Roadside infrastructure for safer European roads: D02 Summary of driver behaviour and driver interactions with roadside infrastructure

D02: SUMMARY OF DRIVER BEHAVIOUR AND DRIVER INTERACTIONS WITH ROADSIDE INFRASTRUCTURE

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Summary

Purpose: The literature review presented here was conducted within Work-Package 1 of the EU-RISER project. Within this Workpackage, Task 1.3 consisted of collecting existing literature identifying the response of the driving public to changes in road design, in order to prevent severe consequences of single vehicle run of road accidents. This Deliverable (D 02) serves as a starting point to include Human Factors principles within the roam of roadside infrastructure design by means of developing guidelines and analysis procedures necessary to select, implement, and operate a safe, efficient and affordable roadside infrastructure in the EU.

Method: Four of the total of 10 partners in the RISER project (Chalmers University of Technology, the Vehicle Safety Research Centre of Loughborough University ,Centre d'Études du Techniques de l'Équipement and TNO-Human Factors) contributed directly by suggesting both national and international studies. At TNO Human Factors this information was compiled and complemented with research completed at TNO as well as other relevant national or international publications.

Results: A total of 144 papers were found in and from, the available sources. Each paper was rated in terms of its relevance to the subject of the review, as defined above. Ratings applied were 'high', 'moderate', and 'low' (where 'low' is to be distinguished from 'none'). As a result 83 of the total of 144 papers was rated 'none', meaning when reviewed in detail the paper did not deal specifically with the driver-roadside-element interaction in some way.

Abstracts from the remaining 61 relevant papers are presented in Appendix A.

Conclusions:

1. There are not that many studies that have actually looked into driver behaviour, or that – at least – present some ideas about the role of driving behaviour in the chain of events leading to a Run-Off-Road-accident (ROR-accidents)
2. The studies that are available, which are mainly field observational studies, do not really use the best 'proxies' for the risk with which drivers execute the driving task.
3. There is, on the other hand, a relative preponderance of accident-analytic studies, leading to predictive models or tools for benefit-cost analysis that can be applied to ROR-accidents. Useful as they are, for the reasons explained in the beginning of this report this cannot be considered a sufficient basis for the development of adequate countermeasures.
4. Almost all countermeasures that are presently under discussion in the literature are directly infrastructure-based. It is surprising that only once or twice is there mention in the literature of the potential of advanced in-vehicle devices, such as Lane Departure Warning systems, as a remedy for ROR-accidents.

In the light of these results it is recommended that more systematic research on the response of the driving public to changes in a road design is to be conducted. The EU-RISER project will contribute explicitly to this objective.

1 Introduction

Injuries and fatalities due to single vehicle collisions are a significant component of annual road casualties. According to Eurostat (Collin, 2000) 33.8 percent of all fatalities in the European Union in 1998 were the result of single vehicle collisions. This represents over 14,000 lives lost each year of which many can likely be saved through better roadside infrastructure design. The chance of road safety professionals is to find methods and design strategies to reduce these casualties.

The challenge today in roadside design is a lack of direction in the implementation maintenance and operation of these devices. Guard rails, crash cushions, breakaway posts, roadside embankments, and sign-posts are common human -made structures beside the road. There is no clear consensus within the international community about how these should be designed positioned, dimensioned, and operated.

This RISER project is part of the European Union's Common Transport Policy Sustainable Mobility: Perspectives for the Future: Action Program 2000-2004; more specifically: the June 2001 GROWTH call for proposals Task 2.2.3/16: Lifecycle safety impact assessment for road planning, design, construction, operation, and maintenance. The project addresses the current omissions in the current state-of-the-art, and the vision of the project is to develop a knowledge base that can provide better roadside design tools and strategies as current resources are conspicuously incomplete.

The main project outputs of RISER are:

1. A collision database containing information on single vehicle collisions exploiting existing and new data sources,
2. Technical performance data for roadside infrastructure describing the physical interaction of vehicle and roadside in addition to the human factors influencing the collision events,
3. Best practice guidelines for designing roadside environments including road safety audit approaches,
4. Best practice maintenance guidelines identifying the operation and maintenance necessary to ensure adequate safety levels.

This deliverable (D02) of Work Package 1.3 contributes to the final output of the RISER project described under point 2 and 3 above.

2 Lane keeping and speed choice in driving

Considerable research has been done on how drivers manage to stay in their lane. The focus of the present review is to study the research that have explicitly considered the effects that *roadside elements* have on the lane keeping task. The concept in which the road and roadside infrastructure directs the driver's path is referred to as *guidance.* The goal is to learn why drivers sometimes fail in the performance of this task. In particular, there are three major questions that have been around for some time, which are:

(1) How do drivers balance the potentially useful *guidance* information that roadside elements provide with the *risk* that is associated with their presence?
(2) Does behavioural adaptation, of a contra-productive nature, occur after roadside risks have been reduced or eliminated?
(3) What do drivers do in case they are so unfortunate as to leave the road?

Behavioural adaptation after roadside hazards have been treated deserves specific mention because this is often raised as an issue of concern when treatment is being considered. For example, we may take away the risk of colliding with trees only to observe that drivers now move closer to the edge of the road and thereby increase their risk of leaving the lane after all. Question (2) is the general question that is of interest for driver behaviour. Both questions (1) and (2) bear on the 'normal' driving task, i.e., before the critical event of the vehicle actually leaving the road happens. An additional, equally important, question (3) is related to how the drivers react after leaving the road. It is important to note that the driver may leave the road more than once during an accident event and their reactions during the early stages of the accident will have significant consequences on the accident outcome.

It should be realised that answers to all these questions cannot be provided by studying accident statistics or even by in-depth accident analyses. It may sometimes be possible, by reasoning backwards from an accident, to get an idea about what must have gone on in a driver's mind on his way to the run-off-roadway crash. However, in most cases this can not be done with any certainty. We see the result, but not the underlying process. Also, there is no available information on accidents that were avoided. Therefore, it is important to explore the alternative approach; measuring driving behaviour and finding ways to extrapolate the ensuing accident risk from driving behaviour.

3 Behavioural measures for estimating the risk of leaving the lane

What one would like to know, for a given road geometry containing roadside elements, is the 'real' level of risk associated with it. This risk is the result of the driver's interaction with the road infrastructure. Substitute measures or 'proxies' are thus needed to bridge the gap between observable driving behaviour and the level of risk that would ultimately ensue. Obviously, the closer the proxy can be shown to reflect the real driver behaviour, the more valid a study is.

In anticipation of the literature review to be made on available behavioural studies some thought should be given to what, in this case, is the best substitute for accident risk.

In order of ascending validity, the following are available:

(a) Position in lane. This is the most general parameter for describing a driver's tendency to stay away from the edge of the road. However, its fixed value – e.g., as an average over a trip – makes it unsuitable for deriving more refined risk estimates.

(b) SDLP (Standard Deviation of Lateral Position). This is a very popular parameter for describing the steadiness, with which drivers follow their course in the lane, i.e., with which they succeed in keeping lateral position at a constant value. By itself, however, SDLP can not provide a probability of leaving the lane.

(c) Extrapolation from lane position and SDLP to probability of lane departure. It is clear that when average lane position and SDLP are combined, and some underlying distribution of SDLP is measured or assumed, probabilities of lane departure can be estimated. A problem with this approach is that it will always be working in the tails of statistical distribution functions, so that the ensuing probability estimates are extremely sensitive to the underlying assumptions and/or sampling error.

(d) TLC (Time to Line Crossing). This is the time left for the vehicle to cross the edge line given its current lateral position, its speed, its turning angle, and its rate of turning. The essence of TLC is that it incorporates all relevant longitudinal and lateral parameters at the same time.

(e) Frequency and/or extent of lane departures. Within a behavioural study one may, finally, decide to measure lane excursions as they actually occur. Although this appears to be the closest to 'real' risk as one could get, problems of sampling error often stand in the way of a direct extrapolation.

All these measures capture the quality of normal, uninterrupted driving. Obviously they have little meaning once the vehicle leaves the road. In that case one would rather look into the more abrupt actions a driver would take.

4 Behavioural measures for estimating speed choice and adaptation

Speed, or rather, speeding, plays a significant role in run-of-road accidents. In many instances drivers lose control of their vehicle because the speed chosen is not appropriate in a given situation. When drivers realise this they tend to release the gas pedal resulting in the fact that the driver now loses complete control of her car, and in many instances a run-off-road accident is the result.
In general it can be said that if a driver can increase speed without increasing perceived task difficulty (or perceived risk) he, or she will do so. This explains why safety interventions that make the driving task easier (such as straightening out a curve) may be consumed by increases in speed. It also explains why it is important to inform a driver about the road environment and it’s task difficulty, for the driver to be able to adapt driving behaviour accordingly. This does not automatically mean that drivers will adapt exactly the way we expect but at least the driver is given enough information to make an informed choice.

One needs to take into account that the highest motivational goal for any driver probably is "to get there as fast as you can", and to maintain their chosen speed level (and thus their chosen progress) as long as possible. This may result in some cases in a speed choice that is not always compatible with the current moment but is a “left over" of the situation beforehand. At higher speeds drivers tend to show a more selective visual search pattern, specifically in a more complex environment. This because drivers have less time available to search the environment when speeds are higher, resulting in possible lower TTC (Time To Contact) measurements. Therefore TTC measurements are an informative measurement in this context.

5 Organisation of the review

Candidate studies were obtained from a literature search in the available sources. A paper was retained for a more detailed review if it dealt with the driver-roadside element interaction in some way. These papers were also scrutinised to see whether they could possibly be included in a so-called meta-analysis – a statistical methodology which extracts a summary estimate of effects from a collection of individual studies (see, e.g., Elvik, 1996 or Hagenzieker, 1999) - to be performed separately.

Each paper was rated in terms of its relevance to the subject of the review, as defined above. Ratings applied were 'high', 'moderate', and 'low' (where 'low' is to be distinguished from 'none'). The criteria for these ratings were as follows:

- 'High': paper reports actual observations of driver-infrastructure (i.e., driver-roadside elements) interaction
- 'Moderate': Either (1) Paper includes some reference to underlying driver-infrastructure interaction mechanisms, though not on the basis of actual observation; or (2) Paper focuses on useful neighbouring driver behaviour issues rather than directly on issues of review.
- 'Low': paper is relevant as background material to driver-infrastructure interaction mechanisms.

The abstracts from the relevant papers are presented in Appendix A.

