ARROWS
Advanced Research on Road Work Zone Safety Standards in Europe

Road work zone accident studies

ARROWS Task 2.2 Internal report

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Summary

The primary objective of this task, part of the ARROWS project, is to draw conclusions about the nature and extent of work zone traffic accidents.
To that end, we collected and reviewed existing empirical studies concerning work zone traffic accidents, as well as literature reviews of such.

We focused on a number of relevant work zone and work zone accident characteristics. E.g.:

- type of road;
- type and duration of works;
- interaction between works and road;
- weather; and
- time of day.

In addition, we attempted to draw conclusions about trends over time, effectiveness of safety devices, and national differences.

Drawing conclusions was hampered by a dearth of studies with sufficient sample sizes and adequate use of statistical techniques. Questions can also be raised about the adequacy of data collection procedures.
In addition, results from different (even adequately done) studies were often contradictory and/or confusing.

Nevertheless, a number of (tentative) conclusions may be drawn.
First of all, accident rates in work zones are higher than in similar, non-work zone situations. In addition, work zone accidents typically account for several percent of all accidents. It turns out, however, to be quite difficult to estimate exactly how unsafe work zones actually are. Estimates vary widely, and a meta-analysis could be profitably done. The relative severity of work zone accidents is also difficult to determine.
Secondly, work zone accidents are mainly often associated with fair weather and daylight conditions. Rear- end accidents seem to be especially common. There may also be an interaction between accident severity, time of day, type of area, traffic density, and type of accident. This possibility should be further investigated.
Thirdly, there is quite likely some structure in intra-work zone accident rates. However, this could not be irrefutably established. Sections 'after' a work zone are, in any case, not substantially more dangerous than a normal road section.
Fourth of all, work zones on the side of the road do not necessarily have any negative safety impact. Work zone of shorter duration might have a higher accident risk, yet the evidence is not airtight. Work zones in the neighborhood of entrance ramps may also have higher accident rates, but the results are mixed, even within the same study. In addition, work zones using full contraflow are often signalled as being relatively dangerous, but the results are mixed.
Fifthly, different types of roads, with and without work zones, have different accident rates. However, we could not clearly establish a differential safety effect.
Sixth of all, no convincing empirical literature concerning accident risks as a function of safety devices was found.
Seventh, the role of contributory human factors (as registered in accident statistics) is unclear and contradictory.

Finally, no overall temporal trend in work zone accident rates could be clearly established, and we did not dare to draw international comparisons.

Overall, the simplest and most robust method for predicting work zone accidents, is to use exposure (e.g., traffic volumes and operational hours) and pre-work zone accident rates.
In addition, we feel that international research, with sufficient sample sizes and appropriate use of multivariate statistics, could form a major contribution towards understanding the epidemiology of work zone accidents.

Contents

1. Introduction

The ARROWS project was originally developed to help meet (some of) the goals of the Road Transport theme of the Fourth Framework Transport Workprogramme.

ARROWS is an acronym for the European research project: Advanced Research on Road Work zone Safety Standards in Europe. Its objectives are multiple:

- to inventorise work zone safety measures;
- the assess the nature and extent of the (traffic) safety problem at work zones, in terms of traffic accidents and road user behaviour;
- to assess the effectiveness of existing safety measures;
- to review methods for assessing said effectiveness, and propose a standard evaluation testbench;
- to propose and evaluate improved sets of safety measures;
- to recommend a framework for European standards; and
- to provide a practical handbook for improving the safety of road workers and users.

This project consists of five different Work Packages, implemented by nine different consortium partners over a period of two years.

The ultimate goal of ARROWS is, of course, to improve the safety of work zones, by reducing the frequency and/or severity of collisions involving road users. A logical pre-requisite for such a task is the review of research concerning said work zone traffic accidents.

The present report, implemented as *Sub-Task 2.2: Accidents Studies,* of the ARROWS project, is intended as a summary of such a review, conducted by the SWOV, NTUA, ZAG, and the BAST, four of the ARROWS partners.

2. Objectives and limitations

2.1. Objectives

The primary objective of this task is to draw conclusions about the nature and extent of work zone accidents. To that end, we have collected and reviewed existing empirical studies concerning work zone accidents, as well as literature reviews of such.

Depending upon the availability of relevant literature, we have attempted to draw conclusions about the relation between relevant accident characteristics and work zones. We have attempted to consider aspects such as:
- type of road;
- type and duration of works;
- interaction between works and road;
- weather;
- time of day
- the effectiveness of safety devices;

etc.

In addition, we have attempted to draw conclusions about trends over time and national differences, if at all possible.

2.2. Limitations in scope

We would like to emphasise that this study has very strictly limited itself to studies in which the primary concern is the analysis of traffic accidents in work zones. Studies concerned with non-accident related work zone characteristics or road user behavior were not be treated in this work package.

We required that reported studies have at least a minimum quality: e.g., anecdotal evidence, unsupported opinions, and inadequately documented studies have not be considered. Case studies were only be considered when presented in a context meant to generalise over cases.
Furthermore, we have restricted ourselves to studies for which at least an English summary could be obtained.

3. Procedure

It was our first impression that the amount of suitable research in this area was quite limited.
This was for two reasons. First of all, a quick look at computerised library files reveal only a handful of hits. Secondly, we assumed that the work zone problem was relatively small in mature road systems, which would mean that the absolute accidents numbers would also be relatively small. And, as is commonly known, small accidents numbers makes reliable research rather difficult.

For this reason, the partners in this work package agreed on a multi-pronged approach intended to ensuring that as much relevant literature as possible would be obtained.

The NTUA agreed to approach all ARROWS partners, as well as other sources in Western Europe and North America.
The BAST agreed to collect all German language literature. However, due to unforeseeable circumstances, this effort did not achieve complete fruition.
The ZAG agreed to approach sources in Eastern European Universities, governments, and traffic and road Institutes. Due to the lack of research and/or responses, the ZAG agreed to implement a portion of the BAST's task.
A more extensive description and NTUA's and ZAG's activities, as well as their findings, are included in the Appendices.

The SWOV utilised standard international computerised traffic research databases (i.e., NTIS and IRRD) to find literature references. The original search mentioned above, making use of the key words 'work zone' and 'accident', was extended to include other key words, such as 'construction site' or 'road works', etc. No expiration dates were placed on the literature. This resulted in more than 100 hits. These hits were further selected on the basis of the accompanying abstracts. The SWOV library then attempted to obtain the selected literature.

The SWOV then processed the results obtained from all sources mentioned above. The results are compiled in the present report.

A quick perusal of the literature list in this report shows that the picture painted here is dominated by research from the UK, the USA, and Germany, although other sources are cited where applicable.
It is quite possible that, unknown to us, other major research efforts have been made in other nations or regions. However, locating such research efforts is comparable to looking for the proverbial needle in the haystack. We would also assume that the resources necessary for conducting such research are not generally available.

Thus, we cannot, and will not, claim that the findings mentioned here are generalisable to all countries and situations, even though the task partners have done their utmost to attempt just that.

4. Provisos and problems

The analysis and interpretation of work zone accidents is complicated by a number of problems.
We will mention five.

First of all, the sample sizes in many of these studies are all too often quite small. This doesn't have to be disastrous as long as one is aware that there are limits to drawing general conclusions from a few accidents. However, it is not uncommon for studies to estimate (and compare) population parameters on the basis of 3 to 5 accidents, without explicitly taking into consideration the enormous error involved in such estimates.

Secondly, the statistical analysis presented in many studies could be improved. We refer to three sorts of difficulties.

- Some reports neglect to explicitly consider that accidents are stochastically distributed. They sometimes include neither the raw accident numbers, nor statistical tests.
- Some studies apparently do not follow the how and why of (the practice of) significance testing. (At least one study offered conclusions based on results which found to be significant at the 60% level.)
- Databases are often split up into a multitude of (combinations of) categories and conditions, whereby each of the possible variations are univariately compared. We would strongly recommend that multivariate models be more often used. This could result not only in an improvement in the quality of (statistical) decision making, but also be easier to grasp for the reader confronted with reams of tables and numbers.

A *third* problem has to do with a lack of unambiguous data. We give several examples.

- Many authorities do not explicitly include the presence of a work zone as a variable in their traffic accident registration forms. There is also apparently little uniformity in how these accidents are registered, even if it is done explicitly.
- The extent, duration, and traffic exposure to work zones is often difficult to determine, for it is not often centrally registered. For studies concerning specific locations, this is troublesome and expensive to solve, but not disastrous. However, studies utilising central accident databases *after the fact* have problems establishing and incorporating this information. This makes comparisons between jurisdictions and over time exceptionally difficult.
  E.g., it may not be possible to refute the hypothesis that differences in the number of accidents are due to differences in maintenance expenditures. One of the more poignant conclusions of a broadly setup study of American states was that traffic exposures to work zones should be registered in order to facilitate such comparisons. (AASHTO, 1987.)
- It is often difficult, or impossible, to determine whether accident victims are road workers or road users.
- It is unclear in some databases whether work zone accidents are traffic accidents or whether they are construction accidents.

- It is also often uncertain whether a work zone is actually in operation during the accident, or whether the work zone may have anything to do with the cause of the accident itself, even though an accident may occur in the vicinity.

A *fourth* problem concerns itself with the design of accident investigations. Many studies involve a before, during and after comparison, i.e., a time series. Exposures are often calculated, yet control areas are not always used. This leaves the possibility open that differences found are caused by other exogenous factors, such as seasonal trends or some such.
Alternatively, one also sometimes sees studies with concurrent controls, but without before- measurements. This approach leaves one exposed to other assaults on the validity of the results found.
Finally, in principle, road sections should be randomly assigned to treated and control conditions. It seems to us that this last condition is hardly ever achieved: one doesn't repair roads at random.
The upshot is that good experimental designs are not very common, albeit for good reasons. Nevertheless, we feel that one should not be too cavalier in drawing hard conclusions from soft experimental designs.

Finally, and most problematical, are the conclusions made by some authors that their data collection procedures are likely to be biased. This goes to the heart of the measurement process, and, as such, is fundamental for the believability of our results. The problems associated with bias in accident reporting are well known (see, e.g., Hauer & Hakkert, (1988)).
For example, Hayes et al. (1994) and Hayes & Taylor (1993) state that accident registration is likely to be higher at work zones than elsewhere, and that *no attempt was made to eradicate, correct, or estimate this bias.* However, numbers subject to such bias are routinely interpreted without hesitancy, or attempt to illuminate the problem. As such, this is a fundamental threat to the validity of all of our findings. (It should also be mentioned that such a problem is not uncommon in traffic safety research.)
Some authors speculate on the nature of processes giving rise to this bias. There are at least two separate aspects that we should consider.
First of all, the presence of a work zone can lead to differences in behavior, types of accidents, and their severity and likelihood. This is exactly what we wish to measure. However, it is a well established fact that different types of accidents are measured with different levels of completeness. Thus it is difficult to establish whether a found difference is due to diffferences in the nature of accident causation or to general differences in sampling reliability, or both.
Secondly, the presence of a work zone can lead to specific differences in sampling process. We believe that this is what is implied by Hayes and his colleagues. (This may be less of a problem in retro-active studies.)

These problems should not surprise anyone with experience in traffic accident analysis. These shortcomings are certainly not unique, or not even especially problematical for the analysis of work zone accidents. However, we must most certainly take them into account when considering our results.
One should not get the impression that all work zone accident research is of limited quality. Good and reliable work is being done. However, we find it necessary to (subjectively) weigh the quality of the research when considering the veracity of the results.
(Ideally, a meta-analysis might be a useful method for systematically disentangling results from research methodology.)

5. Results

5.1. Relative incidence and severity

5.1.1. *Accident rates*

When considering work zone accidents, the first and foremost question that one could ask is: *are work zones relatively dangerous?*

The answer appears to be an unequivocal yes. Let it suffice to say (without references) that we have found:
- a great number of studies which indicate that there is a substantial, and statistically reliable, negative safety effect for work zones, and
- only a few conditions in a few studies indicating that they cannot distinguish between accident rates inside and outside of work zones.

Even considering all of the provisos and criticisms mentioned in the last chapter, it would seem highly unlikely that such a uniform and substantial result would obtain in such a wide variety of different studies.

Having said this, it would seem useful to quantify this statement. That is, *what is the relative safety risk for work zones*?

It is at this point that the situation becomes problematical: estimates vary between 7% and 450%! (See appendices for summaries. See also Ha & Nemeth(1995).) For example, a (poorly documented) recent German language study (Aulbach, 1992) indicated an accident rate between 3.5 to 4.5 times higher in work zones. Another, much older (and also not exhaustively documented) German study (Bruhning & Volker, 1978) indicated only a 17% disadvantage for motorway work zones.
Two American studies are notable. One 7-state study, reported by Graham et al. (1978) analysed more than 14000 traffic accidents, half of which were work zone related. More recently, the NCRP (1996) reported another study involving more than 12000 traffic accidents, of which more than 7000 were work zone related. (Apparently, this study was also a 7-state study done in the late 1980's, possibly a follow-up of the first one.) These two enormous studies noted work zone accident rate disadvantages of only about 7%.

Almost all other relevant studies have intermediate results, and perhaps not surprisingly, most also have small sample sizes, varying from about 150 work zone accidents to less than 35. Studies such as these, while they may convincingly reject the null hypothesis (i.e., no difference in accident rate), also tend to have rather large standard errors, and are thus unreliable point estimators. Furthermore, it is rather common practice to break down these small samples into even smaller sub-divisions, which tends to increase the standard error of estimate.

We would conclude that if one wants to establish a single estimate for the increase in work zone accident rates (relative to non-work zone accident rates), then one would have to combine all of the studies referred to in the body of this report (and in the Appendices) to achieve an estimate. One

should at least weigh each study's results by its sample size and study design (e.g., before-after with or without matched controls, method of data collection, etc.).
An additional possibility would be to include more substantial characteristics, more indicative of work zone characteristics than of statistical vagaries. One could consider including the study year, country, road type, work zone type, etc. into account. Of course, by now we would be implementing a full-fledged meta-analysis. We would find such an undertaking to be time-consuming, yet useful.

If we are disaggregating our analysis into studies, years[1], etc., we actually prefer to go even further and disaggregate onto the level of work zones themselves. Namely, how are accident rate differentials actually distributed over work zone locations?

5.1.2. *Predicting accidents at different locations*

The previously mentioned (and enormous) study of Graham et al. (1978) gives us some idea. Namely, the distribution of accident rates changes (before and during work zone implementation) is approximately normally distributed, with a mean change of about +7% (as mentioned above). This means that a substantial percentage of locations actually enjoy a safety benefit in the presence of a work zone. And a substantial portion (the majority, in fact) suffer an increased accident rate.
However, this approximately normal distribution is nevertheless rather skewed, having a small percentage of locations with extremely high accident rate increases, above 200-300%[2].
See also Pigman and Agent's (1990) before and after accident distributions, where locations may be found with 65% accident *reductions*, and with 150% accident increases.

Three questions arise. First of all, are most accident rate change distributions also highly skewed? If so, can we reliably identify the nature of these outliers? A 'yes' to both questions could imply an opportunity to effectively target a portion of the work zone problem.
Finally, even if we to be satisfied with a 'no', we would want to know whether we can somehow predict how safe a certain configuration of work zone and road characteristics would likely be.

In this last case, we can divide our problem into two parts: which variables are the best predictors of accident rates, and how well do they work? Unfortunately, the answers to these questions are not readily available, even though we may have some indications.

Graham et al. (1978) regressed 17 predictors onto accident rate, had lots of problems with collinearity, over fitting, and apparently treating categorical data as being metric. Even so, they found a multiple R^2 of about 0.24, with 6 independent variables. (The speed limit under normal circumstances, and road type were the most important regressors.) With 17 regressors, he found

[1] Disaggregating into road and work zone types is, of course, quite common.

[2] Multi-lane Interstates reduced to one lane in each direction, or to two lane contra-flow, appear to be particularly vulnerable.

a multiple R^2 of 0.39, though we have our additional doubts about the validity of this analysis.

Pain et al. (1983) also refer to a study which utilised multiple regression techniques. We have no idea of the number of accidents, number of locations, or the quality of fit. However, the regression equations estimated are almost shocking in their simplicity:

- in order to estimate work zone accident rates for freeways or rural roads, take the pre-work zone accident rate and add a small constant.
- for urban streets, it is somewhat more complex. Take a fraction (about 70%) of the pre-work zone accident rate, add a constant, and add a weighted sum of average daily traffic volume, the presence of a median, and the number of pre-work zone lanes. Higher traffic volumes, more lanes, and the absence of a median contribute to a higher accident rate.

We should also refer here to the excellent study of Casteel & Ullman (1992) who investigated 9000 Texas Interstate accidents. They found (on one road) a multiple R^2 equal to 0.58, when predicting (log) accident rates. The most important predictor was accident rate prior to construction!

These three reports are not all as completely documented as one would wish, and perhaps their analyses are not all implemented as cleanly as one would like. Two of these studies are quite old, all three are American, and at least two of them has quite ample sample sizes.
We can draw several conclusions, however. First of all, these studies illustrate that it is possible to analyse and present results in a more uniform and global manner, by means of multivariate techniques. Most other studies do the equivalent of looking at the values of all the cells of all of the independent variables, often without first identifying whether the null-hypothesis for each independent variable can be rejected, and without testing whether the values for each of the cells also differ significantly from each other.

A second, more useful conclusion is that between 25% and 60% of the variance in increases in work zone accident rates can be predicted by rather simple means. Some may not be enthusiastic about the 'simple means' mentioned here, but we should bear two things in mind.

1. We have not established a ceiling for predictive value, something which we should attempt to do as soon as possible. (There are methods for this.)
2. We can use but are not limited to the predictors mentioned above. A more sophisticated Pan-European study with an intelligent choice of predictors could be an interesting option.

5.1.3. *Accident severity*

Having established that work zones are relatively unsafe, the next logical question would be: How large is the problem? Namely, even if work zones were terribly dangerous, they only occur at a small proportion of the road network at any given moment.

As mentioned in the Appendix, approximately 1-3% of all traffic accidents are work zone related, a finding which has been more or less replicated in a number of countries. Interestingly, Van de Nadort (1994) found that 6.5% of her database of 90,000 (!) Dutch motorway accidents involved work zones.

One should realise that even if we could totally eliminate all work zone accidents (thereby structurally reducing the total number of accidents by 1% or so), 1% is within the normal fluctuation of the yearly total number of recorded personal injury accidents in the Netherlands. Thus, if we didn't take a closer look, we probably wouldn't even notice that one of our problems had been solved.
1-3 % is hardly a substantial problem, when compared to the total traffic accident problem[3]. Unless, of course, work zone accidents are unsually severe.
A logical questions is thus: how severe are work zone accidents?

Several studies indicate that accidents on average are slightly less severe in work zones. For example, Hayes et al. (1994) indicate that on motorways in Great Britain the number of serious injuries per personal injury accident is is significantly less in work zones that outside work zones (0.23 versus 0.36). Graham et al. (1977) show that while (changes in) accident rates for property damage only and injury accident were slightly higher in work zones, the fatal accident rate decreased slightly in work zones (+5%,+4% and -9%).

However, the picture is not quite so clear.
Pigman and Agent (1990) report, for example, that in Kentucky there is a higher percentage of injury accidents within work zones than without (27% versus 22%). NCRP(1996) found no appreciable difference between changes in total accident rate and fatal and injury accident rates. AASHTO (1987), on the other hand, found that the ratio of non-fatal to fatal accidents is lower in work zones, i.e., work zone accidents are more severe. These more severe accidents also tend to be on rural roads; the majority of accidents, however, tend to concentrate in urban areas. No statistical testing was done, and while the total sample size was appreciable, the number of fatalities was rather small, especially when on splits them up into sub-categories. It is therefore difficult to know how hard these results are.

Ha & Nemeth (1995), in a review of 10 studies, summarised work zone accident severity findings as "having a great deal of inconsistency". If we consider the tables that they actually presented, we would have the impression that work zone accidents are slightly more severe than non-work zone accidents. (However, only qualitative judgments, with no indication of significance, etc., were offered.) The authors conclude however, in their case of Ohio, there is a slightly lower percentage of reported injury accidents in work zones than compared to all accidents.
A recent Dutch study of immense proportions (Van de Nadort, 1994) found *no difference* in the accident severity distributions in motorway work zone accidents and all motorway accidents.

Our conclusion is that if there is a difference between work zone and non-work zone accident severity, it is either too small, or not well enough understood to be reliably measured.

[3] By no means should the conclusion be drawn that work zone accidents are somehow less relevant. (See e.g., Anderson, 1976.)

Conclusions

We have found that work zones have relatively many accidents. However, we have neither been able to establish with certainty what their relative rate nor relative severity is. This is partially due to uncertainties found in normal statistical variations, which have not been compensated for by studies with sufficient *power*. Another possibility is that, in many cases, the null hypothesis is the correct one. A third possibility is that the phenomenon is just not well understood, and we haven't yet been able to identify the important underlying factors. It is not inconceiveable, although hardly parsimonious, to consider that English all purpose dual carriageway roads in the late 1980s and early 1990s have an entirely different causal structure than American insterstates 20 years earlier.

