# SCHEME FOR EVALUATING A LOCAL QUEUE WARNING SYSTEM

R-77-15

H. Botma, mathematical engineer

H.L. Oei, electrical engineer

Voorburg, 1977

Institute for Road Safety Research SWOV, The Netherlands

SUMMARY

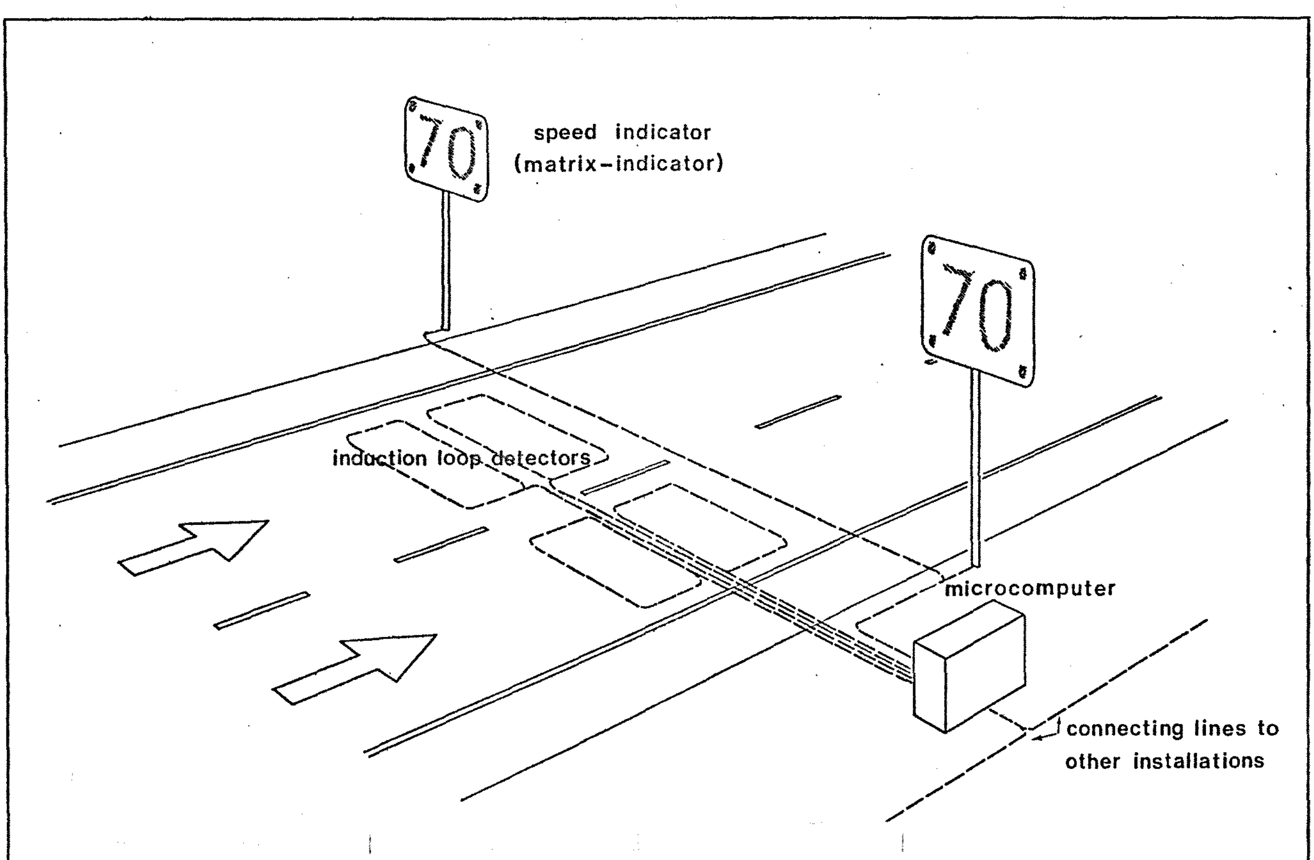
A method of evaluating an automatic queue warning system is outlined. The main object of the evaluation is to measure the effect of such a system on traffic behaviour and road safety, although the overall journey time is also examined. The chosen method of research entails before and after studies, if possible complemented with control groups. Factors likely to have a disturbing effect on this method of research are also discussed, together with their respective solutions. Finally, a look is taken at the number of accidents required for a statistically reliable analysis.