6 Summary of results of the review

Before dealing with the three main questions that were identified at the beginning of this report some general observations on the reviewed literature can be made, given the context the studies should relate driver behaviour to roadside elements:

(1) There are not that many studies that have actually looked into driver behaviour, or that – at least – present some ideas about the role of driving behaviour in the chain of events leading to a ROR-accident.
(2) The studies that are available, which are mainly field observational studies, do not really use the best 'proxies' for the risk with which drivers execute the driving task.
(3) From this paucity of data on driver-road infrastructure interaction at the behavioural level we must conclude that there is no hope of performing a sensible, i.e. statistically warranted, meta-analysis.
(4) There is, on the other hand, a relative preponderance of accident-analytic studies, leading to predictive models or tools for benefit-cost analysis that can be applied to ROR-accidents. Useful as they are, for the reasons explained in the beginning of this report this cannot be considered a sufficient basis for the development of adequate countermeasures.
(5) Almost all countermeasures that are presently under discussion in the literature are directly infrastructure-based. It is surprising that only once or twice is there mention in the literature of the potential of advanced in-vehicle devices, such as Lane Departure Warning systems, as a remedy for ROR-accidents. However, also in the case of an in-vehicle remedy for ROR-vehicles instead of an infrastructural solution it should be noted that the relevance of driver behavioural studies is high, as these systems can only be designed adequately if it is known what behaviour they should deal with in the first place (i.e., prevent or correct).

6.1 How do drivers balance guidance and risk?

The relevant results can be summarised as follows:

- The majority of results appear to indicate that drivers simply tend to move away from obstacles along the roadside, and that this effect can extend to a considerable (lateral) object distance.
- This strategy is followed only as long as moving away would not present a new risk by itself, such as would be the case in a narrow lane. In that case, a reduction in speed is the driver's preferred reaction.
- The moving away response may be temporary; i.e., drivers may get back to their original lateral position after a while (in case of a continuous object).
- The above effects are a function of the type of obstacle, in particular, of the perceived threat of the obstacle. This is particularly the case in narrower lanes.
- A few studies indicate that there may, nevertheless, be situations in which the guidance provided by roadside elements appears so strong that

drivers tend to drive rather close to them. It is not easy to single out the conditions under which this happens, but this may be an effect of the perceived presence of other risks (which may then be reduced by the extra guidance provided by the roadside element).

In conclusion, while there are some bits and pieces available to build a framework to understand how drivers balance the risk and the guidance possibilities of roadside objects and how that translates to their preferred lane position, the total picture is far from comprehensive yet.

6.2 Behaviour after leaving the road

There appears to be overall awareness that this is an important element, and that the degree to which driving behaviour after leaving the road can be adequately represented determines the ultimate success of, e.g., the modelling of encroachment episodes by means of simulation. Nevertheless, we have been unable to locate a single study that has dealt explicitly with this issue.

6.3 Behavioural adaptation

If we knew how drivers trade off guidance and risk elements we would also be capable of predicting behavioural changes after, e.g., an intended treatment of roadside hazards. For reasons given earlier, however, the issue of possible behavioural changes of a contra-productive nature deserves to be mentioned separately.

The evidence that comes from the reviewed studies does not permit an unequivocal conclusion on this issue. While there appears to be no reason for overall concern, there are also indications that unexpected behavioural changes by drivers may sometimes occur. For the time being it is probably wise to be aware of the possibility that drivers could show behavioural adaptation. That is that road designers should not assume that driver behaviour will remain unchanged after an infrastructure change has been performed.

7 What next?

Although fragmented bits and pieces of evidence are available from the literature, and although they permit to sketch the outlines of a framework in a qualitative sense, a major effort is still required to get to a comprehensive model of how drivers deal with the lateral risks (obstacles or hazards) involved in the driving task. A simulator experiment, with its conditions derived on the basis of the available qualitative evidence, appears an appropriate way to do so. It should, in particular, address the following points:

- When do drivers move away from roadside obstacles, and when do they prefer to approach lateral obstacle to seek guidance?
- How do these processes depend on obstacle characteristics?
- How do these processes depend on driver characteristics?

An advantage of doing a driver behaviour investigation in a simulator would be that this permits the measurement of the most sophisticated risk proxies, as discussed in Section 2 of this report. These are often difficult to obtain in field studies, but are run-of-the-mill in a simulator.

A simulator study would also be the most appropriate way to study driver behaviour after the vehicle has left the road. This would require some experimental ingenuity, since the design of the study would have to be such that drivers would experience these occasions with sufficient frequency. Since they do not naturally happen very often, means would have to be found to induce them artificially.

8 References

Collin, C. Statistics in Focus- transport, Eurostat catalogue number CA-NZ-00-003-EN-I, 2000

Elvik, R. A meta-analysis of studies concerning the safety effects of Daytime Running Lights on cars. Accident Analysis and Prevention, 1996(28).

Hagenzieker, M. Rewards and road user behaviour. PhD Thesis, Leiden University, 1999.

Appendix A: Abstracts of literature study

Authors:	AASHTO	
Title:	Roadside Design Guide	
Published:	2002 (supersedes the 1996 2nd Edition)	
Relevance: Moderate		

Abstract:

Roadside design might be defined as the design of the area between the outside shoulder edge and the right-of-way limits.

All guidelines are on the basis of the ‘forgiving roadside’ concept.
Design options for reducing roadside obstacles, in order of preference, are as follows:
(1) Remove the obstacle.
(2) Redesign the obstacle so it can be safely traversed.
(3) Relocate the obstacle to a point where it is less likely to be struck.
(4) Reduce impact severity by using an appropriate breakaway device.
(5) Shield the obstacle with a longitudinal traffic barrier designed for redirection or use a crash cushion.
(6) Delineate the obstacle if the above alternatives are not appropriate.

Rating of relevance is only ‘moderate’ because the document contains very little about driver-infrastructure interaction.

Authors:	Anderson, R.L.	
Title:	Washington's initiative.	
Published:	Utility Safety. Mobilised for Action and State, City, and Utility Initiatives in Roadside Safety. Presentations from TRB Committee on Utilities, 79th Annual TRB Meeting, 2000	
Relevance: Low		

Abstract:

Describes example of successful co-operation and communication between DOT and the utility industry in Washington State (USA).

Authors:	Bakker, P.J. & van der Horst, A.R.A.	
Title:	The behaviour of car drivers near noise barriers on motorways.	
Published:	Soesterberg, The Netherlands: TNO Institute for perception (Report IZF 1985 C-20)	
Relevance: High		

Abstract:

The behaviour of car drivers was investigated in relation to the presence of a noise barrier by means of video observations. A before and after study was performed. The position of free moving cars was analysed on four cross sections covering 200 meters before the noise barrier till 100 meters after the barrier. Near the beginning of the noise barrier a shift to the left of the average lateral position was found compared to the average lateral position 100 meters before the barrier; 100 meters after the beginning of the barrier the average position was the same as 100 meters before: see Figure. This effect was not found in the before study. The effect however was small. Nevertheless this study shows that drivers respond to the ‘beginning’ of objects even if the distance to the barrier is quite large (in this study 5 meters).

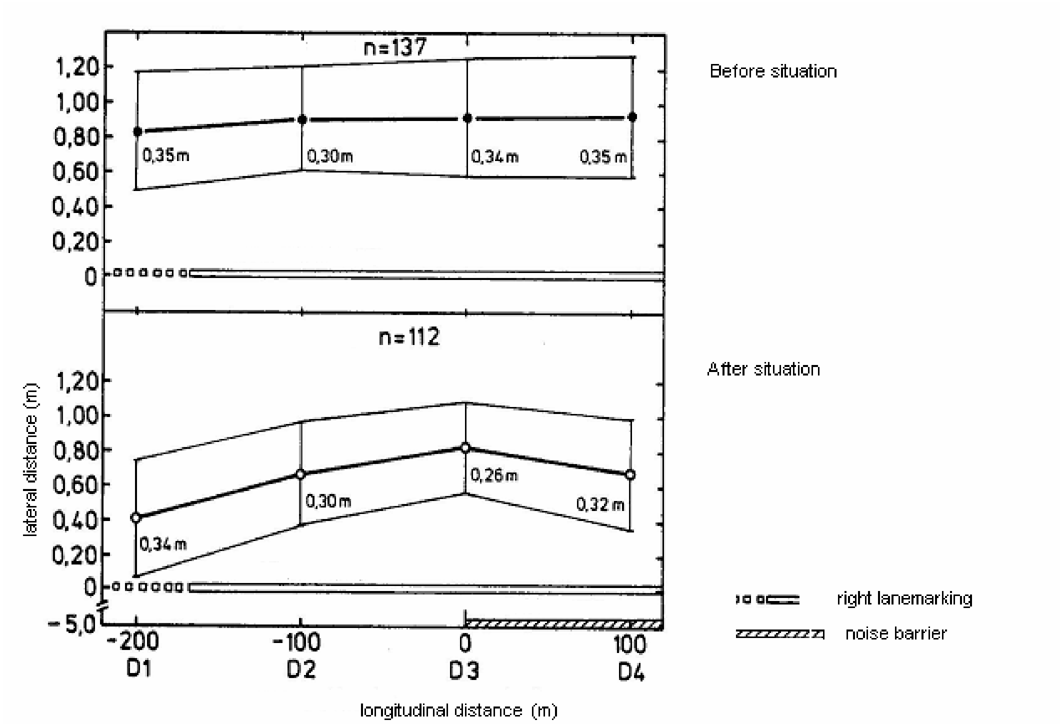


Fig. 1: Lateral position before and after implementation of noise barrier.

Authors:	Blaauw, G.J. & van der Horst, A.R.A.	
Title:	Lateral positioning behaviour of car drivers near tunnel walls – Final report	
Published:	Institute for Perception, Report IZF 1982 C-30	
Relevance: Moderate		

Abstract:

An experimental programme was executed with the aim of analysing the lateral positioning behaviour of car drivers in the vicinity of tunnel entrances in relation to (changes in) the available lateral distance between the right shoulder line and the right tunnel wall. Two tunnels were selected: 1) the Benelux tunnel with a sudden 3.25 m narrowing due to the wall (4.05 to 0.80 m) at 100 m before the tunnel entrance, and 2) the Vlake tunnel (control condition) with a constant free lateral distance of 4.05 m. Normal traffic in the right lane was recorded with video equipment during the approach and entrance to the tunnels, and the lateral positions of cars were analysed quantitatively. At the location of the sudden narrowing of the wall at the Benelux tunnel free moving and clustered cars show a mean shift of 0.33 m to the left in relation to their position 100-m before that narrowing. This shift increases further after the narrowing of the wall, reaching a maximum value of 0.70 m at just the location of the well-known 'black hole' at the tunnel entrance. The shift decreases again after that entrance. No systematic shift in lateral position could be noticed for the cars at the control location of the Vlake tunnel.

Rating of relevance is only 'moderate' because study does not deal with target roadside hazards, yet sheds light on how drivers respond to the presence of lateral objects.

Authors:	Bligh, R.P. & Mak, K.M.	
Title:	Crashworthiness of roadside features across vehicle platforms	
Published:	TRR 1690 (1999), 68-77	
Relevance: Low		

Abstract:

Each year more than 14,000 persons are killed and 1 million persons are injured as a result of roadside crashes. Recent estimates of the annual societal costs associated with these roadside crashes amount to $80 billion. Clearly, there is a need for further understanding of the roadside safety problem. The impact performances of roadside safety features are typically evaluated through full-scale crash testing with two vehicles selected from the extremes of the passenger vehicle fleet in terms of weight and size. The implicit assumption is that if a roadside safety feature successfully passes the test requirements for vehicles at the extremes for the fleet, the feature will perform satisfactorily for all other vehicles in between. Many vehicle parameters could influence performance during impacts, and this assumption may or may not be valid. The safety performances of roadside features for various passenger car platforms and light-truck subclasses were evaluated. The study approach consists of evaluations of the frequency and severity of roadside crashes for these generic platforms and subclasses by using recent crash data from the Fatal Accident Reporting System, the General Estimates System, and the Highway Safety Information System.

