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PRIORITY 1.6. Sustainable Development, Global Change and Ecosystem  
1.6.2: Sustainable Surface Transport

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Safety Handbook for Secondary Roads

Deliverable n° 13 of the RiCORD project, financed by the European Commission under the EU Sixt Framework programme

December 2007
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Credits

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Some handbook’s argument are just a summary of the other Ripcord-Iserest research activities, so all the project partners gave indirectly a contribute for this final issue: their list is reported at www.ripcord-iserest.com, together with a downloadable version of this handbook and of all the other project deliverables.
Section 1 Scope and objectives of the Safety handbook for Secondary Roads

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1 Scope and objectives of the Safety handbook for Secondary Roads

1.1 Introduction

Fatalities and injuries on “secondary roads” in rural areas count up to 40% of the total number of fatalities and injuries involved in road accidents in Europe.

Due to lower traffic volumes, accidents resulting from similar deficiencies in design are not so heavily clustered on “secondary roads” as on primary roads. Therefore it is difficult to set up common intervention criteria for both roads.

Furthermore, fatalities have shown different distribution characteristics in the road network than accidents in general. Moreover different kinds of accidents related to a different environmental as well as behavioural background are likely to happen on “secondary roads” compared to primary roads.

![Figure 1 Evolution of EU road fatalities](image)

The objective of this handbook is to supply a practical tool based on best practices commonly agreed at European Level and focused on “Secondary Roads”, intended as “2 lanes Rural Roads”, as better explained in the following section.

The actual need of this new term for a clear definition of the physical infrastructures targeted by the handbook was discussed during the 1st Ripcord-Iserest conference and a public version of the WP13 first report has been specifically issued for collection of comments and suggestions by external experts, that basically confirmed the usefulness of the new adopted term.
This handbook is addressed to those road managers without accident data availability or with low capability of managing such data: the handbook can also help the local road managers in taking practical decisions about road safety interventions and it is free available by downloading from the project website.

A specific case is examined in the “Annex A”, where are summarized the two-lane roads safety problems and the general applications for the solutions in Turkey.

The handbook is not the only instrument delivered by the RIPCORD-ISEREST project: the figure in the following page shows the position of the different instruments delivered by WPs 8, 9, 10, 11 and 13 in relation to data requirements and applicability by local road managers. The Safety Expert System particularly constitutes the logical integration of the handbook (and vice-versa).

The knowledge raised from the RIPCORD-ISEREST project is hereby summarised to be applicable to a “problem solving approach” by local road managers in Europe.

It is to be underlined that WP8, WP10 and WP11, as well as all the other WPs of the Ripcord-Iserest Project, are nevertheless highly valuable instruments for the improvement of road safety knowledge.
The Position of the European Directors of Road

Due to the objective of the handbook, the position and the needs expressed by the “target group” is a primary aspect to be considered.

In October 2005 there was a meeting between the Conference of European Directors of Roads (CEDR) and the EU Commission where it was agreed that it would be highly beneficial if they summarized their short-, medium-, and long-term road safety priorities to increasing road safety on European roads and specifically to reaching the 50% fatality reduction target of the European Commission.

Following the meeting CEDR’s Technical Group “Road Safety” prepared a report\(^1\), based on data collected from three questionnaires answered by 20 CEDR Member States. The report points out the short-, medium-, and long-term actions qualified as most effective by European Road Directors.

The figures 3, 4 and 5 are taken from the mentioned report and show the strong relationship between the main priorities exposed and the goals of the whole Ripcord Iserest project, but also show the fragmentation of responsibilities and approaches among the European road Authorities.

The aim of this handbook is to suggest a common definition (secondary roads), useful to describe common rules for safety interventions for these kinds of roads; figure 6 (also taken from the CEDR report) is as an example to demonstrate the need of a better and clear definition respect to the term “rural roads”.

\(^1\) Conference of European Directors of Roads – “Most Effective Short-, Medium- and Long-Term Measures to Improve Safety on European Roads”- 14/06/2006
Figure 3 Short-, medium-, and long-term actions qualified as most effective by European Road Directors\(^1\)
Specific Road Safety Responsibilities of Road Directors

The following table summarises the question of responsibility for each of the 22 measures discussed in the above mentioned questionnaires. Here, main responsibility is symbolised by a dark green box, shared responsibility by a light green box, and no responsibility by a red box. It is important to take into consideration the responsibilities of the Road Directorates when reading the report as the priorities given to different measures depend to a certain degree on the actual specific responsibility of the respective Road Directors.

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*Figure 4 Specific responsibility of EU Road Directors*(1)

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(1) The specific responsibilities of EU Road Directors vary across different countries, reflecting the unique road safety landscapes and policies in place.
Speed management and other safety measures on rural roads as for the CEDR questionnaire - Examples are: road hierarchy = self explaining roads, forgiving roadsides (systematic removal or securing of roadside hazards such as tree poles), lowering speed limits, implementation of median barriers etc.

Figure 5   Safety measures on EU rural roads(1)
1.2 Definition of Secondary Roads (Infrastructure)

Many different definitions can be found in the literature and understanding what is meant by “rural” is the key to understand the risks associated with these kinds of roads. Indeed, it has been recognised by the Organisation for Economic Co-operation and Development that the understanding of rural road safety is hampered because "no formal accepted international definition exists to classify rural roads" (OECD, 1999). However, the OECD defines rural roads as roads that are "outside urban areas and that are not motorways or unpaved roads".

The Department of Transportation's Federal Highway Administration (FHWA) uses two definitions for the term, depending on the context. For the purposes of grouping streets and highways according to the service they are intended to provide in relation to the total public road system (highway functional classification) and outdoor advertising regulations, "rural" is defined as anything bordering population centres of 5,000 or less.

For planning purposes, however, "rural" is used in opposition to "suburban" and "urban," which are more populous and can be defined by a combination of different criteria; for instance, "urban" could be considered a population centre of more than 50,000 people.

We can affirm that there is no definition providing a clear picture of what distinguishes a "rural" road from an "urban" one. There are many types of rural areas: some, for instance, have agricultural-based economies and are located far from large metropolitan areas, while others are economically dependent on nearby cities and may have close cultural ties to them.

Furthermore, there are many types of rural roads, including national highways that run through rural areas, rural-area "arterial" roadways (roads that supplement the national system) and "local" roads such as those that connect farms with towns. When analyzing the factors that contribute to the high fatality rate on rural roads, it is important to acknowledge that different areas, even while they may share the "rural" classification, may have different characteristics and therefore different traffic safety needs.

The following example may clarify the problem: the above mentioned CEDR report shows the reduction of fatalities divided into rural and urban areas; the figure reveals the development in the period 2000 – 2004.

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2 Kevin Hamilton and Janet Kennedy - Rural Road Safety: a literature review - Scottish Executive Social Research - 2005
Each point in the following Figure 6 represents a country. The first value of the x-axis represents the reduction of fatalities (2000 – 2004) in rural areas whereas the second value (y-axis) shows the reduction of fatalities in urban areas.

![Figure 6 Breakdown of overall reduction of fatalities (2000-2004) by area type](image)

The figure can be divided into four sections (A to D).

- Countries in section B show a better reduction compared to the target of 20% in rural as well as in urban areas. These countries outperform these targets in both areas.

- Countries in section C are the opposite. They could not reach the target in the rural areas and also did not reach this target in the urban areas. Moreover Austria shows an increase of fatalities in urban areas (8%), Hungary and the U.K. reported an increase of fatalities in rural areas (17%).

- Countries in section A outperformed the target in terms of the target for urban areas but failed to achieve a comparably good result in rural areas.

- Finally, countries in section D outperformed the target in rural areas but failed in urban areas.
But how this important information could be interpreted by the “rural” side? The term in the report includes all the roads outside urban areas, without any further explanation that could help the “decision makers” in planning adequate measures.

The need of a clear and standardised definition raises from the above consideration; in this handbook it is proposed the adoption of the term “secondary road” for a road with the following physical characteristics:

1. Single carriageway, two lanes
2. Paved road
3. Outside Urban Areas

This handbook is also a “Contribution to standards” in the road safety field: a common safety standard and common rules for safety interventions may successfully help to face the dramatic problem of road deaths. Moreover, common standards could avoid the arising divergence in messages signs and put a limit to the problem of different signing and road marking.

