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Summary:

Visual modification of the road environment

Aim of workpackage 2

Workpackage 2 of the EU project GADGET deals with effects on driver behaviour of various measures implying modifications of the visual stimuli from the road environment. The workpackage had the following aims:

- Provide a list of road-related measures, which have been shown to influence traffic safety by changing driver behaviour, or which on the basis of theoretical considerations can be expected to have such effects.
- Present a state-of-the art description of research evidence (both empirical and theoretical) concerning the behavioural effects of these measures, based on a comprehensive screening of research literature, primarily material published during the 80's and 90's.
- Summarise results from available cost-benefit analyses of the listed measures.
- Present recommendations regarding implementations of measures.
- Point out possible weaknesses in the data basis regarding behavioural effects of the measures, and suggest what research efforts seem necessary to provide more definite conclusions.

Working method

At the start of the project in January 1998 the topic of Workpackage 2 was subdivided into the following four thematic areas:

- Road geometry, roadside layout and intersection design
- Road markings, traffic signs and roadside information
- Traffic signals
- Measures to influence driving under impaired visibility conditions

The first stage of the work was the literature search, which was performed separately, and by different work groups, for the four areas. The basic data sources for all working groups were the large international road transport databases IRRD, TRIS and Transdoc. Additional sources of data varied between the areas.

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This search resulted in a list of about 600 literature references, which were tentatively classified in terms of a) *type of study*, b) *countermeasure studied (independent variable),*and c) *behaviour indicator (dependent variable)*. This preliminary list of references was presented in an internal workpackage document in April 1998.

In the next stage the list of references was carefully screened for relevance, and for each of the four subtopics the most relevant references were grouped by countermeasure to provide an overview of the available research work for each combination of countermeasure and behaviour indicator. This overview was presented in an intermediate workpackage report (‘Catalogue of research’) in June 1998. An important criterion for including studies in this stage of the process was the consideration of behavioural data. Since the effect of some of the measures on accident risk had been extensively documented in previous work, it was considered redundant and unnecessary to include an exhaustive assessment of accident studies in this project.

The final stage of Workpackage 2 consisted of an assessment of the measures, based on the literature included in the ‘Catalogue of research’. The results of the assessment are presented in this report, which is the final deliverable from Workpackage 2. For each measure that has been assessed, one or more of the following categories of results are presented: a) behavioural effects, b) benefit/cost assessment, c) effect on accident risk, d) recommendations, and e) identified research needs.

Theoretical background

Driver information needs

Since vision is the primary means for drivers to acquire information from the traffic environment, enabling them to perform the task of driving, it is almost a truism that visual modifications of the road environment can influence driver behaviour. In order to predict the effect of such measures it is important to have correct knowledge about the information processing capacities and limitations of drivers. The most pertinent question is what kind of information the drivers need to perform the driving task in a safe manner.

A very useful general classification of driver behaviour into a three-level hierarchy – macroperformance (navigation), situational performance (guidance), and microperformance (control) - was presented about 30 years ago. The highest level (navigation) comprises behaviours related to trip planning and preparation and route finding; the intermediate level (guidance) concerns subtasks associated with response to road and traffic situations; and the control level includes vehicle control tasks such as steering and speed control.

An essential feature of the driver information hierarchy is that the level of a given task determines the desired allocation of the driver’s attention to the task. For maximum safety, the tasks at the lowest level should have primacy. In particularly demanding situations, the lowest level tasks may require the total attentional capacity of the driver, and tasks higher on the hierarchy will be shed. This “load-shedding” behaviour may for example result in drivers missing information from direction signs in complicated traffic situations.

This conceptualisation of driving in terms of a three-level hierarchy with the properties of attention primacy and “load-shedding” seems to be a promising frame of reference for analysing how the driver behaviour can be assumed to be influenced by various modifications of the road and its environment.