On the basis of the crash data analysis presented herein, the current test vehicles specified in *NCHRP Report 350*, that is, the 820-kg passenger car (820C) and the 2000-kg, ¾-ton pickup truck (2000P), appear to be good surrogates for the vehicle fleet on the basis of the ''worst practical condition'' philosophy.

Authors:	Bottoms, D.J.	
Title:	The interaction of driving speed, steering difficulty and lateral tolerance with particular reference to agriculture.	
Published:	Ergonomics, 1983(26), 123-139	
Relevance: High		

Abstract:

The paper describes an experiment designed to test an index of tracking difficulty for agricultural driving tasks as an analogy to Fitts' Index of Movement Difficulty. The proposed index is defined as a function of the ratio of the vehicle width to tolerance available. The results suggest that while the original proposal had some merit a better index may be one in which the dominant term is the reciprocal of the maximum heading angle error.

A 'swinging gate', with varying tolerances, was constructed through which drivers had to steer a tractor. Tolerances (margins, to two sides) were small, varying between 105 and 510 mm. Driving speed was inversely proportional to tolerance, varying between 0.75 and 3.66 m/s.

Authors:	Boyle, J.	
Title:	Clear the way to roadside safety	
Published:	Traffic Safety, 1998, 98(5), 12-13	
Relevance: Moderate		

Abstract:

More than one in four deaths on U.S. roads involve vehicles that leave the road and hit a fixed object. In 1996, nearly 12,000 people died in roadside-hazard crashes. According to the Insurance Institute for Highway safety, trees are the most common objects struck in roadside-hazard deaths. Embankments, utility poles, and guardrails follow as the next most prevalent causes. Despite the serious threat posed by trees that grow close to the road, there is a great deal of opposition from environmentalists to their removal. While burying power lines or moving utility poles farther away from the road would be the ideal way to remove the hazard, both of these solutions cost money. Utility and light poles can be designed to break away upon impact, which can greatly reduce the potential for serious injury. New devices can also address the threat posed by guardrails. Collapsible crash cushions are yet another device designed to make roadside obstacles less hazardous. While these types of technologically advanced solutions are being increasingly used on federal and state highways, they are less common on rural roads, where 63% of roadside-hazard deaths occur. Pointing out that staying on the road is the key solution to it all, Ken Kobetsky of the American Association of State Highway and Transportation Officials has called for a comprehensive program to improve driver guidance through better pavement markings and delineation, as well as a targeted shoulder rumble-strip program. A sidebar discusses the dangers of rural mailboxes.

Rating is only ‘moderate’ because paper does only indirectly consider driver-infrastructure interaction.

Authors:	Brouwer, R.F.T., Janssen, W.H., & Muermans, R.C.	
Title:	Sustainable safe road categories and characteristics: The influence of the environment on the categorisation of road images.	
Published:	Soesterberg, The Netherlands: TNO Human Factors (Report TM-00-C012)	
Relevance: Low		

Abstract:

As part of the Sustainable Safety programme in the Netherlands the Dutch road network has been reclassified comprising essentially only two urban and three rural road categories or classes. Integral to this is an ongoing research project aimed at defining road and other design elements that visually distinguish the different road classes, making them recognisable to the road user and thereby provoking the correct road user behaviour. This study is part of this research program.

In the experiment three road layout alternatives were combined with three different environments. The environments differed in the type of road marking used and the absence (or presence) of side markers. To investigate the effect of the environment on road classification the different road layout alternatives were embedded in three different environments, called 6-4, 9-1, and neutral. In the 6-4 and 9-1 conditions the environment was altered such that the compatibility between the environment and the road category varied. The compatibility between environment and road category was higher in the 9-1 condition than in the 6-4 condition. In the condition with the neutral environment the complete environment of the road was eliminated with the exception of the relevant road characteristics.

Each combination of road layout alternative and environment was investigated with three different tasks, a sorting task, a learning task and an expectations task. In the sorting task the subjects had to sort photographs of road scenes on basis of expected road user behaviour (i.e., roads where similar behaviour was expected were to be sorted into one category). There were no restrictions. So, subjects could sort the material in any number of road classes they deemed fit and the number of photographs in a class could differ. The learning task was used to investigate whether the road layout could be used to learn the different road categories. The expectations-task was used to investigate the correctness of the subject's expectations regarding the presence of other road users and maximum driving speed on roads. Furthermore, subjects had to indicate, irrespective of the speed limit, at what speed they would drive on the roads.

It was concluded on basis of the results of the three tasks that the alternative road layouts were more in agreement with the official classification than baseline layout. Moreover, the road environment influences the perceived classification of

roads. This latter result is of importance for the re-categorisation of the (Dutch) road system.

Authors:	Carney, J.F. III & Ivey, D.L.	
Title:	Engineering for Action.	
Published:	Utility Safety. Mobilized for Action and State, City, and Utility Initiatives in Roadside Safety. Presentations from TRB Committee on Utilities, 79th Annual TRB Meeting, 2000.	
Relevance: Low		

Abstract:

Safety treatments for poles that can't be moved are:

- Guard rails
- Crash cushions
- Concrete barriers, and
- Steel reinforced safety poles (SRSPs)

Authors:	Case, H.W., Hulbert, S.F., Mount, G.E., Brenner, R.	
Title:	Effect of a roadside structure on lateral placement of motor vehicles.	
Published:	Highway Research Board, 1953(34).	
Relevance: high		

The paper reports the findings on a study on effect of a roadside structure (a barrier) on lateral placement. Lateral placement was measured photographically as the automobiles travelled 300 feet of the highway immediately preceding the barrier object. The barrier object was placed as three different distances from the highway edge. At the same time it was adjustable for three different widths. Thus there were nine experimental conditions investigated. The barrier object was constructed of 1/4 inch plywood and may be described as a U-shaped screen. When the sides were fully extended, it was 8 feet on the side and 8 feet high. The three widths were 3 ½ feet, 5 feet, and 8 feet. The three distances employed were ½ feet, 3 feet, and 7 feet.

The major conclusions are:

1. The reaction to distance is of a higher order of magnitude than the reaction to size; however, neither of these reactions is significant over and above the interaction effect,
2. Maximum reaction occurs farther from the barrier as it is placed closer to the road,
3. Even under minimum size and distance conditions, the average pullover was 5 inch.

Authors:	CETE (Centre d'Études techniques de l'équipement, Normandie Centre, Division exploitation et sécurité)	
Title:	Étude de l'influence des accotements revêtus sur le comportement des usagers	
Published:	Nov. 1989	
Relevance: Moderate		

Abstract:

Calculations on the basis of vehicle speed, driver's reaction time, and the estimated angle at which vehicles cross the edge line lead to a recommended hard shoulder width. These recommendations were put into practice on a number of roads, and their behavioural effects (by means of video recording) as well as their effects on accidents were assessed.

- Speed was measured before and after paving of shoulders on ten sites: no change in speed was observed.
- Accident frequency was reduced considerably but not significant
- Traffic on paved shoulders has been observed with a camera coupled to a sensor: 95 % of the vehicles running out of the traffic lanes encroach less than 50cm-deep on paved shoulders.
- Paved shoulders are used not only for recovery manoeuvres, but also by the vulnerable road users (pedestrians, cyclists) and slow-moving farming vehicles, for emergency parking, and avoidance manoeuvres of vehicles turning left from the traffic lane.

Authors:	CETE (Centre d'Études techniques de l'équipement Normandie Centre, Division exploitation sécurité gestion des infrastructures)	
Title:	Évaluation des marquages à protubérances	
Published:	April 1991	
Relevance: Moderate		

Abstract:

Global results are reported of an evaluation of rumble strips on motorways in France, by automatic video registration methodology. Lane excursions after implementation of rumble strips were less frequent and with a lower amplitude in some but not all cases.

Authors:	CETE (Centre d'Études techniques de l'équipement Normandie Centre, Division exploitation sécurité gestion des infrastructures)	
Title:	Accotements et cinématique des véhicules légers (effet de la dénivellation chaussée/accotement)	
Published:	June 1998	
Relevance: high		

Abstract:

There is a certain type of accident in which a vehicle diverges onto the soft shoulder and the subsequent corrective action of the driver causes it to cross over to the other side of the road. This study reports on the handling required to deal with one of the important parameters in this type of situation, which is the difference in surface levels between the pavement and the shoulder. Three pavement-shoulder drop-offs were compared: 3, 6 and 9 cm.
The testing was carried out on a special track with a panel of 60 car drivers in an instrumented vehicle:

- The driver's action on the steering wheel to get back on the road is disproportionate. Mean angle of the driving wheel to get back onto the road is 68°.
- A 9cm-high pavement-shoulder drop-off generates a higher transverse acceleration and a higher return angle, compared to the 3 and 6 cm drop-off.
- Driving speeds in this study were lower than 80 km/h. A computer model of transverse acceleration as a function of speed shows that the loss of control occurs sooner, that is, with lower speeds when the drop-off gets higher. That difference is 5-10 km/h when comparing the 3 and 6 cm drop off with the 9-cm drop-off.
- A 12cm-high shoulder drop-off was also tested. This was clearly too high.
-

The following recommendations are given:

- The skid resistance of the shoulder should be similar to the pavement's, in order to cope with any high-angle steering wheel action.
- A presumably 9-cm, but certainly 12cm-high pavement-shoulder drop-off should be avoided.
- No pavement-shoulder drop-off is ideal

Authors:	CETE (Centre d'Études techniques de l'équipement Normandie Centre, Division exploitation sécurité gestion des infrastructures)	
Title:	Évaluation sur les vitesses de la suppression des plantations d'alignement – cas de la RD1314 en Seine-Maritime	
Published:	Nov. 2000	
Relevance: High		

Abstract:

This paper reports on a before-and-after study, including a control location, on the effects of cutting down trees that were very close to the roadway (within 0.50-1.50 m) on a rural road (single carriageway with median road marking and two 2.70cm wide lanes). The following results are reported:

- Average as well as 85-th percentile speed dropped by about 2.5 km/h
- Drivers moved their lateral position towards the centre of the road (60% reduction in the number of vehicles driving less than 30 cm from the edge, 40% reduction in driving less than 50 cm from the edge). Apparently, drivers had been using the trees for lateral guidance in the before situation.

Authors:	CETE (Centre d'Études techniques de l'équipement Normandie Centre, Division exploitation sécurité gestion des infrastructures)	
Title:	Influence sur les vitesses de la réalisation d'accotements revetues – cas de la RD56 en Seine Maritime du PRO+500 au PR2+630	
Published:	Nov. 2001	
Relevance: Moderate		

Abstract:

A before-and-after study, with a control location, was conducted on driving speed of passing vehicles on a 6m wide rural road in France to evaluate the effects of implementing a 0.80m wide hard shoulder. There were 8 experimental locations. On 7 out of these there was no difference in average speed and v85 after the change.

