L_{10}) were taken at the position of the house frontages and small reductions in noise level at all sites were recorded in the 'after' period. Most of this reduction was attributed to the reductions in traffic flow rather than speeds and so it is possible that some increases in noise occurred on those roads onto which through-traffic had been diverted.

In order to assess the affect of vibration transmitted by vehicles crossing humps it was necessary to make measurements inside houses. These were time-consuming to collect and analyse and involved obtaining residents' cooperation and thus a vibration study was only carried out at one site. This site, however, was likely to be a 'worst case' as the road was used regularly by buses and was bordered by modern houses, many with wooden floors, built only about 8 m from the kerbside. Vibration spectra obtained showed that although the highest levels recorded (ie for buses crossing a hump directly outside a wooden-floored house) were well below the level likely to cause structural damage to property they were slightly above the human perception limit and could, therefore, be considered a nuisance by some residents.

5. To assess public opinion of the humps used, one resident from each household bordering the humped roads was interviewed. To ensure that this sample was unbiased, the interviewee chosen from each household was the adult whose birthday was nearest the interview date. The interviews were carried out about 3 months after the installation of humps so that residents had sufficient time to get used to the humps but could still remember conditions before humps. The first part of each interview was designed to obtain opinions about changes in the road environment (eg noise, amount and speed of traffic, risk of accident) over the last 4 months without reference to humps. More specific questions about aspects of the humps installation (shape and size, positioning, signing etc) were then asked.

The surveys showed that, generally, residents considered that conditions had improved since humps were installed and at most sites more than 80 per cent of residents were in favour of the use of humps on their road. It should be noted that prior to the installation, all residents on the roads concerned were informed by letter of the proposals and given the opportunity to visit an exhibition caravan which outlined the experiment. In pointing out the aims of the experiment it is possible that this may have had some influence on residents' final opinions.

At the first site[4] the survey was also carried out on similar surrounding roads where the traffic flow had either increased or decreased due to the hump installation. Residents on these roads tended to believe that conditions on their roads had worsened irrespective of actual flow changes but they were generally in favour of the use of humps. A control survey was carried out at this site on another similar estate in the city and no significant changes in replies to similar questions over the same period were obtained.

Roadside interviews of non-resident drivers were also carried out on several of the humped roads and these indicated that the majority of drivers were also in favour of humps. This sample, however, only included those drivers who continued to use the humped roads and were thus less likely to be opposed to the scheme.

The emergency services at each site were asked for their opinions of the humps at the end of the experimental period. Most of the fire and ambulance services were against the use of humps due to the additional time necessary to respond to an emergency but the police services had no difficulty in using the roads and considered humps to be an effective safety measure.

B. Changes in accidents (product evaluation)

Because accident rates at the experimental sites were relatively low, consideration was given originally to the use of 'traffic conflicts' as an evaluation tool. This was, however, eventually decided against because the effects of humps were to be assessed over sections of road up to 900 m length and conflicts were likely to be fairly infrequent events (due to the relatively low flows involved). This would make conflict observations difficult and lengthy requiring more practical resources than were available.

At least 4 years of detailed injury accident data were available for the 'before' period at all sites. The 'after' period at each site was taken to commence from the date when hump installation was complete and care was taken to adjust all annual casualty numbers to this date rather than calendar years.

At the first site, other housing estates in the city were considered for use as control data. It soon became clear, however, that an estate of equivalent size having similar traffic patterns and accident numbers would be very difficult to find particularly in ensuring that no changes peculiar to this control site had occurred during the same period. This method was therefore abandoned in favour of taking injury accidents on all similar types of road (ie class C and unclassified) in that county or city area as the control. This was considered more likely to reflect general trends in accident rates due to changes in county or national policies (eg in local speed enforcement, road safety education, or national petrol and licence costs) during the study period.

It was decided that accidents which occurred at the junctions at either end of the humped roads should be included in the evaluation since the installations had in most cases affected the numbers of turning manoeuvres and also the approach speed of the turning vehicles at these junctions. Table 1 gives

TABLE 1 Road accident casualties at experimental sites

Site	Control ratio*	Road with humps			Alternative routes on surrounding roads		
		Before (4 yrs)	Expected After (1 yr)	After (1 yr)	Before (4 yrs)	Expected After (1 yr)	After (1 yr)
1	0.294	32	9.4	1	69	20.3	34
2	0.314	5	1.6	0	33	10.4	9
3	0.211	23	4.9	1	285	60.2	58
4	0.199	46	9.1	8	176	35.0	30
5	0.241	12	2.9	1	17	4.1	12
6	0.251	2	0.5	0	64	16.1	14
7	0.217	1	0.3	1	170	37.0	39
8	0.246	10	2.5	0	7	1.7	1
9	0.229	8	1.8	0	14	3.2	3
Totals		139	33.0	12	835	188.0	200

$$* \text{ Control ratio} = \frac{\left(\begin{array}{l}\text{Total casualties on class C \& unclassified roads in}\\ \text{District or Borough Council area during After period}\end{array}\right)}{(\text{Total casualties on these roads during Before period})}$$

the changes in numbers of persons injured on the humped roads and on all similar surrounding roads which were assessed as being the most likely alternative routes. Following the method of analysis derived by Tanner[5], the overall reduction of casualties of 64 per cent over the expected number on the roads with humps is significant at the 0.1 per cent level.

Casualties on the surrounding roads at some sites appeared unchanged whilst two sites showed considerable, statistically significant, increases. It is possible that as well as increased traffic flows on these roads, an improvement in reporting of accidents during the 'after' period (due to local interest in the road hump trials) may have contributed to these higher recorded casualty numbers. However, applying Tanner's analysis when the real effects at all sites cannot be assumed equal, there was no overall statistically significant change in casualties on the surrounding roads during the experimental period.

EVALUATION CONCLUSIONS

Advantages

1. Humps were effective in reducing traffic speed at all sites to a low level (less than 27 km/h average journey speed).
2. Traffic flow was reduced by varying amounts dependent on factors such as proportion of through-traffic and availability of alternative routes.
3. Due to (1) and (2) traffic noise was reduced on the roads with humps and crossing the road made easier for pedestrians.
4. The majority of residents at the experimental sites were in favour of the humps and thought they served a useful purpose.
5. Humps reduced the number of road accident casualties on the roads concerned by an overall 64 per cent. But see 2 below.

Disadvantages

1. Fire and ambulance services were in most cases against the use of humps due to the additional time necessary to respond to an emergency.
2. Some traffic was diverted onto similar surrounding roads and at two of the sites studied the numbers of casualties on these roads increased considerably. However, combining data from all sites there was no overall statistically significant change in casualties on the surrounding roads.
3. Vibrations transmitted by heavy vehicles crossing humps caused complaints from residents in some houses close to a hump.

It was not possible to determine by how much each of the two main process changes, ie speed and flow, affected the reductions in casualties. However, as the introduction of humps resulted in a much larger proportional reduction in casualties (64 per cent) than in vehicle flow (about 31 per cent overall), it is likely that some of the improved safety can be attributed to the reduction in speed.

With the exception of the effect on emergency services, the above disadvantageous effects of installing humps may be alleviated to a large extent by giving careful prior consideration to available alternative routes and to the siting of each hump. It is possible that in many circumstances humps may be more desirable than other accident counter-measures such as road closures or width restrictions which can lead to even longer delays to emergency vehicles.

This paper has outlined many of the problems encountered and precautions taken in the evaluation of speed control humps and discussed conclusions made from the rather short evaluation period and limited number of sites. The number of sites is such that a statistically significant change in casualties over all roads possibly affected (ie includes both the ones with humps and surrounding ones) was not to be expected. It was not found. The study has indicated the need to consider the effects of the measure over a wide area due to the secondary effect of humps in diverting some regular traffic to other roads. It has also demonstrated the importance of monitoring as many variables as possible to enable all the advantages and disadvantages of the measure to be assessed.

ACKNOWLEDGEMENTS

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"Short term" and area-wide evaluation of safety measures implemented in a residential area named Østerbro.

A case study

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Abstract

The Danish Council of Road Safety Research proposed in 1971 to the road authorities of the City of Copenhagen to carry out a joint research project. The aim of the project was an area-wide traffic replanning of a part of Østerbro, a residential area with 17,000 inhabitants. The aim of the scheme was to reduce the number of accidents by simple physical countermeasures.

The project consisted of three stages:

1. Collecting data and proposing a scheme
2. Implementing the scheme
3. Evaluating the traffic safety effect of the scheme

The evaluation of safety measures is primarely based on an analysis of the traffic accidents in the area, which have taken place before and after the implementation of the scheme. But also studies of the behaviour of the road users have been carried out in order to registrate whether or not the intentions of the countermeasures were obtained.

In the before-period (1969-1971) 475 police reported accidents took place, and in the after-period (1977-1980) 370 accidents took place. However we are still dealing with small numbers of accidents, since the traffic scheme consists of 25 different countermeasures and each of them are directed towards specific (and more or less different) accident types.