Basic visual functions

For predicting effects of the road environment on driver behaviour it is also important to take into consideration some basic properties of the visual sensory system. Some of the visual functions that may be relevant for perceiving the road environment include visual acuity (both static and dynamic), peripheral vision, contrast sensitivity, night vision, eye movements and visual search, colour vision, distance perception, and the perception of speed and motion. Of special interest for understanding accident risk in darkness is the distinction between *focal visual functions* (such as visual acuity and contrast sensitivity) on one hand, and *ambient (guidance) visual functions* on the other; the latter being of prime importance for orientation in space. On the basis of this distinction the so-called “selective degradation hypothesis” has been proposed, which implies that reduced luminance – e.g. during night driving - primarily affects the focal vision, whereas the guidance vision remains unaffected at luminances close to scotopic threshold levels. This hypothesis has strong implications concerning the effects of measures to influence darkness driving, depending on whether the measures provide support for the focal or the ambient visual functions.

Driver expectations

Violations of drivers' expectations is considered to be a common cause of road traffic accidents. Both planned and unplanned information from the road environment are important sources of drivers' expectations, which govern their behaviour. It is therefore of prime importance that the parts of the traffic system which can be controlled, are designed to suit the "driver information needs" discussed above in conjunction with the three-level model. In other words, correct expectations should be established by advance information by signs, road markings, road design etc. The construct of "positive guidance" has been introduced as a general principle for a good visual road environment, accompanied by the method of "Expectancy Analysis and Review" to assess whether a given road conforms to this principle. These concepts are clearly relevant for the assessment of behavioural effects of visual modifications of the road environment.

Driver expectancies are assumed to be based on different levels of the hierarchical model pointed out previously. An expectancy violation will disrupt performance of the particular subtask that the expectancy is associated with, and may also affect subtasks lower in the hierarchy, and thus create hazardous situations. For example, a violation of an expectancy concerning direction signs (strategic level) may distract the driver’s attention so that he may miss information about other road users behaviour (tactical level) or concerning his own speed or lateral position (operational level).

Mental load

The capacity for information processing is limited. Therefore, when the amount of relevant information exceeds the driver's cognitive (attentional) capacity, some information is lost. If crucial information is lost, erroneous decisions may ensue, possibly resulting in accidents. Mental load can be considered an important intervening variable between the road environment and driver behaviour. An important aspect of information processing pertaining to mental load is the distinction between "controlled" and "automatic" processing. A consistent and predictable road environment (cfr. the discussion of expectancy above) is supposed to entail automatic information processing, and thereby a reduced mental load.

Risk compensation

On the basis of engineering considerations alone, a given safety measure can be estimated to have a large *ceteris paribus* risk-reducing effect. However, the ceteris paribus condition very often turns out not to be true, since it has been demonstrated that several measures actually result in behavioural adaptations that partially or completely offset the theoretically predicted effect. This kind of behavioural adaptation has been termed "risk compensation".

The three-level hierarchical model of driver behaviour is essential also for understanding the behavioural mechanisms behind risk compensation. Compensatory behaviour may take place on different levels. For example, at the strategic level, some drivers may for example be reluctant to drive in darkness on unlit roads, and therefore choose other modes of travel. More commonly, one thinks about behaviour adaptation *during driving*, i.e., on the tactical and operational levels, when talking about risk compensation. However, compensation at different levels may have similar effects on accident numbers. For accident prevention by influencing driver behaviour it is therefore important to know at what level the behavioural adaptation occurs.

An important concern when assessing behavioural effects of safety measures is to consider which measures are likely to result in risk compensation, in order to find modifications that may counteract such behavioural changes.

Driver behaviour and safety

Although the focus of the GADGET project is on influencing driver behaviour, the ultimate goal of changing the driver behaviour is to reduce accident risk. It is therefore crucial that measures to change driver behaviour rest on correct assumptions regarding the relationship between driver behaviour and accident risk. A documented effect of some road measure on some driver behaviour is not always easily interpreted in terms of safety. In addition, accident data or convincing theoretical arguments regarding relationships of the given behavioural observation to safety is needed.

Road geometry, roadside layout, intersection design

Road network and sections

A safety measure on a very general level, in order to provide drivers with correct expectations and support their information handling, is ‘categorisation of roads into a hierarchical network structure’, or the concept of ‘self-explaining roads’. The leading safety principle behind this is that traffic participants must be able to recognise unambiguously the function of the road - and thus the kind of traffic conditions they will have to deal with. As such, geometric design consistency is an important factor in avoiding driver errors.