## 1. GENERAL

In most of the industrialised countries the growth of the road network has been unable to keep pace with the rising number of motor vehicles. This explains the increasing interest being shown towards traffic warning systems. One of the goals of such systems is to detect congestions and provide warning of them, so that drivers may take appropriate steps in good time to promote their own safety. Various systems of this type have already been introduced, some of them on the most heavily used sections of the Dutch motorway network. Rijkswaterstaat also have plans for new warning systems to be implemented in the near future. The international literature contains a great deal of information about warning systems but little about evaluating them. At the symposium on traffic control, held at Monte Carlo in 1974, it was accordingly found that evaluation had been receiving too little attention. This prompted the authors of the accompanying article to design a scheme for evaluating the effect of warning systems on road safety. Determining this effect is of particular importance in enabling the installation of expensive warning systems to be weighed up against the taking of alternative measures. The following article outlines a method of evaluating a system referred to as a "local queue warning system". In principle, this system is intended only to warn drivers of unexpected congestion at known discontinuities of the road geometry (bottle-neck) and give them advisory speed indications. A prerequisite for installing this system is therefore that the cause and location of possible queue formation are known in advance. Such systems have already been installed on Motorway A16 near Dordrecht, where a narrow bridge froms the bottleneck, and on two motorways merging south of the Velser tunnel. In the latter case it is not only a matter of queue warning, but also of merging two streams of traffic. A comparable warning system was recently put into operation in the Federal Republic of Germany, on the motorway between Stuttgart and Munich. The bottleneck there is a long, steep incline (Strassen-Verkehrstechnik, 1976). The local queue warning system was selected for evaluation because a scheme for evaluating this type of warning system may also be used, with slight modifications, in the evaluation of other types of warning systems. The method is designed to determine the effect of the system in operation. Any effects deriving solely from the presence of the system are ignored in this outline.

## 2. PURPOSE OF THE SYSTEM AND OF THE EVALUATION

The primary purpose of the local queue warning system is as far as possible to prevent accidents consequent upon congestion. By activating progressively decreasing speed indications and flashing lights in the event of congestion it is hoped to lower speed gradually and in good time. An additional effect of the system can be to make the traffic stream more homogeneous. This is possible when the traffic flow is just below the level at which congestion occurs. The smoothing effect can be achieved using identical speed indications without flashing lights. This is expected to result in congestion being diminished or delayed, which not only enhances safety but also benefits throughput.
Broadly speaking, the system works as follows. Measuring equipment is installed at intervals of approximately 500 m in both of the lanes leading to the bottle-neck. At each point of measurement two induction loops in the road surface are used to measure, <u>for each lane</u>, the speed of each individual vehicle and its time interval in relation to the one in front (see Figure 1). The traffic flows and speeds characteristic at that moment of the traffic streams at each of the points of measurement are computed from the time intervals and speeds, using a filtering procedure. The values computed are grouped into several classes.



Each class is associated with a particular speed indication. The point of measurement at which the situation is "worst" determines the speed indication to be displayed locally and the increasing speed indications upstream, thus confronting the driver with a gradually decreasing configuration. The speed limits shown are the same for each lane. The result in the case of a queue that is building up is that the speed indications are adjusted appropriately further and further upstream. A more detailed description of the system has been given by Jenezon & Klijnhout (1974).

The primary objective of the evaluation is to examine the extent to which the queue warning system increases road safety. A reliable appraisal of the effect of the system demands that traffic behaviour be investigated too since it is this that forms the link between the measure and its effect upon safety. Failure to investigate traffic behaviour in the past has frequently led to non-interpretable results or even to invalid conclusions. An important by-product of investigating behaviour is the extension of knowledge about the traffic process. Since it is by no means inconceivable that the installation of a queue warning system will affect the throughput of traffic, this aspect is also considered in the study. In this section the terms safety, traffic behaviour and throughput have been used generally; in the next section they will be defined operationally.