Authors:	CETE (Centre d'Études techniques de l'équipement Normandie Centre, Division exploitation sécurité gestion des infrastructures)	
Title:	Evaluation sur les vitesses de la suppression des plantations d'alignement – Cas de la RD27 dans le Calvados	
Published:	June 2002	
Relevance: High		

Abstract:

A before-and-after study, with a control location, on the effects of cutting down trees that were very close to the roadway (within 0.50-1.00 m) on several locations on a rural road led to the following results:

- There was no common effect on the average or on 85-th percentile speed: the effects differed over experimental (treated) locations, although there was a weak tendency towards speed reductions.
- Drivers moved their lateral position towards the edge of the road (increase from 6 to 12% of the total number of passing vehicles driving less than 40 cm from the edge, and from 17 to 28% in driving less than 60 cm from the edge). This is the opposite result from one reported earlier by the same agency (study on RD1314). It could be explained by noting that, after the trees were cut down, a line of bushes became visible that now could have guided the drivers, instead of the trees.

Authors:	CETE (Centre d'Études techniques de l'équipement Normandie Centre, Division exploitation sécurité gestion des infrastructures)	
Title:	Influence de la réalisation d'accotements revêtus sur le comportement des usagers – Cas de la RD982 en Seine-Maritime	
Published:	Nov. 2002	
Relevance: Moderate		

Abstract:

This study reports on the effects of adding a hard shoulder (110 cm wide) next to a two-lane road (2x3.15m). There was no effect on average speed or 85-th percentile speed. An effect was found on lateral position: the number of vehicles that drove close to the edge line increased somewhat. The percentage of vehicles that drove closer than 40 cm to the line rose from 8.2 to 10.1. The percentage of vehicle that drove between 40 and 60 cm from the line increased from 10.7 to 13.5 %.

Authors:	Dijkstra, A.	
Title:	Orientation of quantitative relations between elements of road design and indicators of road safety	
Published:	Leidschendam, The Netherlands: SWOV (Report R-98-49	
Relevance: Moderate		

Abstract:

This study is a literature review research concerning the quantitative relations between road design and the likelihood of accidents. Knowledge on these relations may improve road design. The most relevant part of this study is concerned with the space between the road edge and obstacles, the ‘obstacle free zone’.

The author refers to studies that will also be described elsewhere in this report (e.g., Zegeer et al., 1988). It is concluded that most research on this issue is rather old and not all undisputed. Because of the obvious importance of the distance between road edges and obstacles new research is therefore required.

Authors:	DVK	
Title:	ROA Hoofdstuk VI Veilige inrichting van bermen (Chapter 6: safe construction of shoulders)	
Published:	1989	
Relevance: Low		

Abstract:

Contains guidelines on the safe design of soft and hard shoulders. No reference is made to driver-infrastructure interaction backgrounds.

Authors:	Evans, L.	
Title:	Low-volume road geometric design practices in the national forests of the United States	
Published:	International Symposium on Highway geometric design practices, 1995	
Relevance: Low		

Abstract:

On this type of road – which are usually gravel roads – no shoulders are required. And neither are clear zones, because this is mostly impossible to achieve in forest and mountainous areas. For two-lane roads, however, a clear zone of 1.2m min is desirable.

Authors:	Geary, G.M.	
Title:	Georgia's initiative.	
Published:	Utility Safety. Mobilized for Action and State, City, and Utility Initiatives in Roadside Safety. Presentations from TRB Committee on Utilities, 79th Annual TRB Meeting, 2000	
Relevance: Moderate		

Abstract:

Recommended pole locations in Georgia:
- 12 ft desirable
- 6 ft minimum at 35 mph or less
- 8 ft minimum for speeds over 35 mph

The typical utility pole crash:
- Young male drivers
- Alcohol/drug involvement
- Lack of seat belt use
- Lower-speed roads in metropolitan areas
- Large proportion of cross-over crashes

This paper contains some useful information on the characteristics of drivers who have more than their share of ROR crashes, although not going into detail on their actual driving behaviour.

Authors:	Hogema, J.H. & Brouwer, R.F.T.	
Title:	Estimation of behavioural effects of dynamic cross sections	
Published:	Soesterberg, The Netherlands: TNO Human Factors (Report TM-99-C008)	
Relevance: Low		

Abstract:
The road capacity of motorways can be increased (e.g., during rush hours) by using narrower lanes. Then an extra lane can be introduced while an emergency lane is maintained. In this report a literature survey was carried out to investigate the effects of narrow lanes of driving behaviour. The findings were reviewed in light of a simulation model that could be used to assess the effects of different design options.

The survey showed an effect of lane width on driving speed and on the variation in lateral position. Other effects have been suggested (e.g., overtaking and longitudinal behaviour) but these effects were not based on quantitative data.

The report describes a rule for the assessment of indicated speed limits on the actual speed driven. The relation between speed driven en speed limit is described with the equation

$$Vs = Vl + K * (Vo - Vl) + c,$$

Where *Vs* is the driving speed with the speed limit, *Vl* the speed limit indicated, *Vo* the driving speed without the speed limit and *c* is a constant. The value *K* was interpreted as a ‘disobedience factor’ with a value between 0 and 1. This factor depends upon the level of enforcement. Using this model on ‘normal’ driving simulator data yielded a level of *K* equal to 0.80.

Authors:	Horne, D.A.	
Title:	Precedents for Action.	
Published:	Utility Safety. Mobilized for Action and State, City, and Utility Initiatives in Roadside Safety. Presentations from TRB Committee on Utilities, 79th Annual TRB Meeting, 2000.	
Relevance: Moderate		

Abstract:

Countermeasures to deal with utility pole collisions in the US include the following:

Countermeasures – Highway Agencies

- Keep vehicles on the roadway
  - Pavement markings
  - Delineators
  - Skid resistance
  - Widen lanes
  - Widen, pave shoulders
  - Straighten curves
- Safety devices
  - Steel-reinforced safety poles
  - Guard rails
  - Crash cushions
  - Concrete barriers
- Warn motorists of obstacles
  - Reflective paint, sheeting, markers on poles
  - Roadway lighting
  - Warning signs
  - Rumble strips

Countermeasures – Utilities

- Locate underground
- Increase lateral offset
- Locate where less likely to be struck
  - Behind ditches, guard rail
  - Inside of curves
  - Avoid end of lane drop
- Reduce number
  - Joint use
  - One side of highway
  - Increase spacing
- Breakaway poles, guidelines

Study 1

Authors:	van der Horst, A.R.A., & Hoekstra, W.	
Title:	Effects of speed-reducing measures at 80 km/h roads Drenthe on driving behaviour: a simulator study (Report IZF 1992 C-30, 1992)	
Published:	Soesterberg, The Netherlands: TNO Institute for Perception	
Relevance: Moderate		

Study 2

Authors:	van der Horst, A.R.A., & Bakker, P.J.	
Title:	Effects of speed reducing measures at 80 km/h roads in Drenthe on lateral placement of vehicles (Report TNO-TM 1994 C-25, 1994)	
Published:	Soesterberg, The Netherlands: TNO Human Factors	
Relevance: Moderate		

Abstract:
To improve traffic safety on the 80 km/h roads in the Netherlands two studies were performed regarding the effects of profiled markings on driving behaviour. In the first study, a driving simulator study, the effects of three patterns of profiled markings were investigated (continuing, a small profiled marking each five meters, and a small profiled marking each ten meters). There was an edge strip of either 0.2 m (resulting in a 'lane width' of 2.75 m) or 0.7 m width (resulting in a 'lane width' of 2.25 m). The control condition was a drive on a conventional 80km/h road. The results showed that the largest speed reduction was obtain on the narrower lane width of 2.25 m. The relative lateral position remained the same for the different lane widths, on average subjects drove left of the middle. The different layouts of the edge strips showed only relatively small differences. The conclusion was that the tested design elements offered a good prospective in reducing driving speeds in practice.

In the second study video observations were analysed of a road with speed reduced measures on an 80 km/h road. These measures took place on a 2.25m wide traffic lane with smooth asphalt, a 0.60m profiled edge strip (four meters long blocks of chipping with a spacing of four meter) and a 0.30m central marking also profiled. Video observations of a control location (lane width 2.75m) were also analysed. The results showed that on the experimental location drivers on average drove 0.10m more to the right of the lane than on the control condition. When passing on-coming traffic lateral placement was not influenced by the measures. So with respect to the lateral placement no negative effects on traffic safety were found as a result of the speed reducing measures.

Authors:	Huang, H.F., Schneider, R.J., Zegeer, Ch. V., Khattak, A.J., Amerlynck, V.J. & Lacy, J.K.	
Title:	Identification of severe crash factors and countermeasures in North Carolina	
Published:	August 2001	
Relevance: Moderate		

Abstract:

This report examines the roadway, crash, vehicle, individual, and environmental factors that are associated with fatal and serious injury crashes in North Carolina between 1993 and 1997. Factors associated with significantly high crash severity on all roadway types include curve, run0off0road, utility pole, tree, head-on, pedestrian, bicycle, darkness, and alcohol use. The final section of the report recommends countermeasures that can be used to reduce the incidence of fatal and serious injury crashes associated with these factors.

Run-off-road crashes accounted for almost 40 percent of the severe crashes and 42 percent of the fatal crashes.

Countermeasures:

<ins>Run-off-Road Crashes (General)</ins>
- Install shoulder or mid-lane rumble strips
- Improve delineation of curves
- Provide new or existing pavement markers at appropriate locations
- Improve roadway geometric, especially for horizontal curves
- Provide skid-resistant pavement surfaces
- Ensure consistency in design so that appropriate speeds are chosen

Utility pole crashes
- Remove poles and place utility wires underground
- Relocate poles further from the roadway edge
- Reduce the number of poles
- Install breakaway poles
- Use other countermeasures

Tree crashes
- Remove trees in hazardous locations
- Provide guard rail
- Modify roadside clear zone

Authors:	Hutchinson, J.W. & Kennedy, T.W.	
Title:	Medians of divided highways – Frequency and nature of encroachments.	
Published:	Engineering Experiment Station Bulletin 487, U. Of Illinois, 1966	
Relevance: Moderate		

Abstract:

This paper derives encroachment rates (into median areas) as a function of ADT. This function is found not to be monotonous. First, it rises over low volumes, which is hypothesised to be cause by driver drowsiness or general inattention when there is little traffic in the surroundings. The graph then drops, over the 3000-6000 ADT range, which is explained by drivers now having to pay more attention to surrounding traffic and being at the top of their attention level. Beyond those levels of ADT the curve rises again, possibly because traffic is now becoming so dense that drivers find increasing difficulty in dealing with it.

This paper is highly relevant because it tries to provide an explanation of field data on the basis of hypothesised driver behaviour mechanisms.