In the following sections we will attempt to explore and hopefully illuminate the 'underlying causal structure' of work zone accidents.

5.2. Factors related to the ARROWS taxonomy

The ARROWS project has established a taxonomy of work zones. (See Internal Task Report 1.1.) While such a taxonomy is of limited relevance for describing work zone accidents, it is most reasonable to attempt to relate one to the other.

Three dimensions of said taxonomy have been established:

- road type, sub-divided into:
- - motorways and dual-carriageway expressways
- - rural primary roads
- - rural secondary roads
- - urban main roads
- - urban local roads
- work zone operations, sub-divided into:
- - long-term
- - short-term stationary
- - short-term mobile
- work zone-roadway interaction, sub-divided into:
- - lane narrowing
- - lane closure
- - diversion
- - contraflow
- - alternate one-way traffic
- - shoulder/roadside
- - central reserve (?)
- - foot or bike-path
- - tram

Other common distinctions, such as that between construction, maintenance, and utility work zones will not be explicitly considered.

5.2.1. *Work zone operations*

'Work zone Operations' has some some relation to accident rate. Graham et al. (1978) regressed length and duration of work zones on accident rate for the 79 locations in their study. Slopes of both regression lines were negative, indicating work zones of longer duration and length had lower

accident rates. Unfortunately, the fit of both regressions was very poor. Namely, the R^2's were equal to 0.03 and 0.06. Significance was not mentioned. Of course, the variation in the duration of the work zones was probably quite limited. Mobile and truly short-term work zones were (probably) not included in the sample.
Another recent Japanese study (Kuroda & Inoue (1996)) can also shed some light on this problem. They consider about 300 expressway accidents, subdivided into types of road works: rather static roadworks such as pavement reconstruction, to more mobile roadworks, such as mowing, snow removal, sweeping, garbage removal, lane marking, etc.
No statistical testing was done, yet it would appear that if we contrast the static and the mobile types of work, no substantial differences would be found. In the class of mobile works, mowing and snow removal have relatively high accident rates; garbage removal relatively low.

Our impression is that it would appear that the shorter (or more mobile) the work zone, the higher the accident rate. However, the database is so small, and the results so uncertain, that it would be unwise to draw any hard conclusions.

5.2.2. *Road type*

Concerning 'Road type', we can draw from a number of studies.
First of all, fatal work zone accidents (in the US during the 1980s) occured mainly on rural Interstates and other rural primary roads as opposed to urban interstates and other primary roads (58% and 69%) (AASHTO, 1987). On the other hand, injury and property damage accidents tended to occur on urban Interstates (76% and 78%) and other urban primaries (60% and 67%), as opposed to rural roads. That is, rural work zone accident are especially severe, urban work zone accidents are especially common.
In addition, the Interstate problem is about equal in absolute numbers to the class of 'Other primary roads', even though Interstates account only for 15% of the system miles, 40% of vehicle miles, and the non-work zone accident rate is only a fraction of the same rate for the 'Other primary roads'.

Richards & Faulker (1977) found more or less the same pattern for 8000 work zone accidents on streets and highways maintained by the state of Texas. Work zone accidents on Interstates were over-represented, when compared to all accidents. Work zone accidents on 'other' roads were underepresented. Furthermore, the urban-rural dichotomy is repeated: rural accidents are infrequent and relatively severe; urban accident frequent and less severe. The authors choose the obvious explanation: speeds are generally higher on rural roads; exposures are relatively higher on urban roads.

Interestingly, Graham et al. (1978) find no difference in relative accident rates for rural versus urban work zones.

Pain et al. (1983) found that there is a large difference in accident rates between urban and rural roads, and large differences in rates for the sub-categories. However, with the possible exception of urban two-lane streets (which appears to be safer (?) in the presence of work zones), there is no clear road-type-based differential work zone safety decrement. In other words, all road types appear to become somewhat less safe when work zones are placed. Unfortunately, neither signifcance testing nor sample sizes are mentioned in this last study.

Pigman & Agent (1990) list data for 20 locations, at which a total of more than 2000 accidents occurred. Locations were divided into rural Interstates, rural two-lane roads, multi-lane non-Interstates, and parkways. Cleary, rural interstates and parkways have lower accident rates than rural-two lane roads and the multi-lane non-Interstates, both before and after the implementation of work zones. Unfortunately, no statistical testing was mentioned, althought the accident numbers are easily large enough to draw some conclusions.

NCRP (1996) also subdivided their 12000 accidents into the classes urban/rural and freeway versus two-lane roads. Rural two-lane roads and urban freeways turn out to be especially dangerous, in terms of total accident rates, fatal and injury accident rates, both before and during work zone implementation. Rural freeways turn out to be relatively safe, even in terms of fatal and injury accident rates.
Especially interesting is that the location of the work plays a very important role: work zones where the work is implemented at the shoulder or roadside turns out to be relatively safe, perhaps even a bit safer than the same road without a work zone. Work zones on the 'traveled way' or those resulting in a detour have about a 40% increase in total accident rate. This result obtains for all road classes mentioned here.

In Great Britain, Hayes et al. (1994) found a personal injury accident rate increase of about 130% on motorway work zones, relative to the non-work zone situations. Their study included about 400 accidents, half of which occurred in work zones. Only 6 years earlier, the corresponding difference was only 57%, a difference attributed to a fall in the non-work zone accident rates and an increase in the with-works rate. This increase in the with-works rates is not explained. The authors also mention a lower accident severity in the with-works situation.
Hayes & Taylor (1993) also looked at all-purpose dual carriageway roads (with 2 or 3 lanes) in Great Britain, and found no significant difference between the with-work zone and without-work zone conditions, the measured difference being only about 14%. They recorded about 1500 accidents, of which only about 10% occurred inside of a work zone.
Coombes & Turner (1989) considered all-purpose rural roads and found significant and apparently substantial work zone safety problems for A-class roads. Work zones were about 95%-170% more dangerous than the non-work zone situation. Found differences for other road classes were interesting, but not significant.
This study, however, was plagued by a tiny work zone accident sample, 34 accidents for four road classes, including a 1500m 'influence zone'. The class-A roads only included 20 work zone accidents, which makes attempts at precise estimates of relative risk a rather uncertain business.

In conclusion, we find again that the more extreme results are based on the smaller samples. Sample size is also confounded with which side of the ocean the study is conducted. Furthermore, statistical testing, and explicit comparisons between road types, are not as common as we would like to see.
Nevertheless, we would suggest that the urban-rural dichotomy is rather important in distinguishing between accident severity and frequency. Furthermore, the single versus dual-carriageway distinction is also essential

in predicting accident patterns. It is hardly surprising that we would find that such distinction to be important.
However, we have little hard evidence that work zone accidents behave in a way clearly different from other accidents on the same road type. In other words, we would be willing to accept the null hypothesis in the present case.

5.2.3. *Work zone-roadway interaction*

Concerning 'Work zone-Roadway interaction', we can simply state that most of the categories mentioned in this variable have never been studied. However, as previously alluded to in discussing the results of NCRP (1996), work zones located either on the shoulder or side of the road have no clear detrimental effect on traffic safety. Work zones on the 'traveled way' or those forcing a detour do. We believe that this finding is substantial and statistically significant.

Furthermore, much is made (in that paper) of the relation between posted amount of speed reduction and increases in accident rates. Unfortunately, despite impressive accident rate increases, only one comparison is probably not due to chance. I.e., the increase in fatality and injury accident rates on 'traveled way' work zones on rural freeways is much less for the locations with a posted speed reduction of 10 miles per hour, in comparison to similar locations with other posted speed limit reductions. This result does not obtain for the total accident rate. Other tests either cannot be made or do not lead to rejecting the null hypothesis.

In the UK, Hayes & Taylor (1993) looked at full contra-flow versus partial contra-flow. However, the small magnitude of their overall differences in work zone-nonwork zone safety (14%), in combination with small sample size, precluded making further useful comparisons. Namely, hardly any comparisons even remotely approached statistical significance.

Hayes et al. (1994) in their study of UK motorways were more lucky. Many of the statistical tests comparing a certain type of traffic management scheme with its before condition resulted in significant results: work zones tend to be dangerous.
However, the question here is another one: is one type of traffic management scheme safer than another? The authors explicitly compare injury accident rates for three management schemes (full contra-flow and partial A and partial B), for two directions of travel (primary and secondary), and for three work zone sections (approach, central, and after section). It would appear that the 'secondary' direction and the 'after' section are relatively safe. (See their table 3.6).
In addition, it would appear that full contra-flow has the highest relative accident risk, with the exception of the 'after' section. Partial counterflow schemes had higher 'after' section relative accidents rates, when calculable. Unfortunately, the report neglects here to take the null hypothesis into account: due to (relatively) small sample sizes we suspect that we are being tempted into interpreting statistical noise.

Harlow and Summersgill (1986) studied 400 injury accidents on UK motorways. They split their work zone accidents into the categories full contra-flow with 1 or 2 lane crossovers, and partial contra-flows with a buffer lane or a buffer and estimated accident rates relative to the no-works situations. They conclude that partial contra-flow with a buffer lane was

least safe, followed by full contra-flow. Partial contra-flow with a buffer zone was the safest system. The ratio between the safest and the least safe system is 3.75.
However, these authors contented themselves with a significance level of a= 0.20, which we consider to be sub-standard.

Kuroda and Inoue (1996) looked at 72 Japanese motorway accidents. They found that the majority of accidents occurred when the passing lane was closed, somewhat less when the shoulder lane was closed, and the least when the middle lane was closed. If one corrects for exposure, in terms of closed lane kilometers, or lane vehicle kilometers, then the picture is different. Middle lane closures are the most dangerous, followed by shoulder lane, and passing lane closures. Unfortunately, small numbers and the failure to do statistical tests tends to confuse the matter.

We believe that the uncertainty around the results mentioned above make hard conclusions extremely difficult to make. We are most disappointed by the lack of statistical tests: this failure results in our inability to judge whether an effect is real or not.

We, however, are impressed by the results found in the traveled-way/detour versus shoulder/roadside distinction, referred to in the NCRP study mentioned above. *It appears that work zones can be operated safely when one does not have to divert traffic from its original path.*

5.3. Work zone section

Kockelke (1989) analysed 533 accidents on German motorways, of which 300 occurred in work zones. He divided his work zones into four sections: approach, 1st crossover, inner work area, and 2nd crossover. He found that the first crossover and the inner area had the highest accident rates, followed by the approach area, and the 2nd crossover point. The ratio between the most dangerous and least dangerous section was 1.6. It should be mentioned that these two crossover points also had the smallest numbers of observations (i.e., respectively, 29 and 19 accidents.) The difference is not statistically significant at the 10% level.

Pigman & Agent (1990), in their analysis of more than 2000 Kentucky work zone accidents, divided their work zones into 3 parts: advance warning, transition, and work area. More than half of their accidents occurred in the work area proper, about one third of their accidents had an 'unknown' location, and the remainder was evenly divided over the other two 'approach' sections. We have no idea what the relative lengths of the various sections were.

Aulbach (1992) found, on the other hand, that 50-60% of accidents occur at the approaches to work zones. This finding seems to be in complete contradiction to those of Pigman & Agent (1990).

As previously mentioned, Hayes et al. (1994) found that the 'after' section on UK motorways appeared to be relatively safe. Again, no statistical test was applied. In any case, we are willing to attach some credence to their relatively safe 'after' sections findings.

Boesefeldt et al. (1983) found, in their study of more than 7000 German motorway accidents, only a slight difference (5%) between the accident rate in the transition area and the work area. We don't know if this result is significant. However, we suspect that it is reliable, even if not as substantial as others have found.

Pomareda & Zacharias (undated), in an apparent reappraisal of the Boesefeldt et al. study, further split motorway work zones into 5 regions: approach, transition-in, work area, transition-out, and after regions. With respect to the non-work zone accident rate, the relative rates for the five sections were respectively, 1.62, 2.14, 2.03, 1.91, and 1.20. We don't know whether tests were done, but we suspect that these figures (with respect to the non-work zone rate) are generally rather hard. We don't know how hard they are with respect to each other.
Furthermore, Pomareda & Zacharias mention (apparently with another source study) that 50% of the accidents occur in the approach region, 35% in the work area proper, and only a few percent in the transition in- and out-regions. This seems to confirm the findings of Aulbach, but again contradicts those of Pigman and Agent.
Interestingly enough, this study also apparently finds that work area accident risk in 1970 was 3 times as high as the risk outside work zones.
This is apparent contradiction to Bruhning & Volker (1978) who found a heightened risk of only about 17%.
This is especially interesting because both studies apparently refer to the same type of roads, the same country, and approximately the same year(s).

Hayes & Taylor (1993) in their study of UK all-purpose dual carriageway roads found (see their tables 3.5 through 3.7) that the central section is relatively the most dangerous, and the 'after' section is even safer than non-work zone sites. The approach section appears to be non-remarkable, only being about 10% (on average) more dangerous than non-work zone sites. Three remarks should be made here. First of all, small numbers and small differences in accident rate render almost all of Hayes & Taylor's results insignificant. Secondly, work zone section accident rates are not statistically compared to each other, so we do not know if the found differences are reliable. Thirdly, we find the result that the after section is relatively safe, even compared to open road situations, to be theoretically interesting. (The average speeds should in any case be somewhat lower than the open road situation.)

Casteel and Ullman (1992) looked at more than 9000 Interstate accidents in Texas, in a before- and during-study with a comparison group, with extensive use of statistical hypothesis testing. They had two main independent variables: two different Interstate highways and entrance-ramp versus non-entrance-ramp areas. For one Interstate location, work zones turned out to be more dangerous and the presence of an entrance ramp increased that danger significantly. All accident severities and accident types rates were all relatively more common in work zones, with the exception of single vehicle accidents. The presence of entrance ramps significantly exacerbated all accident severities, as well as the relative frequency of 'other multi-vehicle' accidents. There was no difference for rear-end collisions. We find these results to be quite believable.

The puzzle is that (almost) none of these results obtain on the second Interstate location. Work zones there are not significantly more dangerous, nor are entrance-ramp differentially dangerous. The authors fit a regression model to the log(accident rates) for the entrance ramps on this second location. They found a R^2 equal to 0.58, with the only important predictor being accident rate before construction.

We can conclude in general that this subject matter is not only obscured by the lack of statistical hypothesis testing, but also involves a number of apparent contradictions, whose cause we cannot explain. We, however, find it believable to conclude that the 'after' section is no more dangerous than an open-road section. Furthermore, we find it believable that the central work zone region is also relatively dangerous. Finally, we also believe that the approach and the transition regions are possibly more dangerous than open road sections. However, their relative risk, compared to each other and the central region, is uncertain.
The easiest description would be to just conclude that differential accident risks between sections of the work zone proper have not be conclusively demonstrated.

The case for parts of the central work zone, namely entrance ramp sections versus non-entrance ramps sections, is not very clear either. This confusion exists, despite a very good study aimed at illuminating this situation: sometimes work zone entrance ramps are relatively dangerous and sometimes they are not. How we can distinguish between one and the other is uncertain; pre-construction accident rates are the only clue established here.

5.4. Safety devices

We have found only a very sparse and superficial literature describing the empirical evaluation of safety devices in reducing work zone accident risk. This dearth of research is possibly due to inadequacies in standard accident registration systems, ethical reasons, and limited research funding.

5.5. Accident characteristics

Till now, we have been concerned with characteristics pertaining to the (parts of) work zones themselves. In the following sections, we will focus on the differences between accidents occurring in work zones (as opposed to those not in work zones).

5.5.1. *Human causes and contributing factors*

Pigman and Agent (1983) found an interesting increase in 'following too closely' causes when comparing work zone to all accidents (12% versus 4%). Interestingly, 8-10% of all work zone and of all accidents involve 'excess speed'. Inattention is also cited in about 30% of both work zone and non-work zone accidents.

Van de Nadort (1994) found that 'insufficient distance' was a contributing factor in 48% of the work zone accidents on Dutch motorways, appreciably more than the 34% of all accidents on Dutch motorways.

Ha & Nemeth (1995) reviewed seven studies done in various American states. They summarised their findings by noting that driver error was very often cited as a contributory factor. Following too closely, unsafe speed, failure to yield, and driver impairment were only incidentally over-represented. The authors were surprised, yet not particularly pleased by this apparent uniformity in causal attribution.

Nemeth & Migletz (1978) mention that police cited ‘excessive speed’ in 58% of the accidents they studied. No other cause even follows remotely.

Kuroda and Inoue (1996) find that Japanese drivers are often careless (34%), aren’t looking where they’re going (17%), or are asleep at the wheel (15%). Speeding and improper distance are only cited in respectively 8% and 2% of the cases.

The German police apparently feel that excessive speed (18-28%), inadequate distance (12%-38%), and alcohol & fatigue (9%) are the main accident causes. (Pomareda & Zacharias; Hess (1993).)

Hall & Lorenz (1989) compared 1100 before and during work zone accident cause in New Mexico. He found some small, statistically non-significant changes in causal attributions. Inattention, speeding, and following too closely were noted in respectively 21%,18%, and 7% of the cases.

Lisle (1978) considered 1300 Virginia freeway accidents in a before- and during- study. Driving while intoxicated increased from 8% to 20%. Inattention decreased from 65% to 48%. Speeding remained steady at 8%-10% and following too closely was not even mentioned. We are quite surprised at these results.

Now, are the roads, the drivers, the work zones, or the police reports the real cause of these differences? And does it really matter? We have the feeling that excessive speed, following too closely, and inattention are ‘stories’ often used for ‘explaining’ all accidents, and which contribute little to understanding the present problem.
Nevertheless, it might be useful to examine the kinds of explanations used as function of work zone presence: most reports just don’t even present this basic kind of comparison, noting only the distribution of ‘causes’ while work zones are present.
We would in any case hope that ARROWS task 2.1 (behavioural studies) could shed more light on the behavioural underpinnings of work zone accident causation.

5.5.2. *Other characteristics*

Hall and Lorenz (1989) compared 1100 before- and during- work zone accidents. They looked at the following variables: light conditions, roadway grade, day of week, number of vehicles involved, truck involvement, pedestrian involvement, accident severity, time of day, weather and road surface conditions, and collision type. The *only* significant difference that they found was that work zone accidents tended to occur more frequently in clear weather on dry roads.
This is a before- and during- study: perhaps it rained less in the second period. Another possibility is that road workers don’t like working in the rain. Otherwise, these results seem to be rather clear.

As previously mentioned, Van de Nadort (1994) studied 90,000 accidents on Dutch motorways between 1986 and 1992, of which 5000 were located in work zones.
She compared the following variables: month, day of the week, time of day, accident severity, type of accident, weather and light conditions, and condition of the road surface. Unfortunately, the author did not do any statistical testing, yet the number of accidents are so great as to merit confidence in their reliability.

The results
Work zone accidents tend to be over-represented in the months between April and October, with the exception of July and august. Work zone accidents are over-represented during the mid-week and under-represented during the weekend. There are some differences in the course of the day; work zone accidents are over-represented between 10:00 and 14:00, and between 20:00 and 24:00. They are under-represented between 6:00 and 8:00 and between 16:00 and 18:00.
There is no difference in accident severity. There are relatively more rear-end collisions (insufficient distance is a favorite accident 'cause'), and fewer collisions with fixed objects. The weather is more likely to be dry, as is a dry pavement. Daylight is also likely.

We find these results not only reliable (due to the enormous number of observations), but also quite clear.

An undocumented, unnamed, undated Danish study from the Road Directorate did not refute nor add any additional light to these findings.

Pigman and Agent (1990) used a similar approach, comparing work zone with 'all' accidents. Again, no statistical testing was done.
Their findings are: work zone accidents are over-represented in the summer months and under-represented in the winter months. The time of day plays no really clear role, yet mid-week days are over-represented. Work zone accidents apparently involve slightly more injuries.
These accidents are over-represented in rural situations (?), the road surface is more likely to be dry, and the road is slightly less likely to be straight and level. Daylight is over-represented. Intersections accidents are less likely, mid-block accident more likely. Rear-end, collisions with non-fixed objects, ran-off road, and same direction side-swipe accidents are over-represented. Parking lot, collision with fixed object, and miscellaneous accidents are under-represented.

Lisle (1978) found that injuries are less likely in work zone accidents, as are rear-end collisions. (This is not the only surprising result of this study.) Striking a fixed object is more likely.

Nadler et al. (1988) studied (an unmentioned number of) Austrian motorway accidents. They found no time-of-day difference for work zone accidents. 45% of their collisions were 'rear-end' collisions. They also found higher numbers of accidents in bad weather conditions, which is somewhat surprising. We are not able to evaluate the validity of these findings, and view them with some unease.

Laffont & Schmidt (1996) considered a(n unmentioned) number of German motorway accidents. 63% of their accidents were rear-end collisions. The majority of work zone accidents occurred in dry, daylight conditions, with higher accident risks during rush hours. We are not able to establish the validity of these findings.