## 3. EVALUATION

The dependent variables in the evaluation of the local queue warning system are: safety (S), traffic behaviour (B) and throughput (T).
For methodological reasons a control area is desirable when evaluating a warning system. The high cost of installing a complete measuring system for determining traffic behaviour will make the use of a control area for this aspect impracticable. It is possible to provide a control area inexpensively for the variables safety and throughput (provided the latter can be determined with sufficient accuracy by a simple method; see also section 3.3.2.). Where the use of a control area is not possible, before and after studies of the section of road on which a local queue warning system is to be installed must suffice. The dependent variables must then be assessed in the before and after periods under circumstances that as far as possible are comparable. Since the warning system does not affect traffic continuously in the after period, the study will only cover that part of the after period during which the system is operational. Only that part of the before period will be taken during which the system would have been in operation if it had been present. It is probably too expensive to make continuous recordings during the entire before period. For this reason only the rush hours will be taken. It will be necessary to distinguish between rush hours during which the police provided queue warning and rush hours when this did not occur.
The accident data will have to relate to a period of at least one year, in order to allow for seasonal variation. For traffic behaviour and throughput measurements a shorter time would suffice. In interpreting results of measurements made during the after period, allowance will have to be made for the possible influence of increasing familiarity with the system on the part of drivers.
Many factors may adversely affect the comparability of before and after periods. Changes in certain variables measured outside the period of operation of the system might perhaps be able to provide some relevant information. Since traffic flow and composition is then considerably different, such data must be interpreted with great caution. Comparability may be adversely affected by changes in road

features, traffic characteristics and the weather; the effects of certain measures being introduced may also be relevant. Several possible factors are reviewed below, such remedies as are possible being indicated for each variable (S, B, T).

Road Features

- Road-works that do not radically alter the characteristics of the road. Remedy: exclude the period concerned for S; do not measure B and T in this period.
- Radical alterations to the characteristics of the road. These make a comparison of before and after periods problematical.
- Changes to certain features of the bottle-neck, e.g. time and duration of bridge openings, traffic-light programme. Without further information little indication can be given of any remedy.

Traffic Characteristics

Changes in traffic flow and composition (percentage of lorries); for a road with many foreign traffic participants possibly also the distribution of traffic participants according to nationality. For S traffic flow changes that are not too large may be allowed for by relating accidents to the amount of traffic. Radical changes in traffic composition are not expected. For B and T comparable periods can be taken, and it may be possible to use a measure for T that is independent of small traffic flow fluctuations.

Weather

Major changes in weather conditions (e.g. hard winter affecting only the before period). Remedy: exclude the period concerned from the analysis.

Measures being introduced

- Accident recording. For studying S the extent to which accidents are recorded will have to remain unaltered.
- Police supervision. Intensive police supervision is expected to have such a great effect on traffic that it is essential to ensure that this does not vary appreciably between before and after periods (to the extent that this is justifiable).

- Alteration of the general speed limit (100 km/h for motorways in the Netherlands). On the part of the road that is already subject to local permanent speed limits effective during both before and after periods (e.g. on Motorway A16: 90, 70 and 50 km/h) this will have no effect on S, B or T. Upstream of these local speed limits the change of the general speed limit will probably not affect S, B or T in the rush hours, since speeds will then already be less than the general limit. S, B and T may be affected in this outside the rush hours. It is assumed that any effect on S will be confined to a relatively small proportion of the total number of accidents on the road as a whole. Any information forthcoming about the effect on S will be used to make a correction if necessary.
- Alteration of the local permanent speed limits. These make a comparison between before and after periods problematical.
- Seat-belts. It is assumed that changes in the pattern of seat-belt usage will affect the outcome of accidents. This might influence the number of accidents recorded. The extent of this influence will depend on the quality of accident registration. It is presumed that this influence can be corrected using the control area.
- Alcohol consumption. It is assumed that a change in the pattern of alcohol consumption among drivers (as a result for example, of a change in checks on alcohol) principally affects S at night (22.00 - 05.00 hours). The remedy is to exclude these times.