Authors:	Irving, A. & Bowles, T.S.	
Title:	The importance of driver limitations in vehicle control.	
Published:	Proc. Inst. Mech. Engineers, 1968 (183)	
Relevance: High		

Abstract:

This experiment studied speed choice as a function of available margin (to both sides, i.e., in a ‘gate’) for small obstacle margins (50 cm max). Speed was inversely, and linearly, related to available margin. Furthermore, speed was lower the more ‘threatening’ the obstacle was (plastic vs. wood vs. concrete).

Authors:	Johnson, K.	
Title:	How to prevent run-off-the-road crashes	
Published:	Traffic Safety, 2000(3), 17-19	
Relevance: Moderate		

Abstract:

According to data from the Fatality Analysis Reporting System, in 1998, 15,305, or 37% of the nation's 41,741 fatalities, occurred when single vehicles left the roadway unintentionally. On rural roads, approximately two-thirds of fatalities are the result of run-off-the-road crashes. Thus, it is not surprising that the Federal Highway Administration (FHWA), which has set a goal of reducing the total number of highway fatalities and injuries by 20% in the next 10 years, has made run-off-the-road crashes its top priority. One of the most effective ways to reduce run-off-the-road crashes is the rumble strip. Guardrails, another deterrent, are slightly more complicated. FHWA estimates that virtually all signs and light poles on the national highway system today are of the breakaway type. Minnesota-based 3M is testing magnetic lateral warning and guidance tape as a guide for snowplows operating in heavy snowstorms. Even in poor visibility conditions, drivers can tell where the edge of the road is because of signals from the tape that are picked up by an onboard display in the vehicle's cab. 3M plans to test the tape as a sort of electronic rumble strip to help prevent run-off-the-road crashes.

Authors:	Karr, A.	
Title:	Stayin' alive: avoiding off-the-road crashes	
Published:	Traffic Safety, 2001 (1), 16-22	
Relevance: Low		

Abstract:

Fatalities from run-off-the road crashes have remained fairly constant for many years. Most happen when a vehicle collides with a fixed object such as a tree, a utility pole or sign post near the side of the road. The article describes federal, state and local initiatives to set and implement standards for roadside safety and notes that efforts have stalled in recent decades because of high costs and political resistance. Includes a list of strategies developed by the American Association of State Highway and Transportation Officials.

Authors:	Kim, K.K. & Lei, L.	
Title:	Modelling the causes and consequences of collisions with utility poles	
Published:	Traffic Safety on Two Continents, Lisbon 1997.	
Relevance: Moderate		

Abstract:

In spite of the fact that there has been research on utility pole collisions, the frequency and severity of these collisions continues to increase. While there have been efforts to put utilities underground, at the same time, there has also been an increase in the number of high voltage transmission lines, telephone and cable t.v. lines which often utilise large utility poles. Often these structures are located along major travel corridors and present hazards for motorists. This is a problem common to both Europe and North America. The purpose of this paper is to examine the nature and consequences of utility pole collisions in order to identify appropriate strategies for reducing utility pole collisions and the associated injuries and fatalities.

After describing the characteristics of drivers, roadway and environmental features of utility pole collisions, the medical and financial outcomes, utilising linked data are described. Utility pole collisions are compared to vehicle-to-vehicle collisions in terms of the probabilities of injury using various injury scores (KABC0, ISS, AIS), and average hospital costs. Utility pole collisions are found to be more serious in terms of injury level than vehicle-to-vehicle crashes. A logistic model estimating the odds of being injured in a utility pole collision is also developed. The odds of injury are related to age, gender, belt use, alcohol/drugs, speed, and other characteristics. A preliminary program for reducing utility pole collisions involving engineering, enforcement, and education approaches is developed.

The contribution of this paper might be seen along three different domains. First, it investigates a problem – utility pole collisions, which has continued to plague safety researchers throughout the world. Second, it utilises an interesting database built with probabilistically linked records from many different sources. Finally, the paper provides some examples of spatial and statistical modelling techniques that may be of broader interest.

NB Those striking utility poles tend to be similar in age and gender as those involved in other single vehicle collisions (that is, younger in age and more often male than in vehicle-to-vehicle collisions).

Authors:	Knoflacher, H. & Gatterer, G.	
Title:	Der Einfluss seitlicher Hindernisse auf die Verkehrssicherheit.	
Published:	Wien, Kuratorium für Verkehrssicherheit, 1981.	
Relevance: High		

Abstract:

Reducing lateral clearance to reduce driving speed works to some extent. A reduction of lateral clearance from 30 m to 15 m decreases speed by only 3%. However, when lateral clearance is decreased to 7.5 m a speed reduction of 16% is found. With obstacles directly along the side of the road, driving speed reduces about 13% compared to obstacles placed one meter away from the edge of the road.

Authors:	Kooi, R.M. & Dijkstra, A.	
Title:	Some behavioural effects of non-compulsory lanes on narrow rural roads	
Published:	Leidschendam, The Netherlands: SWOV (Report R-2003-17)	
Relevance: Moderate		

Abstract:

Within the framework of the Sustainable Safety concept a road layout for the so-called ‘rural access road’ was investigated. This road layout consists of a middle carriageway with broken lines as side markings. The remaining asphalt (‘outside’ the side markings) can be coloured (‘red’) and is meant for cyclists. This study present the results of a number of before and after studies to investigate the effect of these ‘non-compulsory (bicycle) lanes’ of driving behaviour of motorists and bicyclists.

The results showed that on non-compulsory lanes both bicyclists and motorists drive further from the road edge, motorists drive slower but the distance between car and bicycle is smaller on these lanes. As yet there is no accident analysis available to indicate safety effects. The results however suggest that road safety is slightly improved.

This research suggests a simple method to ensure that drivers keep away from the road edges and thus from possible obstacles along the road. Applying markings away from the edge of the road. This is already commonly done in the Netherlands on motorways thus creating a ‘recovery’ lane between the left lane and the guardrail.

Authors:	La Belle, D.M.	
Title:	Florida's initiative.	
Published:	Utility Safety. Mobilized for Action and State, City, and Utility Initiatives in Roadside Safety. Presentations from TRB Committee on Utilities, 79th Annual TRB Meeting, 2000	
Relevance: Low		

Abstract:

Description of plans and initiatives; not very concrete.

Authors:	Lee, J. & Mannering, F.	
Title:	Analysis of roadside accident frequency and severity and roadside safety management	
Published:	Washington State Transportation Center (TRAC). Final research Report Research Project T9903, Task 97. December 1999. Also as 'Impact of roadside features on frequency and severity of run-off-roadway accidents', AAP, 2002(34), 149-161.	
Relevance: Low		

Abstract:

In Washington State, priority programming for evaluating accident prevention and mitigation (safety improvement) involves analysis of roadside features, but the effects that such features have on the frequency and severity of accidents is not well understood. This study investigated the relationships among roadway geometry, roadside characteristics, and run-off-roadway accident frequency and severity to provide a basis for identifying cost-effective ways to improve highway designs that will reduce the probability of vehicles leaving the roadway and the severity of accidents when they do.

To better understand the effects of roadside features on accident frequency and severity, the researchers surveyed other states' priority programming practices. The survey showed that proactive approaches, in general, are in their infancy and none of them adequately accounts for the effects of roadside features on accidents.

To quantify the effects of roadside features on accident frequency and severity, the researchers gathered data from the northbound direction of State Route 3 in Washington State. For accident frequency analysis, negative binomial and zero-inflated negative binomial models of monthly accident frequency were estimated. The findings showed both significant differences and similarities in the factors that affect urban and rural accident frequencies. The results indicated that run-off-roadway accident frequencies can be significantly reduced by increasing lane and shoulder widths; widening medians; expanding approaches to bridges; shielding, relocating, and removing roadside hazardous objects; and flattening side slopes and medians. The statistical analysis also provided an estimate of the magnitude of the influence of these factors.

The effects of roadside features on run-off-roadway accident severity were studied with a nested logit model. Roadside features that were found to significantly affect the severity of run-off-roadway accidents included bridges, cut-type slopes, ditches, culverts, fences, tree groups, sign supports, utility poles, isolated trees, and guardrails. As was the case for the frequency analysis, elasticity estimates allowed quantification of the effects of roadside features on accident severity.

Table 24. Summary of findings of roadside feature variables of run-off-roadway accident frequency

Variable (*Urban* sections)	Frequency finding*
Bridge length (in meters)	+
Distance from outside shoulder edge to guardrail (in meters)	+
Fence length (in meters)	+
Number of isolated trees in a section	-
Number of miscellaneous fixed objects in a section	-
Number of sign supports in a section	-
Shoulder length (in meters)	-
Variable (*Rural* sections)	**Frequency finding***
Cut slope indicator (1 if the presence of cut-typed side slopes, 0 otherwise)	
Distance from outside shoulder edge to guardrail (in meters)	+
Distance from outside shoulder edge to luminaire poles (in meters)	-
Number of isolated trees in a section	+

* ‘’+’’ indicates increases accident frequency,
‘’-‘’ indicates decreases accident frequency

Rating for relevance is only ‘low’, because no mention at all of driver-infrastructure interaction factors that may contribute to ROR accidents.

Authors:	Lindley, J.K.	
Title:	Huntsville's initiative	
Published:	Utility Safety. Mobilized for Action and State, City, and Utility Initiatives in Roadside Safety. Presentations from TRB Committee on Utilities, 79th Annual TRB Meeting, 2000	
Relevance: Low		

Abstract:

Recommendations for existing and new trees.
Recommendations for existing and new poles.
Recommendations for existing and new mailboxes.

Authors:	Ljungblad, L.	
Title:	The roadside area and safety fences.	
Published:	VTI Rapport 453, 2000	
Relevance: Low		

Abstract:

The severity of injuries sustained in a run-off-road accident is largely determined by the roadside area. This area was studied through analyses and a review of the literature. A study was first made of the possibility of analysing the influence of the roadside area on run-off-road accidents on roads where the roadside area varies. In order that this should be possible, the location of accidents must be correctly determined. A check on whether position fixing is good enough was made by studying accidents to road barriers where the location of the barriers was known. Position fixing was not sufficiently good to be used.

The accident rate and the injury rate were calculated for run-off-road accidents in which the road barrier had been hit and not hit. These rates are twice as large, or larger, for run-off-road accidents in which the road barrier had not been involved.

The properties of earth cuttings, embankments, hazardous roadside areas and forest/no forest were analysed. The proportions of embankments, hazardous roadside areas and forest/no forest were found significant; although forest/no forest had such little influence that it can be ignored.

Rigid end terminals to safety fences were compared with terminals, which sloped to underground anchorages, but no significant difference was found. In most cases, fatalities or severe injuries were not due to the fact that those concerned had collided with the end terminal, but that they also collided with something beyond the fence. Central barriers are better for preventing head-on accidents than only central reserves. Wide central reserves are better than narrow ones.