Due to the specificity of this handbook, targeted to secondary roads, Annex B contains some brief summaries of other road safety handbooks, to guide the readers interested in more detail.
Section 2 Geometric parameters affecting Road Safety

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2 Geometric parameters affecting Road Safety

An accident is always characterized by multiple causes. The alignment of roads is an important influence factor: dimension of radii, ratio of consecutive curves, dimension of vertical curves and sight distance conditions. The following chapters gives an overview about the current results of research works especially about the main geometric factors which correlates with accident analysis values.

Road safety effect of no-geometric’s factors have been studied in some research, and it will be considered in the 3rd chapter. Moreover, in the 3rd chapter, it will analyse the geometry of particular singular point: junctions, intersections and driveways. Because this manual consider only Secondary Roads, some security parameters will be not consider (e.g. median, number of lane).

In many evaluation studies of the safety effects of road design elements it turns out the present poor capacity to explain accidentality phenomenon; in fact the main causes of accident is the driver’s behaviour, which is mainly influenced by his personality, skills, and experiences. Furthermore external impacts like weather conditions, road conditions, time of day, or light conditions influence the driving behaviour as well.

It is out of question that analysing accidents and their dependence on technical values or human factors has always to consider these interactions. The relation between accidents (all, property damage only, slight injuries, severe injuries, fatalities) and road geometry is proved but it is also a question of the driving behaviour, especially of the velocity. Again and again investigations show that comparable curves (similar geometry) are characterized by a different accident occurrence. One reason could be a different driving behaviour: lower speeds are less critical than higher speeds in curves.

Several studies, oriented to create relationships between accidentality and independent variables, were obtained in a particular context; so, in every other different conditions (weather conditions, user behaviour, etc.) the influence of these factors should be considered, e.g. calibration procedure.

Summarized, accidents do not depend on only one factor; accidents are caused rather by a combination of several factors. For a detailed and serious accident analysis knowledge about the impacts of driving behaviour and road geometry is an important precondition. The following chapters gives an overview about the current results of research works especially about the geometric factors which influence the driven speed (driving behaviour) and geometric factors which correlates with accident analysis values.
2.1 Geometric Parameters and Velocity

2.1.1 Definition and Indicators of Driving Behaviour

Since there is no model to forecast driving behaviour all scientific works based on investigation of objective indicators. In general the driving behaviour is the vehicle control in longitudinal and transverse direction.

Common parameters to describe and analyse driving behaviour are the velocity, the acceleration, and the lateral position. These parameters are physical and geometrical values which can be measured or calculated.

Velocity

The speed is the distance travelled divided by the time of travel. The speed is an important value in road design; several design parameters are influenced by the speed (design speed or 85th percentile velocity).

Basically there are two different speeds: the speed which is only influenced by the traffic facility and the environment and the speed which is additionally influenced by traffic. To investigate the impacts of road geometry and environment a speed which is not influenced by traffic must be considered. For this purpose the spot speed can be used which is the speed in a defined spot at a defined time.

Acceleration

The acceleration is defined as the speed change within a time interval. Regarding the direction of acceleration, there is a longitudinal and transverse acceleration. The longitudinal acceleration is a value of speed change and can be use, as well as the centrifugal acceleration, as comfort criterion which gives information about how fast a driver changes the speed or which curve speed is accepted.

Lateral Position

The lateral position is the position of the vehicle within a lane or at least within the carriageway. It is a geometrical value which is e. g. the distance between the roadside or centre of the road and the vehicle’s longitudinal axis. This indicator gives the possibility to analyse the driven track. Especially in curves the lateral position of cars is a perfect indicator to investigate corner cutting.
2.1.2 Straight Sections

The straight as geometric element does not influence directly the velocity. On straights the driven speed depends primarily on the legal speed limit, on the environment, and on the traffic conditions. Generally velocities on straights are high, especially if there is no impact of other vehicles. Also it is proved the longer the straight the higher the speed. Often serious accidents occur on straights as a result of speeding. Therefore in modern design guidelines the maximum length of straights is restricted to avoid high speeds over a long distance.

2.1.3 Curve Radius

In numerous research projects the influence of curve radius on driving behaviour especially on speed has been proved (e.g. FIEDLER 1967, KÖPPEL / BOCK 1979, DAMIANOFF 1981, SCHNEIDER 1986, STEIERWALD / BUCK 1992, LIPPOLD 1997). Figure1 shows as example some functional approaches of the last decades. Especially in the range of small radii the approaches differ extremely from each other: one reason is the development of automotives in the past. Modern chassis make it possible to drive faster but still safely through a curve.

All these investigations have shown a great impact of curve radii smaller than 250 m; the impact decreases in curve radii greater than 350 m. Generally speed investigations in curves are characterised by a variance above 20 km/h which shows the variety of impact factors. It is proved that also other geometric parameters of curves such as heading change, length etc. must also be considered.

Regarding the road safety the main problem is the transition between a straight alignment and a curve with a small radius. As proved the smaller the radius the lower the speed and therefore the higher the speed difference in consecutive curves of different radii. On historic alignment the absence of a good relation of consecutive elements leads to high accident frequencies: on a short distance drivers have to decelerate the vehicle up to the curve speed. Drivers brake too late and enter the curve too fast which might result in Run-Off accidents or they compensate the speed by corner cutting which might result in crash with oncoming vehicles.
The influence of the grade is only important above a certain value. The reason is the development of automotive engines in the last years. In former times investigations have shown an impact of grades above 2 % (DIETRICH 1965, TRAPP 1971, TRAPP/OELLERS 1974, KÖPPEL/BOCK 1979). Today, grades above 6 % influence the speed of vehicles (LIPPOLD 1997).

Critical are steep downgrades when the velocity increases rapidly caused by the optical distortions. In the case that a curve or curve combined with sag is near the downstation accidents might occur due to speeding.

Steep upgrades might lead to great differences in speed especially between HGV and passenger cars.

### 2.1.5 Curvature Change Rate (CCR)

Various research projects have worked out a correlation between the Curvature Change Rate (CCR) and speed behaviour (e. g. KÖPPEL / BOCK 1979, BIEDERMANN 1984, LIPPOLD 1997). CCR above 100…150 gon/km have an impact, for lower CCR the speed is influenced by non geometric parameters such as legal...
speed limit, environment etc.. Analogous to the models for single curves further parameters have to be considered to analyse the impact of CCR (e. g. road width).

Also the transition between road stretches with huge differences in CCR from a straight alignment into a road stretch with many curves might be critical due to high speed differences.

### 2.1.6 Width

As mentioned the road width (or lane width) is the most appropriate value to characterise cross sections. But there are different opinions about the influence of the lane width.

Former investigations have shown a small impact of the lane width on driving behaviour (TRAPP 1971, LAMM 1973, TRAPP / OELLERS 1974).

KÖPPEL / BOCK (1979) have investigated the influence of lane width in connection with the CCR and determined a lower level of speed with similar CCR and decreasing lane width. LIPPOLD (1997) verifies this correlation for single curves and CCR sections as well. In his investigation the lane width is differentiated in three groups: 5 m – 6 m, 6m - 7 m, and 7 m – 8 m. Lanes wider than 6 m have the same correlation, so that obviously the impact of lane width is unimportant at this value. Widths below 6 m differ significantly.

### 2.1.7 Consecutive Elements

The driving behaviour is also influenced by directly consecutive elements, especially by their parameter differences which result in an inhomogeneous speed profile. It is proved in numerous research works high speed differences might be dangerous. Therefore it is important to balance the parameters of consecutive curves.

KOEPPEL / BOCK (1970) have determined an interaction between the curve radius and the average curve speed if the change of radius is less than 20 %. The results of this investigation were included in the German guideline in 1973 (RAL-L-1 1973). Also LEUTNER (1974) proved large differences in the speed profiles on roads with a discontinuous alignment. AL-KASSAR et al. (1981) determined an increasing accident risk as result of inhomogeneous speed behaviour in unbalanced radii.

LIPPOLD (1997) compared the speed behaviour and accidents on roads with and without balanced alignment. There were significantly less accidents if the alignment was continuously. The results of his research are given in Figure 8. In the diagram
accidents which happened in S-curves or in transition sections between a tangent and a curve (circle symbol) and accidents which happened in consecutive curves (triangle symbol) are distinguished.

Figure 8 shows that especially in transitions from a bigger radius into a smaller radius the accidents risk is significantly higher. Based on this study the German guideline was improved concerning it’s requirements for balancing consecutive elements (curves).