The study will try to provide answers to the following questions:

1. Which conclusions can be drawn from the results concerning the reduced number of accidents and number of persons injured, when defining "short term" as a period of 7-10 years and "area-wide" as a sum of 25 physical countermeasures implemented in a residential area of about half a square kilometre?
2. How do we distinguish between the accident reducing effect of the implemented safety measures, the reduced number of road users in the area and general safety measures implemented in the whole country in the same period?
3. To what extent have the behavioural studies supported or invalidated the results of the accident analysis?

Background

Between 65% and 70% or about 10,500 of all police reported traffic accidents in Denmark take place in built up areas. Looking only at accidents involving the light road users the percentage is between 80 and 90, or about 7,000 accidents.

On that background the Danish Council of Road Safety Research, in 1971, proposed to the authorities of the City of Copenhagen to carry out a joint research project of an area-wide traffic replanning in a part of a residential area, named Østerbro. The City should sponsor the implementation of the traffic scheme (10 mio. d. kr.), the Police should provide the accident data and the Council, primarely supported by the Technical University of Denmark, had the scientific responsibility of the design of the project and the measurement of effect. About 3 mio. d. kr. has been spend on research in this project up till now.

Purpose

The aim of the scheme was to illustrate whether it was possible significantly to reduce the number of traffic accidents in a residential area by means of simple physical countermeasures without affecting town- and trafficplanning in the area.

Design

The project consisted of three stages:

1. Collecting data and proposing a scheme
2. Implementing the scheme
3. Evaluating the traffic safety effect of the scheme.

The evaluation should primarely be based on a before and after study of accidents. The before period was 1.1.1969-31.12.1971. The scheme was based on a very detailed accident analysis, and consisted of a large number of different countermeasures. Each was directed toward certain accident types involving specific road users.

The total scheme was ready in January 1973. The authorities of the City of Copenhagen, however, needed 2 years to approve the scheme. It was in February 1975. Then the implementation of the scheme took another two years and was completed by March 1977. The after period was 1.4.1977-31.3.1980. Caused by the long period between the before and the after period, different behavioural studies were carried out in that period in order to support the accident analysis.

Methods

Such a study exposes a lot of methodological and cognitive problems, which undoubtedly has been known and reflected on by others, but obviously not with very fruitful results. Anyhow, in this project it has been necessary to make a lot of decisions without any support in empirical research. Main topics are *accident-frequency, control-areas* and *behavioural studies*.

1. Accident-frequency

The effect of the traffic scheme has been measured as significant differences in the frequency of accidents between the before period and the after period. *The frequency of accidents is defined as numbers of accidents (in a three years period) pr. traffic-km (in one day between 6 a.m. and 8 p.m.) for each combination of road users.*

The *accident data* consists of police-registrated accidents of which half has been reported and half has been registrated on more simple formulars with less detailed information. No persons have been injured in the last type of accidents.

The *traffic data* is based on two larger traffic censuses in the area, one in 1971 and another in 1978. The traffic volumes of the different road user categories has been counted manually in different road sections and intersections from 6 a.m. to 8 p.m. The volumes have been multiplied with the length of each road section and intersection in order to get the number of km travelled by each road user category on sections as well as intersections.

The *frequency of accidents* in road sections and in intersections is determined as for instance:

$$\frac{A_{p-m}}{\frac{1}{2}(T_p + T_m)}$$

where: A_{p-m} = Accidents between pedestrians (p) and mopeds (m)
T_p = Km travelled by pedestrians
T_m = Km travelled by mopeds

For accidents between road users of the same category, the frequency is determined as for instance:

$$\frac{A_{pc-pc}}{\frac{1}{2}(T_{pc} + T_{pc})} = \frac{A_{pc-pc}}{T_{pc}}$$

where: A_{pc-pc} = Accidents between passenger cars
T_{pc} = Km travelled by passenger cars

Single accidents have not been divided by ½, because this group of accidents then seems to give too much weight to the expression of accident frequency for a total street or intersection.

One of the advantages of this expression for traffic is, that it is possible to sum up accident frequences for road sections and intersections.

We are aware of that accident data is incomplete (not all accidents are reported by the police), and that the calculation of traffic volumes for each road section and intersection is uncertain (traffic has been counted in many but not in *all* road sections and intersections for economical reasons), and that two days traffic censuses hardly give a representative expression for the actual figures in the before and after periods (we do not know whether the variations of traffic over days, weeks and months are equal in the two periods), and that the chosen expression for accident frequency in many ways is vulnerable (its validity has not been proved).

2. Control-areas

A reduction in the accident frequency in our area can not only be attributed to the traffic scheme. 5 years have passed between the before and after period, and a lot af changes in traffic have undoubtedly caused some change in traffic accident numbers. In 1973 the energy crisis came along together with a speed limit of 60 km/h in urban areas. Seat belts were made compulsory in 1976. The change i accidents caused by these factors and possibly other factors is here called *the general accident trend*. We have to consider the change in the number of accidents by *the general accident trend* when estimating the change caused by the traffic scheme alone.

The general accident trend could be expressed in many ways. Very often another area, road, intersection, year, part of the country etc. is used as a *control area*. One of the conditions, however, is that *the experiment "area"* and *the control "area"* are very similar. When reading accident reports one learns that accidents seem to be very sensitive to details in the physical surroundings, road user characteristics, weather conditions, traffic volumes etc. In *built up areas* it is doubtful whether it is possible to find areas which are similar with respect to the variables mentioned above. We, therefore, have rejected the use of *a traditional control area*. We have chosen another model:

The traffic scheme consists of different countermeasures chosen to reduce the number of specific accident types, which have taken place in the before period. These accidents are called *experiment accidents* (i.e. accidents which were expected to be influenced by the scheme). It seems, however, not possible to influence all accidents by physical countermeasures. Therefore a group of accidents was separated from those which were intented to be influenced by our scheme. The same accident types were found in the after period, and the development in this group of *control accidents* is chosen as an exponent for *the general accident trend* in this project.

In that way *the experiment accidents* and *the control accidents* have the possibility of being influenced by the same physical surroundings, weather conditions, traffic volumes and road user characteristic. The development in the *control accidents* then represents the accident situation in the area, which would have appeared in the after period in the case where the traffic scheme has not been implemented.

Comparisons have been made of the two groups of accidents, and in many ways they are quite equal (e.g. road user categories, distribution over day, age). Regarding their distribution on road categories and severity of injury, however, they are definitely not equal.

3. Behavioural studies

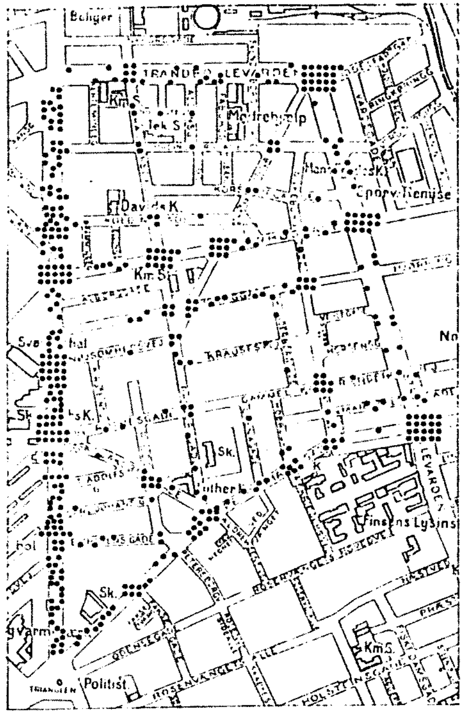
As mentioned before, the number of accidents in the project area is relatively small when operating at a very detailed level. Furthermore there is quite a long distance of time between the before and after period. These circumstances have lead to the implementation of different studies of the road users behaviour before and after the implementation of certain countermeasures. Emphasis has been given to studies concerning the speed of motorvehicles, the lateral position of different road users in the carriageway and pedestrians use of different crossing facilities.

We can tell from these studies whether the road user changes his behaviour according to the intention laid down in the countermeasure. So the purpose of the studies was to enlarge the background for expectations regarding the effect of each countermeasure. We do not know, however, whether the behaviour of the observed normal road users is similar to the behaviour of road users involved in accidents, so we can not use these studies as scientific evidence.

Data

The project area is covering an area of 43 hectar. In 1971 there was 17,250 inhabitants living in 8,400 appartment. About 4,000

persons were working in the area. Figur 1 shows the project area and the distribution of accidents in the before period.



Figur 1. Projekt area with all accidents which have taken place in the period 1969-71.

Table 1-5 show the volumes of accident- and trafficdata in the project in the before and after period.