Authors:	Martens, M.H. & Brookhuis, K.A.	
Title:	4-0 and 3-1 contraflow systems: effects on traffic safety.	
Published:	Soesterberg, The Netherlands: TNO Human Factors Report TM-98-C049	
Relevance: High		

Abstract:

In a driving simulator study and an on the road study driving behaviour was investigated in work zones on motorways. The driving simulator study comprised driving on two contraflow systems where traffic of one carriageway is completely guided to the other carriageway (a 4-0 system) or partly (a 3-1 system). The left lane width where subjects drove of both systems was also varied (2.50 m or 2.75 m). The left lane was separated from oncoming traffic by a barrier.

The results showed that the duration of crossing the left marking was high (much higher than crossing the right marking) and depended upon the lane width (the narrower the lane width the longer line crossings) and contraflow system (line crossings were longer in the 4-0 system than in the 3-1 system). The explanation given for this result was that subjects could better judge the distance between the barrier at the left side and the car than the distance between the barrier (or other traffic) at the right side and the car. So by minimising the distance between the left barrier and the car subjects increased the safety margin at the left side. The authors suggested that the left marking could be used as a visual guidance. However it can also have been the barrier that provided the visual guidance. So a barrier used to prevent collisions with objects along the road may play a role in visual guidance. A better visual guidance may, for example, increase the driving speed, although no evidence for this hypothesis was found in this experiment.

Authors:	Martin, J.L., Derrien, Y., Bloch, P. & Boissier, G.	
Title:	Severity of run-off-crashes whether motorway hard shoulders are equipped with a guardrail or not	
Published:	Traffic Safety on Three Continents, 2001(?)	
Relevance: Low		

Abstract:

Context – On most French highways, hard shoulders are equipped with safety barriers to protect vehicles from running off the roadway from either punctual obstacles like bridge pillars, or in the presence of embankments or ditches for differences of level above 4 m. The research question is to determine if there would be a global safely gain to the user in systematically equipping all hard shoulders with safety barriers.
Methods – The severity of run-off the road accidents is measured and compared according to if they occur with a protected hard shoulder or a non-protected one, and in the latter case, whether what is off the road is at the same level, an embankment or a ditch. The safety indicator used is the presence of at least one casualty inside the vehicle running off the road. A Logistic model is used to take into account all the different relevant cofactors.
Data – The data relates to five years of observation – 1996 to 2000. The network comprises approximately 2,300 km of motorway located in plains. Three quarters of these roads have two lanes in each direction and one quarter has three lanes. Average traffic is between 10,000 and 60,000 vehicles per day, 10 to 20% of which are trucks. A crash report form is completed whenever a vehicle on or off the motorway cannot resume its journey without being towed away after a crash. All injury-crashes and damage-only crashes are recorded. Information is particularly detailed on the highway infrastructure and its part in the frequency and severity of accidents.
Results – The severity of run-off the road accidents on hard shoulders is on average significantly higher in the absence of a safety barrier. Higher values of severity are connected with run-off the road in the presence embankments or ditches (lower than 4 meters, as others have already systematically been equipped). These results take into account the typology of the accident (number of vehicles involved, different impacts, type of vehicle involved) and of highway characteristics. Despite there being less and less non equipped hard shoulders, severity differences are large enough to be significant, and confirm the results of previous research carried out from 1985 to 1995 on a part of the same network.
Conclusion – Systematic equipment of highway hard shoulders appears to beneficial as a whole within the infrastructure and European traffic conditions, with a better control of run-off the road consequences. Moreover, the subsequent suppression of most of the ends of guardrails should also increase safety.

Authors:	McGinnis, R.G.	
Title:	Strategic Plan for Improving Roadside Safety	
Published:	NCHRP Web Document 33 (Project G17-13): Contractor's Final Report, February 2001	
Relevance: Moderate		

Abstract:

This report summarises the results of the 6-year effort to develop a strategic plan for improving roadside safety in the United States.
The roadside safety problem. Overturn, tree & shrubbery, and pole and post are the three most critical events in roadside crashes (72% of fatalities). Second tier: embankment, longitudinal barrier, bridge rail, bridge-end, bridge pier and ditch. These are responsible for 16% of fatalities.
Roadside safety programs. Major elements in approach are:
(1) Keep the vehicle on the roadway, by means of improvements in:
- Roadway/Roadside design
- Vehicle technology
- Driver programs

(2) Remove, remedy, or shield roadside hazards for those vehicles that do leave the roadway; by means of:
- Forgiving roadside
- Roadside barriers

(3) Minimise injury to occupants of vehicles that collide with roadside hazards; by means of:
- Designing crashworthy roadside hardware
- Evolution of US roadside hardware crash test guidelines
- Evolution of vehicle design
- Driver programs

Roadside safety issues. These are:
- (Raising) awareness of the roadside safety problem
- Funding
- Legislation
- Technology (crash test guidelines; role of computer simulation)
- Agency issues (selection of roadside treatments; performance-level concept; installation and maintenance; crash data; international co-operation and harmonisation)
- Public-private issues (accommodating a changing vehicle fleet; utility poles adjacent to roadways; trees adjacent to roadways; motor vehicle event data recorders).

Strategic plan development. This resulted in formulating 5 missions, 25 goals, 78 objectives, and 359 action items, 221 of that are research-oriented. The missions are:
- Mission 1 – Increase awareness of roadside safety and support for it.
- Mission 2 – Build and maintain information resources and analysis procedures to support continued improvement of roadside safety.
- Mission 3 – Keep vehicles from leaving the roadway.

- Mission 4 – Keep vehicles from overturning or striking objects on the roadside when they do leave the roadway.
- Mission 5 – Minimise injuries and fatalities when overturn occurs or objects are struck in the roadside.

Roadside safety research needs. There are a number of them grouped under each of the 5 missions. There are some driver-behaviour-related ones among them, as follows:

Mission 3.

(A) Safety enhancement tools for highway designers:

- Develop design techniques that meet driver expectations
- Develop uses of 3- and 4-dimensional visualisation technologies for highway design

(B) Improved vehicle-based systems to keep drivers on the road:

- Develop vehicular lateral guidance systems
- Develop guidelines for in-vehicle information systems
- Develop systems to enhance driver night-time visibility
- Develop safety effective driver monitoring systems

(C) Improved driver performance and behaviour:

- Develop educational materials to improve driver behaviour
- Identify driver behaviours that lead to loss of control and roadside encroachments
- Develop model driver education programs
- Develop remedial driver training programs
- Develop improved gradual licensing programs
- Determine the effect of vision tests on highway safety
- Develop speed enforcement strategies that improve RS
- Develop enforcement strategies to reduce impaired driving
- Determine the effect on RS of multiple traffic offenders

Mission 4.

(A) Improved roadside treatments that reduce collisions with roadside hazards:

- Develop conspicuity guidelines for roadside appurtenances

(B) Improved driver performance in ROR situations:

- Identify typical driver responses to ROR situations
- Develop a list of correct driver responses for ROR scenarios
- Develop ROR simulation programs for driver training

Authors:	McGinnis, R.	
Title:	Re-examination of roadside encroachment data (with Discussion)	
Published:	TRR, 1999 (1690), 42-58	
Relevance: Low		

Abstract:

Concerns about the Hutchinson and Kennedy (H&K) encroachment data used as the basis for AASHTO's *Roadside Design Guide (RDG)* procedures for computing guardrail runout length have led to proposed revised guidelines based on more recent data collected by Cooper in Canada. The revised guidelines result in guardrail lengths that are approximately 35 percent shorter. Data from the original H&K and Cooper studies were analysed to determine why the two studies seem to have inconsistent findings. The concerns about the H&K data expressed by the authors who proposed the revised guidelines were found to be invalid. However, team-by-team comparisons of the Cooper data revealed inconsistencies in encroachment rates, lengths, and departure angles for highways with similar speed limits. Documented data collection problems and unanswerable questions about the methodology used to measure encroachment lengths and departure angles make it impossible to validate the accuracy of the Cooper data. Adjustments were made to the Cooper data to compensate for possible data irregularities to examine the consistency between them and the H&K data. No evidence indicating that the encroachment lengths reported by H&K are inconsistently high compared with the encroachment lengths reported by Cooper was found. The findings suggest that reducing guardrail runout lengths from current *RDG* guidelines for highways with high speed limits [112 km/h (70 mph)] may not be prudent.

Authors:	Michaels, R.M. & Cozan, L.W.	
Title:	Perceptual and field factors causing lateral displacement.	
Published:	Public Roads, 1963 (32).	
Relevance: High		

Abstract:

The first reaction of drivers to a roadside obstacle that is close to the road is to perform a lateral action (swerve). This is a pre-emptive action, when drivers can not in time assess whether the object might be on a collision course.

Authors:	Michie, J.D., & Bronstad, M.E. (1994)	
Title:	Highway guardrails: Safety feature or roadside hazard (Article in Transportation Research Record 1468)	
Published:	Washington, D.C., USA: Transportation Research Board	
Relevance: Low		

Abstract:

The study presents a re-interpretation of accident statistics involving highway guardrails. The accident statistics at that time indicated that about 50 – 60% of the guardrail accidents involved an injury or fatality. This led to the suggestion that guardrails should only be used when absolutely necessary. The authors dispute this suggestion and provide a number of reasons why the 50 – 60% is exaggerated. The major reason is that the number of 'accidents' involving a guardrail is underestimated. According to the authors a large number of accidents is not reported to the police and they assume that these accidents are (minor) property-damage-only accidents. On basis of other studies they assume that about 90% of guardrail accidents are not reported. And those that are reported represent the most severe ones. Another reason is the way that accidents are coded by the first harmful event. In this way the chain of events involved in an accident does not have to be reconstructed. However, the authors argue that the first harmful event does not necessarily have to be the most harmful event. A third reason according to the authors is the condition and design of barriers. In the end they conclude that considering unreported accidents and properly designed and maintained longitudinal barriers the 50 – 60% guardrail accidents causing injuries or fatalities are reduce to 2 – 3%. Therefore, the authors state that guardrails are quite successful.

Authors:	NCHRP? (TTI & Mak, K.)	
Title:	RSAP	
Published:	2003	
Relevance: Low		

Abstract:

Report describes the development of RSAP (Roadside Safety Analysis Program), a cost-effectiveness analysis procedure for assessing roadside safety improvements, replacing ROADSIDE program. Uses a stochastic solution method (Monte Carlo); uses re-analysed Cooper encroachment data for encroachment rates and lateral extent of encroachment distributions; uses real-world crash data for impact speed and angle distributions instead of theoretical distributions. Has an encroachment module; a crash prediction module; a severity prediction module; and a benefit/cost analysis module.
NB RSAP assumes a straight path in the crash prediction module (given an initial encroachment angle) because there is no information available on driver inputs subsequent to encroachment (!) This is a limitation.

Authors:	Neuman, T.R., Pfefer, R., Slack, K.L., Hardy, K.K., Council, F., McGee, H., Prothe, L. & Eccles, K.	
Title:	NCHRP Report 500. Guidance for Implementation of AASHTO Strategic Highway Safety Plan. Volume 6: A Guide for Addressing Run-Off-Road Collisions.	
Published:	2003	
Relevance: Low		

Abstract:

To reduce the number of ROR fatality crashes, the objectives should be to
- Keep vehicles from encroaching on the roadside
- Minimise the likelihood of crashing or overturning if the vehicle travels off the shoulder, and
- Reduce the severity of the crash.