In this context, the questions arise: do traffic participants rightly identify the type of road; what cues are applied in that; and, vice versa, what cues might support them in recognising the road category?

In a number of empirical studies, drivers generally seemed to be able to identify road classifications. And, vice versa, drivers generally were able to categorise roads into at least some broad groups.

In both cases, identification was the most consistent for upgraded, high speed roads and for low-speed types of roads.

Some rather general aspects or characteristics like ‘inside and outside built-up areas’ or ‘number and width of carriageways’, separately or in combination, might play a role or be helpful in this. Exact relations between driver behaviour and road categories, reliably applicable by, for instance, engineers in designing roadways as part of a consistent road classification, however, are not stated so far.

Concerning some examples of specific design elements, both superelevation and transition curves contribute to drivers’ expectations regarding the sharpness of a curve. Adding transition curves has been shown under certain conditions to convey misleading impressions about the distance to the curve and the radius of the curve. Further research is needed to determine the optimal combinations of design elements in order to provide expectations that result in safe curve negotiation.

Another overall safety measure is the area-wide implementation of traffic calming measures; e.g. in residential areas. Such measures have been shown to have considerable effect on driver behaviour, especially on speeds. Obviously, in an ‘area-wide’ treatment of residential areas it is hardly possible to distinguish which element did cause the speed reductions: visual information, or physical and other type of measures. It is important to carry out further research to elucidate the relative effects of different elements, in order to optimise the total effects of the measures.

An assessment of road design from the point of view of the capacities and limitations of elderly drivers indicate that current standards for sight distances are insufficient. These sorts of findings lead, on the one hand, to recommendations for further research into the necessary length of time and, on the other hand, to develop a standard for road signs on highways and streets, taking minimum required sight distances for older drivers into account.

Intersections

Based on research results concerning non-signalised intersections the following principles concerning safety effects of measures can be stated:

- Generally, intersections should be planned and designed in an overall perspective to ensure a coherency along the route and to contribute to accordance between the drivers' expectations and the intersection that he meets. Also, the importance of simplicity and "readability" as well as good visibility and perception conditions should be underlined.
- Roundabouts have the lowest risk of accidents of the various types of intersections independent of traffic from secondary roads.
- The safety effects of various types of duty to give way increases with increased demands for the driver to stop independent of the circumstances.
- In rural areas, traffic islands on secondary roads seem to reduce crossing accidents, but presumably only in 4-way intersections.
- Painted left-turn lanes have a safety effect on major roads in rural areas, especially in T-intersections.
- Replacing 4-way intersections with two staggered T-intersections is recommended if the size of the traffic from the secondary road is more than 30%.
- Attention between right-turning drivers and straight-ahead going cyclists is improved, if the parties are compelled to drive/ride close to each other, and the cycle track is made conspicuous.
- Painted cycle tracks or other kinds of markings increase attention towards cyclists, when drivers are turning right from a minor to a major road.
- 2-way cycle tracks should be avoided at least in urban areas with considerable non-signalised intersection density. If they are used, the visibility should be made sufficient in both directions at the intersection. Also, speed-reducing measures are recommended plus multiple warning signs.
- Humps or rumble strips on the minor road of an intersection will provide drivers with more time to pay attention to both directions, and to interpret the situation correctly, before entering the intersection.

Behavioural research has to some extent been carried out concerning drivers' difficulties at intersections. Such research often results in recommendations of measures that can help solving the problems, but implementation and evaluation of the behavioural effects of the proposed measure are usually not included.

At the same time there seems to be only limited research of the behavioural effects of various measures at intersections. When the effect of a measure is tested it is often in the shape of accident frequency. Nevertheless knowledge of behavioural changes will provide better opportunities to know the limitations and possibilities of the measures in a broader perspective.

On the basis of the research reviewed in this project, it can generally be stated that research is needed mainly concerning drivers' distribution of attention as well as their deceleration pattern before entering intersections. More specifically, this could be seen in relation to:

- Various kinds of duty to give way
- Various kinds of traffic situations
- Various kinds of driving manoeuvres
- Various kinds of geometric design, including roundabouts and intersections with restricted sight distance in one direction.