## 3.1. Safety

For assessing safety use may be made of the numbers of accidents, vehicles involved, injury accidents and casualities. Which variables will be chosen is dependent on the reliability of the information recorded, its scope and the system's expected effect on the variables. For the sake of simplicity this section only deals with accidents. Accident records indicate the nature, location and time of the accident, the type of traffic participating and the conditions in which the accident occurred. To allow for seasonal variations, a minimum safety measurement period of one year is taken for both before and after periods. If the number of accidents in one year proves statistically inadequate, a longer period will have to be taken. How many accidents are required to provide a sound basis for analysis depends on the effectiveness of the system and on how much risk of arriving at false conclusions is deemed acceptable. Let the actual effect of the system be the ratio (r) of the expected number of accidents in the after period to the expected number in the before period, and distinguish two cases: $r < 1$, the system has a positive effect, and $r \geqslant 1$, the system does not have a positive effect. In the first instance, the conclusion of the analysis is also one of these alternatives. This involves a chance of arriving at a false conclusion, however, in two ways (see Table 1).

| | | Reality | |
|---|---|---|---|
| | | $r < 1$ | $r \geqslant 1$ |
| Conclusion | $r < 1$ | $1-\beta$ | $\alpha$ |
| | $r \geqslant 1$ | $\beta$ | $1-\alpha$ |

Table 1. Definition of $\alpha$ and $\beta$.

The probabilities of concluding incorrectly that an effect is positive or non-positive are $\alpha$ and $\beta$ respectively. The choice of the size of $\alpha$ is influenced among other things by the cost of the warning system; the associated error results after all in unnecessary installation. The size of $\beta$ partly depends on the degree of unsafeness, since the associated error leads to non-installation of the system and thus to the non-reduction of unsafeness.

On the basis of the usual assumption that the number of accidents is a random variable with a Poisson distribution, it is possible to compute the minimum number of accidents required in the before period ($m_{before}$) to keep the probabilities of false conclusions below certain values. For this purpose the null hypothesis $r \geqslant 1$ and the alternative hypothesis $r \leqslant r_o$ are compared with each other. Table 2 shows the number of accidents required as a function or $r_o$, when $\alpha$ and $\beta$ are both taken as 5%.

| $r_o$ | $m_{before}$ |
|---|---|
| 0.1 | 21 |
| 0.2 | 27 |
| 0.3 | 37 |
| 0.4 | 51 |
| 0.5 | 76 |
| 0.6 | 122 |
| 0.7 | 223 |
| 0.8 | 514 |
| 0.9 | 2111 |

Table 2. Statistically required number of accidents in the before period ($m_{before}$) as a function of $r_o$, when $\alpha = \beta = 5\%$.

| $m_{before}$ | $m_{after}$ |
|---|---|
| 10 | 2 |
| 15 | 5 |
| 20 | 9 |
| 30 | 17 |
| 40 | 25 |
| 50 | 33 |
| 75 | 54 |
| 100 | 76 |
| 200 | 167 |
| 500 | 447 |
| 1000 | 926 |

Table 3. Upper limit of $m_{after}$ for significant effect, when $\alpha = 5\%$.

Table 3 is of the type that must be used when the accident totals are available for both before and after periods. For a given number in the before period ($m_{before}$) the maximum number in the after period ($m_{after}$) is computed that will allow a conclusion with reliability $1-\alpha$ that a significant positive effect is present.

The two tables show that for reliable conclusions the number of accidents must be relatively large (in the Netherlands in 1972 there were about 17 accidents per km heavily used motorway, see Beukers 1974) or that the system has a large effect.