Table 1 The total number of accidents (both experiment and control accidents) in the project area in the before and after period distributed on road user categories.

period/ road user categories	before number	%	after number	%
pedestrians	86	18	53	14
bicyclists	56	12	52	14
moped riders	46	10	20	6
other road users	287	60	245	66
total	475	100	370	100

Table 2 The total number of accidents in the project area in the before and after period distributed on *experimental and control accidents*.

period/ accident groups	before number	%	after number	%
experimental	204	43	112	30
control	271	57	258	70
total	475	100	370	100

Table 3 The total number of injured road users (in experiment as well as in control accidents) in the project area in the before and after period distributed on degree of severity

period/ severity	before number	%	after number	%
killed	7	3	5	4
seriously injured	111	48	33	26
light injured	110	49	89	70
total	228	100	127	100

Table 4 The total number of injured road users in the project area in the before and after period distributed on *experimental and control accidents*.

period/ accident group	before number	%	after number	%
experimental	126	55	47	37
control	102	45	80	63
total	228	100	127	100

Results in terms of methodologi

We do not know the validity of the expression of *the general accident trend*. As a consequence we have estimated the accident reducing effect of the traffic scheme with, as well as without, regard to the trend.

Furthermore the effect of the scheme can be estimated in different ways. One can for instance use the total number of *experiment accidents* as a basis for calculation, or one can sum up the

Table 5 The total number of km travelled in the project area (in one day between 6 a.m. and 8 p.m.) in the before and after period distributed on road user categories.

period/ road user category	km before	km after	change %
pedestrians	28,867	27,293	- 5
bicyclists	9,611	11,661	+21
moped riders	3,131	1,343	-57
other road users	56,707	45,664	-19
total	98,316	85,961	-13

estimates for every countermeasure, which has caused a significant change in the frequency of *experiment accidents*.

1. Which conclusions can be drawn from the results?

We shall first look at the consequences regarding the significance of the results concerning the reduction in the number of accidents, when defining "short term" as a period of 7-10 years and "area wide" as 25 different countermeasures implemented in a dense urban area, and with the present number of *experiment accidents*, 204 before and 112 after.

Looking at *the effect of the total scheme* (calculated as a sum of the estimates for every countermeasure, which has caused significant change in frequency of *experiment accident* ($p<10\%$)) one gets the following results, table 6.

The scheme seems to have caused a reduction in *experiment accidents* of approx. 59. This gives a reduction of approx. 36% of the expected *experiment accidents*. Furthermore one can se from the confidence-limits that the reduction in numbers of *experiment accidents* can vary with ±18 accidents or ±11%. When relating the reduced number of *experiment accidents* to the total number of expected accidents, one gets a reduction of approx. 15%. Looking at *the effect of each individual countermeasure*, it has been possible, out of a total of 25 countermeasures, to identify 10 with a significant influence ($p<5\%$) on the frequency of *experiment accidents* or injured in *experiment accidents*. In two cases the influence on the frequency of *experiment accidents* was only significant on a level between 5% and 10%. Consequently approx.

Table 6 The number of *experiment accidents* reduced by the traffic scheme estimated without regard to *general accident trend.*

data	1 experiment accident before	2 experiment accident after	3 expected experiment accidents after	4 reduction in experiment accidents caused by scheme *	5 reduction related to expected experiment accidents %	6 expected total number of accidents	7 reduction related to expected total number of accidents %
accidents	204	112	165.25	77.70 59.46 41.22	47.02 35.98 24.94	409	14.54

* The reduction is calculated as a sum of the estimates for these of the countermeasures, which have caused significant change in the frequency of experiment accidents (p<10%).

1/3 of the countermeasures seems to have an effect on accidents or number of injured, when choosing a level of significance of 10%. This means that the rest of the countermeasures are without any effect or that the numbers of accidents or injured have been to limited for an estimation of effect on this level.

The level of significance of 10% is chosen for the benefit of the very small figures, which on the other hand give information on a very high level of detail.

An example of the effect of one countermeasure is the effect on the freqyency of *experiment accidents* of a ban on left turn, table 7.

The ban on left turn seems to have caused a reduction of approx. 5 *experiment accidents.* Looking at the confidence-limits, however, the reduction can vary with approx. ±3 accidents.

With the chosen test-level this result is significant. But it is obvious that it would be difficult to get similar results with smaller numbers of accidents.

The total change in *experiment accidents* illustrates the effect of the traffic scheme as a whole in the actual area. This kind of evaluation gives information of a change but do not identify

Table 7 The number of *experiment accidents* reduced by a left turn ban without regard to *the general accident trend.*

accidents/ countermeasure	1 experiment accidents before	2 experiment accidents after	3 traffic (after) traffic (before) km	4 reduction in experiment accident caused by change in traffic	5 expected experiment accident after	6 reduced* experiment accident caused by ban	7 reduction related to expected experiment accident %
ban on left turn	6	0	198.10 254.30	2.39 1.33 0.27	4.67	8.41 4.67 0.93	100.00

* p<10%

the locations where the changes have taken place nor the countermeasures which have caused the changes.
Changes caused by the individual countermeasure distinguishes these countermeasures, in the total scheme, which have influenced the *experiment accidents* significantly. The effect of the countermeasures seems to be very dependent among other things on changes in the physical surroundings. It is much easier to find individual road sections and intersections similar to each of the sections and intersections in the project area, than to find another area similar to the project area as a whole. That is why, it is much more meaningful to try to transfer results regarding the effect of an individual countermeasure to other locations than to try to transfer the results of a total scheme to another area.

If one only want to evaluate the effect of a total traffic scheme, the need for large amounts of accidents (i.e. long before- and after periodes) is lower, than what is needed in order to evaluate the effect of individual countermeasures.

The examples show the confidence-limits attached to the numbers from this project, and illustrate thereby the accident figures needed for the production of valid results concerning effect. Taking these considerations into account, the duration of this projekt does not seem to have been extravagant.

2. *How do we distinguish between the effect of the implemented safety measures, changes in traffic volumes and more general safety measures?*

The method of control is already described in the section of the paper concerning methodology. The *general accident trend* is expressed by a group of *control accidents* defined as accidents, which were expected not to be influenced by the traffic scheme. Whether these accidents nevertheless have been influenced by the scheme in an indirect way, we do not know.

Also variations in traffic have been taken into consideration in the way described in the same section of the paper as mentioned above. The traffic of the different road user categories involved in accidents was in general expressed by ½ of the sum of km travelled by each of the categories of road users involved in the actual accidents.

The effect of the traffic scheme as well as the individual countermeasure is then the difference between the expected number of *experiment accidents* in the after period, and the actual number of *experiment accidents*, when having taken into consideration the changes in traffic as well as the *general accident trend*.

An example will show the differences in results, when estimates are made with and wihtout regard to the *general accident trend*.

Table 8 The number of injured in *experiment accidents* reduced by a central refuge without regard to the *general accident trend*.

injured/ countermeasure	1 experiment injured before	2 experiment injured after	3 traffic after / traffic before km	4 reduction in experiment injured caused by changes in traffic	5 expected experiment injured after	6 reduced* experiment injured caused by central refuge	7 reduction related to expected experiment injured %
central refuge	13	2	14,309.56 / 17,621.22	3.77 2.44 1.12	10.56	14.93 8.56 2.18	81.06

* p<5%

The effect of an individual countermeasure, a central refuge which should facilitate the crossing manoeuver for pedestrians, has been chosen, tables 8 and 9.

Table 9 The number of injured in *experiment accidents* reduced by a central refuge with regard to the *general accident trend*.

injured/ countermeasure	1 experiment injured before	2 experiment injured after	3 traffic after / traffic before km	4 reduction in experiment injured caused by changes in traffic	5 reduction in experiment injured caused by general trend	6 expected experiment injured after	7 reduced* experiment injured caused by centr. refuge	8 reduction related to experiment injured %
central refuge	13	2	14,309.56 / 17,621.22	4.13 2.61 1.10	8.35 4.58 0.81	5.81	8.87 3.81 -1.26	65.58

* p>10%

Table 8 column 6 and table 9 column 7 show the reduction in the number of injured persons in *experiment accidents* caused by the central refuge without and with regard to the *general accident trend*.

Paying no attention to the *general accident trend*, the central refuge has caused a reduction of approx. 9 injured persons in *experiment accidents* or approx. 81%. The conficence-limits shows that the reduction in numbers of injured person can vary with ±6. These statements are significant on a level below 5%.

Taking the *general accident trend* into consideration, however, the central refuge has not caused any significant change in the expected number of injured persons. In this study the *general accident trend* may remove as well as reinforce the computed effects of various measures.

The thosen expression for the *general accident trend* seems in many ways to be reliable. On the other hand some of the findings seem quite extreme, and they shall briefly be mentioned here.

Table 9 The general accident trend (GEN) distributed on street categories respectively frequency of accidents and injured.

frequency/ street category		accident frequency general trend (AGEN)	injury frequency general trend (IGEN)
surrounding streets no.	1	AGEN = 1	IGEN < 1
	2		IGEN = 1
	3		
local streets no.	4	AGEN > 1	IGEN = 1
	5		
	6		

It seems reliable that the *general accident trend* and *injury trend* are one in the surrounding streets of the area except from street no. 1. In this street there is a reduction in the frequency of injured person in *control accidents* of approx. 44%. This street is a shopping street and at the same time one of the radial connections between the northern suburbs and the CBD. The other two surrounding streets do not have this double function.