![Figure 2: Speed differences and accidents of consecutive curves (LIPPOLD 1997)](image)

### 2.1.8 Sight Distance

In general the sight distance has an important impact on the driving behaviour, but this impact is evaluated differently. Various research projects have shown that the sight distance correlates with the curvature change rate, the higher the CCR, the lower the sight distance (TRAPP 1971, TRAPP / OELLERS 1974, AL-KASSAR et al. 1981). LAMM (1973) verifies this fact especially for small radii.

KÖPPEL / BOCK (1979) determined that the impact of CCR decreases and the impact of lane width increases at sight distances of more than 200 m. The influence of sight
distances below 150 m was investigated by STEIERWALD / BUCK (1992). Beside a
decreased speed level, the variance of the measured speeds also became lower.

### 2.1.9 Spatial Elements

Spatial elements base on the combination of design elements of the horizontal and
vertical alignment and simplify the evaluation of the spatial alignment.

WEISE et al. 2002 have investigated spatial elements regarding their influence on
driving behaviour. The results have shown that the speed is lower in straight crests with
grade switch than in straight sags with grade switch. Similar are the results for the
curved spatial elements. Higher speeds were measured in curved crests with grade
change than in curved crest with grade switch. Furthermore the speed differences
became higher with increasing curve radius. A similar speed level was determined for
small curve radii and it shows the dominant impact of the curve radius again.

### 2.2 Geometric Parameters and Accidents

Numerous scientific investigations have worked out the importance of geometric
parameters as influencing factor on road safety. In the existing literature are mentioned
especially the following parameters:

- **Horizontal plan**
  - Radius,
  - Degree,
  - Curvature Change Rate,
  - Balanced elements,
  - Radii ratio,

- **Vertical plan**
  - Grade,
  - Radius,

- **Cross section**
  - Lane width,
  - Shoulder width,

- **Sight distance**

Some of these parameters interact like the curvature change rate and the sight
distance so they cannot be discussed separately.
2.2.1 Horizontal Alignment

Curve Radius

Most investigations have shown that with increasing radii the accidents frequency declines. Radii smaller 500 m (McBEAN 1982) or 600 m (JONSTON 1982) are associated with higher accident rates. OECD (1976) suggested radii smaller 430 m as critical. Due to driving dynamic aspects it is suggested that most accidents in curves are run off accidents. KREBS / KLÖCKNER (1977) found a disproportionate portion of accidents caused by speeding in small curves.

LEUTZBACH / ZOELLMER (1988) found the accident rate as well as the accident cost rate decreases until radii of 1000 m. Greater curves are again characterised by increasing accident rates and cost rates. These results confirm the investigation of KREBS / KLÖCKNER (1977) that the safety benefit becomes less in radii above 400 m. In GLENNON et al. (1985) the curve degree is used as a parameter instead of the curve radius. Road segments of 1 km length, consisting of a curve and tangents of at least 200 m were investigated. In general the results do not show a different relationship.

An increasing accident rate of radii below 1000 m and greater than 3300 m was shown in the investigation of HEDMAN (1990). The model of ZEGEER et al. (1991) gives two general conclusions: the narrower the road the higher the number of accidents and the smaller the radius the higher the number of accidents. His model suggests a higher influence of the curve length than the curve degree (or radius), except in small curves if the length is much less than the curve degree. In HAMMERSCHMIDT (2006) were calculated accident cost rates for single curves (Figure 9). Single curves with radii of 50 m – 150 m have shown high accident cost rates, smaller radii are less critical due to lower speeds and radii above 150 are attributed to lower accident cost rates as well.
All investigations have pointed out an important impact of the curve radius on road safety. In fact small radii are characterized by a higher accident frequency as well as accident severity. The most typical accident type is the run-off accident. There are different opinions at which radius the impact decreases; it is discussed a range from 400 m to 600 m.

**Curvature Change Rate**

Various research projects have shown that the curvature change rate (CCR) as value for consecutive elements correlates with safety relevant parameters. The CCR characterises a combination of consecutive elements in spite of the radius which represents only a single element. The background is that identical radii could cause a different driving behaviour and therefore a different accident risk (DILLING 1973, KOEPEL/BOCK 1970, DURTH et al. 1983). Therefore the CCR is a more appropriate value to describe the geometric properties of several elements.

PFUNDT (1969) and BABKOV (1975) investigated the relation between the number of curves and the number of accidents. They found that roads with many curves are characterised by less accidents than roads with few curves. KREBS / KLOCKNER (1977) derived a correlation between the CCR and accident indicators: the higher the CCR the higher the accident rate and accident cost rate. HIERSCHE et al. (1984) investigated roads with modern and historic alignment. Due to an increasing
CCR they found a progressive incline of accident rate on historic alignments but a decline on roads with modern alignment.

These results were also proved in DURTH et al. (1988). Analogous to HIERSCHE (1984) they investigated modern and historic alignments. The results show that roads with similar CCR and continuous alignment are characterised by lower accident risk than roads with a discontinuous alignment. In general a higher CCR is associated with higher accident rates and cost rates. LEUTZBACH/ZOELLMER (1988) derived a slight increase of the accident rate related to the CCR. At CCR=100 gon/km the increase stops and the accident rate becomes lower while the CCR increases. They assume that two different effects are overlapping: on the one hand the number of accidents increases according to the traffic volume and on the other hand the average of accident severity decreases because the increasing CCR causes a lower speed. Due to the various accident types LEUTZBACH / ZOELLMER (1988) found that the number of driving accidents and accidents in longitudinal direction increases with the CCR. This trend is also shown by the accident rate which increased twice. These results show a higher risk of driving accidents if the horizontal alignment is characterised by many curves.

![Figure 4: Accident cost rate and CCR (HAMMERSCHMIDT 2006)](image)

The study of HAMMERSCHMIDT (2006) investigated the relation between CCR and accident parameters on 500 km secondary rural roads. The results are given in Figure 4. Especially CCR about 150 gon/km – 250 gon/km have shown high accident rates,
CCR below 100 caused less than 25% accident costs and CCR above 250 are characterised by a decline of accident cost rate again because of low speeds.

A correlation between the CCR and accident indicators was shown in numerous research projects. The CCR is an appropriate value to characterise a road stretch with many curves. On such road section the driving behaviour is not influenced by single elements but by the combination of consecutive elements: it is known that within these sections with similar geometry the driven speed is approximately constant. Due to the effects on driving behaviour the accident indicators have to be influenced as well. In general it is proved the higher the CCR the higher the risk of an accident. Important is that with increasing CCR the severity of accidents decreases because of declining speeds. This is the main difference between road stretches of similar geometry (CCR=const.) and single elements which discontinue the alignment.

*Transition Tangent – Curve / Balanced Alignment*

As the investigations of curvature change rate have shown that consecutive elements influences the driving behaviour and therefore road safety. It is known that a discontinuous alignment causes a higher accident risk than a continuous alignment. Due to these facts modern road design guidelines requires a so called balanced alignment where the ratio of radii of consecutive elements is within a defined range. With balanced consecutive elements discontinuous transition are excluded so that the driven speed have not to be changed abruptly and therefore the risk of an accidents decreases.

LAMM et al. (1999a) investigated the element combination tangent – curve. They determined a negative influence of curve smaller than 150 m. But also curves up to 300 m must be rated as safety critical (LAMM et al. 1999b). The research work of LIPPOLD (1997) pointed out that transition from a straight line into curve smaller that 100 m – 200 m are characterised by a high accident frequency.

In LEUTZBACH / ZOELLMER (1983) consecutive curves were analysed. The coefficient between the radii of the current curve and the curve before were compared to the accident rate and accident cost rate. In LIPPOLD (1997) accidents occurred in consecutive curves were investigated. The findings are that the accident frequencies is high on stretches where the alignment changed from large into small curves. Such combinations are inappropriate. But, also combinations with smaller differences may cause accidents. As result LIPPOLD improved the so called “radii tulip” which is shown in Figure 11.
The investigation resulted in a definition of recommendable, possible, and unacceptable radii combinations which are based on determined accident rates as well as on accident cost rates. The investigation of LAMM et al. (1999a) shows similar results. Radii ratios below 0.8 result in a significant incline of accident rate and above 0.8 the impact becomes low.

The balancing of consecutive elements such as straight – curve and curve – curve has an important influence on road safety. The transition between straights and curves is safety critical if the curve radius is below 200 m. Consecutive curves with a ratio <0.8 cause a significant higher accident risk.

2.2.2 Vertical Alignment

In contrast to the horizontal alignment the vertical alignment has a smaller impact on road safety.

