

Summary:

Influencing driver behaviour and safety by road system improvements

This report summarizes a project about driver information needs and road system improvements. The project was commissioned by the Swedish National Roads Administration and has been carried out by the Institute of Transport Economics. The data basis for the work is a survey of international research literature covering the following topics:

- behavioural theories related to understanding the interaction between drivers and the road system
- relationships between road design, driver information and speed
- how to present clear and unambiguous information to prevent wrong-way driving, especially on motorways
- optimal direction signing
- how to design the road system to accommodate elderly drivers.

In addition to the present report, the documentation from the project includes five working documents with more detailed discussions of the five main topics.

Theoretical background

Driver errors resulting in crashes are very often due to important information being missed or misinterpreted. The design of the road system should therefore be based on sound knowledge about driver information needs. The information needs are connected to driving tasks on different levels. The *strategic* level comprises higher-order plans and decisions for the trip; the *tactic* level concerns decisions about specific traffic situations; and at the *operational* level we find the continuous adjustments of vehicle speed and position.

The capacity for attention is limited. Therefore important information should be easily available without much visual search, and without competing with other information more likely to attract drivers' attention. For example, direction signs (strategic information) should not be presented in locations where important tactical or operational decisions are likely, as in complex road or traffic environments.

Through experience drivers develop *expectations* (e.g., regarding the continuation of the road) and adjust their driving to these expectations. Expectations can also be influenced *ad hoc* by signs and markings. A general rule is to take care to avoid *expectancy violations*, e.g., a sharp bend on a road where curves are gener-

ally flat. As a rule information should be presented where drivers need it, and where they are likely to search for it.

Experience further implies that driving behaviour gets increasingly more *automatic* and demands less conscious attention. This development is based on similarity of new situations with previous ones, allowing the use of already established patterns for interpreting and reacting to situations (*cognitive schemata*). Complex, surprising or unfamiliar situations on the other hand require conscious attention, and result in increased *mental load*. This increases the risk of missing or misinterpreting information, and making errors.

Typical examples of errors related to information from the road system include:

- missing or misinterpreting signs, markings or signals
- missing or misunderstanding direction signs
- not seeing other road users due to obstacles or visual clutter
- too high speed on the approach to a curve due to misjudgement of curvature.

Too much information may result in errors due to overload and stress, whereas too little information can produce monotony resulting in tiredness and loss of concentration. It is therefore important to design roads, signs and markings so as to avoid both under- and overload of drivers.

Drivers are generally motivated to get reasonably quickly to their planned destinations. Therefore, any improvements to the road, which make drivers feel safer or make the driving task easier, may result in higher speeds and/or less concentration (so-called *risk compensation*). The possibility of such behavioural adaptation should be considered when implementing measures to improve road safety.

Road design and speed

The driving speed is determined both by the driver's perception of speed and by his/her assessment of acceptable or correct speed for the situation. The perception of one's own speed of locomotion is determined by the *relative movement* of objects in the visual field (*optic expansion* and *movement parallax*). The road environment, e.g., the distance to objects along the roadside, is also assumed to influence speed perception.

Most drivers *underestimate* their speed, and more so with low speeds in the presence of acoustic stimuli (noise from tires, engine, wind etc.). Without acoustic stimuli the underestimation is larger with high speeds.

Studies have found a relationship between mental load and driving speed. Speed adjustment appears to be instrumental in maintaining mental load within an acceptable interval.

Some modifications of the road or its environment have been clearly shown to result in *increased* speed.

- *Edge-lines* result in higher speeds, possibly by reducing drivers' mental load.
- *Centrelines* appear to give higher speeds on narrow roads (4 – 4.5 m), whereas no such effect has been found for wider roads. This is consistent with accident

studies showing higher crash risk with centrelines on narrow roads and reduced risk on wide roads. These findings can possibly be explained by reduced uncertainty regarding lateral safety margins. On narrow roads it has been shown that drivers drive closer to the road centre when a centreline is present.

- *Enhanced preview distance in darkness* by reflective post-mounted delineators or high-reflection edge-lines results in increased speeds, and possibly also higher crash risk.
- *Road lighting* also results in higher speeds, but at the same time the crash risk is reduced.

Some other modifications result in *reduced* speed.