It is more difficult to explain an increase in the frequency of *control accidents* in the local streets of approx. 70%. Some intersections have been closed in the inner area, and one can suspect that the increase in traffic caused by the operations could in itself have caused the increase in these accidents. In that case it is either that our expression for traffic is not valid, or that the generated traffic has a higher risk than the "normal" traffic in the inner area. It has not been possible so far to clarify these conditions.
Theoretically, however, this expression for the general accident trend is as valid as more wellknown models and does not seem rejectable.

3. To what extent have the behavioural studies influenced the results of the accident analyses?

As mentioned in the section of the paper concerning methodologi,

we do not know whether the behaviour of "normal" road users is similar to the behaviour of road users involved in accidents, and this is why we can not use the behavioural studies as scientific evidence. They can not in any way replace the accident analysis.

We can see however, from the behavioural studies, whether the "normal" road users behave according to the intentions laid down in the countermeasures. Assuming then, that the "normal" behaviour is very much alike the "accident" behaviour, it is possible to tell from the behaviour studies why a certain countermeasure has caused an increase or a decrease in the numbers of accidents. It is important to underline however, that this assumption is of a purely speculative nature.

An example shall show how the accident analysis in that way can be supported by a behavioural study.

The central refuge, already mentioned at page 12, should provide a safe area for pedestrians to make a halt on, when crossing one of the busy streets in the project area. The carriageway had a width of 22 m. We had the opportunity to observe the behaviour of pedestrians in relation to two lay-outs of the refuge. First the refuge was painted and later on the refuge was built as a raised area. At the same location it was possible to cross the road by a subway. The number of pedestrians walking along the footpath on both sides of the street was counted, as well as the number crossing the street. The pedestrians crossing the street were separated into two groups: the "subway-pedestrians" and the "carriageway-pedestrians". Furthermore we observed the behaviour of the "carriageway-pedestrians" when crossing; i.e. there use of the central refuge were categorized: 1. just crossing, 2. coming to a halt on the refuge and 3. walking along the refuge.

First of all the numbers of "carriageway-pedestrians", related to the total number of pedestrians crossing the street, has increased after the implementation of the raised refuge, from 65% to 80%, ($p<5\%$). Secondly the raised refuge was used in another way than the painted refuge. The number of pedestrians coming to a halt on the refuge or walking along it, were significantly higher on the raised refuge compared to the painted refuge, (p<5%)

The accident analyses show a reduction in the frequency of *experiment accidents* where the refuge has been raised, and no change in the frequency of *experiment accidents* where the refuge has just been painted. (These results are based on figures without regard to *the general accident trend.*)

From these different analyses one can assume that the pedestrians had more confidence in the raised refuge at the same time as it actually was more safe.

In this project the behavioral studies are not used as a surrougate for accident data. All road users, which the actual countermeasure was aiming at, were observed. So the studies are used as a tool for the deduction of the road users degree of understanding and accept of the individual countermeasure, and by doing this the studies supplement the evaluation of the countermeasure based on the accident analyses.

Conclusions

If the aim is to improve safety, i.e. reduce the number of accidents or injured persons pr. road user km, one can not avoid looking at accidents somehow, when evaluating the countermeasures implemented in order to fullfil the aim.

This study shows that the same countermeasure can have different effects on the accidents at different locations. This does not mean that the effect of a countermeasure can not be generalized. It is however nessecary to be careful when selecting locations for further implementation of a certain countermeasure. This also indicates, that one has to evaluate the effect of every single countermeasure at every single location.

In practice this is not always possible. In this study there has been made a total evaluation of the same countermeasure implemented at different locations, if they were comparable, i.e. the number of accidents pr. road user km at different locations were equal in the before period.

Anyhow when operating with different countermeasures in a scheme it is nessecary to be able to identify <u>which</u> (countermeasures) and <u>where</u> (locations) there has been an effect on accidents. If not it will be impossible to transfer the results to other areas.

In areas where accidents only seldom occur, conflicts will be nearly as seldom and hence do not offer a better background for evaluation. Furthermore a reliable connection between accidents and conflicts seems not yet to have been found.(cfr. Thomsen, 1982)

Behavioural studies can express changes in the behaviour of "normal" road users and hence indicate <u>why</u> (or why not) there has been a change in accidents. A connection between the behaviour of normal road users and the behaviour of road users involved in accidents has not been found either. These studies therefore are not valid as scientific evidence.

We are then bound to use accidents as primary expression for improvement of safety, and as we must operate at a rather detailed level in order to discover which and where countermeasures have been most or least effectful, we will be dealing with smal numbers of accidents.

The study has shown that in a densely populated urban area of about half a square km, it has not been extravagant to use three years for both before and after periods if significant results are demanded.

Documentation

This project has not yet been officially reported. For the moment however all studies are documented in working papers. The research reports will be available by the end of 1982.

MEASUREMENTS OF DEGREE OF SEPARATION BETWEEN VEHICLES AND PEDESTRIANS IN URBAN AREAS.

by

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ABSTRACT

Most measures in order to increase traffic safety for unprotected road users are measures which separate vehicles from pedestrians or bicyclists in time or space.

This paper presents some results from emperical studies at pedestrians crossings concerning the proportion of pedestrians who can cross the street without disturbing or being disturbed by vehicles. This proportion of pedestrians is defined as the degree of separation between vehicles and pedestrians. Video technics were used for the measurements.

Both theoretical calculations and emperical measurements of the degree of separation have been made for the central part of Linköping at 16 randomly chosen pedestrian crossings.

The observation period at each crossing was 90 minutes distributed on three 30-minutes periods during daytime for three veekdays. From this it has been possible to estimate the traffic composition during different hours of the day for the central part of the city.

By comparing the total degree of separation of pedestrians during different periods of the day and accidents for the corresponding periods, relationships between risk (number of collisions between vehicles and pedestrians per pedestrian and pedestrian crossing) and pedestrian flow for different degrees of separation have been calculated.

BACKGROUND

On behalf of the National Road Board the National Road and Traffic Research Institute (VTI) is developing different risk estimates concerning unprotected road users in urban areas.

As most of the measures to increase traffic safety for unprotected road users are based on separation/segregation between motor vehicles and pedestrians or bycyclists/mopedists, the research has been directed to develop methods to make quantitative measurements of the magnitude of separation in different locations in urban areas.

The results presented in this paper are preliminary but give some examples concerning the separation between pedestrians and motor vehicles and risk calculations for pedestrian crossing in the central part of a city.

METHOD

The central part of Linköping was defined and 16 pedestrian crossings were chosen at random.

This procedure makes it possible to estimate the traffic composition on pedestrian crossings in the centre of the city. Video technics were used for the measurements. The measurements were made during three weekdays at three different times on every pedestrian crossing. The observation period at each crossing was 90 minutes distributed on three randomly chosen 30-minutes periods during daytime.

Each pedestrian crossing has been evaluated concerning

- pedestrian flow (pedestrian/h) in different directions on the pedestrian crossing
- motor vehicle flow for different types of vehicles
- bicycle flow

In the next phase every pedestrian has been observed during the passage of the pedestrian crossing. This has been divided into two parts (separation areas). One deals with the first half of the passage and the other with the second half. For both the first and the second part it was noted if a motor vehicle was going to drive across the pedestrian crossing or not. The separation areas are marked by unbroken lines (fig. 1). Broken lines mark the boundary for passing motor vehicles. The pedestrian is considered as non-separated and non-disturbed by motor vehicles, if, at the same time both a pedestrian and a motor vehicle are in the separation area or the motor vehicle is within the broken line preceding the separation area.

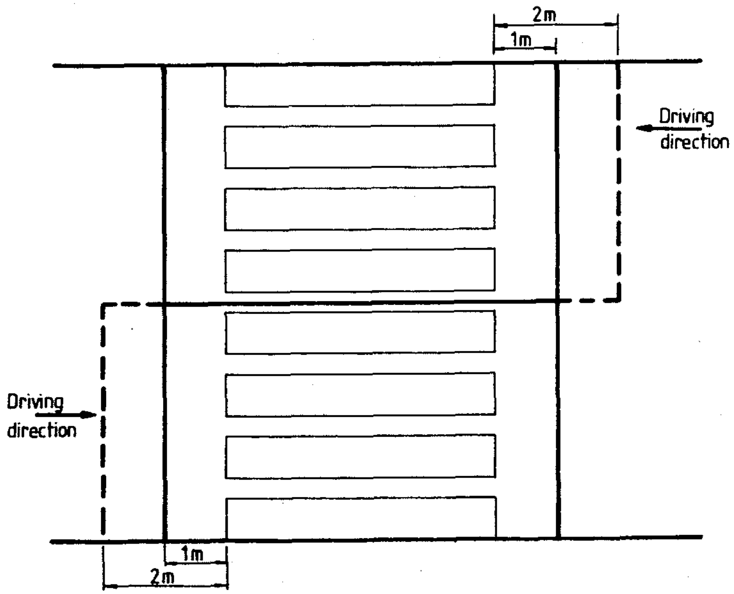


Figure 1. Pedestrian crossing and separation area.