Hayes et al. (1994) considered UK motorway accidents. They found about 60% of their accidents occurred under dry road conditions: work zone did not interact with this finding. They also found that weather conditions had no appreciable effect on work zone accidents. Rear-end collisions were heavily over-represented in work zones, describing almost 50% of the total number of accidents there. Loss of control accidents were under-represented. Work zone accidents are more likely to involve 3 or more vehicles, as opposed to non-work zone accidents.

Ha & Nemeth (1995) 'observed' that rural Ohio work zone accidents are not especially severe, they are over-represented during the daytime and during good weather, and they involve trucks more often than expected. They also tend to be 'rear-end' and object- collisions more often than expected. However, when we consider the tables that they present, it would appear that, while rear-end and fixed object collisions represent 20% and 25% respectively of the work zone accidents, this differs only marginally from the before- accident distributions (i.e., 18% and 28%).
We are puzzled by this apparent contradiction.

Ha & Nemeth also note that fixed object single vehicle accidents predominate at night, while multi-vehicle rear-end collisions tend to dominate during the daytime. They do not present any data to substantiate these, very interesting findings.
We would like these last results to be correct, as it seems to correspond to intuitive ideas.

Conclusions
Again we find apparent contradictions and imperfections in the results reviewed here. Nevertheless, we believe that at least one point has become more clear: we can better understand the distribution of work zone accidents, when we better understand the exposure of traffic to work zones. It would seem, in the present case, that work zone accidents have a tendency to be fair weather accidents. It would seem quite possible that work zone activities are preferably implemented in fair weather.
We should note that construction work zone may continue to influence accidents rates, even though no one is working at the time of the accident. Additionally, as preferred working hours change in response to traffic congestion, we could very likely see changes in the patterns of work zone accidents.

5.6. Accident trends and international differences

5.6.1. *Trends*

Is the work zone safety situation getting worse, or possibly improving? The first case may inspire one to a call to arms; the second case might be used to argue that something is working and that we should intensify our efforts.

Unfortunately, just looking at raw numbers will give us little idea of how things are changing. For example, a recent HSIS[4] publication indicated that the number of work zone deaths nationwide had increased dramatically in the previous year or two. Unfortunately, the HSIS neglected to draw a regression line to see if there was indeed an increasing trend, or if the US was just suffering from some (severe) bad luck. (The two years previous had exceptionally *low* numbers of work zone fatalities.) In addition, one would want to compensate for changes in traffic volumes, and increases in work zone activities.

Nevertheless, Laffont & Schmidt (1996) compared equivalent studies on German motorway work zones, which were conducted 15 years apart. They found that accident rate was about 1/3 lower in the more recent study. Bruhning & Volker (1978) found a similar reduction on German motorways for the period between 1968 and 1973 (0.6 mvkm and 0.4 mvkm). Pomareda & Zacharias (undated) found that the work zone (relative) accident rate was about halved between 1970 and 1980.
We cannot vouch for the statistical reliability of these findings.

On the other hand, Hayes et al. (1994) compared results on UK motorways, and found a almost 50% increase in personal injury accident rates in work zones between 1987 and 1993. There was no difference in the rates between 1982 and 1987. UK personal injury accident rates were about equal to about 0.15 per mvkm.
We've no idea about the reliability of these findings.
(We would like to note that Oliver (1996) points out that the accident rates for the non-work zone sections used in these studies are apparently different from the nationwide motorway accident rate. No convincing explanation for this difference was offered.)

Nemeth & Migletz (1978) found an Ohio Interstate work zone accident rate of about 0.75 per mvkm in the early 1970's. Graham et al., (1978) found accident rates numbers between 0.38 and 1.9 in the early 1970's for Interstates in 7 American states. (The corresponding rates for injury accidents varied between 0.14 and 0.37.) Hall & Lorenz (1989) found a value of 0.55 on New Mexico Interstates in the mid 1980's. Pigman and Agent (1990) found values between 0.35 and 0.61 on rural Kentucky Interstates during the mid 1980's. Casteel &Ullman (1992) found accident rates varying between 1.15 and 7.30 on Texas Interstate work zones in the neighborhood of entrance ramps. Pain et al. (1983) mention urban and rural 'freeway' accidents rates of about 2.0.

One might say that there is an indication of a downward trend between the early 1970s and the mid 1980s, but we wouldn't bet money on it . There are simply too many uncontrolled variables. Unfortunately, no American author has apparently made the effort to compare trends in accident rates, while holding other variables constant.

[4] HSIS: Highway Safety Information System of the U.S. Department of Transportation, Federal Highway Administration.

Conclusions
German numbers are apparently getting better, UK numbers are apparently getting worse, and US numbers are unclear. None of these comparisons has apparently passed some kind of statistical test.
We do not find that the data is conclusive, one way or the other.

5.6.2. *International differences*

We would be hard pressed to draw any conclusions concerning differences between countries. There are often enormous differences between different studies in the same country, at the same period of time, and on the same type of road. In fact, we have even found large differences on two different Interstate roads within the same study, which was not attributable to small sample sizes.
We don't know how to equate road types, methods of data collection, and measurement of traffic exposures, for different countries. Nor, apparently, has any other author ever tried.

We won't even attempt a guess.

6. Discussion and conclusions

6.1. General

When originally starting this study, we had misgivings about what we would find. Namely, we suspected that work zone accident studies would be extremely limited in the generalisability of their findings, due to small sample sizes. This would make these studies prey to the (well known) problems associated with accident studies in general, only with the problems being even more severe.
Our apprehensions turned out to be only partially substantiated. While there are studies that try to draw far-reaching conclusions on the basis of a handful of instances, many of the studies cited here have substantial accident databases. We could seemingly breath a sigh of relief, being only confronted with problems that are reasonably well understood, such as bias in accident reporting, regression to the mean, etc., etc. (We should not belittle the importance of understanding and correcting these problems: they knaw at the root of our knowledge.)

However, even if one begins with a sizable database, one could differentiate it into categories and sub-categories, leaving us ultimately with the same problem of small sample sizes.
Of course, in trying to extend the limits of knowledge, this problem was encountered all too often.
We view statistical hypothesis testing as a safeguard to prevent us from drawing conclusions more quickly than is warranted by the inherent randomness present in accident data. This view is apparently not generally adhered to in the literature studied here.

A second problem has to do with a second use of statistical methodology, namely data reduction. Even if we are firmly convinced that all of our findings are structural reflections of the real-world (instead of coin-tosses), we are still often confronted with pages and pages full of 'results'. A typical study may investigate 5-10 variables, the present report has considered dozens.
The use of appropriate multivariate analytical techniques should, in principle, allow one to obtain a 'bird eye view' of the structure residing in one's data.

In a nutshell, then, our view of our task in the present study is twofold: 1) separate (statistical) noise from structure, and 2) simplify the results to something which can be easily grasped.

6.2. Work zone accidents

It seems rather well substantiated that work zones are relatively unsafe places to be, at least if we are willing to assume that our data collection methodology is unbiased. This assumption is not entirely justifiable, even though everyone chooses to behave as though it is.

Having passed this first hurdle, one would like to know something about the extent of the problem. We know, for example, that work zone accidents account for only a few percent of the total accident picture. However, we would also like to know, for example, how large the relative increase in the accident risk is in a work zone.

Unfortunately, things start getting difficult at this point: the estimates vary from a few to a several hundred percent.
The source of these enormous differences are unclear to us, and they may never be exactly determined except by a pains-taking meta-analysis.
We are relatively certain that the heightened risk is large enough to have to do something about it. However, we would suspect that the former number (of a few percent) is more likely than the latter.

Even so, we are also certain that there are enormous error margins attached to the numbers found. We would recommend extreme caution before attaching (financial) consequences to point estimators derived from a few observations.

Concerning accident severity, there is also a relative lack of uniformity: *some studies indicate that work zone accident are less severe, some studies indicate that they are more severe.* In any case, we have not found that the difference in accident severity is large and well understood enough to be reliably reproduced.

6.3. The ARROWS work zone taxonomy

In the ARROWS task 1.1, a taxonomy of work zones has been proposed. We have taken much effort to relate work zone accidents to the dimensions utilised in the taxonomy of work zone themselves, realising that the mapping is not quite perfect. (I.e., work zone accidents have characteristics not readily associable to the work zone itself.) The relevant dimensions are:
- (duration of) operations
- road type
- interaction between work zone and road.

There only appears to be weak evidence relating relative accident rates to the dimensions mentioned in said taxonomy.

There is some very weak evidence that accident rates are higher for work zones of shorter duration, but we are not entirely convinced of the generality of those findings

*There **is** ample evidence that accident rates* (for both base rates and work zone rates) *do differ greatly from one type of road to another.* For example, there are large differences between urban roads and rural roads, and between dual and single-carriageway roads. This seems reasonable.

However, there is little incontrovertible evidence that work zones are differentially dangerous for different road types. One problem here is that some of the data needed to make such a determination is available, yet has not been adequately investigated.

Concerning work zone and roadway interaction, the results are not extensive. *Some authors conclude that work zones utilising full contraflow are especially problematical.*

We feel, however, that the only clear-cut result is that *working areas located on the side of the road are relatively safe, as compared to those located on the road itself.* This result seems to be reasonable.

6.4. Work zone structure

Work zones have internal structures, and it is reasonable to relate accident rates, etc. to that structure.
Unfortunately, the results here are also hardly clear-cut.

We find it believable, yet relatively uninteresting, to conclude that *road sections **after** a work zone are not more dangerous than a road section which is not in the vicinity of a work zone.* We also have no problem believing that the work zone proper is also relatively dangerous, as compared to an open road section. The problem is with determining whether or not approach and transitional sections are differentially dangerous.
We feel that such a differentiation has not been conclusively established.

One could also consider different types of road section within a work zone. For example, entrance-ramps versus non-entrance-ramp sections could be considered. One well set-up study, with sufficient sample sizes and statistical sophistication, investigated this situation and found a clear difference between the two conditions on one road. On a second road, no such difference was found!
Apparently, the phenomenon is not well understood. Good statistics and research designs could not compensate for such a situation.

6.5. Safety devices

As previously stated, the ultimate goal of the ARROWS project is to reduce the frequency and/or severity of work zone accidents. One of the possible ways of achieving this is through the advocating the use of safety devices or techniques (see sub-task 1.2), either intended to change behaviour, or to attentuate the consequences of an accident. In the first case, one could imagine the use of variable message signs to warn drivers to slow down. In the second case, one could consider the use of guiding barriers or truck mounted attentuaters (TMAs).
It would be highly desireable to (empirically) evaluate the impact of such devices upon accidents.

To be brief, we have found only some superifical and unconvincing literature addressing the effectiveness of such devices in terms of reducing work zone accidents.

This is *not* to say that no research literature exists, nor that safety devices do not work. (We would certainly expect otherwise.)

We are not terribly surprised at this disappointing lack of findings, for reasons already alluded to in §6.1. We do suspect that the evaluation of such devices is primarily founded either on functional arguments or on behavioural studies (see sub-task 2.1).

6.6. Contributing (human) factors

We found enormous differences between jurisdictions and between studies. We feel that this differences have more to do with local police forms and practices than with anything else.

6.7. Other characteristics

Work zone accidents tend to be fair weather, daytime accidents. We suspect that this finding is highly related to driving exposure to (operating) work zones. This possibility should be further investigated.

Also, *many authors refer to appreciable increases in the relative frequency of rear-end collisions.* This seems to be reasonable, noting that transitions into work zones are easily paired with (unexpected) decelerations of lead vehicles.
Interestingly, one author distinguishes between day-time (low severity), multi-vehicle, rear-end collisions and night-time (higher severity), single vehicle fixed-object collisions.
Such a distinction has not been adequately demonstrated, and may only be applicable in some jurisdictions. Nevertheless, we find it to be intuitively appealing, and suggest that this validity of this dichotomy be further pursued.

6.8. Temporal and geographical differences

It is somewhat surprising that not much work has been done concerning temporal trends within jurisdictions. Furthermore, most studies that have been done, either consider rather short periods or do not correct for driving exposure or work zone length.

Even so, German work zone accident rates have apparently improved; UK rates have apparently deteriorated; US numbers are difficult to compare with each other and we can draw no conclusions. No other country apparently has a sufficient research database to even consider temporal comparisons.
We do not find it parsimonious to accept (unexplained) different regional trends, especially when we are uncertain as to the statistical reliability of such findings.

Geographical differences are especially difficult, noting that we know of no study explicitly comparing accident rates in different countries. Differences in American studies alone are enormous.
We suspect that problems of defining which roads and accident collection methods are equivalent has been far too daunting for most researchers.

6.9. The distribution of accidents over locations

Hall & Lorentz (1989) concluded that while accident rates in work zones are high(er than in the pre-work zone situation), the increase was more or less uniform for various accident characteristics. This, of course, makes it difficult to target specific types of accidents which are over-represented in work zones.

We don't agree entirely with these authors, for we have mentioned above a number of characteristics which, quite intuitively, could or should play a role in accident causation.

However, we remain particularly enamored of an elaborated null hypothesis: that if you want to predict work zone accidents you need at least two variables:
- 'exposure' to work zones, which would take operational hours into account; and
- pre-work zone accident rate.

Only when these two (predictors) turn out to be insufficient, do we need to conjure up the unique characteristics of work zone accidents.

This view is not only simple, it is also empirically and rationally sound. In addition, it enables us to make predictions. For example, by altering the operational hours of work zones (in response to congestion), one could predict a change in the predominant types of accidents as sketched in §6.6. above.

However, it also opens up a number of tantalising possibilities. First of all, we could try to predict work zone accidents rates beforehand, and optimally allocate our appropriate countermeasures.
Secondly, there is a some evidence that the distribution of accident rate increases is highly skew over locations. A relatively small number of locations may suffer quite large accident rate increases.
Identification, isolation, and treatment of high risk locations can be especially profitable. (We should not view this as a return to the 'black spot' approach, but as a potentially profitable research question.)

Third of all, it explicitly recognises that there are two sources of variation in predicting accidents: the random variation of accidents for a given location, and the variation in accident risk for different locations. The first is statistical noise, the second is what we really want to predict. Modelling these two aspects of variation is not only useful, it also puts us into the mainstream of applied statistical analysis. (See e.g., Hauer, 1992, Gardner et al., 1995).

6.10. A pan-European accident study

While we seem to be advocating viewing work zone accidents (for the time being) as a normal type of accident tending to occur frequently in work zones, we should not hastily conclude that that is the end of our mission. That we have not been able to ascertain the fine grain and unique structure of work zone accidents, does not imply that such structure does not exist. Splintered studies, with small sample sizes, limited use of analysis techniques, and possibly limited variation in national infrastructure all contribute to the present lack of focus. A well set up pan-European study, of similar design and comparable size to the large-scale American studies, would go far in remedying the present situation.

Of course a *common data dictionary and data collection protocol* are essential prerequisites for a coherent accident study, especially in a multi-jurisdictional environment. we suspect that the realisation of these prerequisites is no sinecure.

Such a pan-European study should allow us to draw conclusions with more confidence, and point the way for forming more precise hypotheses. Until then, we are forced to make uncertain guesses, and tentative comparisons.

6.11. Implications

The results of the present study have implications for other ARROWS work packages, as well as other future studies.

First of all, as perhaps all too often mentioned above, we have not been able to describe with confidence the distinctive, fine-grain structure of work zone accidents. It is not entirely certain whether the fine-grain structure is not really different from other kinds of accidents, or whether our view was somewhat obstructed. We would recommend that we make better use of existing studies, by means of implementing meta-analyses, and by applying appropriate statistical tests. In addition, we could advantageously implement large(r)-scale pan-European studies, in order to gather basic data for extensive analysis.

Secondly, the present task (2.2) has concentrated on accident analyses; the behavioural studies task (2.1) on behaviour. In one sense, this organisation has efficiently 'carved the world at its joints', on the other hand, it prevents us from focussing on the interaction between these two aspects. Namely, work zones have an effect on traffic accidents rates by virtue of their impact upon behaviour. Future work should explicitly take this causal chain into account.

Third of all, task 2.3 ('experimental methods') should take into account the need for incorporating accidents into the pallet of dependant variables, in order to ensure predictive validity. However, as is apparent in the present study, one should not underestimate the enormous practical and methodological problems associated with such research.
As an alternative, it might be useful to utilise conflicts as a surrogate measure.

Fourthly, workpackage 3 ('Workshop on Synthesis of improved sets of safety measures') is certain to be disappointed by the lack of findings concerning the effectiveness of safety measures.
Neverthless, in lieu of such information, one might want to consider the possible co-existence of multiple (accident) causal structures. (E.g., daytime, fair weather, multi-vehicle, rear-end, urban type of accidents versus the night-time, single vehicle, rural run-off-the road type of accidents. Or entrance-ramp versus non-entrance-ramp type of accidents.)
Most frustratingly, one cannot point to the accident literature for a clear elucidation of those (potential) multiple causal chains. Even so, if one could develop potentially relevant, multiple *accident scenarios,* then a number of possibilities would follow:

- one could design devices and layouts to take such scenarios into account;
- one could establish a 'checklist' to ensure that work zone designers explicitly take these scenarios into account for specific work zones;
- one could use them to direct future empirical work; etc.

A second workshop topic could involve a discussion of (statistical) methods for predicting work zone accident rates. Such tools could be useful for selecting sites for special attention, or for the comparison of specific countermeasures. Unfortunately, methods only provide a means for getting answers, instead giving answers directly.

Lastly, for workpackage 4 ('Framework for European Standards and production of practical handbook') perhaps it is tempting to conclude that we already know a great deal (or perhaps very little) about work zone accidents, due to our general knowledge about accidents. (See § 6.9 for a discussion of the elaborated null-hypothesis.)
Furthermore, choices for specific work zone types or safety devices cannot be convincingly based only, or even primarily, on work zone accident studies: the data is too limited to draw such detailed conclusions.
For these two reasons, existing general knowledge of safe design (e.g., guiding road users' from one situation into another, traffic separation, signalling, etc.) may be profitably applied in the design of safe work zones. (See for example the EU project 'International research on safety effects of road design standards'.)

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Appendix 1 Contribution of the Slovenian National Building and Civil Engineering Institute ZAG to the internal task report

ARROWS

TASK 2.2: Accident studies

Contribution to internal task report

A. Introduction and Overview

It was agreed to make a review of studies concerning road workzone accidents and that would have to meet the following criteria:

- empirical accident analyses, excluding anecdotal, unsupported or inadequately - documented studies
- no case studies (unless when presented in a context meant to generalize)
- availability of at least English summary

In plan it was expected that ZAG will make a review of literature from Eastern countries. It happened that after searching for these kind of literature no information about any research works from eastern countries was found.
The present contribution has resulted from a review of European studies from German language area concerning road workzone accidents, carried out by the ZAG from Ljubljana, Slovenia

In order to collect the required material from Eastern countries, the following procedure was followed by ZAG

1. In the middle of October 1996 we make different personal contacts with persons from Eastern countries. Contacts were made with persons from Universities, persons from different traffic or road Institutes and persons from Transport ministries.
2. With some of them we made additional contacts at the middle of November.
3. After our meeting at SWOV at the end of january 1997 we made additional contact in Russia and additional contacts with relevant Ministries in those countries where we have no previous reply.
4. A list of individuals and organizations contacted is presented in Annex I of this contribution. In total we make contacts with 31 addresses from 15 countries.
5. There were 7 answers with explanation that in individual country no any research work was performed in this field and there were no any other answers.

In order to process the material from European studies from German language area the following procedure was followed by ZAG:

1. At Coordintion Meeting at SWOV after explaining the situation in Eastern Europe it was decided to make a review of a part of studies that were not yet analysed.
2. A number of 10 studies concerning road workzone accidents in Germany(9) and Austria(1) have been received from SWOV and have already been reviewed. Results are presented in the present report. As agreed, emphasis is placed on

categorization of the literature collected; specifically, the following points were considered:

- compatibility with ARROWS Typology (type of road, type and duration of works, and interaction between road and workzone
- type of safety devices used, weather conditions, traffic flow and other circumstances
- country and period covered
- data types and collection/analysis procedure
- presentation and brief evaluation of main findings from report

Final reference lists of studies reviewed appear in Annex III to this contribution.

A. Procedural Summary

In plan it was expected that ZAG will make a review of literature from Eastern countries. We were asking them to inform us about their research works in the field of Accident studies in areas of workzones. It happened that no information about any research works from eastern countries was found. This was the main deviation in this subtask.
The procedure of making fax contacts was repeated with some other institution but with no any success.

The answers we got are explained in next table:

Country name	Country code	Status of research works
Czech Republic	CZ	no answer
Hungary	HU	no any work in this field
Italy	IT	no answer
Latvia	LV	no any work in this field
Lithuania	LT	no any work in this field
Slovakia	SK	no any work in this field
Slovenia	SI	no any work in this field
Poland	PL	no answer
Romania	RO	no answer
Croatia	HR	no any work in this field
Estonia	EE	no any work in this field
Russian Federation	RU	no answer
Bulgaria	BG	no answer

There were 7 answers with explanation that in individual country no any research work was performed in this field and there were no any other answers.