Grade

Over the last decades numerous research works have shown a different influence of grades on road safety.

KREBS / KLÖCKNER (1977) have determined an influence of high grades above 6 % - 7 % on accident rates. Lower grades are characterised by a small impact. In
HIERSCHE et al. (1984) downgrades and upgrades were investigated separately concerning accident rates and a beneficial interval between 0 % and ±2 % was determined: the accident risk decreases slightly on downgrades >2 %.

LEUTZBACH / ZOELLMER (1988) investigated nine grade classes on 1273 km and determined a slight incline of accident rates due to increasing grades. This incline is higher for grades ≤3 % than in the interval 3 % - 6 %. They assumed the higher the grade the lower the accident severity. DURTH et al. (1988) found a larger increase of accidents in sections with grades above 7 %. Steeper grades are generally associated with higher accident rates. HOBAN (1988) confirmed the fact that grades above 6 % are associated with higher accident rates.

HEDMAN (1990) found that grades of 2.5 % and 4.0 % increase accidents by 10 % and 20 % compared to horizontal road sections. ZEGEER et al. (1992) showed that downgrades are characterised by a higher accident risk. MIAOU (1996) worked on the relation between the change of grade and accident risk. He also determined a different influence of down- and upgrades.

LAMM et al. (1999a) classify grades into three groups: 0 % to 4 % safe, <6 % small impact and >6% relevant impact.

The results of investigations of the existing literature have changed the opinion about the influence of grades on road safety. Due to the development of automotive engineering the impact has declined. Today an increasing accident risk in steep downgrades is proved.

**Vertical Curves**

Vertical curves are distinguished in crests and sags. Both elements deal with different safety problems.

Safety problems which are associated with vertical curves are distinguished in two groups: sight distance problems and distortion of horizontal curves.

The radius of crests mainly influences the sight distance. Therefore the minimum for a crest radius is usually limited to guarantee a required stopping sight distance. In most countries the stopping sight distance is defined as a minimum sight distance which drivers need to perceive an obstacle and to stop safely the vehicle. Also dangerous are crests which occlude unexpected curves. However, problems of crest are problems of sight distance. Sags do not deal with sight distance problems during day, but at night the sight is restricted by the light beam of the vehicle.
More important is the effect of distortion which is associated with sags. In contrast to crests sags cause an optical enhancement of horizontal curves, so that curves may appear larger than they are. This may result in an inappropriate speed and finally in an accident. It is proved that curved sags are characterised by a higher accident rate (DURTH et al. 1988). Also crests influence the optical appearance of horizontal curves. Unlike sags the horizontal curve in crest is compressed, so that curves may appear smaller than they are. This effect results in lower speed and LAMM (1982) found a below average accident rate.

**Lane width**

Generally most studies agree that lower accident rates are attributed to wider lanes. But it seems that there is an optimal lane width around 3.50m. Studies have also noted that approaches should base on more parameters of the cross section, at least also on traffic volume.

ZEGER et al. (1981), ZEGGER / COUNCIL (1993), and McLEAN (1985) have shown that widths of 3.4 - 3.7 m show the lowest accident rates. In LEUTZBACH / BAUMANN (1983) the effect of cross section and traffic volume was investigated. There is a four times higher accident rate on cross sections with 6.50 m width of the carriageway compared to cross sections with 12 m width. A similar effect is shown by HIERSCHE et al. (1984) who investigated the German standards. 90 km of road were redesigned corresponding to the national guidelines. According to the regression analysis, the accident rate has shown a decrease, but the accident-cost rate increased with increasing carriageway width. That means the severity of accidents became higher while the number of accidents was reduced. In LEUTZBACH/ZOELLMER (1989) a decline of the accident rate was determined up to a width of 8.5 m. Roads with a wider cross section have shown an incline again.

TRB (1987) pointed out lanes wider than 3.70 m do not contribute to a higher safety because they may result in unsafe manoeuvres such as over taking despite of oncoming traffic. Another reason is the higher speed on wider lanes which leads to more accidents. VOGT / BARED (1998) have developed a model which is based on investigations with lane width widening in Minnesota and Washington. They figured out that the higher lane width increment the lower the accident risk. LAMM et al. (1999) found a significant decline of accident rate up to 7.5 m cross sections. COOUNCIL / STEWART (2000) analysed data of four US states to develop a prediction model for non-intersection and non-intersection related accidents. The results were statistically significant for two states only and indicate huge differences regarding the benefits of
widening cross sections. In North Carolina widening the surface by 1 m reduces accidents by 14%, in California by 34%.

ELVIK et al. (2004) also figured out a decline of accident cost rates if the cross section is widened by maximum 3 meters. Wider cross sections are not attributed by positive influence on road safety.

All mentioned works have pointed out a decline of accident risk for wider cross sections. This positive trend is proved up to a certain lane width, wider cross sections are characterised by a lower safety benefit or even by increasing accident risk.

**Shoulder width**

About the impact of shoulder width or shoulder in general there are various opinions. In the literature several positive as well as negative aspects are discussed. As an obstacle free zone the shoulder gives drivers the possibility to regain control after loosing control over the vehicle. Also, shoulders provide space for emergency stops but it might cause a dangerous situation when the vehicle rejoins traffic. Furthermore, shoulders may be used for travel as well to allow passing faster traffic.

The study of ZEGEER et al. (1981) has shown that increasing the shoulder width is associated with a decline of accidents. 21 % reduction of total accidents was determined on roads with shoulders of 0.9 m – 2.7 m compared to road without shoulders. They suggest that for roads without shoulders the optimum shoulder width is about 1.5 m. An investigation by TURNER et al. (1981) has shown that on 2-lane roads with unpaved shoulders the accident rate is much higher than on 2-lane roads with paved shoulders and still higher than on 4-lane roads without shoulder. A multivariate model was developed by ZEGEER et al. (1987) based on data of seven states of USA. The model considers ADT, lane width, shoulder width and type, roadside hazard and terrain as variables. The results are: increasing the width of a paved shoulder by 1 ft reduces accidents by 6%, increasing the width of an unpaved shoulder reduces accidents by 4%, and paving 1 foot of a shoulder reduces accidents by 2%.

Similar results were worked out by HEDMAN (1990) who found an accident reduction when shoulder increases up to 2 m, above 2 m the benefit became less. For 2-lane roads a reduction of accidents by 1 % - 3 % and of injuries of 2 % - 4 % when the shoulder is widened by one foot is given by HADI et al. (1995). Up to a shoulder width of 3 m an accident reduction was determined in ODGEN (1996). MIAOU (1996) indicates a reduction of single-vehicle accidents by 8.8 % related to one foot widening.

STEWARD / COUNCIL (2000) analysed data from four US states and developed a prediction model for non-intersection and non-intersection related accidents. The
parameter for shoulder width was statistically significant. Regarding the determined correlations there are differences whereas the results for California, Minnesota, and Washington are somehow similar (especially above 1 – 1.5 m) but the result for North Carolina is completely different. In North Carolina widening the shoulder by 1.0 m reduces accidents by only 12 %, but in Minnesota by 26 %, in California by 29 % and in Washington by 39 %.

In general the design of shoulders regarding the pavement and width has positive influence on road safety. These effects were shown in numerous research works over the last years. Alike the road width the positive effect becomes smaller up to a certain shoulder width. Wider shoulders have no positive impact. Also paved shoulders influence positively safety especially on narrow roads.

2.2.3 Sight Distance

In general sight distance affects road safety since the sight distance is the result of the geometry overlapped with the existing terrain and the influence of geometric parameters is proved.

In KREBS / KLÖCKNER (1977) various radii which correspond to different sight distance were investigated. The radii and sight distances were subdivided into groups. Especially in curves with small radii (R < 400 m) the accident rate is much higher than in other curves if the sight distance is shorter than 99 m. With increasing sight distance the difference between the curves getting smaller.

On sites with short sight distances due to vertical curves (e.g. crests) the accident frequency is 52 % higher (TRB 1987). The mentioned study has developed a model to determine the cost effectiveness of lengthen of crests. They concluded that a reconstruction of such site has a cost benefit when:

- Design speed is more than 33 km/h above the operating speed,
- Traffic flow exceeds 1500 veh./d,
- High volume intersection,
- Sharp curve,
- Steep downgrade, and/ or
- Lane drop.
GLENNON (1987) points out that improving sight distances in curves is associated with high cost effectiveness, especially when low cost measures such as clearing vegetation etc. are realised. He found that improving sight distances on crests is only effective if the road is characterised by a high traffic volume.