The number of pedestrian observations without any disturbing motor vehicle(s) in relation to the total number of pedestrian observations is defined as the degree of separation for pedestrians.

Traffic safety and traffic composition

The observations of the hourly flow of passenger cars, lorries, buses, motorcycles, mopeds, cyclists and pedestrians resulted in estimates of the traffic composition between 0630 and 1830. These estimates are presented in figure 2. In figure 3 the estimated hourly flow is presented for passenger cars, buses, bicyclists and pedestrians.

In figure 2 it can be seen that the proportion of bicycles and buses is relatively high during the morning hours.

The proportion of pedestrians increases during morning and early mid-day and reaches maxima about 12 and 15-16.

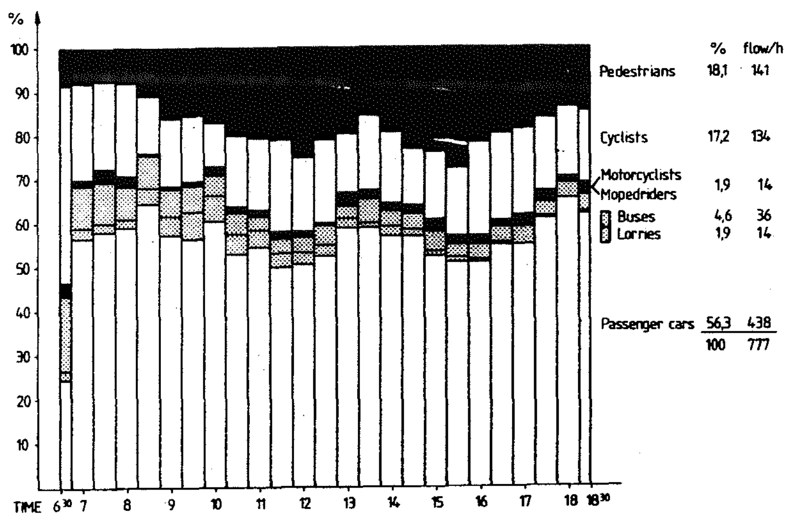


Figure 2. Traffic composition in the central part of Linköping, Sweden.

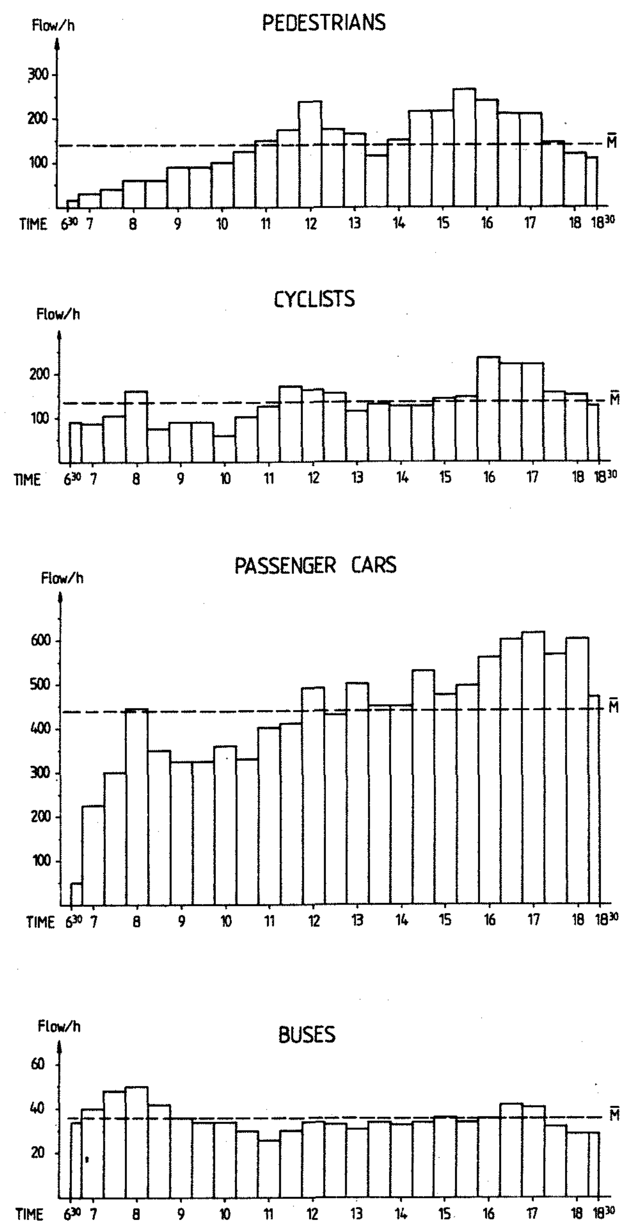


Figure 3. Estimated flow/h for pedestrians, cyclists, passenger cars and buses in the central part of Linköping.

As we now have an estimate of the proportions of different road user groups, it can be of some interest to investigate the corresponding appearance in police reported accidents concerning collisions with personal injuries. We also present this figures for all urban areas in Sweden (table 1).

Buses, pedestrians and cyclists are over-represented in the central part of Linköping - a business, service and administration centre for about 100.000 persons - compared with all urban areas in Sweden.

Table 1. The proportions of different vehicle or road user groups in Linköping and the corresponding appearance in police reported accidents in Linköping and all urban areas in Sweden.

	Proportion of the traffic in the central part of Linköping	Proportion of collisions with personal injury (policereported)	
		Central part of Linköping	All urban areas in Sweden
Passenger cars	56.3	44.1	52.6
Lorries	4.9	2.9	6.3
Buses	4.9	10.7	2.9
Motorcyclists	1.9	1.8	4.1
Moped riders		7.7	8.1
Cyclists	17.2	16.2	12.7
Pedestrians	18.1	16.5	13.2
	100%	100%	100%

Pedestrian safety. Relationship between degree of separation and traffic flow.

The measurements of the degree of separation for pedestrians show that the degree of separation is independent of the pedestrian flow but is by definition negatively correlated with the motor vehicle flow.

The choice of measurement method has a theoretical background based on the fact that pedestrians and motor vehicles are arriving at the pedestrian crossing with a constant probability in time. Time appearance for cars on the pedestrian crossing is A seconds, and B seconds for the pedestrians passing the pedestrian crossing. The theoretical degree of separation the becomes:

$$S_T = 1 - \frac{\text{Motorvehicle flow/h} \cdot (A+B)}{3600}$$

This means that the theortical degree of separation is decided by the product of motor vehicle flow and the sum of the average passing times across the pedestrian crossing for motor vehicles and pedestrians.

If it is a signalized intersection only the left and right turning traffic is treated and only the period of green light for pedestrians. The theoretical degree of separation can then be calculated as:

$$S_T = 1 - \frac{\text{Left and right turning motorvehicle flow/h} \cdot (A+B)}{X}$$

X = number of seconds per hour when both pedestrians and motor vehicles have green phase.

Both the theoretical (S_T) and empirical (S_E) degree of separation are calculated for 13 pedestrian crossings (table 2).

The figures mean that if the degree of separation is 0.90, 90% of all pedestrians can pass the street without disturbing or being disturbed by motor vehicles. Passage time for motor vehicles has not been accounted for in the calculation of the theoretical degree of separation for the crossings. The passage time for the pedestrians was assumed to be 4 or 5 seconds, depending upon the street width.

Table 2. Emperical (S_E) and theoretical (S_T) degree of separations from motor vehicles for pedestrians on pedestrian crossings. - Signalized and non-signalized crossings.

Pedestrian crossing (nr)		S_E	S_T
Signalized crossings	1	0.62	0.63
	2	0.61	0.80
	3	0.62	0.61
	4	0.54	0.95
	5	0.54	0.58
	6	0.69	0.63
	7	0.49	0.55
	8	0.37	0.58
	9	0.76	0.73
Non-signalized crossings	10	0.77	0.91
	11	0.90	0.90
	12	0.90	0.89
	13	0.92	0.95

The empirical observations can also give different measurements of the degree of separation for pedestrians crossing the street depending on direction and lane.

Relationship between collision, risk and flow

A model close at hand for predicting the number of collisions between pedestrians and motor vehicles is a muliplicative model with pedestrian and motor vehicle flow as predictors. One such regression model was tested on police reported collisions between pedestrians and motor vehicles, which had occured during daytime in central Linköping during the last five years. For this, the daytime period was divided into six two hour periods. The result indicates an increase in the number of collisions both with increasing pedestrian flow and increasing motor vehicle flow (figure 4).