- *Decreased road width* results in speed decreases of about 3 km/h per m width decrease. The speed difference per m road width is larger the narrower the road. Narrowing the shoulders also results in lower speed. Increasing the lane width and reducing the shoulder width (without changing the total roadway width) results in higher speeds. This seems to be explained by drivers experiencing the road as safer (larger lateral distance to oncoming vehicles) and the driving less demanding with a wider driving space.
- *Objects close to the road* (trees, buildings, etc.) tend to result in lower speeds, especially on narrow roads. This can be explained both by a sense of high speed caused by visual cues, and by fear of hitting objects. In addition, the objects may reduce visibility distances.
- *Perceptual illusions and other road markings to reinforce the perception of speed.* Transverse lines along the edges or across the whole lane reliably produce decelerations. Progressively decreasing distance between lines is assumed to induce a stronger feeling of speeding, and some studies have shown larger deceleration with decreasing as compared to fixed distance.
- *Visual narrowing* of the lanes on two-lane roads, by means of a hatched central area and/or wider edge-lines effectively reduces driving speeds.
- *Reduced visibility distance* is likely to reduce speed. The speed reduction in curves is, however, often not sufficient to maintain the safety margin. The same goes for speed reductions in darkness.

The effects regarding speed and crash risk in darkness can be explained by the theory of “selective degradation” of visual functions. Low illumination primarily affects the ability of *object identification*, and to a lesser extent the ability of *spatial orientation*. The adjustment of speed is based mostly on the latter ability.

Some modifications which have been introduced to increase safety, have not so far been shown to influence driving speed, but may all the same have a positive effect on safety.

- *Profiled edge- and centrelines* (rumble lines) do not influence speeds, but they reduce the frequency of encroachments and increase the safety.
- *Special edge markings in curves* have been used also in curves to give an impression of sharpness of the curve. One such measure is an extended hatched

edge-line along the inner edge of the curve. Variable effects on speed have been shown; there is possibly a beneficial effect for blind curves.

- *Safety fences* can be assumed to influence both the assessment of danger and the mental load among the drivers, especially on narrow roads. The effects of safety fences on driving speeds among free vehicles have, however, not been systematically investigated.

The perception of curvature is expected to determine approach speeds. The most important design parameters that influence the perception of curvature include:

- curve radius
- curve angle (or length)
- the presence of transition curves
- super-elevation
- visibility through the curve (transparency).

The speed on entering a curve is not only determined by the characteristic of that particular curve, but also by expectations formed by driving through previous curves on the same road. *Design consistency* implies that the road geometry is in accordance with driver expectations about the alignment and about tolerable speeds. This also implies that curves on the same road should not vary too much in curvature.

There are several methods for assessing design consistency. One method measures deviation in curvature of a given curve compared to the average curvature for a certain distance upstream of the curve. Another indication of consistency is the variation in operational speeds between successive road sections.

Due to limitations of methods to assess consistency on the basis of road geometry or operational speeds, and alternative approach using measurement of driver *mental load* has been tried. The more consistent the design, the less the variation in mental load. This concept is also difficult to measure, and there is a need for further development of this approach.

Wrong-way driving

The problem of wrong-way driving received much interest in the USA already in the early 60ies, related to the construction of several new motorways, and many accidents caused by such driving errors. In Europe the problem was focussed from about 1980, first in Germany and the Netherlands, and later also in other countries, including the Nordic countries. Crashes caused by wrong-way driving make up less than 1 % of all casualties on motorways, but between 3 and 6 % of the fatalities. Several studies show elderly drivers to be over-represented in wrong-way driving incidents and crashes. Studies from the USA and Germany show alcohol-impaired drivers to be over-involved in wrong-way driving.

The most frequent form of wrong-way driving on motorways originates by entering the motorway from an off-ramp instead of the on-ramp. This error seems partly explainable by poor design of the intersections between ramps and cross-roads and/or to inadequate signs and markings. U-turns on motorways occur now

and then, probably being in most cases the result of “forgetting” that one is driving on a motorway. There are, however, instances of deliberate violations of this kind, against which efficient countermeasures are difficult to imagine. A less frequent error is turning from a motorway onto the *on-ramp*. This is likely to be a deliberate act and difficult to prevent by traditional measures.

There are systematic differences in crash risk between different intersection and ramp solutions. The problem is rare in full cloverleaf intersections, because these are characterised by all ramps joining the crossroad at sharp angle, and by a median barrier on the crossroad at the termination of ramps.

There are several examples showing reduced frequency of wrong-way driving after improvements of signs and markings. Often complete intersection redesign is necessary, especially in places with a high information load and a high risk of overlooking a sign. The design should contribute to guiding drivers into the correct ramps, and to make wrong movements difficult or impossible.