HEDMAN (1990) found that accident rates decrease with increasing sight distance. But if the sight distances are above the stopping sight distance but below the overtaking sight distance drivers may start overtaking manoeuvres even though the sight distance is too short for passing. In LAMM et al. (1999a) high accident rates were determined for sight distances shorter than 100 m. Above 150 m no further positive effect was determined.

ELVIK/VAA (2004) worked out that improving sight distance does not lead inevitable to a decline of accident risk. They figured out that improvements of short sight distances of 200 m to more than 200 m caused a significant worsening of accident risk.

Several research works have shown the influence of sight distances on road safety. Especially short sight distances correspond with high accident frequency. Also was shown that an improvement is not only characterised by positive aspects. Larger sight distances which suggest the possibility of overtaking might cause accidents even though the full overtaking sight distance does not exist.

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3 Other Factors affecting Road Safety

3.1 Road surface conditions

Traffic, weather conditions and ground conditions expose road surfaces to wear and tear. Ruts, cracks and unevenness in the road surface reduce driving comfort and can be a traffic hazard. They may make it more difficult to keep a motor vehicle on a steady course. Besides large holes in the road surface can damage vehicles and lead to the driver losing control of his vehicle. Friction and evenness are two important characteristics that influence road safety.

Friction

One such contributing factor that has been discussed and evaluated over the years about road surface characteristics is skid resistance (friction) of roadway pavements under various weather and aging conditions.

Skid resistance of pavements is the friction force developed at the tire-pavement contact area. In other words, skid resistance is the force that resists sliding on pavement surfaces (Figure 1). This force is an essential component of traffic safety because it provides the grip that a tire needs to maintain vehicle control and for stopping in emergency situations.

Skid resistance is critical in preventing excessive skidding and reducing the stopping distance in emergency braking situations.

![Figure 1  Friction Force and its Properties](image-url)
Skid resistance has two major components: adhesion and hysteresis (Cairney, 1997). Adhesion results from the shearing of molecular bonds formed when the tire rubber is pressed into close contact with pavement surface particles. Hysteresis results from energy dissipation when the tire rubber is deformed when passing across the asperities of a rough surface pavement.

These two components of skid resistance are related to the two key properties of asphalt pavement surfaces, that is microtexture and macrotexture.

**Microtexture** refers to irregularities in the surfaces of the stone particles (fine-scale texture) that affect adhesion. These irregularities are what make the stone particles feel smooth or harsh to the touch.

**Macrotexture** refers to the larger irregularities in the road surface (coarse-scale texture) that affects hysteresis. These larger irregularities are associated with voids between stone particles. The magnitude of this component will depend on several factors. Macrotexture is also essential in providing escape channels to water in the tire-surface interaction, thus reducing hydroplaning.

A recent European study reports that increased macrotexture reduces total accidents under both wet and dry conditions (Roe, et al. 1998). Furthermore, this study shows that increased macrotexture reduces accidents at lower speeds than previously believed.

There are two other road surface texture properties that are less significant than micro and macrotexture in the generation of skid resistance, yet a key component in the overall quality of the pavement surface, namely megatexture and roughness (unevenness).

**Megatexture** describes irregularities that can result from rutting, potholes, patching, surface stone loss, and major joints and cracks (McLean and Foley, 1998). It affects noise levels and rolling resistance more than it affects skid resistance.

**Roughness** refers to surface irregularities larger than megatexture that also affects rolling resistance, in addition to ride quality and vehicle operating costs. It provides a

---

good overall measure of the pavement condition and is usually computed through the International Roughness Index (IRI).

These properties of pavement texture are the features of the road surface that ultimately determines most tire-road interactions including wet friction, noise, splash and spray, rolling resistance, and tire wear. At the 18th World Road Congress, the Committee on Surface Characteristics of the World Road Association (PIARC) proposed the wavelength range for each of the categories as shown in Figure 2 (PIARC, 1987). Sandberg listed their influence in more detail in Figure 3 (Sandberg, 1997).

Figure 2  Texture Wavelength (m) Influence on Surface Characteristics.

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Different numerical values of skid friction are used around the world. In Sweden, road surface wet friction is measured with fixed slip devices (Skiddometer BV-11 or Saab Friction Tester, SFT). Friction values of 0.5 are desirable. Finland established the levels of acceptable friction as a function of speed as shown in Figure 4 (Wallman and Ström, 2001, Larson 1999). Values were obtained following Finnish standards for testing (PANK 5201 or TIE 475).

In the U.K., a policy was developed to establish acceptable friction levels for different road and traffic situation. Friction levels are called investigatory levels where an investigation or surface treatment needs to be made if friction is at or below this level. Figure 5 summarizes the values taken with the SCRIM device (Side force Coefficient Road Inventory Machine).

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<tr>
<td></td>
<td>Megatexture</td>
<td>Very high</td>
</tr>
<tr>
<td></td>
<td>Unevenness</td>
<td>High</td>
</tr>
</tbody>
</table>
Porous asphalt surfaces offer high values of skid resistance and contribute to the removal of water from the pavement surface. A summary of the mixture characteristics for different porous pavements as used in the United States and Europe is provided in Figure 6.
A study of the Finnish National Road Administration examined the extent to which drivers take pavement slipperiness into consideration (Wallman and Ström, 2001; Heinijoki, 1994). Drivers were asked to evaluate the roadway slipperiness on a scale measured and divided into four categories of friction coefficients (f):

- Good grip (f > 0.45);
- Fairly good grip (0.35 < f < 0.45);
- Fairly slippery (0.25 < f < 0.35); and
- Slippery (f < 0.25).

The results showed that drivers were poor at evaluating actual road conditions. Less than 30 percent of the evaluations coincided with the measured values, and more than 27 percent differed by 2 to 3 of the categories listed above. According to the study, as

---

Wallman and Ström, 2001;
Heinijoki, 1994

8 Heinijoki H. Kelin kokemisen, rengaskunnon ja rengustyypin vaikutus nopenskäyttäytymiseen (Influence of the Type and Condition of Tires and Drivers’ perception of Road conditions on Driving Speed). FinnRA reports 19/1994, Finnish Road Administration, Helsinki, 1994.
friction values decreased, the relationship between drivers’ estimate of friction and actual conditions increased. Consequently, the skid resistance of the pavement did not have significant influence on driving speed.

In 1984, the international Scientific Expert Group on Optimizing Road Surface Characteristics of the (OECD) Organization for Economic Co-operation and Development indicated that in the U.S. any reduction in friction was associated with a steady increase in accidents (OECD, 1984).

Detailed analyses revealed a linear crash-skid resistance relationship as the proper function for interpreting the data (OECD, 1984). This behavioral function conflicts with other relationships obtained from Europe. A study of high-speed rural roads in Germany suggested a non-linear relation, with a higher slope for low friction values than for high friction values (Figure 7).

![Wet Accidents vs. Friction](image)

Figure 7 Non-Linear Relationship Between Wet-Pavement Crashes and Friction
Wallman and Astrom (2001) also reported a similar regression analysis in Germany by Schulze (1976). Figure 8 shows the general trend of the increasing percentage of wet surface crashes with the decreasing friction level (Wallman and Astrom 2001).

Another study described by Wallman and Astrom with similar behaviour is the Norwegian Veg-grepsprosjektet. In this study, comprehensive friction measurements and roadway observations were completed resulting in the assessment of crash rates for different friction intervals as summarised in Figures 9 and 10.

The Nordic TOVE project provided similar results for two lane highways in Denmark (Figure 11) for friction values obtained with a side force device, Stradograph.
International literature shows some Spanish study about the relationship between bitumen properties and adherence.

I. Pérez Barreno\(^\text{10}\) analyses the relationships between bitumen properties and the bituminous mixes rutting resistance. A good linear relationship has been observed between the inverse of the different values from binder properties, and the results from the wheel-tracking tests of the mixtures on conventional and modified binders.

M. Á. Rodríguez Valverde et al.\(^\text{11}\) observed that Cold-mix paving technology based on bitumen emulsions involves complex phenomena of mainly kinetic character. The key stage of bitumen film formation on aggregates, in order to obtain high-performance dense-graded cold mix asphalt, is the emulsion breaking. The bituminous phase and aqueous phase break their colloidal equilibrium in this step. The speed of this stage is used to classify emulsions manufactured upon different conditions. A suitable parameter to quantify these differences is the breaking time. In this work, an objective and reliable method to measure easily the characteristic time during phase separation is explained. This approach improves the qualitative results of conventional assays.

designed to this task and requires little amount of materials (emulsion as well as aggregates). Besides, the experimental conditions are closer to real ones with few initial restrictions.