The above mentioned research should be followed up by studies of the behavioural effects of measures to prevent insufficient and erroneous attention.

Finally as drivers seem to have difficulties in assessing other vehicles' high speeds, research is needed concerning the effect of speed reducing measures on the major road before intersections.

Road markings and traffic signs

Longitudinal road markings

The application of *wider edge-lines* has been discussed as a measure to improve steering behaviour of drivers. The main intention is to provide better visual guidance information leading to a reduction in single-vehicle accidents. There is no evidence of any effect on accident risk. A possible explanation may be risk compensation by increased driving speed.

On the basis of studies of the lateral position of vehicles it is recommended that centrelines should always be applied together with edge-lines. Vehicles tend to move to the centreline without the reference provided by an edge-line which probably leads to a higher rate of accidents with vehicles of opposite direction.

It has been estimated that benefits through the application of edge-lines on roads will by far exceed their costs and are therefore strongly recommended.

Longitudinal road marking is used also to indicate lane drop exits. *Lane drop markings* consist of larger-width lane striping that begins in a certain distance in advance of the theoretical gore point. White pavement marking arrows can also be included to indicate the situational demand on driver behaviour. Lane drop lines seem to be a very useful tool to improve drivers' orientation and to avoid hazardous erratic manoeuvres. A smooth flow of vehicles can be obtained by an early information (and its redundant repetition) using appropriate lane drop markings together with directional information.

Thermoplastic *raised-rib markings* (RRM, or rumble lines) comprise a continuously screeded thermoplastic base line, with transverse ribs. Besides advantages in dark and wet conditions, the raised-rib pattern produces an audible noise and vibrations as a warning sign when a vehicle passes over it. This measure should result in better lane-keeping because of inducing discomfort when driving on the markings. On the other hand this device could be a problem for novice drivers in respect of being surprised and carrying out abrupt manoeuvres. This measure has been shown to result in large initial speed reduction. The effect seems to become less as drivers get adapted to the lines. It has been recommended that: a) RRM should be discontinued at defined pedestrian/cyclist crossing points; b) RRM should not be used as any form of centre of carriageway marking on curves less than 1.000 metres radius; c) RRM should stand up 6 +/-2 mm for all-purpose roads and 9 mm on motorways or roads where cyclists and pedestrians are permanently banned; d) RRM still have to be investigated for cost-effectiveness on urban roads; and e) riblines should be sited as close to a possible hazard as it is practicable.

Post-mounted delineators (PMD) are commonly used as a supplement to standard pavement markings at horizontal curves on two-lane rural highways. Adequate path delineation is particularly important at such curves. Because of difficulties in maintaining PMDs, *raised pavement markers* (RPM) are used as an alternative to, or combined with PMD. The effectiveness of RPMs in relation to retro-reflectivity over time should be investigated and a minimum performance level should be estimated. The general problem of obliteration and regular maintenance intervals has to be considered.

Transverse road markings

Paint stripes are used as a series of lines across the carriageway with the spacing between them decreasing as a roundabout is approached. The markings are designed to help drivers to slow down after a period of sustained high-speed driving, during which they might become used to high speeds (“speed adaptation”). Appropriate speed behaviour, a better orientation and a reduced accident rate are the main expected effects. Paint stripes are a very cheap measure to implement, a reduction in speed and a change in braking behaviour at approaches to intersections can be expected. A reduction in accidents is likely. The best location for the markings would be where they produce maximum speed reductions. Paint stripes have been compared with *rumble strips*, which are painted lines that are elevated (12 to 15 mm above the pavement), thus producing auditory and tactile (vibration) stimulation in addition to the visual input. Rumble strips resulted in a larger deceleration and more long-lasting effects than paint stripes. A 150-m zone ahead of the intersections is long enough to produce the positive effects of rumble strips. The appropriate height of the strips is about 12mm.