It was decided later to make a review of literature from German language area.
After making a review of ten reports in the close relevance to the subject, that is accidents in work zones, and the value (significance) of their content in terms of the extent in which the criteria, already set from the beginning of the research, are met.

C. Summary Overview

The main research questions dealth with in the analysis of the collected reports (see Annex III) were:

- What are found to be the indicators of accident risk at a road workzone, in particular as compared to the without-works situation?
- What are the commonest road workzone accident types?
- How do findings relate to road workzone typology (road type, work type and duration, and the interaction between roadway and workzone)?
- Are there any significatnt national, regional or other differences or patterns?
- What is the effect of different safety measures on the safety level at workzones?
- What is the disaggregation of safety impacts on different affected groups (in particular, road users and workers)?
- What other factors are significant in determining road workzone accident level?

The following is an attempt to respond to the above research questions.

- *What are found to be the indicators of accident risk at a road workzone, in particular as compared to the without-works situation?*

Workzone accident figures: Workzone has a definite influence upon the rate of accidents involving fatalities and injuries. The risk in workzone is 1.5 to 4.5 times higher from those outside the workzone (3.5 to 4.5 times higher - Aulbach, 2 times higher - Boesefeldt, Emde, Hamester, 1.5 times - Pomareda, Zacharias). In generally also the number of accidents in workzone is higher than outside; +50% to +80% appears to be a typical range. The percentage of truck accidents (37,4%) in the WZ is higher than those outside (24.4%).

- *What are the commonest road workzone accident types?*

Nearly 45 - 63 % of all accidents are rear-end collisions, 18-21 % loss of control accidents and 20% side collisions (same direction).

- *How do findings relate to road workzone typology (road type, work type and duration, and the interaction between roadway and workzone)?*

Road type - motorways

- accident rate on 2-lane carriageways with emergency lane is essentially lower than those occurring on motorways without emergency lanes
- no difference in accident rate between 2-lane carriageway with emergency lane on 3-lane carriageway
- the highest risk was found at traffic leading 4 + 0.

Type of work

Two reconstructions, other not specified; all longterm works.

Interaction between road and workzone

Lane closure: majority of accidents for passing lane closure, list accidents for middle-lane closure.

- *Are there any significatnt national, regional or other differences or patterns?*

None of the studies reviewed involves an internation comparison. Conclusions may be more safely drawn at a later stage in this task.

- *What is the effect of different safety measures on the safety level at workzones?*

Higher intensity of warning light and sighns in approach region help by speed reduction and by more even traffic flows. The form of speed "funnels" has no influence on traffic handling; but when the marker distance is greater than 20 m, the effect of funnel disappear.

- *What is the disaggregation of safety impacts on different affected groups (in particular, road users and workers)?*

No information obtained.

- *What other factors are significant in determining road workzone accident level?*

Section along workzone

The accident risk is almost the same in all four parts of WZ: in the approach region 1.08, in the transition-in 1.42, in the work area 1.35 and in the transition-out 1.27, while after section has been found a decrease in accident risk (0.8).

Time

daylight versus darkness: the proportion of night time accidents falls at workzones.

time of day: accident risk is higher in rush hours, disposition of accident number through the day shows similar picture for workzone and non-workzone.

Driver behaviour

The main causes of accidents (police opinion) are inappropriate high speed (21-25 %), inadequate safety distance (12-38 %) and drivers attention (9 %).

Other

weather conditions: daylight and wet, night and dry conditions occure less accidents as sections without worksites; higher number of all accidents and accidents with injuries in bad weather conditions (rain, ice, snow)

- *Overall critique of studies reviewed, their methodologies, findings, and importance to subsequente ARROWS stages*

The reports reviewed refers to research of traffic safety conditions in WZ on German motorways. Although some of them are from the year 1970, we found out evident improvement of traffic safety in WZ, nevertheless it happens still 50% more accidents. Most of studies are empirical, two of them case studies. It's true that only some of them are of good quality regarding the data collection procedure, transparency and significance check of their findings, usage of the proper analytical.

The reports were mostly not of a comparative nature regarding different countries and different road WZ types. All studies are dealing only with traffic safety conditions in WZ on motorway, no comparison has been done with safety conditions on other roads.

Otherwise it was also found which type of accidents to be expected with a predominance of rear-end collisions, loss of control and side collisions. It appears reasonable to give emphasis to those measures that are overall found to be most effective in dealing with such types of accidents in particular.

It is also doubtful whether selection among alternative road WZ types can be made on the grounds of accident experience. A tentative conclusion is that lane closures (expecially those involving middle lanes rather than slow or fast lanes) are to be preferred over contraflows and where contraflows are necessary, partial contraflows would probably be more favourable.

Regarding WZ accident causes it would be necessary to find out interface between driver behaviour and accidents; driving too close (associated with congestion) can be associated with rear-end collisions and inproper lane changing with same direction side colisions. All this should be reflected in the joint consideration of Tasks 2.1 and 2.2 within the second deliverable.

Annex I

List of persons or institutions being contacted

NAME	INSTITUTION	COUNTRY
Mr.Stamen Stamenov	Ministry of Transport	BG
Mr.Boguslaw Liberadzki	Ministry of Transport	PL
Dr.L.Rafalski	Road and Bridge Institute	PL
Dr.Mate Sršen,dipl.ing.	Institut graðevinarstva Hrvatske	HR
Mr.Alvis Pukitis	Road and Traffic Safety Directorate	LV
Mr.Radu Andrei	CESTRIN	RO
Dr.Thakaa Al-khafaji	Warsaw University of Technology	PL
Mr.Yuri V. Domratchev	Ministry of Transport	RU
Mr.Franco Sardina	ANAS	IT
Mr.Jozef Mikulik	CDV	CZ
Mr.Jozsef Timar	Ministry of Transport	HU
Mr.Hennkas Jurkuvenas	Lithuanian Road Administration	LT
Mrs.Benjamina Veleckaite	Transport and Road Research Institute	LT
Mr.Edvard Archutowski	General Directorate of Republic Roads	PL
Mr.Ioan Druta	Romanian National Administration of Roads	RO
Mr.Peter Ondrušek	Ministry of Transport	SK
Mr.Harri Kuusk	Estonian Road Administraton	EE
Mr.Virgaudas Poud iukas	Transport and Road Research Institute	LT
Mr.Girts Rorbaks	Road Traffic Safety Department	LV
Mr.Alexandru Pasnica	INCER-TRANS	RO
Mr.Tamas Nagy	Directorate for Road Management and Co-ordination	HU
Prof.Ryszard Krystek	Technical University of Gdansk	PL
Dr.Ivo Babiè	Institut graðevinarstva Hrvatske	HR
Mr.Jekabs Kolesnikovs	Latvian Road Administration	LV
Mr.Aurel Novac	Ministry of Transport	RO
Mrs.Boyka Pashova	National Road Safety Commission	BG
Mr.Vassil Gueoeguiev	Roads and Road Safety	BG
/	Federal Highway Department	RU
Mr.Karol Filipek	General Directorate of Public Roads	PL
Mr.Mircea Puiu Fierbinteanu	National Administration of Roads	RO
Mr.Drago Bole	National Road Directorate	SI

Annex II

Contact letter

The attached letter was prepared for collection of material From Central and Eastern countries needed for: Task 1.1, 1.2 and 1.3 Task 2.1 and 2.2.

Dear Colleagues,

ARROWS - Advanced Research on Road Workzone Safety Standard in Europe carried out at European level has recently been launched. This comprehensive project was accepted by European Commission of the European Communities. Project is leaded by the European consortium of various Institutes from eight countries.
Main activities and goals within the project are:

- review of safety measures, standards and practices on road workzones;
- review of behavioral and accidental studies and experimental evaluation methods;
- prepare synthesis of improved sets of safety measures and
- prepare framework for European standards and production of practical handbook.

You are kindly asked to answer to three questions:

1. First question

As a member of this consortium the Slovenian National Building and Civil Engineering Institute - ZAG from Slovenia we have a task to collect all relevant documents concerning Road Safety Workzone Standards in Central and Eastern Europe.
The goal of collecting these documents is to prepare the review of Typologies and Safety measures in all the mentioned countries.
Presuming, some of the listed regulations concerning the mentioned area of Safety in your country can be achieved, we kindly ask you to provide us with next relevant and valid documents. We need a copy of these documents also if they are written only in your national language.
Standards,
Guidelines,
Regulations and other type of practices on area of Road Workzone Safety Standards.
Whether you are not in possibility to present us these documents we further request for the list of source addresses and persons where these documents could be obtained from.
You are kindly asked to inform us with any information on this field through the enclosed fax as soon is possible.

2. Second question

Our next activity within the project is compilation of research works or any studies concerning the traffic accidents in Road Workzone areas. We need to know the titles of these works and authors with an abstract of contents in national language or with an abstract translated to English or German.
We would be obliged if you could also provide us such information.

3. Third question

Our next activity within the project is compilation of research works or any studies concerning the behavior in Road Workzone areas. We need to know the titles of these works and authors with an abstract of contents in national language or with an abstract translated to English or German.
We would be obliged if you could also provide us such information.

We hopefully look forward in your cooperation and will be glad to inform European Community of your activities in this area.

Thank you very much for your co-operation

Best Regards

Bojan Leben

Annex III

List of the analyzed Reports

Friedrich Nadler, Walter Hanko, Johannes Schrefel
Verkehrssicherkeit in Bereich von Baustellen auf Autobahnen
Bundesministerium führ wirtschaftliche Angelegenheiten
Strassenforschung Heft 372, Wien 1988

Winfried Krux, Dirk Determann
Sicherheitsbezogene Beurteilung von Autobahnstellen
RWTH Aachen
Berichte der Bast, Verkehrstechnik, Heft V28

Jochen Boesefeldt, Wolfgang Emde, Hajo Hamester
Unfallgeschenen an Autobahnbaustellen
Vehrkehrsplannung und Strassenwesen, Heft 14, München-Neubiberg, 1983

Jochen Boesefeldt, Wolfgang Emde, Hajo Hamester
Unfallgeschenen an Autobahnbaustellen
Vehrkehrsplannung und Strassenwesen, Heft 14, München-Neubiberg, 1983

Stefan Laffont, Gerhard Schmidt
Schmale Fahrstreifen in Arbeitsstellen auf Bundesautobahnen
Aachen, Dezember 1996, Berichte der Bast

Ekkehard Brühning
Untersuchung der Unfälle mit Personenschäden auf Autobahnen,
Der Einfluss von Reparaturbaustellen
Forschung und Strassenverkehrstechnik, Heft 223, 1977

Ekkehard Brühning, Rolf Völker
Unfallgeschehen auf Autobahnen, Strasse und Autobahn - Heft 6/1978

Fidel Pomareda, Uwe Zacharias
Vehrkehrssicherkeit und Verkehrsablauf in Bereich von Baustellen auf Betriebsstrecken der BAB
SNV Studiengesellschaft Nahverkehr mbH Berlin

Manfred Hess
Verkehrssicherkeit im Bereich von Autobahnbaustellen
Institut f ür Strassenwessen, RWTH Aachen, 1993

Winfried Krix und Dirk Determann
Alternative Absieherungskonzepte an 4+0 - Baustellenverkehrführungen, RWTH Aachen.
Strassenverkehrstechnik 7/9C

ARROWS

TASK 2.2: Accident studies

Conceptual contribution to internal task report

ZAG

The present contribution has resulted from a review of 10 studies concerning road workzone accidents in Germany (9) and Austria (1), which we have received from SWOV at last Arrows meeting in Leidschendam. In order to collect and process the required material, we made use of the same procedure as NTUA.

Friedrich Nadler, Walter Hanko, Johannes Schrefel
Verkehrssicherkeit in Bereich von Baustellen auf Autobahnen
Bundesministerium fhr wirtschaftliche Angelegenheiten
Strassenforschung Heft 372, Wien 1988

Road:	Motorways
Works:	Not specified
R-WZ Interaction:	
Safety devices:	
Other:	
Country:	Austria
Period:	1981-1984
Samples:	
Data collection procedure:	Road administration data, police reports
Data types:	Accident type, location and date, number of fatalities and injury accidents, workzone types
Analysis procedure:	Calculation of accident rates, comparison of rates inside and outside of workzone
Findings:	- the risk in workzone is greater than those outside of workzone - in generally also the number of accidents in workzone is higher than outside - accident rate is higher when type of workzone requires also the lane closure on opposite carriageway - 45% of all accidents are "rear-end" collisions - disposition of accident number through the day shows similar picture for workzone and for free section - higher number of all accidents and accidents with injury in bad weather conditions (rain, ice, snow) - higher number of accidents by daylight

Winfried Krux, Dirk Determann
Sicherheitsbezogene Beurteilung von Autobahnstellen
RWTH Aachen
Berichte der Bast, Verkehrstechnik, Heft V28

Road:	Motorway (dual 2-lane with emergancy lane)
Works:	Pavement reconstruction on Berliner Autobahnring (BAB A10 - first test with traffic flow 38000 vehicle/day, 13% trucks) and on motorway Mnster-Nord-Greven (BAB A1 - second test with traffic flow 65000 vehicle/day, 21% trucks)
R-WZ Interaction:	Lane closure (4+0 traffic leading)
Safety devices:	All
Other:	
Country:	Germany
Period:	1st test 20-28.10.1993 and 08.11.-16.11.1993 2nd test 18-24.06.1993 and 10.07.-16.07.1993
Samples:	2 sites - real tests 1 field test on motorway section as yet unoppened to traffic
Data collection procedure:	Record of speed and time intervals between consecutive vehicle
Data types:	Volume, speed, deceleration, time intervals between vehicles, time (day/night)
Analysis procedure:	Two concept variants of the control and of the constructional arrangement of workzone was compared with the design in accordance with the "Guidelines for Protection of Construction Sites on Roads" (RSA)
Findings:	- it was ascertained that the speed can be significantly reduced with a lane width of 2,5m. This can be available only for cars; that is to say only for overtaken lanes - the form of speed "funnels" has no influence on traffic handling; but when the marker distance is greater than 20m, the effect of funnel disappear - higher intensity of warning light and signs in approach region help by speed reduction and by more even trafficflows - the improvement in the optical guidance and the lengthening of the transition in the second variant together with the continuous centre line for prevention of hazardous lane changes, likewise achieved a speed reduction although not to the same extent as in the first concept variant - in both concepts greater time intervals between consecutive vehicles
Evaluation:	Useful for RSA changes and for international comparisons

Jochen Boesefeldt, Wolfgang Emde, Hajo Hamester
Unfallgeschenen an Autobahnbaustellen
Vehrkehrsplannung und Strassenwesen, Heft 14,
Mnchen-Neubiberg, 1983

Road:	Motorways (dual 2-lane and dual 3-lane); traffic flows form 30-60 thousand vehicle per day
Works:	No type specification; duration: 54 WZ 1 week 31 WZ 1 week - 1 month 141 WZ 1 month
R-WZ Interaction:	Various
Safety devices:	No specification
Other:	
Country:	Germany
Period:	1.1.1979-31.12.1980
Samples:	226 sites with 7204 accidents
Data collection procedure:	Requests from county authority; police accident records
Data types:	Location and date, accident type, number of fatalities and injury accidents, traffic conditions
Analysis procedure:	Calculation of accident and cost rates
Findings:	- accident rate (AR) in the workzone is nearly 2-times higher than AR outside of workzone - AR in the transition region is 1,42; AR along working site is 1,35; the national accident rate on all motorways is 0,68 - according to the several types of traffic leading the number of workzone accidents is about 80% greater than number of non-workzone accidents - accidents costs per vehicle and kilometer (WZ) is about 60% greater than those outside of the WZ

Johannes Aulbach

Lichttechnische Gestaltung von Arbeitsstellen
Technische Hochschule Darmstadt, Januar 1992
Forschungsbericht FE-Nr, 03,213 G 89 F

Road:	Not specified
Works:	Not specified
R-WZ Interaction:	Not specified
Safety devices:	Not specified
Other:	
Country:	Switzerland
Period:	Not specified
Samples:	
Data collection procedure:	
Data types:	
Analysis procedure:	
Findings:	- accident rate in WZ is 3,5 to 4,5 times higher than those outside of the WZ - 50-60% of all accidents occur at the approaches to the WZ

Stefan Laffont, Gerhard Schmidt
Schmale Fahrstreifen in Arbeitsstellen auf Bundesautobahnen
Aachen, Dezember 1996
Berichte der Bast

Road:	Motorway (dual 2-lane with emergency lane)
Works:	Not specified
R-WZ Interaction:	Various
Safety devices:	RSA 1995
Other:	
Country:	Germany
Period:	1995
Samples:	7 sites with 4+0 traffic leading 1 site with 3+1 traffic leading
Data collection procedure:	Record of speed and traffic, video recording
Data types:	Traffic volumes, speed, number of accidents, accident type, weather conditions, time (day/night)
Analysis procedure:	Statistical analysis
Findings:	- comparison to 15 years old equivalent studies shows fall of accident and cost rate from 2 to 1,4 respectively 1,7 to 1,4 - accident and cost rate is higher in transition region - 55% of all accidents represent only material damage, 36% are slight-injury accidents and 9% fatalities and serious injury-accidents - about 63% of all accidents are rear-end collisions, 18% loss of control - over 50% of all accidents occur by daylight and by dry pavement - daylight and wet, night and dry conditions occur less accidents as sections without worksites - accident risk is higher in rush hours - the percentage of truck accidents (37,4%) in the WZ is higher than those outside (24,4%)

Ekkehard Brhning
Untersuchung der Unflle mit Personenschden auf Autobahnen,
Der Einfluss von Reparaturbaustellen
Forschung und Strassenverkehrstechnik, Heft 223, 1977

Road:	Motorways (dual 2-lane with and without emergency lane and dual 3-lane)
Works:	Reconstructions on motorway A15 Kln-Frankfurt
R-WZ Interaction:	Various types of layout
Safety devices:	No specification
Other:	
Country:	Germany
Period:	1968
Samples:	
Data collection procedure:	Not specified
Data types:	Police reports; road administration data
Analysis procedure:	Statistical analysis
Findings:	- workzone has a definite influence upon the rate of accidents involving fatalities and injuries - accident rate in the WZ (0,614) is about 16% higher than those outside (0,561)

Ekkehard Brhning, Rolf Vlker
Unfallgeschehen auf Autobahnen
Strasse und Autobahn - Heft 6/1978

Road:	Motorways (dual 2-lane with and without emergency lane and dual 3-lane)
Works:	No type specification; duration more than 10 days
R-WZ Interaction:	Various
Safety devices:	Not specified
Other:	
Country:	Germany
Period:	1968, 1970, 1973
Samples:	
Data collection procedure:	Not specified
Data types:	Accident data, road administration data
Analysis procedure:	Statistical analysis
Findings:	- from 1968 to 1973 PIA rate decline from 0,614 to 0,407 - accident rate in the workzone is still 17% higher than those outside the workzone - accident rate on 2-lane carriageways with emergency lane is essentially lower than those occurring on motorways without emergency lanes - no difference in accident rate between 2-lane carriageway with emergency lane and 3-lane carriageway - the mean value of accident ate also goes up as a result of an increasing mean gradient of the road as well as there are repair sites

Fidel Pomareda, Uwe Zacharias
Vehrkehrssicherkeit und Verkehrsablauf in Bereich von Baustellen auf Betriebsstrecken der BAB
SNV Studiengesellschaft Nahverkehr mbH Berlin

Road: Motorways
Works: Various
R-WZ Interaction:
Safety devices:
Other:
Country: Germany
Period: 1970-1988
Samples:
Data collection procedure: Collecting the results of studies different authors
Data types: Accident rates, accident types
Analysis procedure: Critical analyse
Findings:
- in the year 1970 was the risk in transition region 10-times higher from those outside the WZ. In the year 1980 this value is only 4
- in work area the risk was 3-times higher from those outside the WZ
- in the year 1980 this value was only 1,5
- the number of accidents in workzone is higher than outside WZ
- about 47,5% of all accidents are rear-end collisions, 21,7% are loss of control accidents
- according to fatalities, 37,8% of all accidents are front collisions; 22,2% of all are loss of control accidents
- nearly 50% of all accidents occur in approach region, 35% in work area and 9% respectively 6% in transition-in or transition-out area
- in approach region 41% of all accidents are rear-end collisions, 26% loss of control accidents and 20% side collisions among cars driving in the same direction
- in transition-in region 42% of all accidents are loss of control accidents, 28% side collisions and 26% rear-end collisions
- in the work area 28% are rear-end collisions, 26% side collisions and 25% loss of control accidents
- in the transition-out region 34% of all accidents are loss of control, 22% rear-end collisions and 15% side collisions among cars driving in the same direction
- in all 4 parts of WZ only 4% of all accidents represent front-collisions
- the main cause of accidents (police opinion) are "inappropriate high speed" and "inadequate safety distance"
- analyze of 7204 accidents in 266 workzones shows accident rate of 0,978 outside workzone 0,665

- accident rate in approach region is 1,077 in transition-in region 1,42, in the work area 1,351, in transition-out area 1,271 and after this region 0,795
- the mean value of AR goes up according to the type of workzone; analysis show the highest AR (1,9) for type I with traffic leading 2+1
- at workzone type II the highest risk was found at traffic leading 4+0

Manfred Hess
Verkehrssicherkeit im Bereich von Autobahnbaustellen
Institut fr Strassenwessen, RWTH Aachen, 1993

Road:	Motorways
Works:	Not specified
R-WZ Interaction:	
Safety devices:	
Other:	
Country:	Germany
Period:	Last 15 years
Samples:	
Data collection procedure:	Collecting the results of several studies different authors
Data types:	Accident location and type, accident cause
Analysis procedure:	Critical analyse
Findings:	- according to the location and type most of rear-end collisions (41%) occure in approach region - in the transition-in/out region are most frequent loss of control accidents - part of front collisions is very small, yet 40% of fatalities is the result of this type of accidents - 20% of fatalities occur by loss of control - the main cause of accidents (police opinion) are inappropriate high speed inadequate safety distance and drivers attention (AUTOBAHNAMT Frankfurt am Main, 1985) - AHRENS (1992) found inadequate safety distance (38%) as main cause, follow inappropriate high speed with 21%, tiredness and alcohol with 9% - KCKELKE & ROSSBANDER (1988) found in approach region inappropriate high speed as main cause (25%) and inadequate safety distance with 12%. In the transition-in region 28% of accidents occur as the result of inappropriate high speed and 26% as drivers fault. In work area and in transition-out region the main cause is inappropriate high speed with 18% respectively 23%

Winfried Krix und Dirk Determann
Alternative Absieherungskonzepte an 4+0 - Baustellenverkehrfhrungen, RWTH Aachen.
Strassenverkehrstechnik 7/9C

This study is only one part of study already reviewed (same authors) !