In the section of road in which a local queue warning system is installed there should be a permanent counting station, for recording hourly traffic flows, in both the before and after periods. This can be used to determine the peak periods and number of vehicle-kilometers in before and after periods. Table 4 shows the overall situation.

| | Before period | | After period | |
|---|---|---|---|---|
| | $T_{1,1}$ * | $T_{1,2}$ ** | $T_{2,1}$ * | $T_{2,2}$ ** |
| Vehicle kilometers | $P_1$ | $Q_1$ | $P_2$ | $Q_2$ |
| Accidents | $n_1$<br>$n_{1,1}$ $n_{1,2}$ | $m_1$ | $n_2$<br>$n_{2,1}$ $n_{2,2}$ | $m_2$ |

* $T_{1,1}$ and $T_{2,1}$ = peak periods

** $T_{1,2}$ and $T_{2,2}$ = remaining periods minus night-time

Table 4

When determining the effect of the system by comparing $n_1/P_1$ with $n_2/P_2$, a comparison of $m_1/Q_1$ with $m_2/Q_2$ may serve as a check. It is not impossible that as a result of restrictions on $T_{1,2}$ and $T_{2,2}$ (exclusion of night periods etc.) the quantities $m_1$ and $m_2$ will become too small. Moreover, it must be borne in mind that this control group is not ideal. A better solution is to use a control area.

It is desirable to subdivide the accidents $n_1$ and $n_2$ further into accidents that the system can prevent (in particular head-to-tail collisions resulting from shock waves or queue formation) and accidents to which this does not apply (e.g. accidents resulting from vehicle defects). It is to be expected that this subdivision will reveal many doubtful cases: for instance, is a collision with a fixed object during the rush hour the result of an attempt to avoid a queue or not? These considerations have led to the subdivision of $n_1$ into head-to-tail collisions ($n_{1,1}$) and other accidents ($n_{1,2}$); the same applies to $n_2$. This enables the effect of the system to be appraised separately for head-to-tail collisions and for other accidents, making it possible to check with $m_1/Q_1$ and $m_2/Q_2$. A similar analysis can be performed for the other variables.

## 3.2. Traffic Behaviour

During the before and after study the relevant aspects of traffic behaviour should be measured in comparable conditions. In this way it should be possible to detect a relationship between warning system, traffic behaviour and safety. Since only external vehicle characteristics are observed, other features and changes in them (e.g. level of driver attention) will be ignored. It is nevertheless important to know whether drivers understand the purpose of the system and what their attitude is towards the behaviour recommendations. Information about this can only be obtained by interviewing; this method will not be discussed here. Traffic behaviour recording can make use in part of the measuring equipment which is a component of the warning system; this is installed at intervals of approximately 500 m. The length of interval seems to be too large for an adequate analysis of the traffic flow; particularly in respect of speed reduction and the transmission of the shock wave. Determination of the optimum interval demands further study and consultation with the designers of the system. The high cost is likely to mean that only a limited part (e.g. 1000 m) of the road section can be provided with extra measuring points. The location will be selected on the basis of accident data and road characteristics. This also permits better investigation of the response to advisory speed indication and enables an attempt to be made to follow individual vehicles using pattern recognition techniques. Up to now, however, this latter method has not proved sufficiently reliable. In addition, a cine or still photographic method could be used incidentally to record the traffic stream from a suitable high point or aircraft. In this way an almost complete picture can be obtained of the behaviour of the traffic, usable in interpreting the more limited information provided by the fixed measurement system.

### 3.2.1. Measurement of traffic behaviour

At several sampling points in each lane the measuring equipment records the moment of passage, speed and length of every passing vehicle. These are the basic data from which all other relevant parameters are derived. What is relevant is deduced from the supposed method of operation of the system. The installation of a local queue warning system is expected to affect the following parameters:

- Average speed (averaged over a short period or a small number of vehicles). Advisory speed indications decreasing as a function of the distance to the tail of the queue are expected to result in a smoother-speedreduction that starts earlier. This is the main idea behind the warning system.