J. J. Potti et al.\textsuperscript{12} designed a generation of emulsions in order to provide excellent adhesion between layers and reduce excess tack

\textbf{Evenness}

Evenness is a measure of the regularity of a road surface. All types of road surfaces (rigid, flexible, gravel, etc.) deteriorate at a rate which varies according to the combined action of several factors: axial load of vehicles; traffic volumes; weather conditions; quality of materials; construction techniques.

These deteriorations have an impact on the road surface roughness by causing either cracking, deformation or disintegration.

Various indicators can serve to estimate the quality of the longitudinal evenness of a road surface, but the International Roughness index (IRI), developed by the World Bank in the 1980’s, is the one most used today.

The IRI measures the vertical motion of the suspension of the vehicle travelling on the road under standardized testing conditions (meters of vertical displacement per kilometre driven). One of the main advantages of the IRI over older measurement methods is its reliability. The standardized testing conditions facilitate both repeatability and comparisons of results. Typical IRI values range between 0 m/Km and 20 m/Km (“0” representing perfect conditions).

The measurement of the transverse profile of the pavement allows the detection of various types of problems: inadequate camber, lane/shoulder drop-off, rutting, etc.

A number of road administrations use rut depths as a trigger to road surface remedial actions. The presence of ruts makes lateral shifts more difficult and increases discomfort and manoeuvre difficulties. Moreover, the presence of ruts can cause water accumulation, thereby increasing the risk of aquaplaning. The situation is particularly hazardous for two-wheeled vehicles. A rut depth of 20 mm to 25 mm is often considered critical. It can be measures manually or with laser devices.

\textsuperscript{11} M. Á. Rodríguez Valverde et al.. Velocidad de rotura de las emulsiones bituminosas en contacto con áridos. Revista Carreteras, N\textsuperscript{o} 130, 2003.

\textsuperscript{12} J. J. Potti et al.. Emulsiones termoadherentes para riegos de adherencia. Revista Carreteras, N\textsuperscript{o} 127, 2003.
The pavement condition can also be expressed in terms of Present Serviceability Rating (PSR). The PSR ranges from 0 to 5 (very poor to very good) as defined in Figure 12 and includes a description of rideability, physical distress such as cracking, and rehabilitation needs.

<table>
<thead>
<tr>
<th>PSR &amp; Verbal Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>Only new, superior (or nearly new) pavements are likely to be smooth enough and distress free (sufficiently free of cracks and patches) to qualify for this category. Most pavements constructed or resurfaced during the data year would normally be rated very good.</td>
</tr>
<tr>
<td>4.0</td>
<td>Pavements in this category, although not quite as smooth as those described above, give a first class ride and exhibit few, if any, visible signs of surface deterioration. Flexible pavements may be beginning to show evidence of rutting and fine random cracks. Rigid pavements may be beginning to show evidence of slight surface deterioration, such as minor cracks and spalling.</td>
</tr>
<tr>
<td>3.0</td>
<td>The riding qualities of pavements in this category are noticeably inferior to those of new pavements, and may be barely tolerable for high speed traffic. Surface defects of flexible pavements may include rutting, map cracking, and extensive patching. Rigid pavements in this group may have a few joint failures, faulting and cracking, and some pumping.</td>
</tr>
<tr>
<td>2.0</td>
<td>Pavements in this category have deteriorated to such an extent that they affect the speed of free-flow traffic. Flexible pavement may have large potholes and deep cracks. Distress includes ravelling, cracking, rutting, and occurs over 50 percent, or more, of the surface. Rigid pavement distress includes joint spalling, faulting, patching, cracking, scaling, and may include pumping and faulting.</td>
</tr>
<tr>
<td>1.0</td>
<td>Pavements in this category are in an extremely deteriorated condition. The facility is passable only at reduced speeds, and with considerable ride discomfort. Large potholes and deep cracks exist. Distress occurs over 75 percent or more of the surface.</td>
</tr>
<tr>
<td>0.0</td>
<td></td>
</tr>
</tbody>
</table>

Figure 12   Variability of PSR
When the evenness of a whole road section has sharply deteriorated, users tend to reduce their speed in order to maintain their comfort at an acceptable level, thus minimizing potential safety impacts.

The equation as developed from the AASHO Road Test was the following:

$$PSI = 5.03 - 1.91 \log(1 + a) - 0.01 \sqrt{b + c} - 1.38d^2$$

where:

- $a =$ slope variance at time $t$;
- $b =$ crack length in feet per 1,000 ft$^2$;
- $c =$ patching in ft$^2$ per 1,000 ft$^2$;
- $d =$ average rut depth in inches.

C.J. Bester$^{13}$ suggests the following relationships:

1) \(TOT = -0.295 - 0.12 \cdot P^2 + 0.71 \cdot T^2 + 0.933 \cdot psi - 0.648 \cdot T \cdot psi\)

\(TOT = \) accidents percent \([\text{number of accidents/}10^6 \text{ vehicle*Km}]\)

\(P = \) shoulder width \([\text{m}]\)

\(T = 1 \) if flat terrain; \(3 \) if mountainous terrain;

\(psi: \) present serviceability index

2) \(SIN = 0.275 - 0.055 \cdot P^2 + 0.41 \cdot T^2 + 0.70 \cdot psi - 0.0496 \cdot C - 0.43 \cdot T \cdot psi\)

\(SIN = \) percentage single vehicle accidents \([\text{number of accidents/}106 \text{ vehicle*Km}]\)

\(P = \) shoulder width \([\text{m}]\)

\(T = 1 \) if flat terrain; \(T = 3 \) if mountainous terrain

\(psi: \) present serviceability index

$^{13}$ C.J. Bester – The effect of road roughness on safety – Department of Civil Engineering University of Stellenbosch, 2002
C = carriageway width [m]

When road surface deficiencies are likely to increase the risk of accident and corrective measures cannot be immediately implemented, warning signs must be installed as a temporary measure, in order to warn approaching road users.

Improving the friction of the road surface can be achieved in several ways. Such treatments are as follows:

**Surface Treatment** - *Any application applied to an asphalt pavement surface to restore or protect the surface characteristics.*

- **Chip Seal** - A surface treatment in which the pavement is sprayed with asphalt (generally emulsified) and then immediately covered with aggregate and rolled. Chip seals are used primarily to seal the surface of a pavement that has non load-associated cracks and to improve surface friction, although they also are commonly used as a wearing course on low volume roads. This is typically used to extend the life of the pavement surface by sealing out moisture, which can cause major damage to pavement, until major repairs can be made.

- **Diamond Grinding** - A process that uses a series of diamond tipped saw blades mounted on a shaft or arbor to shave the upper surface of a pavement in order to remove bumps, restore pavement rideability, and improve surface friction.

- **Grooving** - The process used to cut slots into a pavement surface to provide channels for water to escape beneath tires, improve skid resistance and reduce the potential for hydroplaning.

- **Sandblasting** - A procedure in which compressed air is used to blow sand particles at a pavement surface to abrade and clean the surface. Sandblasting is a construction step in partial-depth patching and joint resealing.

- **Sand Seal** - An application of asphalt binder, normally an emulsion, covered with a fine aggregate. It may be used to improve the skid resistance of slippery pavements and to seal against air and water intrusion.

- **Slurry Seal** - A mixture of slow-setting emulsified asphalt, well-graded fine aggregate, mineral filler, and water. It is used to fill cracks and seal areas of old pavement, to restore a uniform surface texture, to seal the surface in order to prevent moisture and air intrusion into the pavement, and to improve skid resistance.

- **Pavement resurfacing** – This treatment consists in laying a new road surface with extra good friction on the top of the old surface, such as porous or drainage asphalt providing high friction characteristic even in rain condition.
**Pavement Reconstruction** - Complete removal and replacement of the existing pavement structure, which may include new and/or recycled materials, in order to improve surface friction.