This is elaborated into the following strategies:

Keep vehicles from encroaching on the roadside:
(1) Install shoulder rumble strips
(2) Install edgeline' profile marking', edgeline rumble strips or modified shoulder rumble strips on section with narrow or no paved shoulders
(3) Install median rumble strips
(4) Provide enhanced shoulder or in-lane delineation and marking for sharp curves
(5) Provide improved highway geometry for horizontal curves
(6) Provide enhanced pavement markings
(7) Provide skid-resistant pavement surfaces
(8) Apply shoulder treatments (eliminate shoulder drop-off/widen and/or pave shoulders)

Minimise the likelihood of crashing or overturning if the vehicle travels of the shoulder
(1) Design safer slopes and ditches to prevent rollovers
(2) Remove/relocate objects in hazardous locations
(3) Delineate trees or utility poles with retroreflective tape

Reduce the severity of crashes
(1) Improve design of roadside hardware
(2) Improve design and application of barrier and attenuation systems

Each strategy is dealt with in detail.

NB Relevance only rated as 'low' because no mention is made of driver-infrastructure interaction as potential remedial factor.

Authors:	Neuman, T.R., Pfefer, R., Slack, K.L., Hardy, K.K., Council, F., McGee, H., Prothe, L. & Eccles, K.	
Title:	NCHRP Report 500. Guidance for Implementation of AASHTO Strategic Highway Safety Plan. Volume 3: A Guide for Addressing Crashes with Trees in Hazardous Locations	
Published:	2003	
Relevance: Low		

Abstract:

Prevent trees from growing in hazardous locations:
(1) Develop, revise, and implement planting guidelines to prevent placing trees in hazardous locations
(2) Develop, revise, and implement mowing and vegetation control guidelines

Eliminate the hazardous condition and/or reduce the severity of the crash
(1) Remove trees in hazardous locations
(2) Providing guardrail to shield motorists from striking trees (NB Keep in mind that guardrail is reported to be the fourth most frequently struck fixed object for fatal crashes in the United States)
(3) Modify roadside clear zone in the vicinity of trees
(4) Delineate trees in hazardous locations (only if the other alternatives are not appropriate).

NB Relevance only rated as ‘low’ because no mention is made of driver-infrastructure interaction as remedial factor.

Authors:	Opiela, K.S. & McGinnis, R.M.	
Title:	Strategies for improving roadside safety	
Published:	Traffic safety on Two Continents, Lisbon, 1997	
Relevance: Low		

Abstract:

Roadside safety is a major component of highway safety in the United States. Roadside crashes account for one third of the total highway fatalities in the U.S. each year and they cost society $80 billion a year. Crashes with trees account for about 10% of the national fatalities and crashes with utility poles about 5%. Rollovers are the most severe type of roadside crashes. Roadside safety has not improved as much as other aspects of highway safety. The driver, vehicle and roadway all need to be addressed when considering roadside safety. A vision for improved roadside safety includes the following. 1. Increase the awareness of roadside safety and support for it. 2. Build and maintain information resources and analysis procedures to support continued improvements in roadside safety. 3. Keep vehicles from leaving the roadway. 4. Keep vehicles from overturning or striking objects on the roadside when they do leave the roadway. 5. Minimise injuries and fatalities when overturns occur or objects are struck in the roadside. Some strategies to address these improvements include: installing shoulder rumble strips to alert drivers; removing or shielding trees or utility poles close to the roadway; using public service announcements and citizen initiatives to increase awareness; improving safety management systems; implementing highway maintenance programs; improving driver education programs; soliciting support in identifying hazardous roadside locations; increasing speed enforcement at locations with known roadside safety problems; promoting development of innovative technologies to keep vehicles on the road; and improving vehicle design to increase compatibility with roadside hardware.

Authors:	Padmos, P.	
Title:	Visual problems on motorways during darkness	
Published:	Soesterberg, The Netherlands: TNO Institute for Perception (Report IZF 1988 C-17)	
Relevance: Low		

Abstract:

In this study the elements on motorways that are insufficiently visible during darkness were identified. To this end eight subjects drove a number of rides on motorways and provided comments on items that were seen insufficiently clear or too late for driving safely and smoothly. They study took place under different weather conditions and public lighting conditions (on or off).

The results showed that visual problems were most often related to geometrical road characteristics (lane boundary, course of road, place of exit). On wet road surfaces the problems were higher than on dry road surfaces and public lighting decreased the frequency of problems.

The authors concluded to improve the visibility of geometrical road characteristics for instance by using material that keeps it reflecting quality during wet weather.

Authors:	Powers, R.D., Hall, J.W., Hall, L.E. & Turner, D.S.	
Title:	The 'forgiving roadside' design of roadside elements	
Published:	International Symposium on Highway geometric design practices, 1995	
Relevance: Low		

Abstract:

The AASHTO 1988 R*oadside Design Guide* addresses four general categories of roadside design elements:

1. roadside topography or slopes,
2. drainage features,
3. highway appurtenances such as sign and light supports, and
4. traffic barriers.

For each of these features, the paper reviews the historical development, describe the current situation, highlight existing shortcomings, and identify where efforts might be directed in the near future.

Authors:	De Ridder, S.N. & Brouwer, R.F.T.	
Title:	The influence of the road environment on driving behaviour	
Published:	Soesterberg, TNO Human Factors, Rep. TM-02-C065 (in Dutch)	
Relevance: High		

Abstract:

Report summarises effects found or hypothesised in behavioural studies of driver-infrastructure interaction: see Table.

	Speed	Lateral position
Reduction in width of hard shoulder		To the left
Noise suppression screen		To the left
Reduction in lane width	Down	
Reduction in distance to roadside obstacles	Down	
Nature of roadside obstacles: - Trees vs. guardrail - Threatening object	Down in case of trees Down	
Undergrowth of continuous nature	Up	
Undergrowth of discontinuous nature	Down	
Buildings alongside road	Down	
Vehicles next to road	Down	
Reduction in road comfort	Down	
Optical narrowing of lanes	Down	
Reduction in sight distance	Down	

Authors:	Schoon, C.	
Title:	Roadside design for enhancing safety	
Published:	Traffic Safety on Two Continents, Lisbon, 1997	
Relevance: Low		

Abstract:

Can we reduce the high percentage of fatal accidents (about 20%, on motorways) resulting from a collision with a safety barrier, and if so, how?
The possibilities for achieving this are:

- A shoulder without obstacles. How wide should this zone be? Presents a graph on the ratio of tree accidents as a function of distance to the edge line of the right lane.
- A shoulder with safe slopes (1:4 – 1:6).
- A shoulder with road furniture that yields easily upon collision. This is to be preferred from the point of view of motorcycle safety (many motorcycle fatalities result from safety barrier collisions).
- Shoulder with crash cushions.
- A shoulder with an effectively functioning safety barrier (technical developments are discussed).

Authors:	Selim, A.A. & Josy, J.L.	
Title:	Mathematical model that describe lateral displacement phenomena.	
Published:	TRR 681 (1978), 92-94	
Relevance: Low		

Abstract:

This research studied the lateral displacement of vehicles in the right lane of freeways as they approach vehicles parked on the right shoulder. This was done by means of recording the scenes on movie films that were later analysed. Vehicles of different sizes were used and placed on the right shoulder at various distances from the freeway edge of the pavement, and at different locations. No general models could be developed, i.e., that were applicable to different locations, although reasonably fitting models could be developed for a separate location.

Authors:	Taragin, A.	
Title:	Driver behaviour as affected by objects on highway shoulders.	
Published:	Proc. Highway Research Board, 1955, 36.	
Relevance: High		

Abstract:

This study investigated the effect of obstacles on speed by putting obstacles on the highway shoulders. With two-lane highways, the reduction in speed was somewhat stronger than with four-lane highways. Three different kinds of objects were used, a stationary car, a road maintenance car and a red-and-white barricade. All three objects had about the same effect on driving speed, only the barricade did not have as much effect on a 4-lane highway. On the right lane, there was a small tendency to reduce speed, although there was no specific effect on driving speed of proximity to the obstacle to the right lane. This may be the result of the presence of an emergency lane, which still left quite some space between the vehicle and the obstacle.
Thus, roadside obstacles result in a speed decrease on narrow roads only (< 6 m), presumably because on these roads there is less opportunity for a corrective lateral excursion. A lateral correction is the ‘natural’ response of drivers to a roadside obstacle.

Authors:	Tenkink, E.	
Title:	The effect of road width and obstacles on speed – and course behaviour	
Published:	Soesterberg, The Netherlands: TNO Institute for Perception (Report IZF 1989 C-4; in Dutch)	
Relevance: High		

Abstract:

In this study the results of two experiments are reported investigating how drivers adjust their speed and course when driving on a narrow lane and in the presence of obstacles. The obstacles used in this study were reflecting road studs ('cat's eyes'), plastic cones or large metal panels that were red and white striped. The lane width was 2, 3 or 4 meters. If the car was exactly in the middle of the road the remaining distance to an obstacle was 0.34, 0.84 or 1.34 meter.

The results showed that only with the narrowest lane width there was an effect of speed on the type of obstacle. The speed was most reduced by subjects with the metal panels; there was also a difference between plastic cones and the reflecting road studs. This study also refers to the results of other studies that report similar findings. However, these studies also suggest a relation between the type of obstacle (and thus the consequences of an accident) and speed; the speed was lower with obstacles with more serious consequences of an accident.

Authors:	Tenkink, E. & van der Horst, A.R.A.	
Title:	Effects of road width and curve characteristics on driving speed	
Published:	Soesterberg, The Netherlands: TNO Institute for Perception (Report IZF 1991 C-26)	
Relevance: Low		

Abstract:

In two driving simulator experiments the effects of road width and curve characteristics were investigated. In the first experiment subjects were free in their choice of speed while in the second experiment the speed was fixed. Although the experiment was not related to hazards along the roadside it does contain potentially valuable information. The results showed that the number of errors (defined as roadside crossings) increased with a smaller radius or a larger deflection angle. Although the speed was reduced at the beginning of the curve, this reduction was not enough to compensate for the increased probability of an error. The authors concluded that a close relationship between effective curvature (the actual curvature of the path driven) and number of errors suggests that the effective curvature is a good measure for safety rating of curves. Furthermore, the design speed of a curve should depend upon both curvature and deflection angle and not only on curvature. In that case negotiating a curve could result in fewer errors.