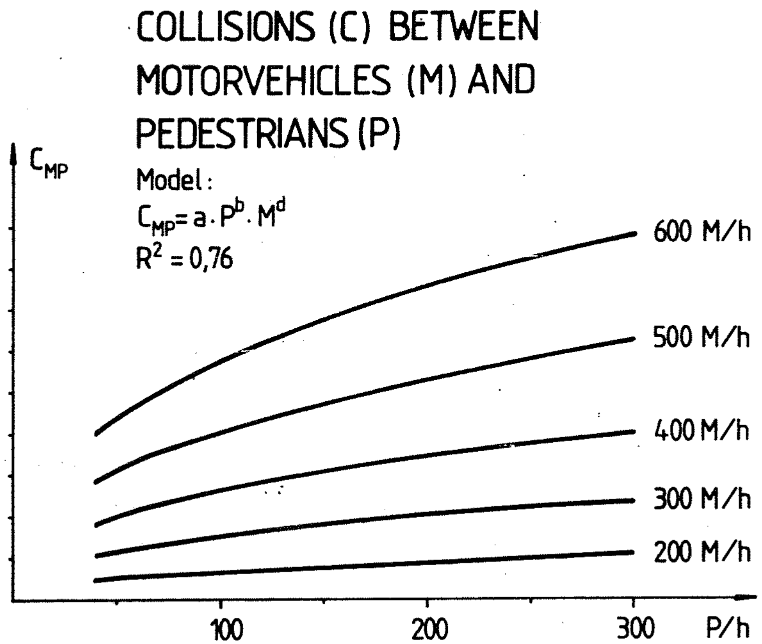
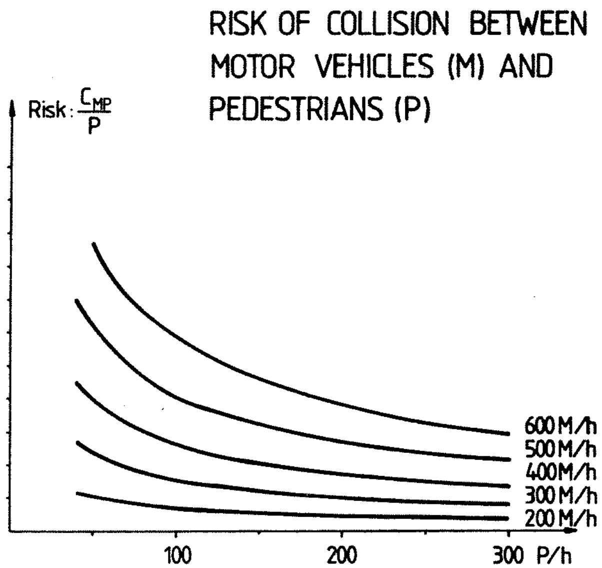


Figure 4. Calculated relationships between collisions and pedestrian flow for different motor vehicle flow.

A possible risk measurement for pedestrians crossing street is

$$r_p = \frac{\text{Number of collisions between pedestrians and motor vehicles}}{\text{Number of pedestrians crossing the street}} = \frac{C_{MP}}{P}$$

When the predicted number of collisions according to the regression model is used in the expression for risk, the following relation is obtained for different pedestrian flows (figure 5). The risk increases with increasing motor vehicle flow and it increases with decreasing pedestrian flow at a certain constant motor vehicle flow.



Figur 5. Calculated relationships between collision risk and pedestrian flow for different vehicle flow.

Relationship between collision, risk and degree or separation

As we have seen above a great part of the pedestrians are separated from the motor vehicle traffic and therefore of no value for explaining the probability of collison. This also means that it is better to use the number of non-separated pedestrians than the total pedestrian flow, as a predictor for the number of collisions.

If the number of non-separated pedestrians is used as a predictor in the regression model, the degree of explanation becomes somewhat higher (0.81) i.e. somewhat stronger relationship (correlation 0.9), than if the total number of pedestrians is used. The character of the relation does not change. In these results the degree of separation has been calculated from three randomly chosen 5 minute periods of every observation period.

Another risk measurement can be defined, in which the denominator consists of those pedestrians who are not separated from the motor vehicle traffic.

$$r'_p = \frac{C_{MP}}{P(1-S)}$$

The number of collisions can be estimated according to the definition of risk with the following espression:

$$C_{MP} = r'_p \cdot P \cdot (1-S)$$

The number of collisions then becomes a function of risk, pedestrian flow and degree of separation.

The material used here indicates that risk (r'_p) and pedestrian flow are independent. This means that for a certain degree of separation, the risk is constant for varying pedestrian flow. The number of collisions will at a certain degree of separation increase or decrease proportionally with the pedestrian flow.

It has been possible to study the relation between number of collisions and pedestrian flow for two degrees of separation - 0.60 and 0.75 (figure 6). The result shows that a change in degree of separation from 0.60 to 0.75 will lower the risk for collisions between pedestrian and motor vehicles 10% and decrease the number of collisions by 40%

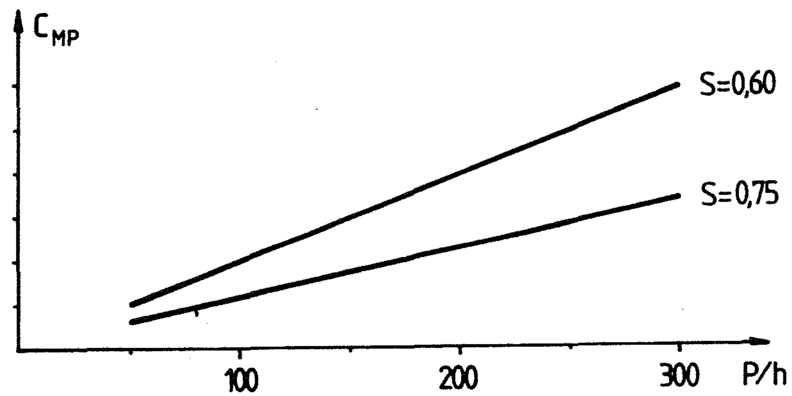


Figure 6. Calculated relationships between collisions and pedestrian flow for two different values of the degree och separation.

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Conclusions

The aim of this paper is to point out some possibilities in order to evaluate the traffic safety situation in urban areas by quantitative estimation of the effectiveness of measures to increase the traffic safety situation for unprotected road users.

EVALUATION OF LEFT TURN SOLUTIONS AT URBAN INTERSECTIONS

(Research Project No. 7329/7 of the Bundesanstalt für Straßenwesen (Federal Highway Research Institute), Cologne, in collaboration with the Hanseatic City of Hamburg)

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1. Objectives

In the past years, 70 per cent of all injury accidents in the Federal Republic of Germany accurred in urban areas.

A closer look at the relevant statistical data reveals intersections to be the critical points of urban traffic and cars making left turns to be particular exposed to the risk of accidents.

The conventional administrative measures on the local authority level to improve urban road safety can be characterized as follows:

Based on the pin-maps of accident types and locations, which are maintained at the police stations responsible, hazardous intersection sites and road locations are determined at the end of each calender year by means of established limit values, whereupon a preliminary analysis of these hazardous locations is carried out. The results are made known to specific accident comittees (representatives of the police, traffic authorities and road construction agencies) who, in their turn, based on the information from the pin-maps and on-site observations, develop proposals for remedial measures, fix priorities among alternative proposals and see to it that countermeasures are implemented.

It is evident that this is a procedure directed at individual locations or specific time periods rather than one giving due consideration to the area traffic context in which hazardous locations are embedded and the factors causing the accident, and which often originates from the unique circumstances of a single situation. That is why every attempt should be made, in particular within the frame of the removal of hazardous road locations, to find supplementary "objective" and standardized aids for a short-term and area-wide evaluation of certain traffic engineering and management facilities.

The objectives of the study describes below, resulting from these considerations, include the development of a method and the instrumentation needed to evaluate left turns at urban intersections. To begin with, a systematic catalogue of all variables possibly relevant for the accident scene on this isolated area of study was compiled. From this, measuring quantities not varying in space and time were derived for the constructional and traffic engineering characteristics and for those of the intersection environment. The traffic flow characteristics largely varying in space and time required definition of corresponding measuring units. The assumption of a sufficiently close relationship between the characteristics studied and the accidents associated with left turns was the basis for drafting a basic evaluation scheme.

To ensure the validity of the method, an adequate number of representative urban intersections had to be included in the study. The traffic control facilities, selected jointly with the highway construction agency of the Hanseatic City of Hamburg, had to meet the following requirements:

- an adequate number of intersection approaches with typical forms of left turn control (≥ per form) were to be included in the study;
- full accident data covering the preceding years were to be provided for all intersections;
- intersection accidents were to be as uniform as possible in number and composition to be meaningful for the study;
- traffic volumes of individual intersections were to be constant over the preceding three years but varying from intersection to intersection;
- for all intersections, complete and, if possible, up-to-date location plans, plans of road markings and phasing diagrams were to be available.

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2. Data Collection and Evaluation

Data were collected on 102 approach roads to the 28 intersections studied in the Hanseatic City of Hamburg and processed; for economic reasons, the survey of traffic conflicts and encounters was limited to 61 intersection approach roads. On the 102 of the 112 approach roads studied left turns were or are still permitted. The data analyzed for the period Jan.1, 1976 to Dec. 31, 1979 included 1180 accidents involving cars making left turns.