Special pavement markings

Road markings in the shape of arrows (*chevrons* – inverted ”v” painted on the surface) have been used in several countries to improve the drivers‘ following behaviour on high-speed roads. Such chevrons are laid on the road surface at regular intervals. As an easy to remember thumb-rule drivers should leave two chevrons between the front of their vehicle and the rear end of the vehicle they are following in order to maintain a reasonably safe following-distance. This measure seems to result in decrease in close following, a small speed reduction, and reduction of single-vehicle accidents (but not in rear-end collisions). Since there was no reduction in rear-end collisions, it is likely that the markings act as an alerting device. This general alerting function seems to be irrelevant to achieve the primary aim of the measure.

The use of ‘crash cushions’ to protect vehicles from crashes with fixed objects in freeway gore areas has become a widespread practice in the U.S. Although crash cushions reduce fatalities and injury severity, previous studies showed an increase in the *frequency* of traffic accidents. Additional delineation should reduce the problem of lacking conspicuity of crash cushions in gore areas. Investigations of *special markings to increase the conspicuity of the crash cushions* have failed to find any significant effects. As there is no evidence of effectiveness of the investigated measures, other warning or visual guidance devices should be given priority.

Traffic signs

Improving the *retro-reflectivity of traffic signs* potentially could make a contribution to an earlier perception of traffic signs and therefore reduce accident rates. Whereas the relevance of retro-reflectivity is evident under night-time conditions, this feature also plays an important role under daytime conditions when the surrounding luminance tends to „mask“ traffic signs. Reductions in speed, conflicts and accident risk have been demonstrated. The use of high-retro-reflective and fluorescent sheeting for traffic signs are very effective measures to reduce speeding and accident rate at dangerous sites. Maintenance or cleaning intervals should take place not only according to a fixed time schedule but also according to weather conditions (e.g. traffic signs should be cleaned more often during wintertime).

Excessive sign posting can cause informational overload and lead to general ignoring of traffic signs by the drivers, so that even crucial information will be missed. In many countries there exists a tendency to compensate failures in road layout with over-regulation through traffic signs. This over-regulation mainly serves the interests of authorities in the case of accidents to avoid legal problems. A German study showed that following a systematic approach about 20% of all traffic signs could be removed without compromising road safety and traffic flow conditions.

Overload due to direction signs may also be a problem. An overloaded direction sign is defined as a sign with more destinations than can be read in the time available. Many signs contain more than the recommended maximum number of destinations (and other additional information). This is particularly the case in urban areas, where drivers may also have more demands drawing on their attention capacity and that are limiting the amount of time available to read direction signs. A limitation in the number of destinations at a single site seems to be necessary to obtain appropriate information processing by the drivers. A maximum of 6 destinations is recommended as the best compromise between informational load and the demand for directional information. Map signs should be used rather than a stack sign where possible. If the situation permits, flag signs pointing in opposite directions should better be mounted alongside each other than one above the other.

Poor combinations of traffic signs can lead to an increase in perception time and thus result in informational overload. Such combinations of traffic signs can produce undesirable qualities of „Gestalt“ that can also cause neglect (e.g. two triangles can produce a shape that is no direct warning stimulus anymore.) A standardized syntax for useful combinations of traffic signs as a measure to avoid informational overload and neglecting of information should be developed and consequently applied on the basis of psychological knowledge. Guidelines should also take into account that each combination of signs produces its specific “Gestalt” features.

The use of *supplemental plaques* serves the purpose of improving drivers’ comprehension and acceptance of the warning signs. The standard warning signs just provide the most general information. Recently, such plaques have mainly been used for speed limits and general warning signs. There exists evidence that supplemental plaques can be a useful tool to inform drivers about certain aspects of the situation. For descriptive information there remains the general problem that such information requires time for reading which often is short at intersections Additional studies should be carried out to answer open questions about complexity and amount of information on supplemental plaques.

Besides the official directional information that is presented to achieve orientation among drivers, supplemental information concerning tourist attractions, commercial sites or other services can often be observed. This information is added to the official ones more or less systematically. The question is whether such information disturbs the main function of directional information or not. It has been shown that supplemental signing, in addition to the already existing official information, on a rural freeway interchange was generally impairing driver control behaviour (speed differential, lateral placement, acceleration noise and recognition distance). A possible solution could consist in a separate placement of official and unofficial information. This would clarify the situation for the approaching drivers.