When advisory speed indications (decreasing or otherwise) are shown the difference in average speed between the two lanes will become smaller. This is because the speed indicated is the same for both lanes.

- Speed distribution. It is expected that this will concentrate more around the average, which may be characterised by a smaller standard deviation.
- Individual speeds. These will also decrease more gradually and may perhaps form a more reliable criterion for assesing the operation of the system than the average and distribution. Whether it is possible to analyse this parameter depends on the degree of success of pattern recognition techniques.
- Time intervals and speed differences between two successive vehicles. It is expected that these will be influenced too. The question is how these changes can best be characterised as parameters that are interpretable in terms of safety. With the following parameters, which are based on traffic stream theory and similar research, the relationship to safety is put as a hypothesis:

a) Time interval distribution; this will concentrate more around the average, in particular the proportion of very short time intervals will decrease;

b) "Turbulence"; this parameter, inspired by car following theory, is defined as:

$$\left( \frac{1}{n} \sum_{i=1}^{n} \left[ (v_i - v_{i-1})/\tau_i \right]^2 \right)^{0,5}$$

where $v_i$ and $v_{i-1}$ are the speeds of two successive vehicles and $\tau_i$ is the associated time interval (see Courage & Bissell, 1972, although he divides by the following distance instead of the time interval); the turbulence is expected to decrease as a result of the smaller speed differences and the reduced frequency of short time intervals;

c) Number of potentially unsafe followers; by comparing the amount of braking deceleration required with that available it is possible, subject to certain assumptions, to deduce from speeds, vehicle length and time intervals whether a vehicle is maintaining sufficient following distance. The following behaviour of individual vehicles has been assessed, among others, by Leutzbach et al. (1970). It is expected that the number of potentially unsafe followers, identified in this fashion, will decrease.

With all these parameters the associated traffic flow and occupancy (= percentage of the time that a detector is activated) should be determined at the same time. This is necessary since there is generally no point in comparing the more detailed characteristics of traffic flow unless overall characteristics are comparable.

### 3.2.2. Comparability of Conditions

The conditions in which measurements are taken will have to be comparable in respect of:

- season;
- day of the week (working day, Saturday, Sunday);
- time of day (light, dark);
- weather conditions;
- traffic flow (+ traffic composition) and average speed (occupancy) of the traffic entering the section of road under consideration, including the slip roads; also the variation with time;
- period and location of the beginning of queue formation.

### 3.2.3. Scope of the Investigation

If it is desired to study the hypothetical relationship between traffic behaviour and safety, the traffic behaviour must in principle be typical for the conditions in which the accidents occur. In order to make investigation of traffic behaviour practicable the conditions selected here are those in which the system might be functioning, i.e. the morning and evening rush hours on working days.

It may be that an analysis of accidents taking place prior to the before period will lead to this selection being revised or extended. It is provisionally assumed that measurements will be carried out, in both before and after periods, for at least ten times one hour in the morning rush hours and for a similar number in the evening rush hours. Assumed is that the data thus collected will contain sufficient comparable cases. Each measurement period should preferably be longer than one hour, so the most suitable hour can be chosen for analysis.

## 3.3. Throughput

The positive effect on the throughput could come about as follows:
- Queue warning with decreasing speed indications ⟶ less incidents and accidents ⟶ smaller queues ⟶ shorter journey times;
- Identical speed indications at high traffic flows ⟶
a) fewer irregularities, less incidents and accidents (more stable traffic flow) ⟶ smaller queues ⟶ shorter journey times;
b) better utilisation of the road upstream of the bottle-neck (higher average speed for the same traffic flow and a more even distribution of the carriageway traffic flow over both lanes) ⟶ shorter journey times.

The reduction of queue size (in length and/or time) and of journey time is a side-effect of the warning system whose primary purpose is to benefit road safety. Taking this consideration into account it was decided to study only the overall effect of the system on the variables queue size and journey time.