Appendix 2 Contribution of the National Technical University of Athens NTUA to the internal task report

ARROWS

TASK 2.2: Accident Studies

Contribution to internal task report

A. Introduction and Overview

The present contribution has resulted from a review of European and international studies concerning road workzone accidents, carried out by the National Technical University of Athens (NTUA).

It was agreed that studies qualifying for consideration would have to meet the following criteria:

- empirical accident analyses, excluding anecdotal, unsupported or inadequately-documented studies
- no case studies (unless when presented in a context meant to generalize)
- availability of at least an English summary

In order to collect and process the required material, the following procedure was followed by NTUA:

1. Contacts were made with ARROWS partners, other sources in West European countries, as well as North American sources. The list of contacts was later enriched with individuals recommended by our initial contacts. Several of the sources contacted were able to either send or identify reports that would be of interest to Task 2.2.
2. Through libraries and bookstores, it was possible to obtain several reports, including those identified by our contacts, on road workzone accidents.
3. Copies of reports received have been forwarded to SWOV. In addition, we have maintained a list of individuals and organizations contacted.
4. A number of the studies received have already been reviewed and are presented in the present report. As agreed, emphasis is placed on categorization of the literature collected; specifically, the following points were considered:
   (a) Compatibility with ARROWS Typology: type of road, type and duration of works, and interaction between road and workzone
   (b) Type of safety devices used, weather conditions, traffic flow and other circumstances
   (c) Country and period covered
   (d) Data types and collection/analysis procedures
   (e) Presentation and brief evaluation of main findings from each report
   (f) Comparative and summary evaluation of findings: major findings, degree of completeness, further study needs, overall conclusions

Final reference lists of studies collected and reviewed, as well as of individuals and organizations contacted, appear in Annex I to this contribution.

B. Procedural Summary

NTUA attempted contacts with ARROWS partners and other persons and institutes (*see: Annex I: List of Contacts, and Annex II: Contact Letter/fax regarding the request for literature)*, in Europe and North America, involved in research activities. The initial list was enriched later with other persons which were suggested by our first contacts. The outcome of these contacts was the formulation of a bibliography which includes various reports and studies more or less relevant to the issue. Most of the recommended reports were obtained through libraries and bookstores. The selection of the reports to be analysed *(see Annex III: List of the anaylzed Reports, Summary of the Reports*) was made on the basis of the close relevance to the subject, that is accidents in work zones, and the value (significance) of their content in terms of the extent in which the criteria, already set from the beginning of the research, are met.

C. Summary Overview

The main research questions dealt with in the analysis of the collected reports (see Annex III) were:

- *What are found to be the indicators of accident risk at a road workzone, in particular as compared to the without-works situation?*
- *What are the commonest road workzone accident types?*
- *How do findings relate to road workzone typology (road type, work type and duration, and the interaction between roadway and workzone)?*
- *Are there any significant national, regional or other differences or patterns?*
- *What is the effect of different safety measures on the safety level at workzones?*
- *What is the disaggregation of safety impacts on different affected groups (in particular, road users and workers)?*
- *What other factors are significant in determining road workzone accident level?*

The following is an attempt to respond to the above research questions.

- *What are found to be the indicators of accident risk at a road workzone, in particular as compared to the without-works situation?*

Workzone accident figures: The available information does not allow for conclusions regarding "typical" accident rates (Finland: 2.6 to 5.8 inj.acc./bn veh-km; U.K. motorways: 0.154 inj.acc./m veh-km, compared to 0.098 inj.acc./m veh-km without works; Japan case: 70 to 90 acc. per 100 m veh-km).
Workzone accident figures compared to totality of accidents: A proportion of 1% to 3% appears to be typical (Finland 1.2% to 3.1%, and 0.6% to 3.6% for fatal; Spain 2%; 3 U.S. States 1.92% to 3%; Japan case 0.5% to 0.8%).
Workzone accident figures compared to non-workzone accident figures: Almost universally, a road workzone results in an increase in accident rates. Figures vary, but +30% to +100% appears to be a typical range (U.K. motorways: +129% rate ('93), +57% ('88), +45% ('82); U.K. dual-carriageways: +14% rate; U.K. rural: +65% ('88), +10% ('73); U.S. urban arterial: +35% to +77% freq., +59% to +106% rate; Japan case: +30% to 60% rate; U.S.: +6.7% rate, +6.9% for fatal and injury accidents; U.S. freeway ramps: +35% to +61% freq.; U.S. 7-State: +7% rate;

California: +21% rate, +132% for fatal acc. ('65), +7% rate, -4% fatality rate ('70); U.S. State: +61% freq., +67% fatal, +68% injury; Virginia: +119% freq., +320% fatal, +35% injury).
Workzone accident severity: The overall picture appears to be one of a decrease in severity compared to non-workzones (U.K. motorways and dual-carriageway: fall in no. of overall casualties, fatalities and seriously injured per accident, rise in proportion of slight-injury accidents and in no. of slightly injured per accident; Ohio: decrease in severity; U.S. 7-State: slight shift towards less severe accidents with-works)

- *What are the commonest road workzone accident types?*

A remarkably consistent finding is the higher (compared to all-roads) proportion of **rear-end** and (same-direction) **sideswipe** accidents, as well as of **multi-vehicle** crashes. U.K. studies also report a marked decrease in the proportion of **loss-of-control** accidents. Studies from the U.S. (Virginia, Ohio) and Denmark identify accidents involving **collision with objects** as fairly common. It is worth adding that two U.S. studies also mention the over-representation of **truck** involvement.

- *How do findings relate to road workzone typology (road type, work type and duration, and the interaction between roadway and workzone)?*

<u>Road type</u>
Motorways: the risk at workzones is about 1/2 that of rural major roads (without works) and about 1/6 that of urban major roads (without works) (U.K.)
Interstate routes: highest number of accidents (U.S.)
Rural interstates, +33% in accident experience; **rural primary**, +17%; **rural secondary**, +23% (U.S., New Mexico)
Dual 2-lane versus dual 3-lane: no significant difference in accident experience (U.K.)
All-purpose roads, most marked increase in accident rate for the trunk-plus-A-road combined group (U.K.)
Urban arterial roads: significant increase in accidents at or near intersections (U.S.)

<u>Type of work</u>
Expressways, different work types: **snow removal and de-icing** exhibit highest accident frequency and rate, and highest frequency of non-injury accidents; **obstruction removal** shows lowest accident rate and lowest injury-accident rate; **marking** is associated with highest injury-accident rate; **pavement reconstruction** is linked with highest frequency of injury accidents (Japan expressways)
Short-duration and short-length works: higher accident rates; **stationary** works: higher fixed-object accident rate (U.S.)

<u>Interaction between road and workzone</u>
Comparison between **full-contraflow and partial-contraflow**: the former exhibits a higher increase in accident rates (U.K. motorways; U.K. dual-carriageway)
Contraflow (from 4-lane-divided to two-lane-two-way): 5 of 15 accidents on travelled way, 10 on median crossovers (U.S., Nebraska)
Expressways, **lane closure**: majority of accidents for passing-lane closure (42% to

58%), least accidents for middle-lane closure (of 3-lane expressway) (Japan case)
Travelled way / detour workzones: rural freeways, 41% increase in total accident rate, 31% increase in fatal and injury accident rate; urban freeways, 34% increase in total accident rate, 25% increase in fatal and injury accident rate; rural 2-lane, 47% increase in total accident rate, 73% increase in fatal and injury accident rate (U.S.)
Shoulder and roadside workzones, urban freeways: substantial increases in accident rate for 20-mph speed-limit reduction (U.S.)
One-lane projects: large number of rear end accidents; contraflow more severe than lane closure, and alternate-one-way more severe than detour (U.S.)
Accident increases more marked in **interchanges and transitional areas** (U.S., Virginia)

- *Are there any significant national, regional or other differences or patterns?*

Conclusions about possible national (or regional) differences or patterns may be more safely drawn when studies from a larger sample of countries are jointly considered at a later stage in this Task. None of the studies reviewed involves an international comparison.

- *What is the effect of different safety measures on the safety level at workzones?*

Information on the effect of safety measures (such as traffic control devices, layout arrangements and the like) on road workzone accident experience seems to be sparse. Two U.S. studies (Ohio) cite inadequate traffic control and inadequate barrier protection as workzone accident causes, in particular for single-vehicle accidents involving drums used for tapers and closures. Another U.S. study (7-State) backs up this conclusion by identifying a strong correlation between traffic control devices and construction-related fixed-object accidents, and also states that the accident rate increase is slightly more marked for projects with a speed limit reduction. It would appear that this relative lack of results on that topic has to do with the accident recording system. It is noted that another U.S. report mentions the proposed WZADP (WorkZone Accident Data Process), which should involve recording accidents in relation to the traffic control measures used.

- *What is the disaggregation of safety impacts on different affected groups (in particular, road users and workers)?*

Apart from a dedicated U.S. study for highway construction workers' safety, the only other available information on disaggregation of safety impacts comes from Spain (workers involved in 1.34% of road workzone accidents), Illinois, U.S. (a "small percentage" of truck drivers had workzone accidents), an NCHRP study for the U.S. (the accident rate for pedestrian accidents rose by 29%), and data from the U.S. National Safety Council (highway workers experience 1.7 times the all-industry average of work injuries per time unit, and municipal street / maintenance workers experience 5 times the all-industry average).

Main findings from the dedicated study on highway construction workers are:
- 23% of fatalities involve traffic-worker accidents; 19% involve machinery-worker; 28%, traffic-machinery; and 31%, diverse other events

- 1/3 of fatalities involve construction labourers, 17% involve operating engineers, and 12% involve truck drivers

- *What other factors are significant in determining road workzone accident level?*

Section along workzone
This appears to be the factor most consistently associated with accident risk. The **advance / approach** section (U.K. motorways; U.S.), **transition** section (U.S., Illinois) and the **central / works** section (U.K. motorways and dual-carriageways) are the ones most severely affected, while the **"after"** section has been found (U.K. motorways) to exhibit a decrease in accident risk. Although different definitions for these sections may exist in practice, the consistency of this finding is such that it should not be ignored.

Time
Time-related factors with an apparent link to road workzone accidents include:
(a) **daylight versus darkness**: the proportion of nighttime accidents falls at workzones (U.K. motorways, U.S. Ohio), but other U.S. studies report an increase in the number of nighttime accidents, and highest severity for nighttime accidents
(b) **time of day**: worker fatalities are highest between 1pm and 3pm (U.S.), and the accident rate is higher between 6am and 9pm (U.K. motorways)
(c) **weekday vs. weekend**: Denmark reports a fall in the weekend accident proportion, while on U.K. motorways the weekend accident rates are found to be higher than weekday accident rates

Driver behaviour
A remarkable finding is that "driver error" (U.S.) and loss of control (U.K. motorways and dual carriageways) are less often found to be factors associated with accidents than on roads without works. However, "following too close" and improper lane changing (U.S.) are cited as accident causes. A Japan study also reports "dozing" and "reckless driving" as accident-related factors on expressway workzones.

Other
Other factors associated with road workzone accidents in various studies include:
- **direction of travel** (U.K. motorways: higher accident rates in diverted contraflow direction),
- **traffic conditions** (U.S.: traffic slowdown, congestion, "bad driving situations"),
- **weather conditions** (U.S.: less accidents with adverse weather; (related finding) Denmark: smaller percentage of winter accidents),
- **road conditions** (U.S.: uncovered hole, edge drop; U.K.: "presence of contraflow" considered as a contributory factor in over 1/2 of workzone accidents),
- **workzone length** (U.K. motorways: accident rates increase with contraflow length; however, a U.S. study - Nebraska - states that no relation was found between accident rate and segment length),
- **worker fatalities** (U.S.) are mainly attributed to "overexertion" (27%) and "falls" (23%)

- *Overall critique of studies reviewed, their methodologies, findings, and importance to subsequent ARROWS stages*

The reports reviewed were not of uniform quality regarding the scope, analytical procedure and value of findings. On the whole, it was possible to adhere to the agreed procedure of considering only empirical accident studies, excluding case studies where they were not in a "generalized context"; however, due to the relative scarcity of road workzone accident studies, as well as to the fact that some studies not fully fitting the specified requirements nevertheless provided some insights considered to be potentially helpful, the present review also includes some case studies and some non-empirical or very sparsely and briefly reported studies. It is true that only some of the studies reviewed were judged to be of considerably good quality regarding (a) the data collection procedure, (b) the transparency and significance check of their findings, (c) usage of the proper analytical tools. This is particularly true of some U.K. and U.S. studies.

In addition, the reports were mostly not of a comparative nature regarding different countries / regions or different road workzone types; quite commonly, they can be described as "focused" on certain aspects of the situation. Regarding applicability of findings on a wider context, this is not satisfactory; however, the consideration of a large and varied range of aspects, however fragmentary, does have its value, in particular since some studies are focused on issues that are sometimes overlooked, such as worker safety and self-reported accident experience.

A common focus of road workzone accident studies was found to be the comparison of the safety level between roadworks and either all roads or works-free roads. If applied at an aggregated level, the information available can be considered as sufficient to allow for an approximate prediction of the accident rates and severity to be expected, especially if the pre-construction safety level is known. However, there are no conclusive results to allow for comparison of the relative safety along the various sections of a workzone (with the obvious exception of the "after" section, found to be consistently safer than the advance, transition and works areas).

Another parameter that can be quite safely deduced from existing studies is the type of accidents to be expected, with a predominance of rear-end collisions (especially multi-vehicle), same-direction sideswipes, and fixed-object crashes. Thus, even though not much is revealed about the effect of safety measures (including traffic control devices) on road workzone accidents, it appears reasonable to give emphasis (especially within **ARROWS WP's 3 and 4**) to those measures that are *overall* found to be most effective in dealing with such types of accidents in particular.

However, from the information available in the studies reviewed, it is doubtful whether selection (and related **proposals in the ARROWS WP 4**) among alternative road workzone types (provided, of course, that true alternatives exist for a given situation) can be made on the grounds of accident experience. A tentative conclusion is that lane closures (especially those involving middle lanes rather than slow or fast lanes) are to be preferred over contraflows, and where contraflows are necessary, partial contraflows would probably be more favourable than full contraflows; similarly, detours appear to be safer than alternate one-way traffic.

Regarding workzone accident "causes" (or simply factors associated therewith), a mention should be made about environmental factors (darkness, adverse weather), which appear to be associated with a smaller percentage of workzone accidents than is the case with non-workzone accidents. Perhaps a more challenging issue from a research viewpoint is the interface between driver behaviour (and associated traffic conditions) and accidents; following too close (associated with congestion) can be associated with rear-end accidents, and improper lane changing with same-direction sideswipes, which constitute dominant types of road workzone accidents. However, possibly due to increased alertness, loss of control and driver error are less often cited as accident causes on workzones than on non-works sections, although object-hit crashes are not rare. This highlights car following and lane changing behaviour as all-important regarding road workzone safety, and this should be reflected in the joint consideration of **ARROWS Tasks 2.1 and 2.2** within the **second Deliverable**.

Annex I

List of contacts[1]

Name	Institute
Mr. Jean -Pierre Cauzard	INRETS
Mr. Allan Quimby	TRL
Ms Jacqueline Prigogine	IBSR
Ms Fermina Sanchez Martin	DGT
Mr. Werner Klemenjak	KfV
Mr. Finbarr Crowley	ERU
Mr. Pierangelo Sardi	SIPSIVI
Mr. Antonio Figueiredo da Silva	PRP
Mr. Antonio Barros	U_Minho
Mr. Juha Luoma	VTT
Mr. Raphael Denis Huguenin	BPA/BFU/UPI
Mr. Uwe Ewert	BPA/BFU/UPI
Mr. Terje Assum	TOI
Ms L. Herrstedt	Vejdirektoratet
Mr. Chris Glen	Highways Agency Headquarters
Mr Carlos de Almeida Roque	Divisao de Circulacao e Seguranca Junta Autonoma de Estradas Praca da Portagem
Mr.Joao Cardoso	LNEC
Ms Camara Pestana	BRISA- Autoestradas de Portugal
Esko Tuhola	Finnish National Road Administration
Seija Vilander	Finnish National Road Administration
Jari Mustonen	TKK
Hannu Tarvainen	Federation of Accident Insurance Institutions
Jorma Lappalainen	Tampere Regional Institute of Ocupational Health
Mr.Justin True	Federal Highway Administration
Ms. Anne Kight	Institute of Transportation Engineers
Ms. Laura Haza	Institute of Transportation Engineers
Mr. Richard A. Cunard	Transportation Research Board
Mr. Michael F. Trentacoste	Office of Highway Safety U.S. Department of Transportation Federal Highway Administration

[1]ARROWS partners are not included in the above list of contacts

Annex II Contact letter

Dear Colleagues,

ARROWS is the acronym for *Advanced Research on Road Workzone Safety Standards in Europe*, a research programme under European Commission - Directorate General for Transport (DG VII) within the 4th Framework for Research and Technological Development with the following participants:

NTUA	-	National Technical University of Athens (GR), Project Coordinator
SWOV	-	Institute for Road Safety Research (NL), partner
BAST	-	Federal Highway Research Institute (DE), partner
VTI	-	Swedish Road and Transport Research Institute (SE), partner
3M	-	3M Hellas Limited (GR), partner
CRR	-	Belgian Road Research Centre (BE), partner
CROW	-	Centre for Research and Contract Standardization in Civil and Traffic Engineering (NL), partner
CDV	-	Transport Research Centre (CZ), partner
ZAG	-	National Building and Civil Engineering Institute (SI), partner

ARROWS aims to contribute to European standards harmonization through the development of a range of road workzone safety measures and principles applicable across Europe and the production of a relevant practical handbook.

One of the necessary steps towards the achievement of the above objectives is a review of road workzone accidents. It is important for the ARROWS consortium to collect existing accident studies from European countries.

For the purposes of this task, we would be grateful if you could provide us with any empirical studies you may have concerning workzone accidents or relevant literature, based on which conclusions can be drawn about the nature and extent of workzone accidents. More specifically, it is desirable for these studies to include:

- documented studies with at least an English summary
- empirical accident analyses
- not case - specific studies, unless in a general context

In case you do not have the above described material, could you possibly send to us by fax the address of someone who might be able to help us? If possible, could you also forward the present request to any such persons?

We would be obliged if you could send your responses to:

National Technical University of Athens
Department of Transportation Planning and Engineering
Attention: Dr George Kanellaidis
Mrs Sophia Vardaki
Iroon Polytechniou 5, 15773 Zografou,
Athens,Greece
Phone: +30.1. 7721282 7721331
Fax: +30.1. 7721327

Email: . g-kanel@central.ntua.gr (George Kanellaidis)

The ARROWS consortium will appreciate your prompt response.