Variable message signs (VMS) can serve the following goals of traffic regulation: a) to achieve a better distribution of the vehicles in the whole system; b) to achieve a better orientation of drivers; c) to show the best roundabout ways in respect of traffic flow; and d) to indicate dangerous situations in a more effective way. Favourable effects on accident risk have been demonstrated. Highly persuasive VMS configurations resulted in less hesitating behaviour than in conditions with a lower persuasiveness. As the costs for VMS are extremely high compared to static information, additional accident data analysis seems to be necessary to replicate benefit/cost estimations.

The purpose of *incident warning systems* (IWS) is to give drivers an early warning stimulus concerning some disturbance on the road ahead. It has been shown that IWS has positive effects on traffic safety: early speed reduction and early change of lane compared to the control group. The optimal detail in a message from an IWS seems to be that it depends on the type of incident and the type of action a driver has to perform. Before a decision is made on what type of IWS should be used for a certain road, the nature of probable incidents should be analysed.

High-speed signal-controlled intersections at unexpected or hidden locations provoke a potentially hazardous situation for drivers when the signal indication changes from green to yellow. *Advance warning signs* have been suggested to minimise so-called „dilemma zone problems“. Drivers are uncertain what to do next: braking or rushing through. The use of dynamic signs that indicate the status of the traffic signal in advance should be given low priority, as they did not show to have any practical advantage compared to the cheaper static signs.

A *stop ahead* sign should warn drivers of an upcoming, unexpected, partially concealed stop sign and intersection. This could lead to better prepared and orientated drivers who are able to slow down in time and who will not be forced to perform hazardous „manoeuvres of the last minute“. Changes in eye-scanning, velocity, longitudinal deceleration, gas pedal deflection, and lateral lane position have been observed after implementing this measure. However, since there was no change in the stopping behaviour between test and control condition, the ‘stop ahead’ sign doesn’t seem to fulfil its purpose sufficiently. Additional warning devices could therefore be used to improve the stopping behaviour of drivers.

Signs with the function to warn motorists that traffic on the cross street does not stop can be found at some intersections that are not all-way stop controlled. These *cross traffic signs* function as an additional warning device at dangerous intersection sites. There exists a large variety of form, message, colour, and shape. Cross traffic signing can be an effective way to reduce accidents at dangerous intersections. Efforts concerning a standardisation in designing such signs are necessary. Advance warning signs ahead of passive railway crossings should alert drivers to prepare themselves for a complete stop at sites with restricted lateral sightline visibility. This measure is recommended, as such signing showed to be effective in reducing average speeds and as drivers will have more time to watch out and react in time.

Speed limit signs function as a regulatory and warning device when entering zones where a certain maximum driving speed is necessary to avoid exceeding of physical limits or mental overload, to guarantee safety for residents or for in-time preparation at approaching to intersections or work zones. The application of speed limit signs at ill-designed sites can improve the situation to a certain extent. *Embedded speed limits* (built-up area sign) should not be used instead of explicit speed limit signs. The most effective way to reduce speed at dangerous sites results when using flashing signs.

At special sites or under special conditions *advisory speed limit signs* are used. The main advantage of the advisory character is that drivers are not enforced to lower speeds when the actual situation does not fit the mandatory limit. This can be the case for seasonal or temporary changes in weather conditions. The idea is that drivers tend to ignore regulatory information in general, when discrepancies between situation and demanded behaviour occur very often. Sometimes the combination of warning signs together with advisory speed limits has been suggested. Additional advisory speed signs have not been shown to be more effective in motivating drivers to reduce their speeds through curves than the curve warning sign alone. New installations of speed limits at sites with an existing curve warning sign should be given low priority. The implicit information of curve warning signs to reduce speed seems to be sufficient. There exists no information about the principal functionality of advisory speed limits. A problem could be that the („weak") advisory information is neglected completely because of the yet well established selective obedience of the („strong") mandatory speed limits.