### 3.3.1. Queue Size

For determining queue size in the evaluation the following definition is used. A queue exists at a given point of a road if the average speed (e.g. minute value), when the traffic concentration is high, is lower than a certain value (e.g. 50 km/h). The length of the queue is taken as equal to the length of the section of road ($X_i$) regarded as being represented by the point of measurement (e.g. between points half-way towards the neighbouring measuring points; see Figure 2).

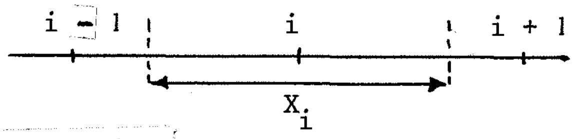



Figure 2

Queue size = $\sum X_i T_i$ kilometer hours; where $T_i$ = time during the period considered for which the average speed at measuring point i is less than the critical value. Queue size with and without the warning system will be determined under comparable conditions (see section 3.2.2.).

3.3.2. Journey Times

Another variable with which the throughput may be characterised, besides queue size, is journey time. Moreover, this is simple to interpret and can be converted into money terms if required. It therefore seems appropriate to determine journey time by estimating the total journey time (J) of the vehicles over the section of road and period under consideration. There are various methods for determining the total journey time. The following two seem appropriate here because the same data can be used as is collected for the analysis of traffic behaviour:

1. Input-output method. All that is needed for this is the variation in traffic flow at the entrance and exit of the section of road considered. For an artery with one entrance and one exit, for example, the total journey time over AB during the period T is:

$$J = \int_o^T \int_o^t (q_1(t') - q_2(t'))dt'dt + n_o T$$

In this formula $q_1$ and $q_2$ are the traffic flows at the entrance and exit respectively (see Figure 3), $n_o$ is the number of vehicles in AB at time t=o. The value of $n_o$ is estimated using a test vehicle that travels from A to B at the average speed. The number of vehicles passing B is counted from the moment that the test vehicle leaves A until the moment that it reaches B.

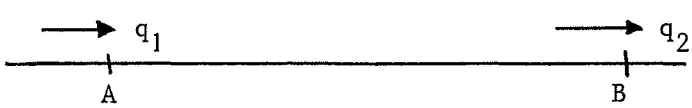



Figure 3

A disadvantage of this method is that measurement errors may have a large effect on the result, necessitating a preliminary study. The method has been used, among others, by Courage (1970).

2. Local speeds. Total journey time may be estimated from local speeds in a manner analogous to that used for determining queue size. The formula is:

$$J = \sum_{i=1}^{m} X_i \sum_{j=1}^{n_i} 1/v_{ij}$$

summing over m road sections of length $X_i$ and the speeds measured in them $v_{ij}$. In order to use this method it is necessary to know how the speeds of very slow and temporarily stationary vehicles are determined. Speeds of value 0 must not occur, since J would then become infinitely large and non-comparable.

Perhaps the best results are obtained from a combination of both methods. This has been used, among others, by Nahi (1973), who describes a method for estimating the number of vehicles on a section of road and their average speed. His method is based on moments of passage and speeds that were observed at the ends of the section of road concerned. Some preliminary research is still necessary, however, before a definitive choice can be made of a particular method.

### 3.3.3. Measurement Period

For both queue size and journey time the same study period may be selected as for traffic behaviour. For journey time, however, it is desirable that the primary measurement should cover at least one whole peak period, which may be longer than one hour.

## 3.4. Recording and Processing

Data from the detectors are recorded on magnetic tape in digital form, so all the information can be processed directly by a computer, see Lenz & Hotop (1974). Where several tape recorders are used synchronisation will be necessery. The speed indications will need to be recorded at the same time. In addition, human observers will register special features while traffic behaviour is being recorded during the before and after periods. For processing, it may be possible to use software already available at Rijkswaterstaat. The quantity of information recorded is initially rather large. Substantial compression is achieved, however, if the first processing step is to transform the raw data into time series of moment of passage, speed and vehicle length. In this way it will be possible, for example, to store on three magnetic tapes (of length 3200 ft and recording density 1600 b.p.i.) the results of 100 hours of recording at 25 points of measurement with traffic flows of 3600 vehicles/hour.