**Improving road foundations**

Colder areas obviously require winter maintenance of road consisting in:

- snow clearance
- sanding icy areas
- salting (chemical de-icing)
- increasing maintenance preparedness
- general increase in the standard of winter maintenance

snow screens in areas exposed to snowdrifts

### 3.2 Roadside Design

The hazardousness of the roadside influences in accident occurrence and severity. The Interactive Highway Safety Design Model (IHSDM) takes the quality of roadside design into account. Therefore an accident modification factor (AMF$_9$) based on Zegeer et al.$^{14}$ was developed. As no satisfactory studies about the relationship between roadside design and accidents could be found AMF$_9$ was derived directly from the base model for roadway sections presented in the following equation.

\[
AMF_9 = \frac{\exp(-0.6869 + 0.0668 \cdot \text{RHR})}{\exp(-0.4865)}
\]

where:

\text{RHR} = \text{roadside hazard rating for the highway segment considering both sides of the road}

The subsequent Figure 13 shows the possible values for AMF$_9$, gives a description of the corresponding rating and shows an example of a typical road for each rating.

---

<table>
<thead>
<tr>
<th>RHR</th>
<th>AMF&lt;sub&gt;9&lt;/sub&gt;</th>
<th>Description</th>
<th>Example for typical roadway</th>
</tr>
</thead>
</table>
| 1   | 0.87           | Wide clear zones greater than or equal to 9 m from the pavement edgeline  
|     |                | Sideslope flatter than 1:4  
|     |                | Recoverable                | [Image](#) |
| 2   | 0.94           | Clear zone between 6 and 7.5 m from pavement edgeline  
|     |                | Sideslope about 1:4  
|     |                | Recoverable                | [Image](#) |
| 3   | 1              | Nominal or base condition  
|     |                | Clear zone about 3 m from pavement edgeline  
|     |                | Sideslope about 1:3 or 1:4  
|     |                | Rough roadside surface  
|     |                | Marginally recoverable     | [Image](#) |
| 4   | 1.07           | Clear zone between 1.5 and 3 m from pavement edgeline  
|     |                | Sideslope about 1:3 or 1:4  
|     |                | May have guardrail (1.5 to 2 m) from pavement edgeline  
|     |                | May have exposed trees, poles, or other objects (about 3 m) from pavement edgeline  
<p>|     |                | Marginally forgiving, but increased chance of a reportable roadside collision | <a href="#">Image</a> |</p>
<table>
<thead>
<tr>
<th>RHR</th>
<th>AMF&lt;sub&gt;9&lt;/sub&gt;</th>
<th>Description</th>
<th>Example for typical roadway</th>
</tr>
</thead>
</table>
| 5   | 1.14           | Clear zone between 1,5 and 3 m from pavement edgeline  
Sideslope about 1:3  
May have guardrail (0 to 1,5 m from pavement edgeline)  
May have rigid obstacles or embankment within 2 to 3 m of pavement edgeline  
Virtually non-recoverable | ![Example of a typical roadway with a clear zone, sideslope, and guardrail.](image) |
| 6   | 1.22           | Clear zone less than or equal to 1,5 m  
Sideslope about 1:2  
No guardrail  
Exposed rigid obstacles within 0 to 2 m of the pavement edgeline  
Non-recoverable | ![Example of a typical roadway with a clear zone, sideslope, and exposed rigid obstacles.](image) |
| 7   | 1.31           | Clear zone less than or equal to 1,5 m  
Sideslope 1:2 or steeper  
Cliff or vertical rock cut  
No guardrail  
Non-recoverable with high likelihood of severe injuries from roadside collision | ![Example of a typical roadway with a clear zone, sideslope, and cliff.](image) |

Figure 13  Definitions of the Roadside Hazard Ratings used with the Accident Prediction Algorithm

AMF<sub>9</sub> applies to total roadway segment accidents.

**Slope flattening**

To reach a high level of road safety it is advisable to build embankments as flat as possible. One should never build a slope steeper than 3:1, because drivers are not able to control vehicles on those slopes - the vehicle would overturn.
Embankments with slopes between 3:1 and 4:1 are passable if they are uniform, which means that there shouldn’t exist any type of important irregularities down to the point where the slope ends.

Embankments with slopes less steep than 4:1 are passable and drivers can recover vehicles that got beyond control and ascend again to the road. Slopes should be built solid to minimize problems when a vehicle is forced to drive on them.

The subsequent graphical presentation shows the chance on single vehicle accidents (only one vehicle is involved) on different slopes compared to a slope 1:7

![Graph showing chance on single vehicle accidents on different slopes compared to a slope 1:7](image)

**Figure 14** Chance on single vehicle accidents on different slopes compared to a slope 1:7

The roadside hazard rating $H$ is present in others models:\(^{15}\)

$$AA = 0.0015 \cdot ADT^{0.9711} \cdot 0.8897^W \cdot 0.9403^{PA} \cdot 0.9602^{UP} \cdot 1.2^H$$

$AA =$ Total Accidents [mile/year]  
$ADT =$ average daily traffic  
$W =$ carriageway width [feet]  
$PA =$ paved shoulder width [feet]  
$UP =$ unpaved shoulder width [feet]  
$H =$ roadside hazard rating

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\(^{15}\) Zeeger C., Reinfurt D., Hummer J., Herf L., Hunter W. – Safety effects of cross-section design for two lane roads – FHWA-RD-87/008, 1987
$AA = 0.0019 \cdot ADT^{0.8824} \cdot 0.8786^W \cdot 0.9192^P \cdot 0.9316^{UP} \cdot 1.2365^H \cdot 0.882^{T1} \cdot 1.3221^{T2}$

$AA = \text{Total Accidents [mile/year]}$
$ADT = \text{average daily traffic}$
$W = \text{carriageway width [feet]}$
$PA = \text{paved shoulder width [feet]}$
$UP = \text{unpaved shoulder width [feet]}$
$H = \text{roadside hazard rating}$
$T1 = 1 \text{ if flat terrain; 0 other}$
$T2 = 1 \text{ if mountainous terrain; 0 other}$

The measures to improve the “roadside safety” are the following:

**Increasing the distance to fixed obstacles** - A driver who lost control over his vehicle and left the road tries to get the vehicle back on the road. If the roadside is “forgiving” in the multitude of cases this manoeuvre should be possible. If there were obstacles (trees, very steep embankments…) situated it would lead almost inevitable to an accident. For that reason obstacles should be situated as separated from the roadside as possible. Uncovered roadside gutters involve a serious risk, even at the slightest inattention. Walls of subsurface drainage structures should be situated adequately. Studies show that the larger is the distance between roadside and obstacles the less accidents happen and the less severe are the remaining accidents. Recommendations for obstacle free zones in the Netherlands are:

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>100 Km/h</th>
<th>80 Km/h</th>
<th>60 Km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>normally</td>
<td>8.00 m</td>
<td>6.00 m</td>
<td>4.50 m</td>
</tr>
<tr>
<td>minimum</td>
<td>6.00 m</td>
<td>4.50 m</td>
<td>3.00 m</td>
</tr>
</tbody>
</table>

Figure 15 Recommended widths for obstacle free zones according to Handbook Road Safety

In special occasions it may be advisable to build an even wider obstacle free zone:
- To comply with the necessary stopping sight distance
- On road stretches where higher speeds are allowed
Installation of safety barrier systems

Crash barriers should only be installed if their existence reduces the impact of potential accidents, as the fundamental purpose of crash barriers is to prevent vehicles from abandoning the road in an uncontrolled way and hit an object which brings it to a violent halt or fall down a side slope. In other words: The probable consequences of the accident should be considered as more serious than those provoked by the proper collision with the crash barrier. A collision with the barrier should not cause neither the roll-over of the vehicle nor such a deceleration as to cause serious damages to the occupants of the vehicle itself: in fact, the human brain remains permanently damaged if a deceleration of 80 g (g=9.81 m/sec²) is applied for more than 3 milliseconds, as well as heart and lungs can not tolerate values greater than 60 g for more than 3 milliseconds.

The vehicle will have to be brought back on one such trajectory not to become a danger for the other circulating vehicles on the same roadway: this means that the rebound trajectory must have the lowest possible angle related to the road axis. Such a result can be obtained with the absorption from the barrier of the greatest possible percentage of the vehicles transversal acceleration.

Two typologies of safety barriers exist:

- iron (double and triple wave)
- concrete (New Jersey)

The first ones are constituted by a series of iron vertical supports, from one or more metallic horizontal bands double or triple wave shaped, with several division elements. The transversal component of the speed is adsorbed by the plastic deformation of the barrier and the vehicle.