The design of the evaluation method was at first based on a detailed analysis of the accidents involving left turns and the traffic characteristics which were supposed to have measurably contributed to the accidents.

The data collected were categorized as follows:

o Risk exposure indicators
- time and location of accident
- type of accident

- accident consequences
- No. of traffic conflicts by type and severity
- traffic encounters

(source: accident records and on-site observations)

o Traffic facility characteristics not varying in space or with time
- intersection geometry
- road markings
- public transport facilities
- protection facilities for pedestrians and cyclists
- parking facilities
- street lighting
- traffic signs
- types of traffic signals
- lost times
- visibility

(source: plans, drawings and on-site observations)

o Traffic flow and intersection environment characteristics varying in space and with time
- traffic volumes
- pedestrian streams

(source: traffic counting records of the Highway Construction Agency, Hanseatic City of Hamburg, or on-site observations)
- weather
- pavement condition.

A classification of the data was made by associating the variables with the following three study elements: accident, conflict and intersection approach road. The first data pool contains all the accidents and the second all the conflicts with the characteristics studied. The third data pool contains, for each intersection approach studied, the accident and conflict characteristics from the first and second data pool combined with the intersection characteristics varying or not varying with time and in space.

3. Determination of the Safety of Intersection Approach Roads with Left Turns by Means of a Typology

The 28 intersections studied have the following features in common:

- signal control
- four-leg intersection
- medium to high traffic volume

(secondary roads, main roads)

The forms of left turn control on the 102 intersection approach roads studied were classified by the types shown in Fig.1 (See Annex).
With respect to the constant and varying characteristics, at first correlation calculations and contingency tests were carried out to ascertain their relationship with the accident scene.
The weekday accident rate on the intersection area (URWI)[1] was used as indicator for the risk exposure at intersections. The results permitted the relevancy of the following characteristics for the accident scene to be derived:

- sum of lanes on the approach road
- visibility as a function of traffic flow
- type of land use (buildung development)
- exclusive left turn phase
- visibility as a function of traffic facility
- type of land use (commercial, residential, etc.)
- road markings.

The cumulative frequencies shown in Figure 2 to 5 (See Annex) are meant to visualize the relationships found. The distributions over the population represent approach roads with safety characteristics which are above average; distribution under the population represent approach roads with less than average unsafe characteristics.

In accordance with the above, the approach roads with an exclusive left turn phase demonstrated the lowest accident rates (URWI) of the approach roads studied, and are grouped under Type 1. The flow of left turn maneuvers, due to the exclusive left turn phase, does not interfere with the flow of opposite intersection approach and the flow of pedestrian and cycling traffic. Due to the close relationship between the characteristic "exclusive left turn phase" and a relatively high approach road safety level, the effects on accidents of other risk exposure factors, such as visibility, type of building or land use, are much reduced.

1) $\text{URWI} = \dfrac{\text{accidents}}{10^6 \text{ vehicles}}$

The second best result with respect to the level of safety was found on intersection approach roads provided with early cut-off phases. Left turns are made during the early cut-off phase and thus under conditions similar to those of the "exclusive left turn phase".

The safety levels of approach roads without exclusive left turn phase or early cut-off, being below the ones just mentioned, were rated by means of:

- the number and arrangement of lanes on the approach road
- existence of left turn lanes
- number and arrangement of lanes on the opposite approach road (on-coming traffic).

(See Fig. 1).

By means of statistical analysis (T-test), significant differences in the means were found for individual approach roads, based on the weekday accident rate on the intersection area (URWI) and/or the number of weekday accidents on the intersection area.

4. Range of Application of Instrumentation

Proceeding from the typology of intersection approach roads, based on the external characteristics shown in Fig. 1, there are the following possibilities of application of the knowledge derived from the study.

4.1 Area-wide Measures

In order to solve decision-taking problems concerning larger problem areas (e.g., area-wide removel of hazardous road locations, programs of remedial measures with respect to certain types of accidents), formalized methods to identify accident black spots and a successive selection of suitable measures are a particularly good means of dealing with such matter. The study of approach roads in Hamburg revealed the following information with respect to working procedures and steps:

1. Formulation of a decision-taking problem and pin-pointing the study area.
2. Identification of accident black spots, based on the accidents involving cars making left turns on approach roads to signal controlled four-leg intersections.

The identification requires the following steps:

- determination of the type of approach road under study in accordance with the information in Fig. 1;
- analysis of accidents (mean of two years) involving cars making left turns and determination of the traffic volume making left turns per approach road;
- calculation of the accident rates associated;
- comparison of the actual accident rate with the safety level threshold value resulting from the specific type of approach road (expressed in terms of URWI).

An alternative possibility is also the incorporation of safety levels into existing identification models as expected mean accident risk values.

3. Compilation of the intersection approach roads, defined as hazardous road locations, and selection of suitable remedial measures and/or combinations of measures for accident black spot removal. The following information might be a guide to the finding of countermeasures:
   (a) Comparision of the actual situation with the situation given by the the typology and, if possible, attempt at achieving a situation corresponding to an approach road type associated with a higher safety level.
   (b) Selection of appropriate remedial measures and/or combinations of measures by changing the risk characteristics of approach roads shown in Fig. 2 to 5.
   (c) Selection of suitable remedial measures and/or combinations of measures taking into consideration additional traffic, environmental, city structure and other aspects as well as investment and operating costs.

4.2 Individual Location Measures

In order to solve decision-taking problems with respect to the cause-effect relationship for local accident scenes and the selection of suitable measures to remove individual hazardous road locations, check-lists may be drawn up. If the problems of decision-taking are to be solved without reverting to formalised procedures, a check-list could include the following working steps, derived from the knowledge acquired thus far:

1. Formulation of the decision-taking problem and pin-pointing the area under study.

2. Data collection, as far as available, on the basis of
   - accident statistics
   - accident diagrams
   - location plans.

3. Checking to find out whether accident causes can be cleared up and, if possible, deriving suitable remedial measures therefrom.

4. If it should not be possible to state the facts of the case satisfactorily on the basis of data collected, further steps need to be taken:
   (a) On-site observations to find further information, in particular by means of the following characteristics:
      - sum of lanes on the approach road
      - visibility as a function of traffic flow
      - type of land use (building development)
      - parking adjacent to the roadway
      - road markings.
   (b) Hearing of experts, adjacent owners, and road users.
   (c) Use of other survey methods to improve the data material acquired. In particular, use of the traffic conflicts technique as a diagnostic tool under the following conditions:
      - if accident data do not provide sufficient details or data are incomplete
      - under certain circumstances (e.g., great variation of traffic volume during the day due to trip generation sites, such as shopping centers, sports facilities, and public transport stops)
      - if statistical data are not yet available due to major constructional or traffic management changes in the area studied.
   (d) Interpretation of results and identification of countermeasures.

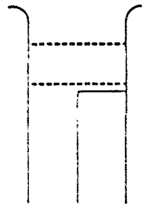
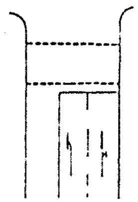
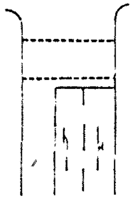
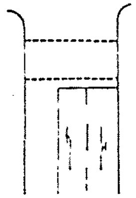
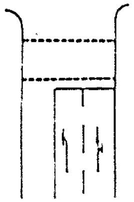
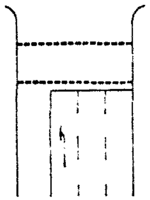
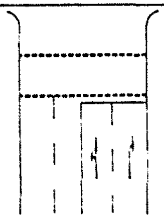
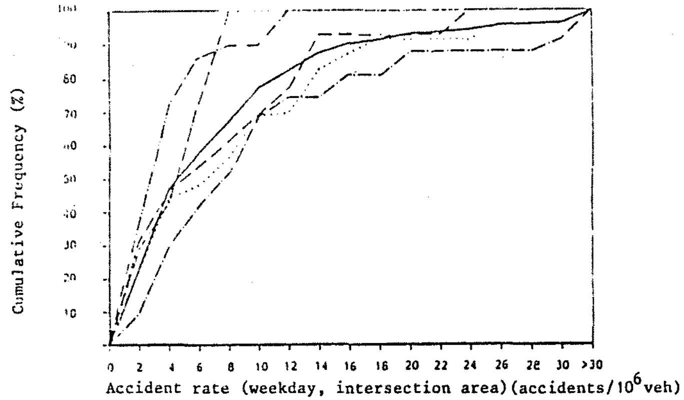
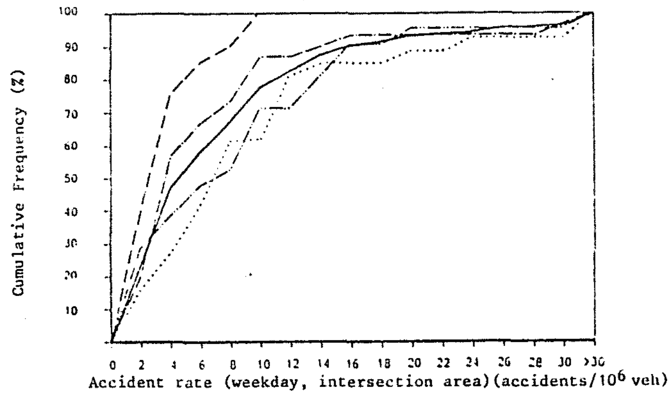
type	Arrangement of lanes: left turn approach	Arrangement of lanes: approach for through traffic from opposite	type of signal control: left turn phase	type of signal control: early cut-off	left turn lane
1	all forms	all forms	yes	no	yes
2	all forms	all forms	no	yes	yes
3		 and less	no	no	no
4		 and less	no	no	yes
5	 and more	 and more	no	no	yes
6	 and more	all forms	no	no	no