Repeated speed limit signs should remind drivers of the existence of a speed limit hoping that they might respond by keeping their speed reduced or to adjust speed, in the case a driver ignored, overlooked or already forgot the first sign. This measure has not been shown to result in reductions of speeds or in the percentage of vehicles exceeding the speed limit. Speed limit repeater signs on highways/motorways should be given low priority. In many countries there already exist guidelines under which circumstances a sign has to be repeated.

Roadside feedback messages have been reported as a powerful means to reduce speeding. A 'mobile roadside speedometer' measures the speed of individual vehicles before presenting it back on a display readable to the passing drivers. As the information is visible for all other drivers present at the scene, a decrease in the number of violations of the speed limit is expected due to social comparison mechanisms. Most drivers do not slow down in response to the standard speed limit signs at work zones. Therefore, additional speed feedback displays, designed to warn drivers that their speed exceeded the maximum safe speed, have been suggested to improve the situation. For all work zones on highways or expressways speed feedback should be used to control speed and speed variance effectively. Speed feedback seems to be a very useful tool to motivate drivers to reduce speed according to the limits. It still has to be investigated whether the effect diminishes when the measure is used very often or over a longer time. Especially at the approach to work zones, schools or hospitals the application of this measure is recommendable.

Improving driver behaviour and safety at signalised intersections

The importance of improving safety at signalised intersections can be derived from the fact that in the USA, 39% of fatal crashes at urban intersections in 1991 occurred at intersections with traffic signals. Similar rates of fatal crashes were found in other countries.

The driving task at the guidance level is considerably simplified for signalised road intersections when compared with non-signalised intersections. The task of the road user in relation to the traffic signal lights is to register the signal, to recognise and interpret the information from the signal display, and to make a decision that leads to an adequate behaviour.

An example of an important behavioural aspect of the driver's task is the decision whether to stop or to proceed when the signal changes from green to yellow and then to red. These types of decisions have safety consequences.

A possible precaution to provide drivers with extra time to clear the intersection if necessary, is an extension of the inter-green period by using all red. All red has a positive effect but should be treated with caution. If the all red period is too long, drivers may take advantage of it and proceed into the intersection at the end of the yellow interval.

As a result of the existing problems mentioned above, the optimising of the yellow interval has an important role in increasing safety at signalised intersections. Optimising the yellow interval reduces the number of vehicles in the dilemma zone and thereby reducing the number of red light infringements and rear-end collisions by using a dynamic approach. This is done, by detecting vehicles in the dilemma zone, and postponing a decided change from green to yellow. Yet, while optimising yellow interval, it should not be lengthened too much since long intervals make the driver's decision-making process more difficult.

Non-optimised yellow interval results in red running violations. Red running is encouraged by long duration of cycle times, frequent waiting time in peak hours, and meeting many signal installations while driving. Mostly the red-running offences appear to take place at the first few seconds of the red phase in an intersection.

The major ways to deal with red running are good geometric design of the intersection, optimal design of inter-green timings, improved signal head design, surveillance and enforcement.

Studies showed a significant reduction in total number of accidents as a result of improving signal head design. Results show that enhancing the signal visibility through the use of a larger, brighter traffic signal head design contributes to improving reaction time and safety, especially when distances between signals are long and speeds are high. Special attention should be paid not only to signal head design at urban areas, but also at rural junctions.

Another problem, which is familiar at signalised intersections, is left turns. Left turn movements during the ordinary green signal are often a complicated situation that creates a risk of misjudgement and wrong decisions. Permissive and protective signals have different effects on this problem. The protected signals are by far the best understood and they are also found to be the most preferred signals since they are associated with less confusion compared to the permissive signals.

Three programs were mentioned in this document:

- LHOVRA for safer traffic signal control of isolated intersections.
- The UK technique "Microprocessor Optimised Vehicle Actuation" MOVA for safer traffic signal control of isolated intersections, and
- The UK technique SCOOT optimising the split, cycle and offsets in a signal controlled network on line.

Positive safety effects of LHOVRA were observed in urban areas. There is an accident reduction of up to 49%, and no increase in the severity of accidents. The safety benefit of LHOVRA is mainly due to the fact that rear-end collisions are reduced. It is also noticed that percentage of drivers violating red is reduced when introducing LHOVRA at a signalised intersection. The percentage of drivers facing yellow in the dilemma zone, where a sudden braking manoeuvre can lead to rear-end collisions, is also reduced. SCOOT appeared, in several studies, to decrease accidents/casualties while in others there appeared to be an increase.