Sincerely,

Dr George Kanellaidis

Annex III List of the analyzed Reports

M. R. Hayes, P. J. Taylor and H. C. R. Bowman (Halcrow Fox)
TRL Project Report 81: A study of the safety performance of major motorway roadwork layouts
1994

M. R. Hayes and P. J. Taylor (Halcrow Fox and Associates)
TRL Project Report 37: A review of the accident risk associated with major roadworks on all-purpose dual carriageway roads
1993

R. D. Coombe and D. R. Turner (Halcrow Fox and Associates)
TRRL Contractor Report 150: Accidents at roadworks on all-purpose rural roads
1989

Kalevi Katko (Finnish National Road Administration)
Safety at Roadworks
Safety at Roadworks(PIARC)
1996

Oscar Gutierrez-Bolivar
Safety at Roadworks (PIARC)
1996

Investigation of Highway Work Zone Crashes
Summary Report
HSIS - Highway Safety Information System
U. S. Department of Transportation
Federal Highway Administration

Bea Blacklow, Ken Hoffner
Fatalities and Serious Injuries among Highway Construction Workers
Summary Report
Laborers' Health and Safety Fund of North America
December 1995

Accidents cost evaluation - QUADRO 2
Traffic management and Safety at Highway Work Zones, OECD, Paris 1989, and THE VALUATION OF ACCIDENTS, Part 2 The valuation of Costs in QUADRO, Volume 14, Section 1, Quadro Manual, September 1996

Tae-Jun Ha and Zoltan A. Nemeth
Detailed Study of Accident Experience in Construction and Maintenance Zones
TRR No.1509 Maintenance Management and Safety, 1995

Rahim F. Benekohal, Eunjae Shim, and Paulo T. V. Resende
Truck drivers' Concerns in Work Zones: Travel Characteristics and Accident Experiences
TRR No. 1509 Maintenance Management and Safety, 1995

Jerry G. Pigman and Kenneth R. Agent
Highway Accidents in Construction and Maintenance Work Zones
TRR No.1270 Safety Research: Accident Studies, Enforcement, EMS, Management, and Simulation, 1990

H. Gene Hawkins, Jr., and Kent C. Kacir
Traffic Control Guidelines for Urban Arterial Work Zones
TRR No. 1409 Maintenance Management, Traffic Safety, and Roadsides, 1993

Road Directorate,
Ministry of Transport
Denmark,
A Danish Study

John Oliver, Department of Transport, United Kingdom
Safety at Roadworks
Safety at Roadworks (PIARC)
1996

Koji Kuroda and Junichi Inoue, Japan Highway Public Corporation
Analysis on Expressway Work Zone Safety
Safety at Roadworks (PIARC)
1996

National Cooperative Research Program
Research Results Digest Number 192, September 1996
Procedure for Determining Work Zone Speed Limits

J.W. Hall and V. M. Lorenz
Characteristics of Construction- Zone Accidents
TRR No. 1230 Work-Zone Traffic Control and Tests of Delineation Material
1989

Patrick T. McCoy and David J. Peterson
Safety Effects of Two-Lane Two-Way Segment Length Through Work Zones on Normally Four Lane Divided Highways
TRR No. 1163, Traffic Control in Work Zones
1988

David B. Casteel and Gerald L. Ullman
Accidents at Entrance Ramps in Long-Term Construction Work Zones
TRR No. 1352 Maintenance Management, Traffic Safety, and Snow Removal
1992

Jerry L. Graham and James Migletz
Collection of Work-Zone Accident Data
TRR No 933 Traffic Delineation, Work-Zone Protection, and Winter Maintenance
1983

Robert J. Paulsen, Howard Needles Tammen and Bergendoff, Douglas W. Harwood and Jerry L. Graham, John C. Glennon
Status of Traffic Safety in Highway Construction Zones
TRR No 693 Safety in Construction and Maintenance Work Zones and Transportation of Hazardous Materials

J. L. Graham, R. J. Paulsen and J. C. Glennon
Accidents and Speed Studies in Construction Zones, FHWA, Final Report 1977

J. L. Graham, R. J. Paulsen and J. C. Glennon
Accident Analyses of Highway Construction Zones
TRR No 693 Safety in Construction and Maintenance Work Zones and Transportation of Hazardous Materials

National Cooperative Research Program
Research Results Digest Number 100, February 1978
Safe Conduct of Traffic Through Highway Construction and Maintenance Zones

Traffic behaviour at roadworks, Final Report
Transport and Road Research Laboratory, The Department of the Environment, London October 1973

M.R. Hayes, P.J. Taylor and H.C.R. Bowman (Halcrow Fox)
TRL Project Report 81: A study of the safety performance of major motorway roadwork layouts
1994

Road: Motorways (excluding urban), at least dual-3 lane; criteria for selection included traffic flow (daily flows ranged from 25 to 154 thousand vehicles)

Works: "Major motorway roadworks"; criteria for selection included length and duration (ranged from 1 to 59 days)
- *Higher values for the selection criteria were preferred, for contributing to a larger sample of vehicle-km and accidents*

R-WZ Interaction: Main layouts considered include: full contraflow ["CFA": two-lane crossovers] and partial contraflow ["CFD": part of the primary direction on hard shoulder; and "CFE": part of the primary direction on offside lane]; exclusion of unusual features; approach defined as 6 km either side

Safety devices:

Other: History of road works (within 6 km, for past 4 years); weather conditions for accidents; road surface conditions; effects of Motorway Safety Initiative (policy measures introduced in 1988)

Country: United Kingdom

Period: Works intended for completion in financial year 1992/93

Samples: 22 sites (traffic flow data for 17 sites without-works, 10 sites with-works), covering 106 traffic management phases; 206 accidents with-roadworks, 227 accidents without roadworks (exclusion of accidents that occurred /a/ during removal of traffic management; /b/ outside the area of influence of a particular traffic management phase)

Data collection procedure: Site identification from annual maintenance programme; DOT regional offices; DOT maintenance agents. Selection through criteria. Questionnaire to maintenance agents. On-site visits.

Data types: Nature of traffic management; drawings and plans of layouts and safety devices; history of road works; incident logs; listings of Personal Injury Accidents or "PIAs" (location - date/time - weather conditions - no. & severity of casualties - no. & class of vehicles - lighting conditions - cause & type of accident - traffic conditions); accidents for a number of years prior to roadworks commencement; traffic flows (with-/without-works)

Analysis procedure: - Definition of three-year averaged Equivalent Works Period (EWP), to take advantage of large sample and take into account the "natural" fluctuations: comparison between with- and without-works PIA rates (standardized per million veh-km), statistical significance (confidence level) of comparisons indicated

- Derivation of accident rates for QUADRO programme
- No analysis of damage-only accidents
- "No attempt to eradicate bias due to higher accident recording rates at roadworks"
- Strip-plan analysis for identification of clusters

Findings:

- PIA rates 2.29 times higher with-works than without-works (difference significant at 99.9% confidence level). In 1987 the corresponding rate was 1.57. Increase is attributed to consistent fall in without-works (base) PIA rate and to increased with-works PIA rate.
- Comparison to 1982 and 1987 equivalent studies, in particular investigation of the effect of the MSI, or Motorway Safety Initiative of 1988 (50 mph speed limit at workzones; lorry ban on offside lane of contra-flow section): cautious indication of increase in accident risk after introduction of MSI, but not of sufficient statistical significance.
- Difference between with- and without-works is consistent in any direction of travel, all contraflow types, and any traffic management section.
- For the whole site, PIA with-works is higher in primary (=diverted) direction: 27% higher risk level compared to secondary direction.
- Approach section (particularly in primary direction) shows highest increase in PIA rates; followed by central (works) section. Previous studies showed the central section to have a higher increase in rates.
- Full contraflow (2-lane crossover) shows highest increase in PIA rates. However, it also shows lowest absolute PIA rates both with- and without works.
- Proportion of daylight-to-darkness PIAs is similar between with-works and without-works periods (70-30; base case: 67-33). Rate for daylight = 2.29; for darkness = 2.10.
- Reduction in proportion of fatalities and serious-injury accidents, and increase in proportion of slight-injury accidents in the presence of works. Also, number of fatal / seriously-injured casualties per PIA decreased with-works, and number of slightly injured per PIA increased, in comparison with base case.
- Overall casualties per PIA is lower with-works than without-works. Distribution of number of casualties per PIA by severity follows the national trend.
- Road surface conditions or weather conditions not important.
- 30% increase in "shunt" (rear-end) accidents, and marked decrease in proportion of "loss-of-control" accidents, compared to without-works.
- Larger proportion (compared to without-works) of accidents involving over 4 vehicles
- No clustering of accidents identified: no change in layouts recommended.

Evaluation: Focused; well-documented

M.R. Hayes and P.J. Taylor (Halcrow Fox and Associates)
TRL Project Report 37: A review of the accident risk associated with major roadworks on all-purpose dual carriageway roads
1993

Road: Dual 2-lane and dual 3-lane (excluding urban); with or without continuous hard shoulders; with at-grade and/or grade-separated junctions [but without *intervening* at-grade junctions]. Traffic flows from 7 to 75 thousand vehicles/day.

Works: "Major maintenance schemes", with a "significant" duration of works (duration range from 2 to 68 days).

R-WZ Interaction: Various types of layout (not limited to contraflow)
Disaggregation into subgroups on the basis of road type and work layout. Five main subgroups:
- Dual-2 without hard shoulder, grade-separated junctions, full contraflow
- Dual-3 with hard shoulder, grade-separation, full contraflow
- Dual-3 with hard shoulder, grade-separation, other contraflow
- Dual-2 without hard shoulder, grade-separation, offside lane closure in both directions
- Dual-2 without hard shoulder, at-grade, full contraflow

Safety devices:

Other: History of road works (within 6 km, for past 3 years); weather conditions for accidents.

Country: United Kingdom

Period: Works intended for completion in financial year 1991/92 (plus some from 1990/91)

Samples: 27 sites (traffic flow data for 26 sites without-works, 13 sites with-works); covering 132 traffic management phases; 150 accidents with-roadworks, 1362 accidents without roadworks (exclusion of accidents that occurred /a/ outside the extent of defined "site"; /b/ outside the defined duration of works; /c/ within previous maintenance schemes; /d/ within periods of removal of traffic management; /e/ outside area of influence of a particular traffic management phase)

Data collection procedure: Site identification from annual maintenance programme; DOT regional offices; DOT maintenance agents. Selection through criteria. Questionnaire to maintenance agents. On-site visits.

Data types: Nature of traffic management; drawings and plans of layouts and safety devices; history of road works; incident logs; listings of Personal Injury Accidents or "PIAs" (location - date/time - weather conditions - no. & severity of casualties - no. & class of vehicles - lighting conditions - cause & type of accident - traffic conditions); accidents for a number of years prior to roadworks commencement; traffic flows (with-/without-works)

Analysis procedure: - Definition of one-year equivalent works period: comparison between with- and without-works PIA rates (standardized per

million veh-km), statistical significance (confidence level) of comparisons indicated
- Derivation of accident rates for QUADRO programme
- No analysis of damage-only accidents
- "No attempt to eradicate bias due to higher accident recording rates at roadworks"

Findings: - PIA rates 1.14 times higher with-works than without-works (difference *not* significant at 80% confidence level). Difference is 1.20 for dual-2 and 1.04 for dual-3; differences between dual-2 and dual-3 are not significant.
- Increase in accident risk with introduction of works (14.5%) is lower than in motorways (60%) and in single-carriageway roads (170%); however, absolute PIA rates are higher in rural dual than in motorways (either with-works or without-works).
- Given the 14.5% difference, sample size was not sufficient for determining suitable levels of confidence for much of the disaggregation. Future similar studies should consider larger sample.
- Central section has largest increase in PIA rate, followed by approach section; after section has *decrease* in PIA rates. The latter two comparisons are only significant at 60% and 80% levels respectively.
- Full contraflows (2 lanes open) result in substantial (but not statistically significant) increases in PIA rates in both primary (=diverted) and secondary directions. Highest rates in full contraflows for dual-2 (not significant).
- Primary direction apparently less safe (not significantly).
- Daylight-to-darkness split is 77-23 with-works, compared to 67-33 without-works. 31% increase in rate for daylight, 9% decrease for darkness. 23.5% increase in darkness for with-works, 77% increase in darkness for without-works.
- Reduction in proportion of fatalities and serious-injury accidents, and increase in proportion of slight-injury accidents in the presence of works, significant at 90%. Fatal and seriously-injured casualties per PIA decreased with works, number of slightly-injured casualties per PIA increased (significant at 85%).
- Overall casualties per PIA with-works compared to without-works presents no significant difference.
- Two-fold increase in "shunt" (rear-end) accidents, and marked decrease in proportion of "loss-of-control" accidents, compared to without-works.
- Larger proportion (compared to without-works) of accidents involving over 4 vehicles
- No evidence found to permit alteration of practice of defining a 6-km approach and after section.

Evaluation: Fairly comprehensive; well-documented

R.D. Coombe and D.R. Turner (Halcrow Fox and Associates)
TRRL Contractor Report 150: Accidents at roadworks on all-purpose rural roads
1989

Road:	All-purpose roads (trunk, A-class, B-class, C-class; mostly single-carriageway), rural.
Works:	Duration of at least two weeks.
R-WZ Interaction:	On links (rather than junctions)
Safety devices:	
Other:	Weather conditions for accidents; road surface conditions
Country:	United Kingdom: Norfolk and Berkshire
Period:	Sites operative from year 1983/4 to 1987/8.
Samples:	155 sites (26 trunk, 54 A, 45 B, 30 C); 34 workzone accidents
Data collection procedure:	Combination of "retrospective" (relying on county records and discussions with officers) and "current-passive" (relying on recording of data by the highway authority at the time of the roadworks) methods. Initial identification of possible counties/statutory undertakers. Selection through criteria. Options of data collection were compared on the basis of value-for-money comparisons, given a target level of million vehicle-km.
Data types:	Route no.; start and end dates/times; details of weekend/nighttime occupation; road width and lane configuration; lighting; speed limits; length/width of road occupied by works; signing and coning layouts; purpose of works; method of traffic control; PIA data for site and for a distance up to 1650 m either side; traffic data (ad-hoc); weather conditions; road surface condition.
Analysis procedure:	- Factoring of ad-hoc traffic data for conversion to AADT - Definition of works zone = 150 m + works length + 150 m - Definition of influence zones: 300, 600, 900, 1200, and 1500 m zones beyond "works zone" - Two samples: one for working day, one for recorded timing of the works one-year equivalent works period: comparison between with- and without-works PIA rates (standardized per million veh-km), statistical significance (confidence level) of comparisons indicated - Accident data collected from 1 Feb '83 (introduction of seatbelt law) and an arbitrary date after completion of works; deletion of post-works data
Findings:	- Analysis for B and C class roads, as well as for dual-carriageway roads, was inconclusive. Increases in PIA rate of at least 65% were observed for both works zone and influence zones (most markedly for 900 and 1200 m zone). Increase was least marked (and less statistically significant) on trunk roads, and most marked on trunk and A class single-carriageway roads combined.
Evaluation:	Fairly-documented but inconclusive

Kalevi Katko (Finnish National Road Administration)
Safety at Roadworks
Safety at Roadworks(PIARC)
1996

Road:	All.
Works:	No type specification.
R-WZ Interaction:	All.
Safety devices:	
Other:	
Country:	Finland
Period:	1987 through 1991.
Samples:	
Data collection procedure:	Police reports; road administration data
Data types:	Aggregate (no definitions provided)
Analysis procedure:	Not specified.
Findings:	- Number of traffic accidents at work sites varying between 230 and 450; PIA's from 50 to 134; fatal accidents from 2 to 14. Percentage of injury accidents at work sites vs. total varies from 1.2 to 3.1 percent; fatal ones: from 0.6 to 3.6 percent. - PIA rate at work sites varied from 2.6 to 5.8 per billion veh-km. - Work accidents from 566 to 697, i.e. between 27.1 and 34.8 accidents per million work hours.
Evaluation:	Useful for international comparisons

Oscar Gutierrez-Bolivar
Safety at Roadworks (PIARC)
1996

Road:	All.
Works:	No type specification.
R-WZ Interaction:	Not specified.
Safety devices:	
Other:	
Country:	Spain
Period:	1992
Samples:	
Data collection procedure:	Not specified.
Data types:	Aggregate data.
Analysis procedure:	Not specified.
Findings:	- 2% of 1992 accidents occurred on workzones. In 1.34% of workzone accidents (0.03% of all accidents), workers were involved.
Evaluation:	Indicative value only

Investigation of Highway Work Zone Crashes
Summary Report
HSIS - Highway Safety Information System
U. S. Department of Transportation
Federal Highway Administration

Road:	All
Works:	All
R-WZ Interaction:	All
Safety devices:	
Other:	
Country:	United States (three states)
Period:	1991 and 1992
Samples:	Respectively in the three states: 1541, 5132 and 5386 workzone accidents
Data collection procedure:	Accident data files from HSIS (Highway Safety Information System); only two states use an explicit variable to indicate a workzone; no national data bases exist that can provide details for non-fatal (workzone) crashes
Data types:	Type of accident; accident severity; type of roadway; type of workzone; lighting condition; roadway surface; weather; intersection relationship; fixed object
Analysis procedure:	Chi-square testing of proportion distributions for workzone vs. non-workzone accidents.
Findings:	- Proportion of workzone over total accidents ranged from 1.92% to 3.00% in the three states - Differences in injury severity were statistically significant at the 0.05 level in two states - In all 3 states, percentage of accidents involving a rear-end collision or a sideswipe was significantly higher for workzones than for non-workzones (attributed, respectively, to speed differential and shoulder/lane closures) - It is believed that "underreporting" exists, especially regarding (a) minor accidents; (b) crashes that occur near work activity (e.g. at the end of a queue prior to a workzone) are not coded as workzone accidents; (c) the coding process, in the case of missing explicit indication of a workzone - Comparison of the proportion of workzone over total accidents for two different periods, in which different coding of workzones was practiced ("non-explicit" indication of a workzone in 1988-89; versus "explicit" indication in 1991-92), shows that the proportion of workzone accidents was increased; this is attributed to the improved definition, rather than the increase in the proportion of workzone-related activity and traffic exposure. However, a 1986 investigation by the Michigan D.O.T. shows that the absence of construction activity may be the cause of failure to check the "workzone" code in the police accident report (resulting in even greater underreporting)

- Questions are raised regarding the definition of a workzone accident: (a) during work activity only? (b) include upstream accidents?
- The need is stressed for (a) explicit "workzone" reference in the police report, (b) qualitative data related to characteristics and conditions existing at the time of the accident, (c) determination of an appropriate exposure measure for calculating the workzone crash rate, (d) uniform definition of workzones, (e) a more detailed understanding of relationships between workzone designs and crashes

Evaluation: Highlights relevant problems; conclusions not related to workzone type

Bea Blacklow, Ken Hoffner
Fatalities and Serious Injuries among Highway Construction Workers
Summary Report
Laborers' Health and Safety Fund of North America
December 1995

Road:	All
Works:	All
R-WZ Interaction:	All
Safety devices:	All
Other:	
Country:	United States
Period:	1992-93 (Fatal Occupational Injuries); 1985-88, 1990-95 (Serious Injuries)
Samples:	236 fatalities; 29,391 serious injuries
Data collection procedure:	Census of Fatal Occupational Injuries (Bureau of Labor Statistics); OSHA investigations of occupational fatalities; FARS (Fatal Accident Reporting System, U.S. D.O.T.); BLS Supplementary Data System; highway construction contractors; state highway administration
Data types:	- Fatalities: No. of employees; occupation; type of fatality event; vehicles involved and other causes; time - Serious injuries: nature of injury, affected part of the body, source of injury, type of event causing injury, lost time, duration of employment
Analysis procedure:	- Fatalities: Calculation of rates; classification by occupation, type of fatality event; sources of fatalities - Serious injuries: classification
Findings:	- 39 fatalities per 100,000 employees for private employees (approximately twice the rate for the rest of the private construction industry; and over six times that of all private sector industries); 12 per 100,000 for governmental agencies - 1/3 of all deaths: construction labourers; 17%: operating engineers; 12%: truck drivers - 22.9% of all fatalities involved pedestrian workers and vehicular traffic; 18.6% involved pedestrian workers and construction machinery; 27.5% involved vehicle and machinery operators/passengers (of which, 15.2% in workzone and 12.3% on roadway); 31% involved other fatal events (tools, construction materials, falls, electrical contacts, etc.) - Sources of fatalities involve mostly traffic/construction vehicles (total 69%), most commonly trucks - Most common fatality time (21% of cases) was 1 pm to 3 pm. Overall, 83.7% occurred between 5 am and 5 pm. For governmental-agency work, no fatalities were reported between 5 pm and 5 am. - The most common event causing serious injury was "overexertion" (27%), followed by "falls" (23%), "being

struck by objects other than vehicles" (17%); "pedestrian and vehicle-occupant events" (13%); "caught-in and electrical contact events" (3.6%), and other serious non-fatal injury-causing events (16%).
- The median no. of lost days plus restricted work activity was 105.0 for injuries involving pedestrian workers struck by errant vehicle; 45.0 for roadway-travel accidents; 14.0 for pedestrian workers struck by workzone machinery; and 11.0 for overexertion
- Inexperience was a "major factor" in fatalities and serious injuries.
- Vehicles were the primary sources of lost time and restricted work activities; secondly, the "work surface" (falls from elevations, and falls from the same level)
- Historically, more attention has been paid to hazards from vehicular traffic, which covers about 35% of fatalities (=22.9%+12.3%), than to other hazards such as those involving machinery. Suggestions for action include: increasing visibility of pedestrian workers; increasing awareness by workers of encroaching machinery; preventing machinery overturns and collisions within the workzone; improving standards to more properly address issues relative to falling hazards; application of "lockout/tagout" principles; ergonomic interventions to prevent overexertion injuries.