Fig. 1: Typology of signal-controlled intersection approaches



Sum of lanes on intersection approach

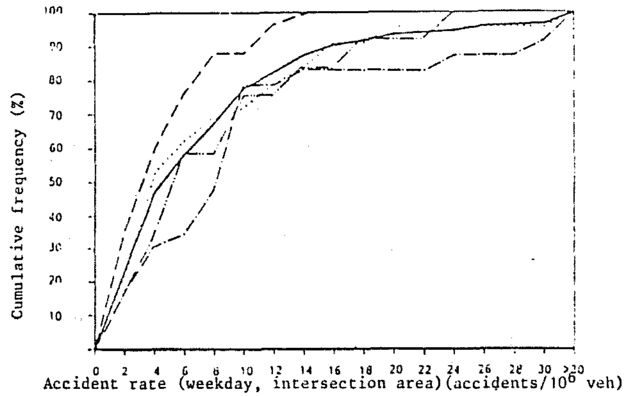
—— population	(n = 102)	χ^2-significance = 0,1982
– – – 1 lane	(n = 13)	cc_{corr} = 0,4967
–·–·– 2 lanes	(n = 31)	
········ 3 lanes	(n = 23)	
–··–··– 4 lanes	(n = 28)	
–·–·– 5 lanes	(n = 7)	



Sight distance, depends on vehicular traffic

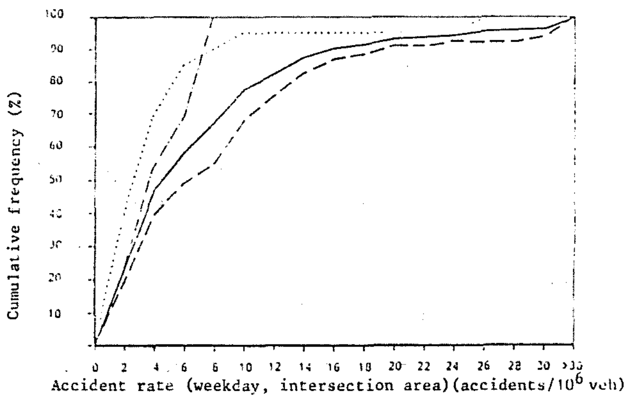
—— population	(n = 102)	χ^2-significance = 0,0174
very good	(n = 1)	cc_{corr} = 0,5414
– – – good	(n = 20)	
–·–·– satisfactory	(n = 30)	
········ adequate	(n = 26)	
–··–··– poor	(n = 21)	
very poor	(n = 4)	

Fig. 2: Cumulative frequency of accident rate (URWI++) as a function of buildings and left turn phase of traffic lights
++) URWI: weekday accident rate on intersection area



Buildings

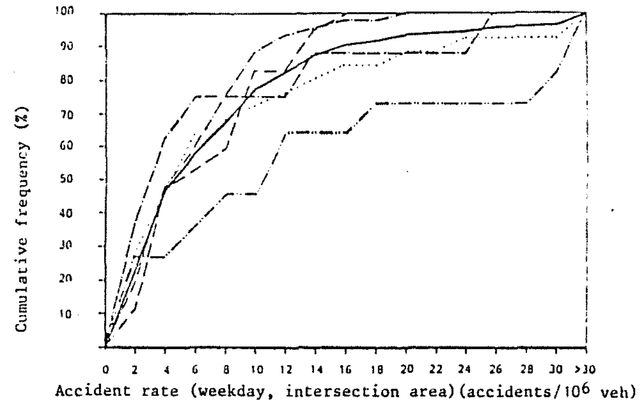
population	(n = 102)	χ^2 significance = 0,0262
none	(n = 25)	CC_{corr} = 0,5308
open, single family houses	(n = 23)	
open, multistory	(n = 42)	
compact building development	(n = 12)	



Left turn phase

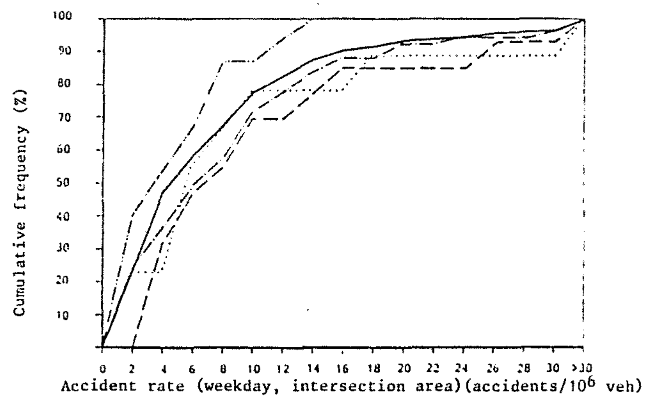
population	(n = 102)	χ^2 significance = 0,0096
none	(n = 69)	CC_{corr} = 0,5285
early cut-off	(n = 13)	
special left turn phase	(n = 20)	

Fig. 3: Cumulative frequency of accident rate (URWI)++) as a function of buildings and left turn phase
++) URWI: weekday accident rate on intersection area



Sight distance (function of buildings)

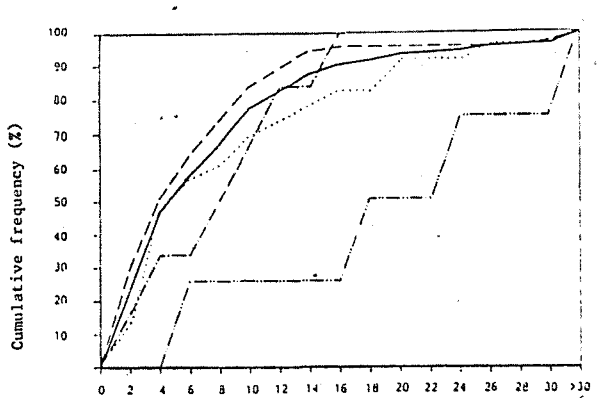
population	(n = 102)	χ^2 significance = 0,1955
very good	(n = 17)	CC_{corr} = 0,4973
good	(n = 40)	
satisfactory	(n = 25)	
adequate	(n = 11)	
poor	(n = 8)	
very poor	(n = 1)	



Type of land use (predominant)

population	(n = 102)	χ^2 significance = 0,2559
shopping	(n = 13)	CC_{corr} = 0,4818
dwelling	(n = 49)	
comercial	(n = 9)	
recreation	(n = 15)	
other	(n = 16)	

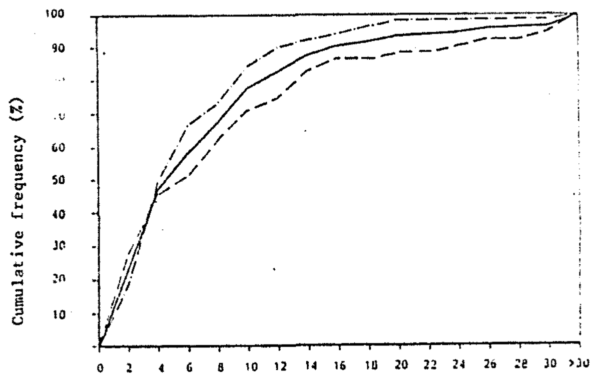
Fig. 4: Cumulative frequency of accident rate (URWI)++) as a function of sight distance and type of land use
++) URWI: weekday accident rate on intersection area



Accident rate (weekday, intersection area)(accidents/10^6 veh)

Parked vehicles on the side of the street(adjacent to the roadway)

——— population	(n = 102)	χ^2 -significance = 0,3630
– – – none	(n = 69)	cc_{corr} = 0,4285
–·–·– on the sidewalk	(n = 6)	
········ on marked parking strips	(n = 23)	
–··–·· on the left side of the street	(n = 4)	



Accident rate (weekday, intersection area)(accidents/10^6 veh)

Left turn pavement markings on the intersection area

——— population	(n = 102)	χ^2 -significance = 0,1218
– – – none	(n = 51)	cc_{corr} = 0,3964
–·–·– existing	(n = 51)	

Fig. 5: Cumulative frequency of accident rate (URWI)++) as a function of parked vehicles on the side of the street (adjacent to the roadway) and left turn pavement markings on the intersection area
++) URWI: weekday accident rate on intersection area