Among countermeasures, purported to increase safety at signalised intersections, there are measures, which deteriorate safety instead of increasing it. Two of these are *right-turn-on-red* (RTOR) and *blinking green*.

Proponents of the RTOR cite the benefits of increased intersection capacity, reduction of vehicle pollution emissions, and savings of energy and time through reduced delay. Still, researchers found that RTOR causes a significant increase in right turn crashes involving vehicles, pedestrians and bicyclists as well. Effects of RTOR were more significant in urban areas, and were observed a long time after its implementation. Elderly people and people under 16 years of age are the most likely to be involved in RTOR conflicts.

The *blinking green period* is a phase at the end of the green signal, which indicates to the driver that the green light is about to end, and intends to allow drivers the opportunity to cross the intersection safely. Studies showed that blinking green increases accident rate, places additional decision pressure on the driver and creates greater opportunity for error. The practice of introducing a 2-3 second blinking green phase has consistently shown to be detrimental to safety, in all studies evaluating its effect.

Measures to influence driving under reduced visibility

Based on accident data and behavioural findings together the following measures can be assumed to have favourable safety effects under conditions of reduced visibility in darkness and/or inclement weather:

- Road lighting is effective for reducing accidents in darkness in spite of increased driving speeds.
- Road lights with beam approximately perpendicular on the roadway increase visibility in fog.
- Raised pavement markers are effective in reducing erratic manoeuvres in darkness and rain. Probably more efficient as lane dividers than as edge-lines.
- Internal illumination of signs results in increased detection distance. The same is found for symbols as compared to text. The earlier detection is probably a beneficial effect although behavioural and accident data are lacking.
- High-luminance pavement material has been shown to result in decreased accident risk.
- Fog warning signs, preferably controlled by both visibility and driving speeds, seems to be a promising measure.

Several other measures (post-mounted delineators, high-reflecting edge-lines, etc.) have been shown to provide increased preview of the road alignment. The safety effect of these measures is, however, uncertain, as long as they may result in increased speed without increasing the drivers' possibility of detecting objects in the roadway. In other words, there is a risk of a selective improvement of ambient vision (spatial orienting) without a corresponding increase in focal vision.

For driving in tunnels, the following measures can be assumed to have favourable effects on safety:

- High luminance at entrance and exits, combined with low luminance of approach zone
- Uniform luminance in tunnel interior
- Counter-beam illumination
- Gradual narrowing of tunnel portals, and increased lateral clearance
- High and diffuse reflection of pavement and tunnel walls
- Horizontal lines to provide visual cues of upgrades and downgrades
- A minimum of signs in the approach sections
- A minimum of sharp vertical and horizontal curves

Most of these conclusions are based on rather meagre research data. A general conclusion is therefore that there is a great demand of further behavioural research before any final recommendations can be made regarding the most efficient measures to influence drivers towards higher safety in poor visibility conditions. Further research should, among other things, focus on the relationship between visibility of long-term guidance measures (showing road alignment), driver decision-making and behaviour, and accident risk.

For some of the measures, though, there is more firm documentation. The measures with the clearest empirically documented positive effects on safety seem to be *road lighting* (accident data) and *fog warning signs* (speed data).

It should also be pointed out that there is very little research addressing the issue of how the various measures satisfy the information needs of different driver groups. For example, cognitive and perceptual limitations among older drivers may imply that measures considered adequate for young and middle-aged drivers do not satisfy the needs of the elderly. Young and inexperienced drivers for their part have other limitations. They are, for example, probably prone to information overload related to the lack of adequate search strategies for extracting relevant information from the traffic environment, or, in other words, to hazard perception.

It is also conceivable that measures addressed at accommodating the needs of certain driver groups could have adverse effects for other drivers. For example, guidance information dimensioned according to older drivers' perceptual capacities might possibly be utilised for increased speeds among the young and middle-aged.

Consequently, there is a strong need for more research trying to assess possibly differential effects of modifications of the road environment on different driver subgroups.