Evaluation: Provides worker-side viewpoint; conclusions not related to workzone type

Accidents cost evaluation - QUADRO 2
Traffic management and Safety at Highway Work Zones, OECD, Paris 1989, and THE VALUATION OF ACCIDENTS, Part 2 The valuation of Costs in QUADRO, Volume 14, Section 1, Quadro Manual, September 1996

Road: Classification into 15 types, using the descriptions "modern" (=built by post-1980 standards) and "older", along with standard British classification into A, B, C, single/dual carriageway, etc.; further subdivision by speed limit (without works)

Works: No specification

R-WZ Interaction: Standard contraflow; tidal contraflow (=alternate one-way); lane closure

Safety devices: No specification

Other:

Country: United Kingdom

Period:

Samples:

Data collection procedure:

Data types:

Analysis procedure: [Reference: TRRL RR42, 1985]

Findings: Workzone accidents, for the purpose of evaluation by QUADRO, can be subdivided into site-length accidents (concerning accidents at the work area) and site-presence accidents (concerning accidents at the approaches). Default rates for these two types (the former per million vehicle-km, the latter per million vehicles) have been derived.

Evaluation: Not empirical; indicative of possible classification approaches

Tae-Jun Ha and Zoltan A. Nemeth
Detailed Study of Accident Experience in Construction and Maintenance Zones
TRR No.1509 Maintenance Management and Safety, 1995

Road:	Rural "state" highways
Works:	Duration / type of construction work
R-WZ Interaction:	Various
Safety devices:	Traffic control; drums/barricades; warning signs; guardrails
Other:	
Country:	United States (Ohio)
Period:	1982-86
Samples:	Statewide data; 60 projects; 9 case studies
Data collection procedure:	Ohio Dept. of Highway Safety data bank: (a) statewide aggregate data; (b) 60 projects selected (on the criteria of high accident frequency and availability of detailed information); (c) individual accident reports at 9 (case-study) sites
Data types:	exposure per time unit (no reliable information on vehicle-miles was available); type of accident; type of vehicles; severity of accident; time of accident; cause of accident - Problems cited including lack of detail; inaccuracy; inconsistency in nomenclature and definitions (coding errors, especially regarding angle and head-on accidents)
Analysis procedure:	Statistical analysis (accidents per time unit; analysis of cause-and-effect relationships; trends)
Findings:	- Severity of workzone accidents not greater (rather slightly less) than that of other accidents - Less workzone accidents at night and with adverse weather; higher daytime frequency attributed to congestion being a cause of many workzone accidents - Over-representation of trucks - Over-representation of object-hits and rear-end accidents - "No driver errors": more frequently reported for workzone accidents - Injury accidents: associated with rear-end and angle accidents; heavy vehicle damage: with multi-vehicle accidents - Nighttime accidents: mostly object-hit, single-vehicle; daytime accidents: mostly rear-end, two-car - Percentage of workzone accidents over total accidents tends to decrease over the years - Case studies identified causes / circumstances such as: inadequate traffic control; uncovered holes; inadequate protection by barrier; edge drop of soft shoulder; traffic slowdown; lane changing/merging; hitting guardrails; use of berm as travel lane; drunk driving
Evaluation:	Comprehensive but inconclusive regarding workzone type

Rahim F. Benekohal, Eunjae Shim, and Paulo T. V. Resende
Truck drivers' Concerns in Work Zones: Travel Characteristics and Accident Experiences
TRR No. 1509 Maintenance Management and Safety, 1995

Road:	Not specified
Works:	Not specified
R-WZ Interaction:	Areas (advance, buffer etc., as defined in U.S. manual)
Safety devices:	Not specified
Other:	
Country:	United States (Illinois)
Period:	1992
Samples:	9949 crashes (of which 29 fatal; 2422 injury); interviews of 930 truck drivers
Data collection procedure:	Interviews
Data types:	Aggregate statistics; personal accident experience and travel characteristics
Analysis procedure:	Correlation
Findings:	- Steady increasing trend in total and injury crash figures; fluctuation in fatal crash figures - Drivers who had experienced BDS (Bad Driving Situations) in the advance and transition areas showed a significant correlation to accident experience; accident experience at the work area was also related to BDS experience and was significant at an 89% confidence level; however, buffer space and termination areas did not show a significant relationship between accident and bad driving experience. The BDS experience is judged as a good indicator of the problem areas in work zones. - A relatively small percentage of truck drivers had accidents in the work zones; about one-third of the accidents happened in the advance area and two thirds in the transition area; efforts to improve traffic safety in work zones should mainly focus on these two locations.
Evaluation:	Interesting attempt to investigate in terms of self-reported accident experience; not conclusive

Jerry G. Pigman and Kenneth R. Agent
Highway Accidents in Construction and Maintenance Work Zones
TRR No.1270 Safety Research: Accident Studies, Enforcement, EMS, Management, and Simulation, 1990

Road:	Interstate and other
Works:	Construction and maintenance
R-WZ Interaction:	
Safety devices:	Traffic control devices
Other:	
Country:	United States
Period:	1983-86
Samples:	20 study locations
Data collection procedure:	
Data types:	Three-year pre-construction period accidents; contributing factors
Analysis procedure:	
Findings:	- Approximately 500 accidents per year at workzones - Mostly on Interstate routes - Workzone accidents are more severe than other accidents; accidents during darkness and those involving trucks were the most severe; higher severity was found for accidents occurring in the advance warning area. - The percentage of workzone accidents involving rear-end or same-direction sideswipe was almost three times the statewide (nonworkzone) percentage. - Higher percentage of workzone accidents with "following too close" as a contributing factor; congestion was the most common factor; other frequently occurring factors were: striking or avoiding construction equipment; material such as gravel or oil on roadway; relating to flagger; and vehicle merging too late. - In the 4-year period of analysis, there were 18 accidents at the 20 locations; and two fatalities involving a pedestrian or construction worker. - The percentage of workzone accidents involving trucks (25.7%) was higher than the corresponding one for all accidents (9.6%).
Evaluation:	No association to workzone types

H. Gene Hawkins, Jr., and Kent C. Kacir
Traffic Control Guidelines for Urban Arterial Work Zones
TRR No. 1409 Maintenance Management, Traffic Safety, and Roadsides, 1993

Road:	Urban arterial (4-lane being widened to 6-lane)
Works:	Widening
R-WZ Interaction:	
Safety devices:	
Other:	
Country:	United States (Houston and Dallas)
Period:	
Samples:	3 sites
Data collection procedure:	
Data types:	Accident frequency, rates, types, causes, locations, periods; volume; travel time; surveys of motorists; measurement of the capacity of an arterial lane closure; signal operations analysis near a lane closure
Analysis procedure:	Comparison of pre-construction and during-construction accidents
Findings:	- Overall increases (compared to pre-construction) in accident frequency and rate in an urban arterial work zone: increase in frequency ranged from 35 to 77 percent; increase in rate from 59 to 106 percent. - Construction appears to have caused a statistically significant increase in the number of accidents occurring at or near intersections and driveways and in the number of night time accidents.
Evaluation:	Case study approach; inconclusive

Road Directorate,
Ministry of Transport
Denmark,
A Danish Study

Road: "Main roads" including motorways
Works:
R-WZ Interaction:
Safety devices:
Other: Surface conditions, weather conditions, lighting conditions, visibility
Country: Denmark
Period: 1990-95 (all accidents: 1993)
Samples: 201 workzone accidents (66 on motorways); involvement of 450 persons (19 killed; 257 injured, of which 140 seriously)
Data collection procedure:
Data types: Accidents and casualties; types of accidents; times of accidents
Analysis procedure: Comparison with all accidents
Findings: - Main accident types: 21% with vehicle coming straight from behind (typically when there is a queue); 13% head-on collisions (often because vehicle tried to avoid obstacles put up in the work zone); 15% involving obstacles like road block material; 13% of the accidents are one-vehicle accidents
- In the weekends, 20% of the workzone accidents occurred, which is a little less than comparing with all accidents; there are fewer workzone accidents in January, February and March than all accidents
- Concerning road surface conditions, visibility degree, daylight situation, weather conditions and street lights at the scene of workzone accidents, no deviance was observed compared all accidents.
Evaluation: Useful for international comparisons

John Oliver, Department of Transport, United Kingdom
Safety at Roadworks
Safety at Roadworks (PIARC)
1996

Road:	Motorways (dual 3-lane interurban); traffic flows from 20 to 90 thousand vehicles per day
Works:	"Major roadworks"; duration varied from 5 to 77 days
R-WZ Interaction:	Full and partial contraflow
Safety devices:	Signs, barriers, crossovers
Other:	
Country:	United Kingdom
Period:	1987/88; reference to earlier study (1982)
Samples:	17 sites (1987/88), with 65 phases; 155 accidents with-works, 89 without-works
Data collection procedure:	Requests from county or city authority; police accident records; exclusion of damage-only accidents
Data types:	Engineering drawings/plans; history of roadworks; accident location, date, time, weather conditions, casualties, vehicles involved, lighting conditions, cause of accident, type of accident; traffic conditions
Analysis procedure:	Definition of site including 6-km length each way; comparisons (tests of statistical significance)
Findings:	- PIA rate of 0.154 per mvk (million veh-km); equivalent rate without works is 0.098; the ratio of the with-works to without-works accident rates is 1.57; similar ratio (1.45) in 1982 study - 1987/88 accident rates did not differ significantly from 1982 rates - Rates derived for the without-works period are lower than the corresponding average rates for all motorways; one possible factor to partially account for this difference may be that the national data represent overall conditions on the network and include both works and nonworks situations. - "Lane rental" contract schemes did not show significant differences in PIA rates than sites managed conventionally - By multiplying the national motorway PIA rate per mvk of 0.11 with the ratio of 1.6 derived in this study, the national PIA rate at motorway roadworks is estimated at 0.18. This rate compares favourably with the rates, which include junctions, on non- builtup major roads and on builtup major (A-class) roads. The accident risk at motorway works is about half that found on rural major roads and one-sixth of the risk encoutered on urban major roads. Thus, roadworks on motorways in 1987 were still appreciably safer than all-purpose roads without works. - The accident rates in the approach and contra-flow sections of the full contra-flow layout sites were statistically different from the nonworks rate: high ratios were observed in the

central contra-flow region of the works; the contra-flow section shows the highest rise in accident ratio compared with the without-works rate. The approach section also shows a small increase; the accident ratio drops in the "after" section. A possible explanation for this lower figure may be that the drivers, having negotiated the roadworks, are now fully alert and drive with additional care.

- The comparisons have been constructed using the ratios for the contra-flow section, and the approach and after sections combined, in conjuction with the national average rate of 0.11 injury accidents per mvk for motorways in 1987. It is shown that the partial contra-flow layout is safer than the full contra-flow system.
- While the relationships for the full contra-flow layout are almost identical for the two studies, the relationship for the partial contra-flow in 1987 showed a greater increase in accident rate (injury accidents per million vehicles) with increasing contra-flow length than the 1982 relationship.
- Accident rates rose as the length of the contra-flow increases. The 1987 relationship for the full contra-flow (with two-lane crossovers) parallels and is higher than the 1982 curve. However, in contrast to the flat relationship of the partial contra-flow (with buffer zone) layout derived from 1982 data, the 1987 sample yields a curve, supporting the full contra-flow result that the accident ratio is dependent on the length of the central contra-flow section.
- Despite the large scale of this study, covering about 2,000 million vehicle-kilometres of travel, the numbers of accidents involved are not large (19 fatal in total). Consequently, none of the apparent differences are significant at the 95% confidence level. At roadworks in 1987, there was a reduction in the proportion of serious injuries and a corresponding increase in the proportion of slight injuries with no change in the proportion killed.
- The 1987 results reflect an hourly variation of accident rate similar to the 1982 survey. In particular a markedly higher accident rate, both with- and without- roadworks, between the times midnight to 0300. The increase in personal injury accident rate at roadworks is apparent for most of the day. From 0600 to 2100 hours, the rate at roadworks is significantly higher. However in the intervals 0300 to 0600 and 2100 to midnight, the 1987 accident rate with roadworks is little changed from that recorded without roadworks.
- Both the 1987 and 1982 studies showed that accident rates increase with roadworks, and the daily rates reflect this result. The exceptions are Tuesday and Friday which show little difference between works and non-works rates. The Saturday and Sunday values show that the accident rates at roadworks over the weekend are higher than the corresponding rate on weekdays.

- There was a sharp rise in the proportions of rear-end collisions that occur at roadworks compared with the non-works situation.

Evaluation: Focused; well-documented

Koji Kuroda and Junichi Inoue, Japan Highway Public Corporation
Analysis on Expressway Work Zone Safety
Safety at Roadworks (PIARC)
1996

Accident Analysis at Work Zones :
Are Road Works Dangerous for Drivers?

Road: Tomei Expressway (design speeds of 120, 100 and 80 kph); ADT varied from 60 to 130 thousand vehicles and trucks averaged 30% of the traffic volume

Works: Pavement improvement and traffic safety works

R-WZ Interaction: lane closure

Safety devices:

Other:

Country: Japan

Period: 1990-92

Samples: Length of 250 km; 2,682 road works with lane closure in 1990; 72 accidents

Data collection procedure: Accident reporting system

Data types: Definition does not include accidents occurring at the end of traffic congestion (queue) caused by a lane closure; location, time schedule, lane closure management, traffic control arrangement; exposure data; accident type; length of restriction

Analysis procedure: Exposure by no. of closures, kilometres, and vehicle-km

Findings:

- During the 1990 to 1992 period, the total number of accidents annually on the expressway was 3500 to 3750, and of these, work zone accidents numbered 20 to 30 (0.5 to 0.8 % of the total).
- Of the total 72 accidents during the three years 1990 to1992, 26 to 36% occured when the shoulder lane was closed, 4 to 6 % where the middle lane was closed (for 3-lane sections the shoulder lane and passing lane remained open), 42 to 58% where the passing lane was closed. No accidents occured on sections where the shoulder and middle lanes were closed (for 3-lane sections, passing lane remained open). No accidents were reported on sections where the middle lane and the passing lane were simultaneously closed (for 3-lane sections shoulder lane remained open).
- The majority were rear end collisions, followed by other collisions with guard fence and minor bumping.
- Sections where the shoulder lane was closed had accident rates varying from 70 to 100 per 10,000 lane closures. Those on sections where the middle lane was closed were 2 to 5 times higher.
- The number of accidents per length of traffic restriction was 60 to70 per 10,000 km. This figure broken down by the closed lane: 70 to 80 cases per 10,000 km were for slow lane

closures and 70 cases per 10,000 km were for passing lane closures.

- The accident rate tended to be higher on sections where the shoulder lane was closed. The accident rate where the middle lane was closed showed a similar trend to the previous analysis.
- The accident rate over 3 years varied from 70 to 90 per 100 million-v-km, which is 1.3 to 1.6 times the total accident rate of 55 to 60 100 million-v-km of Tomei Expressway. When classified by closed lane, the rate was 90 to 120 per 100 million-v-km over sections where the shoulder lane was closed, and 60 to 80 per 100 million-v-km over sections where the passing lane was closed. In this analysis the accident rate was derived from the number of accidents, divided by the number of vehicles that passed through the lane closure section while lanes were closed, and multiplied by the total length of the lane closure section.

Evaluation: Focused; local; fairly-documented

Koji Kuroda and Junichi Inoue, Japan Highway Public Corporation
Analysis on Expressway Work Zone Safety
Safety at Roadworks (PIARC)
1996

Accident Analysis at Work Zones :
Which Road Works are Dangerous for Workers?

Road:	Expressways
Works:	Various types (snow removal/deicing; obstruction removal; sweeping; lane marking; pavement reconstruction; mowing)
R-WZ Interaction:	Lane closures
Safety devices:	
Other:	
Country:	Japan
Period:	Financial years 1986-90
Samples:	315 accidents
Data collection procedure:	
Data types:	Reported causes of accidents
Analysis procedure:	Exposure in terms of no. of days of lane closure; analysis by type of works
Findings:	- Reported causes of accidents were: 258 were reportedly caused by drivers, 43 by workers, and 14 in which workers harmed themselves. - For accidents caused by drivers, dozing and reckless driving were dominant and suggestive that these drivers would not react to any existing workzone traffic control devices and would cause accidents independent of roadworks. - For accidents caused by workers, the accidents occured when maintenance vehicles were moving backward and workers were hit by the vehicle. - Characteristics of accidents at snow removal and de-icing works: highest number of accidents; highest number of accidents among accidents caused by drivers; highest accident rate; lowest injury rate; more drivers than workers injured (heavy trucks are used for these works and thus, workers are not frequently injured when hit by car); highest number of property-damage-only accidents (non-injury accidents); vehicle impacting vehicle rather than workers - Characteristics of accidents at obstruction removal works: third highest number of accidents; second highest number of accidents caused by drivers; lowest accident rate; lowest injury accident rate; highest probability of injuries once accidents occur; high number of worker injuries and a few driver injuries (when a vehicle enters maintenance works - because of the lack of protection); highest number of injuries; few vehicle-worker impacts - Characteristics of accidents at sweeping works: low number of accidents and low accident rate; frequent driver injuries;

median injury rates; vehicle-worker impacts uncommon

- Characteristics of accidents at lane marking works: low number of accidents (5th highest); no worker caused accidents; high accident rate (3rd highest); highest injury accident rate; high probability of injuries in accidents; all vehicle-vehicle accidents; workers and drivers are injured
- Characteristics of accidents at pavement reconstruction works: second highest number of accidents (next to snow removal and de-icing works); highest number of accidents caused by workers; low accident rates; second highest number of injuries and the highest number of accidents with injuries; second highest probability of injuries in accidents; highest number of vehicle-workers and vehicle-equipment accidents; workers and drivers are injured
- Characteristics of accidents at mowing works: low number of accidents; low number of injuries; second highest accident rate

Evaluation: Interesting consideration of work types; focused.

National Cooperative Research Program
Research Results Digest Number 192, September 1996
Procedure for Determining Work Zone Speed Limits

Road:	Rural and urban freeways, rural two-lane highways
Works:	Stationary works
R-WZ Interaction:	Travelled-way, detour, shoulder and roadside workzones
Safety devices:	
Other:	
Country:	United States
Period:	
Samples:	66 work zone sites included in the accident study. The data base developed for the study consisted of 12150 accidents, including 5017 accidents in the "before construction" period and 7133 accidents in the "during construction period" for the individual sites. In the study 444.9 miles of roadway are included, or an average 6.74 mi per site.
Data collection procedure:	Field data collection (on vehicle speeds, traffic accidents, and traffic conflicts in work zones
Data types:	Total length, exposure (million vehicle miles of travel), number of accidents, accident rates before and during construction for 66 work zone sites. The accident data included records of accidents that occurred at stationary construction zones.
Analysis procedure:	Comparison of the accident rates between "before" and "during" construction period
Findings:	- The objective of this research was to develop a uniform procedure for determining workzone speed limits. The accident and speed data were analysed to determine the effects of specific levels of speed limit reduction on sites with a variety of roadway, area, and work types. The literature research indicated that traffic accident rates in work zones are generally higher than the traffic accident rates experienced at the same site during normal operations before the beginning of construction or maintenance. The accident analysis showed that the total accident rate of the study sites was, on average, 6.7 percent higher during construction, while the fatal and injury accident rate was, on the average, 6.9 percent higher during construction than before construction. - Analysis of Travelled Way and Detour Work Zones on Rural Freeways: The largest accident data set available for analysis consisted of 29 sites involving travelled way or detour work zones on rural freeways. Overall these zones experienced an increase 41.3 percent in total accident rate and of 30,7 percent in fatal and injury accident rate during the construction period.. The minimum percent increase in accident rate during the construction period occurs for a 10-mph speed reduction(table 11). The differences between the mean percentage increase in accident rate for a 10-mph speed

reduction and the other values (shown in table 11) are not statistically significant for total accident rate, but they are statistically significant for fatal and injury accident rate. The findings imply that, at least for travelled way and detour work zones on rural freeways, a speed limit reduction of 10 mph will provide the minimum increase in accident rate.