- *Continuous or frequent* information about driving direction, e.g. by painted arrows (or yellow line along the median as in the USA) may possibly prevent U-turns caused by unawareness.
- *Construction a left curve at transitions from two-lane roads to four-lane divided highways* may prevent driving to the left of the median. The left curve is designed so that the outer curve continues onto the right side of the median.
- *Improved design of ramps* between motorways and roadside facilities (service areas, petrol stations, etc.) can prevent wrong-way driving out from the facility. The facility should be designed so that the off-ramp is difficult to see or unnatural to enter for exiting drivers, whereas drivers are positively guided onto the on-ramp by means of signs, markings and physical design.
- *Using two-way rather than one-way ramps*. For connections to roadside facilities, as well as in other partial intersections it should be considered whether two-way ramps are safer. This will reduce the number of intersections between the motorway and a crossroad or other facility, thus simplifying the driver’s decision-making when entering the motorway. The transition between the two-way section and the one-way sections of the ramp must then be designed as in the above-mentioned example regarding transition from a road with two-way traffic to a motorway.
- After exiting from a motorway onto an ordinary two-lane road, drivers occasionally misperceive the two-lane road as one side of a divided highway, and therefore choose the left lane, apparently unaware of the risk of oncoming traffic. *Clear and unambiguous design, aided by direction information* to drivers coming from the motorway, is likely to prevent such incidents.
- In some at-grade intersections between a crossroad and a road with a median, left-turning drivers from the crossroad may misperceive the median as the right-hand roadside and enter the left (wrong) side of the median. *Clear view of the intersection, as well as special road markings* may prevent this.
- To prevent wrong-way driving on one-way streets in urban areas, both signs and *pavement arrows* are useful. It is important that *positioning of signs* is based on an analysis of the likely visual search behaviour of the drivers.

Optimal direction signing

Direction signs should be considered in a totality, implying that each sign should satisfy information needs and expectations as determined by previous information about the destination(s) in question.

General guidelines are not universally applicable. Efficient implementation of signing, road markings and other information requires sound knowledge about driver behaviour, in order to make adjustments due to special local conditions.

Research indicates that direction information is often misunderstood. To improve understanding, the following recommendations seem warranted

- Destinations on stack signs are perceived more quickly when destinations in different directions are placed beside each other (left/ahead/right) rather than in one column.
- The recommended maximum number of destinations on a sign varies between 3 and 6.
- Map signs result in quicker identification of the correct destination, compared to stack signs.
- The amount of information on one sign should be limited to what is strictly necessary. On main roads it is often unnecessary to include “ahead” destinations on the same sign as destinations for crossroads. Where appropriate, information should be distributed between successive signs.
- The use of *well-known* abbreviations may facilitate sign legibility.
- Consistency between sign contents and position is important; e.g. signs for left-hand destinations should be positioned to the left of signs for right-hand destinations.
- Direction signs for exits from roundabouts should be easily seen by drivers in the roundabout. For advance information, map signs should be used, especially for destinations to the left (to avoid driving to the left of the island in small roundabouts, which may be confused with an ordinary intersection).
- For street names and house numbers, small signs and inadequate placement is a common problem. Larger signs and better placement is therefore needed.

Designing the road system to accommodate older drivers

From the age of about 70 years the average risk of accident involvement increases with age. And since the proportion of elderly drivers is rapidly increasing, issues related to traffic safety for this group are receiving much interest. Reducing older driver crash risk by road system improvements requires knowledge about age-related changes in sensory, cognitive and motor functions, which may all contribute to increased risk.

- Visual impairments are more common with increasing age, but only weak relationships have been found between visual acuity and crash risk.

- Cognitive functions are impaired with increasing age, and clear associations between cognitive impairment and crash risk have been shown.
- The UFOV (“useful field of view”) test, which measures perceptual speed, divided attention, and selective attention, predicts crash involvement and driving performance particularly well.
- Persons with dementia have a particularly high risk, and this may explain a large part of the elevated risk among elderly persons as a group.

It has been hypothesized that elderly people have special problems with identifying relevant visual information against a complex background, but research findings on this issue are ambiguous. Research has shown that elderly drivers:

- take longer time to read and interpret signs, and have therefore more problems finding their way on unfamiliar roads,
- have longer reaction times, which implies that design values for sight distances, e.g. in intersections, may be too low,
- are over-involved in crashes at intersections, especially during left turns. This may be related to poor perception of depth as well as movement, and consequently reduced ability to perceive the speed of and the distance to oncoming traffic. Poor observation of signs, e.g. stop and yield signs, may also contribute to this over-involvement.

There are two main categories of suggested measures to accommodate older drivers in the traffic system. First, means for improving *visibility and legibility* of information to elderly drivers include:

- increased letter height on signs
- higher contrast and/or retroreflectivity
- use of wider lines for pavement markings
- better maintenance of signs and markings
- reinforced information by repetition and redundancy.

The second category comprises measures to *facilitate information processing* for elderly drivers, including:

- more use of separate left-turn lanes
- longer sight distances
- reduced number of intersections
- replacing 4-legged intersections by two T-junctions
- redesigning complex intersections
- speed reduction on locations with high information load.