## 4. INFORMATION NEEDED FOR IMPLEMENTING THE EVALUATION SCHEME

Implementing the evaluation scheme in a concrete situation requires more information than indicated in the foregoing.
In respect of the road, traffic and accidents the following are required, inter alia:

- detailed road characteristics;
- data concerning any road-works during the before and after periods;
- data about special factors affecting the bottle-neck, such as bridge opening times and traffic light programmes;
- traffic flows (hourly values), traffic composition and level of service in the last two to three years;
- detailed accident statistics for the last two to three years;
- details of the recording system;
- information about the extent of supervision and queue warning by the police.

The following must be available, inter alia, in relation to the system:

- quantitative expectations as regards improvements in road safety (based, for example, on experience elsewhere with the same type of warning system);
- locations of the measuring and warning points, switch-on and switch-off criteria (the criteria may depend on the nature of the bottle-neck).

## 5. CONCLUDING REMARKS

The foregoing gives a broad outline of the way in which a local queue warning system may be evaluated.

When the scheme was being developed it was deliberately designed to be quite comprehensive. The question that arises is to what extent the various parts can be realised in practice, e.g. the subdivision of accidents and the comprehensive recording of traffic behaviour. A number of concessions are possible, but these are likely to reduce to a certain extent the reliability and completeness of the conclusions. It therefore seemed better not to introduce them immediately. In this way a good starting point has been obtained for further elaboration in practice, while the evaluation scheme may also serve as a reference for the appraisal of any study ultimately implemented in practice.

The results of an evaluation carried out according to this scheme will contribute to the information needed for performing a cost-benefit analysis of warning systems.

Of the possible benefits, increased safety and reduced journey times have been discussed. Any reduction in the cost of road maintenance, achieved by faster closing off for roadworks, will probably be slight in the case of a local queue warning system, since the warning signs are the same for each lane. Benefits will result from a reduction of the police effort required; an estimate of this can best be provided by the police themselves.

Furthermore execution of an evaluation scheme will lead to increased knowledge about the traffic process. Finanlly, it is possible that the results of the evaluation will provide indications of how the warning system may be improved. It is difficult to make advance predictions about this, however. The cost of carrying out the evaluation itself has been disregarded in this article. This can be better assessed when the scheme has been elaborated for a practical application.

REFERENCES

Beukers, B. Traffic control on motorways. In: Intertraffic 74, International Congress on Traffic Engineering "Controlled Traffic", Amsterdam, 15 and 16 May 1977, pp. 113-128. RAI, Amsterdam, 1974.

Courage, K.G. Evaluation and improvement of operations in a freeway corridor. Traffic Engineering 40 (1970) 6 (March): 16-24.

Courage, K.G. & Bissell, H.H. Recording and analysis of traffic engineering measures. In: Highway capacity and quality of service evaluation. Highway Research Record No. 398, pp. 2-11. Washington, D.C. Highway Research Board, 1972.

Jenezon, J.H. & Klijnhout, J.J. A queue detection and queue warning system. Traffic Engineering and Control 15 (1974) 12/13 (April/May): 552-553.

Lenz, K.H. & Hotop, R. Fully-automated acquisition and processing of traffic data. Traffic Engineering and Control 15 (1974) 16/17 (August/September): 754-759.

Leutzbach, W. et al. Über den Zusammenhang zwischen Verkehrsanfällen und Verkehrsbelastung auf einem deutschen Autobahnabschnitt. Accident Analysis & Prevention 2 (1970) 2 (December): 93-102.

Nahi, N.E. Freeway-traffic data processing. Proceedings of the IEEE 61 (1973) 5 (May): 537-541.

Strassen-Verkehrstechnik. Industrie-Berichte: Erste Stauwarnanlage auf der Autobahn Stuttgart - München. Vollautomatische Steuerung mit Verkehrsrechnersystem. Strassen - Verkehrstechnik 20 (1976) 3 (May/June): 112-113.