- Analysis of Travelled Way and Detour Work Zones on Urban Freeways: In this case total accident rate increased by 34.2 percent and fatal accident rate increased by 24.7 percent during the construction period. The data (table 12) imply that speed limit reductions up to 15 mph do not have an adverse effect on accident experience, but the accident rates increase substantially for a work zone speed limit reduction of 20 mph. However the data for a 20 mph speed limit reduction are based on only one site. Despite of the inability to test the statistical significance, the substantial increase in accident rate associated with this site is consistent with the other results presented in the report.
- Analysis of Shoulder and Roadside Work Zones on Rural Freeways: Data were not sufficient
- Analysis of Shoulder and Shoulder and Roadside Work Zones on Urban Freeways: The data (table 13) imply that substantial increases in accident rate are associated with a 20-mph speed limit reduction. This observation is consistent with the results of the speed variance analysis and the rural freeway accident analysis.
- Analysis of Travelled Way and Detour Work Zones on Rural Two Lane Highways: In this case data showed that the total accident rate increased by 46.7 percent and fatal injury rate increased by 72.9 percent during the construction period. The data for the total accident rate (table 14) appear to confirm the finding that no speed limit reduction is better from a safety standpoint than a large speed limit reduction. The fatal and injury accident data are highly variable; most sites experienced only one or two fatal injury accidents. None of the differences between the values shown in table 14 are statistically significant.
- Analysis of Shoulder and Roadside Work Zones for Rural two-lane Highways: Accident data are available for four sites. Only one of these experienced a substantial number of accidents during the study periods. Because of the small number of accidents that occurred in those sites no meaningful statistical conclusion can be drawn.
- Analysis of Worker and Pedestrian Accident Data: Both the accident analysis results and the speed variance analysis suggest that it may be desirable to reduce work zone speed limits by 10 mph; however consideration must also be given to the question of whether or not a speed limit reduction of 10 mph is adequate to provide for the safety of construction personnel who must work in exposed conditions along the

travelled way. There is no information in the literature that indicates what reduction in speed is required to provide for worker safety. The speed analysis results obtained in this study indicate that motorists do slow down more when they are adjacent to active work than when they are not. The accident data for the 66 work zones in this study were reviewed for any indication of problems related to worker accidents. Because worker accidents cannot be explicitly identified in any of the accident data supplied by the participating states, this analysis focused on pedestrian accidents and accidents involving construction vehicles. Fourteen pedestrian accidents occurred on the study sites during the period before construction and 24 pedestrian accidents occurred during construction. This is equivalent to an increase of 29 percent in pedestrian accidents per million vehicle miles of travel during the construction period. There is no indication that any of these pedestrian accidents involved construction workers and several were explicitly identified by the investigating officer as involving pedestrian violations . During the construction period 3 accidents which occurred in three different work zones, involved collisions between a motorist and construction vehicle that resulted in an injury. Although these data do not suggest any major safety problems involving construction workers the data do not indicate whether any of the injured parties in the accidents discussed previously were construction workers.

Evaluation: well documented, focused

J.W. Hall and V.M. Lorenz
Characteristics of Construction- Zone Accidents
TRR No. 1230 Work-Zone Traffic Control and Tests of Delineation Material
1989

Road:	Rural sections of New Mexico's Interstate and Federal Aid Primary (FAP) and Secondary (FAS) highway systems
Works:	Construction zones
R-WZ Interaction:	
Safety devices:	
Other:	
Country:	United States
Period:	construction-zone accidents for a 3-year period, 1982-1985
Samples:	Among 355 projects during the above period there were selected 177 after the application of criteria set in order to eliminate minor projects
Data collection procedure:	accident record system, construction project data
Data types:	Accident types (number and rate)
Analysis procedure:	comparison between before and during construction period, comparison between frequency of accidents in construction zones and frequency of accidents indicated by the accident record system
Findings:	- The number and rate of accidents increased during construction, but the increase appears to be uniform for various accident characteristics. It is therefore not possible to recommend safety measures to counteract a specific set of accident types that increase disproportionately during construction. The authors have found that the frequency of accidents in construction zones is substantially greater than indicated by the accident record system. The existing records do not provide a definite answer to the role of engineering in the occurrence of construction-zone accidents. - In comparison with the identical period in the prior year, accident experience in construction areas increased 33 percent on the rural Interstate system and 17 percent on the rural FAP and 23 percent on the rural FAS systems. The data clearly indicate that adverse weather conditions are not responsible for the increases. The data also suggest that certain accident characteristics may be over-represented in construction-zone accidents. These parameters include accidents involving multiple vehicles, rear-end collisions, large trucks, and the contributing factors of following too close and improper lane changing. On the other hand, the relative proportions of accidents resulting in injury or occurring at night remained virtually unchanged. - Although the accident characteristics differ less than expected, they do suggest some opportunities for remedial action. For example, the proportion of rear-end collisions increased from 9% in the before-construction period to 14%

during construction. This collision pattern may be partially corrected by the proper application of traffic control devices and use of flaggers and by techniques to enhance the visibility of work sites.

- The data collection effort required to assemble the appropriate information prompts a few conclusions regarding the adequacy of the record systems. The inaccurate recording and the miscoding of construction accident data are more serious than previously considered.
- The FHWA and NMSHD inspections, as well as some engineers' diaries indicate that improper traffic control is the most prevalent problem in construction areas. A need exists to heighten the awareness of both state employees and contractors' personnel regarding the importance of installing, maintaining and monitoring the adequacy of these devices.

Evaluation: Interesting insights but not adequate focus

Patrick T. McCoy and David J. Peterson
Safety Effects of Two-Lane Two-Way Segment Length Through Work Zones on Normally Four Lane Divided Highways
TRR No. 1163, Traffic Control in Work Zones
1988

Road:	Four-lane divided highways, level terrain
Works:	
R-WZ Interaction:	
Safety devices:	
Other:	
Country:	United States
Period:	1986
Samples:	Four TLTW segments (length ranged from 6.68 to 7.22 mi) on one highway, on level terrain, they were selected because their lengths were longer than the usual maximum segment length of 5 mi. 100 spot speeds observed at 20 study locations (five per segment). A total of 15 accidents was reported on the four TLTW segments. 5 of these reports were for accidents that actually occurred on the TLTW segments. The other ten were for accidents that occurred at the median crossovers. Of the five accidents that occurred on the TLTW segments , two involved collisions with deer: these two accidents were eliminated from the analysis. None of the three TLTW accidents resulted in fatality. Two of them were property damage-only accidents, one a rear end collision and the other a vehicle running over an object lying in the roadway. The third accident was a nonfatal injury accident in which a construction vehicle attempting to make a U-turn was struck by an oncoming vehicle in the near line.
Data collection procedure:	accident reports from Nebraska Department of Roads
Data types:	100 spot speeds at 20 study locations, segment lengths, average daily traffic rates, days of operation and numbers of accidents
Analysis procedure:	analysis of accident experience, accident rates
Findings:	- In 1979 an equation was derived for the optimum length (range 3.0 to 5.0 mi) of two-lane two way (TLTW) segments through work zones on normal four-lane divided highways. - For prevailing roadway and traffic conditions representative of those on I-80 in Nebraska optimum segment lengths computed using the 1986 values in the initial equation were found to be about 60 % longer (in the range 4.8 to 8.0) than those used previously (1979) in Nebraska. The objective of the study was to determine the effects of longer TLTW segments on the safety of traffic operations. The study examined the relationships between segment length and five speed distribution parameters used as indicators of traffic safety. The relationship between segment length and TLTW accident rate were examined.

- No relations were found between TLTW segment length and either the accident rate or any of the speed distribution parameters. Therefore it was concluded that there is no relationship between TLTW segment length and the safety of TLTW operations for the conditions studied.
- It was also concluded that the longer optimum segment lengths computed with the initial equation using the 1986 cost factors are applicable.
- The findings of the study are limited to TLTW segments no longer than 7.22 mi. and on level terrain with paving markings of a certain pattern, which featured a 3-ft median composed of raised pavement markers and 18-in. tubular posts.

Evaluation: case study approach, not conclusive

David B. Casteel and Gerald L. Ullman
Accidents at Entrance Ramps in Long-Term Construction Work Zones
TRR No. 1352 Maintenance Management, Traffic Safety, and Snow Removal
1992

Road: Freeways entrance ramp areas

Works: reconstruction zones, long term projects

R-WZ Interaction:

Safety devices:

Other:

Country: United States

Period: 2 or 3 years before construction, and for the duration of the construction phases studied

Samples: two projects (on I-35W and I-45 in Texas), 2 sites

Data collection procedure: Accident data were obtained primarily from Department of Public Safety accident file tapes

Data types: Accident frequencies, accident types

Analysis procedure: Accident frequencies; comparison of pre-reconstruction and during construction accidents; determination of changes in accident occurrence during construction at urban freeway entrance ramp areas compared with changes in accident occurrence at non-entrance ramp areas within the studied work zones; regression analysis, to explore the potential relationship between accident rates at entrance ramps in construction work zones and selected geometric factors believed to contribute to entrance ramp accidents.

Findings:
- Both non-entrance and entrance ramp areas on I-35 experienced statistically significant (a=0.05) increases in total accident frequencies during construction. Total accident frequencies increased 35% in non-entrance ramp areas and 61% in entrance ramp areas during construction. Increases in accidents in the entrance ramp areas during construction were found to be significantly greater than increases in accidents in the non-entrance ramp area. On I-35W, total accident frequencies increased 30% more in entrance ramp areas relative to non-entrance ramp areas. (statistically significant at a= 0.05).
- On I-35W, PDO (Property Damage Only) and severe accident increases were disproportionately concentrated in entrance ramp areas. Also, daytime and multivehicle accidents (other than rear-end accidents) were found to have disproportionately increased in entrance ramp areas on I-35W during construction.
- On I-45, neither non-entrance ramp nor entrance ramp areas experienced statistically significant (a=0.05) increases in total accident frequencies during construction, when examined separately. The increases for non-entrance and entrance ramp areas (though not statistically significant) on I45 were found to be 27% and 12% respectively. Accidents in entrance ramp

areas increased 4% more relative to accidents in non-entrance ramp areas on the I-45 project. The difference in proportional increase was not statistically significant at a=0.05. No accident category increased disproportionately in either non-entrance ramp or entrance ram areas on I-45.

- Because of the limited data, relationships were not found between geometric data and accidents in the entrance ramp areas in either project. However the I-45 data may suggest that entrance ramps having higher accident rates before construction were more adversely affected during construction than were ramps with lower accident rates before construction. It may be wise to give extra attention to the workzone traffic control at entrance ramps with higher accident rates. In some case, it may be prudent to actually close these ramps during construction rather than further compromise ramp geometrics (or sight distance) during construction.

Evaluation: Case study approach

Jerry L. Graham and James Migletz
Collection of Work-Zone Accident Data
TRR No 933 Traffic Delineation, Work-Zone Protection, and Winter Maintenance
1983

Road:
Works:
R-WZ Interaction:
Safety devices:
Other:
Country: United States
Period:
Samples:
Data collection procedure:
Data types:
Analysis procedure:
Findings:
- The objective of this research was to recommend, based on the analyses of current practices and the trial implementation of a promising new system, an effective yet simple information procedure that relates accident factors to traffic control deficiencies in highway work zones. The procedure, called the work-zone accident data process (WZAPD) and which approved to be usable, is appropriate for two major applications: (a) it provides information that can be used to determine if a correction or change is needed in the traffic at the work site where the accident occurred, and possibly the type of change indicated; and (b) it provides information that can be combined with that from other sites to form a data base from which accident trends and the relations between accidents and the various traffic control devices and strategies can be determined.
- There is a need for a great amount of flexibility in the design of WZADP.
- Project-level personnel who are expected to record work-zone accident data should be trained by user's manual
- Police cooperation should be established.
- Discrepancies in the number of accidents reported under WZADP and other (state) accident record systems were discovered. These types of cross-checks should be made to ensure that all regularly reported accidents within work zones are coming to the attention of project managers

Evaluation: Interesting attempt towards an effective and useful procedure of accident data collection

Robert J. Paulsen, Howard Needles Tammen and Bergendoff, Douglas W. Harwood and Jerry L. Graham, John C. Glennon
Status of Traffic Safety in Highway Construction Zones
TRR No 693 Safety in Construction and Maintenance Work Zones and Transportation of Hazardous Materials

Road:	Various, including rural freeways
Works:	
R-WZ Interaction:	
Safety devices:	
Other:	
Country:	United States
Period:	1977
Samples:	Respectively, 21 and 79 projects
Data collection procedure:	
Data types:	Type and rates of accidents
Analysis procedure:	
Findings:	- The paper identifies methods by which more effective planning, design and management of construction zones can improve traffic safety. - The basis for evaluation of traffic safety in construction zones must be a comparison between accident experience before and during construction activity. The results of some studies (comparisons) are presented in the following:

Study:
D.J. Migletz
Analysis of Traffic Accidents Occurring on Ohio's Rural Freeways During Safety Upgrading Construction Projects
1977

1. Analysis of the reports of nearly 3000 accidents that occurred in 21 construction zones on rural Interstate highways in Ohio. Accident experience before and after the construction activity were also analysed and the following conclusions were made:
2. Accident rates before construction were lower than those during construction but higher than those after construction
3. Safety upgrading construction projects on the rural Interstate system of Ohio generate traffic accidents but these accidents are primarily minor in nature
4. During the construction period, construction related accidents are less severe than non-construction related accidents
5. A large number of improper merge and side-swipe accidents were in lane taper areas, occurred at night and involved vehicles of the tractor trailers-bus class
6. Many rear-end accidents were in lane closure areas, occurred during the daylight hours, and involved automobiles and motorcycles
7. Large numbers of single vehicle fixed-object accidents involved drums used for lane tapers and lane closures

Study:
J. L. Graham, R. J. Paulsen and J. C. Glennon
Accidents and Speed Studies in Construction Zones, FHWA, Final Report
1977
The study evaluated accident rates before and during construction on 79 projects in seven states. (Conclusions on which the current report based from this study are found in more detail later)
Safety problems related to construction and maintenance activity involve construction workers as well as motorists. Data from the National Safety Council indicate that state highway workers experience 1.7 times the all-industry average of work injuries per million person-hours worked. Street and maintenance workers in municipalities experience 5 times the all-industry average.
The literature synthesis of a number of accident studies reveals that the total accident experience in construction zones increases from 2 to 119% during the period of construction.
A study (in one state) shows that accident experience decreases dramatically when construction-zone traffic control practices are improved.

Evaluation: Literature synthesis, conclusive regarding accident characteristics and some workzone types

J. L. Graham, R. J. Paulsen and J. C. Glennon
Accident Analyses of Highway Construction Zones
TRR No 693 Safety in Construction and Maintenance Work Zones and Transportation of Hazardous Materials

Road:	Various types
Works:	Construction (long term, short term)
R-WZ Interaction:	various
Safety devices:	
Other:	
Country:	United States
Period:	Accident data were requested for the period of construction and the period 1 year before construction
Samples:	79 construction zones in seven states
Data collection procedure:	accident experience of construction zone roadways before and during construction
Data types:	Data from seven states were obtained. The data were classified into two major categories: construction and accident data
Analysis procedure:	The data were analysed using several methods: a comparison of the number of accidents before and during construction; analysis of time-trend effect of monthly accident differentials; accident rates before and during construction; regression analyses with construction-zone characteristics as independent variables and accident rates during construction as dependent variables; three construction project case studies that included determination of construction-related accidents
Findings:	- The 79 construction zones experienced an average increase in accidents of about 7%; however, 31% of the projects experienced decreased accident rates during construction. Twenty-four percent of the projects experienced increases in accident rates of 50% or more. The percent differences may be understated because of the lack of data about traffic volume during construction. The analyses assumed that traffic volumes are equal before and during construction; however for many projects the traffic volumes during construction were probably lower than those before construction. - Based on detailed analysis of three construction zones that experienced increase accident rates during construction the increase in accidents was highly related to the construction - Short duration and short length construction projects experience higher accident rates. This finding may be the result of a concentration of construction-related accidents in lane taper and transition areas - Bridge work and roadway reconstruction experienced the largest increases in accidents of any construction projects - The number of night accidents increased during construction, but the proportion of night accidents to total accidents remained the same. This was supported by a

relatively high degree of correlation between night accident rates and total accident rates in the regression analyses.

- The proportion of fatal and injury accidents in construction zones is nearly equal to the accident experience before construction, with a slight shift toward less severe accidents during construction. Both analyses show a great degree of variability in the number and rate of fatal accidents. This was supported by the regression analysis in which there was very little correlation between construction-zone variables and fatal accident rate.
- The regression analysis also indicated a strong correlation between traffic control devices and construction fixed-object accidents and a poor correlation between construction zone variables and ran-off road accidents; the presence of construction zones is more likely to increase fixed-object, rear-end, and head-on accidents but decrease right -angle, turning, and ran-off -road accidents
- The fixed-object accident rate is higher in stationary construction zones than in zones where traffic control are moved periodically (daily, weekly, monthly)
- The time-trend analysis showed that the construction zones where speed limits have been reduced do not experience lower accident rates than other zones. The accident rate analysis also showed that those projects with speed reductions had a slightly higher percentage accident rate increase. According to the linear regression analysis the project speed limit, which is highly correlated with area type, accounts for the largest portion of the total accident rate variability.
- Road type accounted for 4 of the 30 highest correlations between construction zone and accident variables in the linear regression analysis. Accident rate analysis resulted in some interesting results concerning road types. Six- or eight lane Interstate projects reduced to one lane in each direction had accident rate increases of over 100 %, but those reduced to two lanes in each direction had increases of only 5%. The case studies showed that the one-lane projects experience a great number of rear-end accidents. Four lane divided Interstate projects reduced to two-lane, two way had percentage increases more than double those in which the roadway was simply reduced to one lane in each direction. Five lane undivided highways with two way left -turn lanes reduced to two lanes during construction experienced the largest accident rate increase of all road types. And finally two-lane roads reduced to one-way alternating operations experienced worse construction accident rates than those placed on new alignment during construction.
- The time-trend analysis indicated a much higher monthly increase in accidents in urban areas. However, since urban areas normally have higher accident numbers, this does not necessarily mean their construction accident experience is any

worse. The linear regression analysis indicated a moderately high correlation between area type and total accident rate. The accident number and accident rate analyses both showed that construction accidents went up by similar percentage in urban and rural areas.

- The time-trend analysis showed that the first month after construction begins is not significantly different than the other months of construction and that construction zones do not necessarily have better experiences over time. The linear regression analysis showed a negative correlation between the length and duration of projects and the accident rate; thus, the longer duration of a project (both in time and in space), the lower the accident rate.

Evaluation: Well-documented, ambitious analysis, coverage of multi-state American experience.

National Cooperative Research Program
Research Results Digest Number 100, February 1978
Safe Conduct of Traffic Through Highway Construction and Maintenance Zones

Road: Interstate; two-lane rural
Works: Various projects (incl. resurfacing)
R-WZ Interaction:
Safety devices:
Other:
Country: United States (California and Virginia)
Period: 1965, 1970
Samples: 10, 31, 207 projects and a case study (22.1 miles)
Data collection procedure:
Data types: Accident rates (incl. fatal); accident types
Analysis procedure: Comparison of pre- and during-construction accidents
Findings:
- A 1965 California accident study of 10 randomly selected construction projects indicated that the total accident rate increased 21.4% during construction. Also noteworthy is that the fatal accident rate increased 132.4 % during construction.
- A later study of 31 construction projects was made in 1970 after many new principles of handling construction-zone traffic were put into practice. The results of the two California studies indicate that the new principles may have some positive effects. In the second study the total accident rate increased only 7% and the fatality rate decreased 4%. However it is not possible to verify the statistical comparability of these results.
- An unpublished report from another state provided results similar to the 1965 California study. The data were for 207 resurfacing projects on the two-lane highways and indicated a 61 % increase in total accidents, 67 % increase in injury accidents, and a 68% increase in fatal accidents during construction. The only conclusion of this analysis is that construction zones for resurfacing projects on two-lane highways appear very hazardous for that one state. What is not resolved is whether these kind of projects are intrinsically hazardous or whether that state's construction-zone traffic control practices are inadequate to meet optimum safety requirements.
- A report by the Virginia Highway and Transportation Research Council regarding the safety practices in the construction zone of I-495 in northern Virginia indicated a 119 % increase in the accident frequency, compared to a preconstruction baseline. The project experienced a large increase in fatal and injury accident rates (320% and 35% respectively). The report also noted that although the frequency of accident occurrence was increased along the entire project length (22.1 mi) interchanges and transitional areas experienced an even higher increase. Of the reported

accidents during construction, 52.5% involved vehicle contact with timber barricades. Among barricade-involved accidents, 73.5% involved vehicles that straddled or penetrated the barricades.

Evaluation: Indicative only, not well-documented

Traffic behaviour at roadworks, Final Report
Transport and Road Research Laboratory, The Department of the Environment, London October 1973

Road: Rural
Works:
R-WZ Interaction:
Safety devices:
Other:
Country: United Kingdom
Period:
Samples:
Data collection procedure:
Data types:
Analysis procedure: Comparison with versus without roadworks
Findings:
- Accident Records: It is suggested that the standard accident report form "Stats 19", on which the police record the details of road accidents resulting in personal injury, should contain reference to roadworks if the accidents occurred at or near roadworks; for example, presence of roadworks could be reported under "Attendant Circumstances". This would be very useful when retrieving accident reports containing roadworks as a contributory factor to the cause of accident, and for further accident analysis
- Accident Rates: The results of the accident analysis indicated that the accident rates for rural roads with roadworks are, on average 10% higher than for rural roads without roadworks. Since the presence of roadworks was found to be a contributory factor to more than half of the accidents at roadworks, it is considered that further work could usefully be carried out.

Evaluation: Very sparse