Authors:	The Road Information Program (TRIP)	
Title:	Traffic safety and older Americans: making roads safer for motorists	
Published:	Oct. 2000	
Relevance: Moderate		

Identical to:

Authors:	Knoblauch, R.L., Nitzburg, M. & Seifert, R.F.	
Title:	Older driver freeway needs and capabilities	
Published:	?	
Relevance: Moderate		

Abstract:

Among the recommended set of safety improvements for improving older driver safety we find:

<u>Streets and Highways:</u>

- Wider lanes and shoulders to reduce the consequences of driving mistakes
- Rumble strips to warn motorists when they are running off roads

Study 1

Authors:	de Vos, A.P., van der Horst, A.R.A. & Bakker, P.J.	
Title:	Lane keeping behaviour at profiled road markings: Video observations in the after situation on the motorway A50	
Published:	Soesterberg, The Netherlands: TNO Human Factors (Report TM-95-C048)	
Relevance: Low		

Study 2

Authors:	de Vos, A.P., van der Horst, A.R.A. & Bakker, P.J.	
Title:	Lane keeping behaviour at profiled road markings: Video observations in the after situation on the motorway A28	
Published:	Soesterberg, The Netherlands: TNO Human Factors (Report TM-96-C057)	
Relevance: Low		

Abstract:

Profiled road markings may reduce the number of single vehicle accidents. This is achieved by an increased visibility of the markings and/or by the acoustic and haptic signal that is the result of crossing the profiled marking. In these studies the effect on driving behaviour of profiled road markings on motorways was investigated by means of video observations in a before and after study and under different road surface conditions (dry and wet; in the first study on the A50 the wet road surface condition was only in the after study) and lighting conditions (during day and night time).

The results of the first study showed that the duration of driving on the line marking was shorter with profiled markings than with conventional markings. There was no effect with respect to the duration of lane crossings beyond the marking. However, the number of the lane crossings beyond the marking was larger with profiled markings. So this study partly confirmed the hypothesis that profiled road markings might decrease the number, duration and extent of lane crossings by the haptic and acoustic signal. It was expected that the increase in visibility would especially show up on wet road surfaces at night. This condition was not included in the before study. As a side effect was found that the driving speed increased in the after study although slightly (2 km/h).

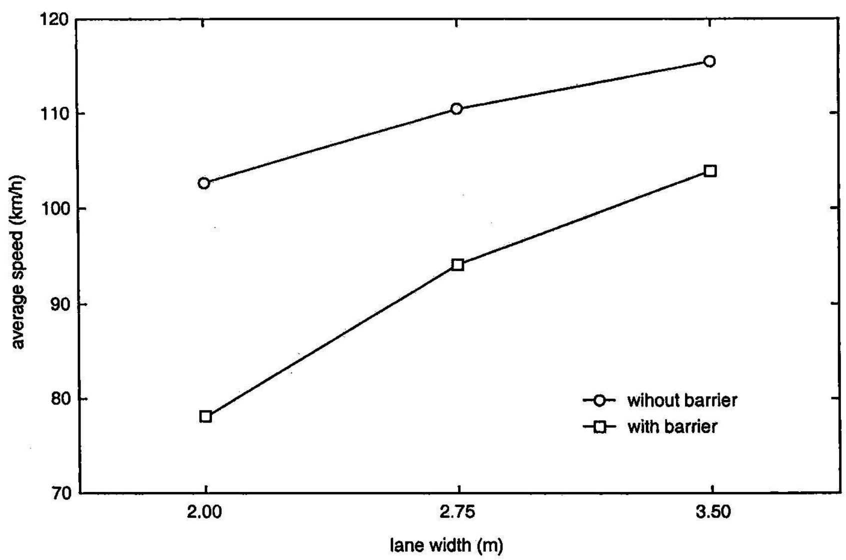
In the second study evidence was found for the increased visibility of the applied profiled markings. On a wet road surface during the night there were less lane crossings in the after study. The authors, however, indicate that this can not only be attributed to the profile of the marking but also (and to what extend is unknown) to the use of a different paint for the markings in the after study. With respect to the haptic and acoustic signalling of the profiled marking no effect was found. However, an increase in driving speed was found on the wet road surfaces (day and night condition) in the after study due to the better visibility.

The results of both studies suggest possible benefits of profiled road marking but also possible negative effects (increased speed). This outcome suggests no reason to use profiled marking on a large scale on motorways.

Authors:	De Vos, A.P., Hoekstra, W. & Pieterse, M.T.J.	
Title:	Effects of lane width and physical separation on driver comfort.	
Published:	Soesterberg, TNO Human Factors, report TM-98-D003, 1998.	
Relevance: High		

Abstract:

In a driving simulator, these authors investigated the influence of lane width and obstacles on driving behaviour. The results showed a decrease in driving speed with decreasing lane width. When a barrier was added at the subject's right-hand side, driving speed decreased further compared to the no-barrier condition. The barrier also caused a shift of the mean lateral position, away from it (see Figure).



Authors:	Zegeer, Ch. V.	
Title:	Setting priorities for reducing utility pole crashes.	
Published:	Utility Safety. Mobilized for Action and State, City, and Utility Initiatives in Roadside Safety. Presentations from TRB Committee on Utilities, 79th Annual TRB Meeting, 2000.	
Relevance: Low		

Abstract:

Presents a crash prediction model for utility pole crashes on roadway sections that is a function of average daily traffic (ADT), number of utility poles per mile, and average distance of the poles from the roadway edgeline (the ''offset'' distance). The relationship shows clearly that poles close to the roadway (particularly within about 10 feet of the travel lane) result in a greatly increased risk of a vehicle collision with a utility pole.
Analysis indicates that relocating poles further from the roadway can be cost-effective in some situations, particularly for telephone and most power poles within 10 feet of high-volume roadways.
Recommended steps for reducing utility pole crashes are:
(1) Look at the crash history of vehicle collisions with utility poles.
(2) Think before replacing a damaged pole.
(3) Identify the utility poles with a high potential to be struck.
(4) Develop a plan and relocate such poles to lower-risk locations.
(5) Adopt a clear-zone policy.
(6) Establish funding and make improvements.

Authors:	Zegeer, C.V., Reinfurt, D.W., Hummer, J., Herft, L., & Hunter, W.	
Title:	Safety effects of cross-section design for two-lane roads (Article in Transportation Research Record 1195)	
Published:	Washington, D.C., USA: Transportation Research Board	
Relevance: Low		

Abstract:

The purpose of the first study was to construct a model to predict the effects of changes in lane width, shoulder width, and shoulder surface on accidents. A database was created comprising 1801 rural road sections (4785.14 miles) and 143 urban street sections (166.14) miles. These data were gathered from different states and all roads were two-lane roads covering a wide range of geometric and traffic conditions. The final sections for the predictive models were based on rural roads only. For each selected roadway section a number of traffic and geometric variables were collected:

- section information (section identification, length, pavement type, terrain, etc.),
- average annual daily traffic,
- speed limit,
- horizontal curvature
- vertical grade
- side slope ratio and length
- width of lanes and shoulders and shoulder type
- number of bridges, intersections, overpasses, etc.,
- type of delineation and on-street parking,
- roadside condition (a roadside hazard scale was developed to indicate the accident likelihood and damage expected to be sustained by errant vehicles. The ratings were determined using a seven-point pictorial scale.

Of the different sections accident statistics were gathered covering property damage only accidents, injury accidents and fatal accidents. The database was analysed for which specific accident types that were most highly correlated with lane width, shoulder width, shoulder type, sideslope, and roadside rating and for the most important traffic and roadway variables.

The final predictive model presented was:

$$AO/M/Y = 0.0019 \times (ADT)^{0.8824} \times (0.8786)^{W} \times (0.9192)^{PA} \times (0.9316)^{UP} \times (1.2365)^{H} \times (0.8822)^{TER1} \times (1.3221)^{TER2},$$

with

AO/M/Y: number of single vehicle accidents, opposite direction head-on and sideswipe and same direction sideswipe per-mile-per-year,
ADT: average daily traffic,
W: lane width (feet),
PA: average paved shoulder width (feet),
UP: average unpaved shoulder width (feet),
H: mean roadside condition rating,
TER1: terrain (equals 1 if flat, else 0),
TER2: terrain (equals 1 if mountainous, else 0),

This predictive model explained 45.6% of the variation in accidents by traffic and roadway variables. For the Riser project the variables *H* (roadside condition), *PA* (average paved shoulder width) and *UP* (average unpaved shoulder width) are of relevance. Assuming that other variables are kept constant one can assess the effect of changes in number of accidents by changing the levels of, for example, *H*. In this study a number of nomographs were developed for different variables indicating the effect on the number of accidents by changing the values of the different variables. For example, widening the unpaved shoulder with 2 ft would result in a reduction of the relevant accidents with 13%.

Authors:	Zegeer, C.V., Reinfurt, D.W., Hunter, W., Hummer, J., Stewart, R., & Herft, L.	
Title:	Accident effects of sideslope and other roadside features on two-lane roads (Report in Transportation Research Record 1195)	
Published:	Washington, D.C., USA: Transportation Research Board	
Relevance: Moderate		

Abstract:

This study continued along the line of the other Zegeer study. The purpose of this study was threefold, (1) develop methods for quantifying roadside hazards, (2) define factors that influence run-off-roads accidents, and (3) estimate the accident benefits of various roadside improvements. The analyses performed were an extension of the analyses performed in the first study. The predictive model presented in the other Zegeer study (see above) could be replaced with a similar model with average roadside recovery distance (*RECC*; distance from outside edge of shoulder to nearest roadside obstacle or hazard) in place of roadside hazard rating (*H*; see above). The model then became

$AO/M/Y = 0.0019 \times (ADT)^{0.8545} \times (0.8867)^{W} \times (0.8927)^{PA} \times (0.9098)^{UP} \times (0.9715)^{RECC} \times (0.8182)^{TER1} \times (1.2770)^{TER2}$.

This model explained 46.1% of the variation in accidents by traffic and roadway variables. An increase of 5 ft of 'roadside recovery distance' results in a reduction of 13% of related accidents.

A second model presented in this study was related to single vehicle accidents (AS; fixed-object, run-off-road rollovers, and other run-off-road accidents). This model is described as

$AS = 793.58 \times (1.191)^{SS} \times (0.845)^{W} \times (0.974)^{RECC} \times (0.99994)^{ADT} \times (0.908)^{SW}$,

with

AS: the rate single-vehicle accidents,
SS: median sideslope measure, with *SS* = 1 if side slope is 3:1 or steeper, or zero otherwise,
W: lane width (feet),
RECC: median roadside recovery distance,
ADT: average daily traffic,
SW: total shoulder width (paved or not).

This model explained 18% of the variation. In this study it was refined to encompass more sideslope categories. The resulting model explained 19% of the variance. Furthermore, a model was constructed to predict rollover accidents, which explained 25% of the rollover accidents. The authors used these models to predict what would happen when one of the variables would change (for better of for worse). For example if the sideslope ratio was reduced from 2:1 to 7:1 then a reduction would be expected of 27% of the relevant accidents.

This study further presents an analysis to determine the types of roadside obstacles that are most often struck. The obstacles that could be identified and that were most often struck were trees and utility poles. The fixed-object accidents were distributed as follows:
Trees: 14.8%,
Utility poles: 14.1%,
Guardrail: 9.6%,
Signs: 6.5%,
Mail boxes: 4.7%,
Bridge ends: 1.1%,
Other obstacles: 49.1%.