New Jersey is constituted by blocks of concrete that introduce a particular profile able to produce the followings valuable effects for a car or a heavy vehicle:

- reduction of the kinetic energy, due to the creeping along the profile and the negative job of the gravity forces;
- straightening of the vehicle’s wheels and the consequent assessment of the trajectory in a direction parallel to the road axis.
- avoiding, due to the continuity of the barriers, to bump against more rigid and strong elements (the supports of the metallic barriers).
Flattening side slopes

To reach a high level of road safety it is advisable to build embankments as flat as possible. One should never build a slope steeper than 3:1, because drivers are not able to control vehicles on those slopes - the vehicle would overturn.

Embankments with slopes between 3:1 and 4:1 are passable if they are uniform, which means that there shouldn’t exist any type of important irregularities down to the point where the slope ends.

Embankments with slopes less steep than 4:1 are passable and drivers can recover vehicles that got beyond control and ascend again to the road. Slopes should be built solid to minimize problems when a vehicle is forced to drive on them.

The subsequent graphical presentation shows the chance on single vehicle accidents (only one vehicle is involved) on different slopes compared to a slope 1:7.

Edge-line treatments

Road engineers attempt to improve the visibility of highways by delineating the road ahead and there are a number of edge-line treatments that can reduce the incidence and severity of run-off-road type crashes, particularly those that have been used to either alert a driver to the imminent departure of their vehicles from the roadway and/or to reduce the danger once they have actually left the paved surface.

Edge-line treatments include: rumble strips, increased number of posts on bends, and installation of raised pavement markers.


3.3 Road markings

In order to drive safely and comfortably, drivers are dependent on reference points in the proximity of the vehicle and further ahead in the direction they are driving. In the dark in particular, but also in other poor visibility conditions (for example in fog), such reference point are essential when it is hard to identify the road form its surroundings.

At complicated intersections, it is important for road users to be able to find the right place on the carriageway using reference points. Road markings are intended to:

− direct traffic by indicating the path of the carriageway and marking the road in relation to the surroundings;
− warn road users about specific or hazardous conditions related to the road alignment;
− control traffic, for example by reserving certain parts of the road for certain traffic groups and by allowing or prohibiting overtaking and lane-changing);
− supplement and reinforce information given by means of traffic signs:

The following road marking can further improve safety:

− longitudinal lines on the road surface made of retro-reflective paint or plastic
− shoulder rumble strip (edge lines)
− delineator posts
− combinations of several types of road markings, including road markings and other measures.

3.4 Road lighting

Most of the information drivers utilise in traffic is visual. Visual conditions can therefore be very significant for safe travel. In the dark, the eye picks up contrast, detail and movement to a far lesser extent than in daylight for all road users. In particular, in the dark the risk increases more for younger drivers than for older age groups and more for pedestrians than for people travelling by motor vehicle.

Around 35% of all police reported injury accidents occur in the twilight or in the dark. The percentage of accidents in the dark is highest for accidents involving pedestrians and accidents where vehicles run off the road. The objective of road lighting is to reduce the accident rate in the dark it easier to see the road, other drivers and the immediate surrounding of the road.
In some countries, road and street lighting is reduced during certain periods in order to save energy. The usual way of reducing lighting is to turn off every other lamp with the effect of halving the level of lighting. The effect of reducing lighting on the number of accidents has subject of study, since halving the level of lighting is associated with an increase of about 15-25% of the number of accidents at night\(^\text{16}\).

Aspects connected with the lighting of the road also have to be considered in the building of the roads of the new generation. It concerns assurance of suitable parameters for:

- the luminosity of the surface of the road;
- the evenness of the lighting of the road;
- the limitation of the dazzle;
- the visual leading by the lighting system.

The **Luminosity (the intensity of the light) of the surface of the road** - it is the measure of brightness from what the given surface is noticed by the observer. The better are properties of reflecting the surface of the road, the larger quantity of the light will be returned and the surface will be seem brighter. The definite level of luminosity will assure the good visibility on the road. On the basis of researches it is known, that for the lighting of street on the level of 0,5 CD / m\(^2\) (intensity of lighting 2,5 lx) the ability of the perception is 10%, and for the value of luminosity of 2 CD / m\(^2\) (intensity of lighting 10 lx) the ability of the perception is 85%.

The **evenness of the lighting of the road** - it is the ratio of minimum luminosity to the average luminosity of the surface of the road. The smaller is relation (the worse is evenness), the worse will be ability of perception of objects against the background of the surface of the road. And, for example, reducing evenness from 0,4 to 0,2 causes reducing of the ability of notice from 85% to 55%, that is deterioration about 65%.

The **dazzle** - it occurs when there are excessively garish sources of the light against the dark background in the field vision. The degree of the loss of visual efficiency depends both from the construction of the lighting case, and road lighting installation treated as the whole.

This effect can bring to the weakness of the quality of the vision, for example lowering of indicator of visual efficiency caused by dazzle about 20% causes falls of ability of notice from 85% to 70%.

\(^{16}\) R. Elvik – T. Vaa – The handbook of road safety measures
The visual leading by the lighting system – driver driving the vehicle receives information focusing on driving, and foreseeing the far direction reacts in the right way. The correct designed lighting system allows to direct the driver sight by light.

Lighting bindings hung over the road give additional information about the direction of the turn of the road to the driver. Driveways and exits from the main road should be carried out by the different kind of lighting. It can be carried out for example by cases hung on the different height or equipped in different colour of the light. Then driver has already information about the direction of the drive in advance.

### 3.5 Traffic volume and traffic composition

Traffic volume is generally defined as the number of motor vehicles using a road per unit of time. Pedestrians and cyclists tend not to be included, usually because there are no reliable counts of their numbers. The volume of travel includes passengers in addition to drivers.

The relationship between exposure and accidents can be expressed in terms of a mathematical function of the following form:

\[
\text{Number of accidents} = \alpha Q^b
\]

where

- \( Q \) is a measure of traffic volume, raised to the exponent \( b \);
- \( \alpha \) is a scaling constant.

The coefficient \( b \) shows the percentage of change in the number of accidents when traffic volume changes by one percent or equivalently the elasticity of accidents with respect to traffic volume. A sample of results, taken from a Norwegian doctoral dissertation (Fridstrøm 1999), shows that the total number of injury accidents increases by almost 1 percent if traffic volume increases by 1 percent. Accidents involving multiple vehicles or road users, such as pedestrians and cyclists, increase slightly more than 1 percent when traffic volume increases by 1 percent. Single vehicle accidents increase by less than 1 percent when traffic volume increase 1 percent. The traffic volume above considered is defined regardless its composition.

In literature the accident prediction models link the number of accidents to the traffic composition, assuming the percentage of heavy vehicles as input variable.
M. Roine, R. Kulmala proposed:

\[
FacT = \exp(-2.482 + S - 0.24448 \cdot RFL(2) + 0.003411 \cdot KA + 0.001267 \cdot TYL - 0.1857 \cdot FNR(2) + 0.01246 \cdot R - 0.01547 \cdot RKVL + 0.006312 \cdot RFL(1) \cdot MA + 0.01858 \cdot RFL(2) \cdot MA)
\]

\(FacT\) = percent accidents (1979-1986)
\(S\) = total traffic [MV]
\(RFL\) = 1 if 7.60m < carriageway width < 8.50m; 2 if carriageway width > 8.50m;
\(MA\) = average hilliness [m/Km];
\(KA\) = average bendiness [Grad/Km];
\(FNR\) = speed limit: 0 if FNR < 80 Km/h; 1 if FNR = 80 Km/h; 2 if FNR = 100 Km/h;
\(TYR\) = number of access per Km;
\(R\) = heavy vehicles percent;
\(RKVL\) = AADT (100 vehicles).


\[
Fac = \exp(-1.734 + S - 0.1989 \cdot RLE(2) + 0.001409 \cdot KA + 0.0009253 \cdot TYL - 0.1495 \cdot FNR(2) + 0.02680KPI + 0.004529RLE(1) \cdot MA + 0.02221 \cdot RLE(2) \cdot MA - 0.03401 \cdot RLE(1) \cdot RKVL - 0.04668 \cdot RLE(2) * RKVL)
\]

\(FacT\) = accidents percent (1979-1986); collisions with pedestrians, cyclists and animals not included
\(S\) = total traffic [MV]
\(RLE\) = 1 if 7.60m < carriageway width < 9.50m; 2 if carriageway width > 9.50m;
\(MA\) = average hilliness [m/Km];
\(KA\) = average bendiness [Grad/Km];

\footnote{M. Roine, R. Kulmala – Accident models for major roads in Finland. Links on single carriageways outside densely populated areas – Research Report 730, VTT, 1990.}
FNR = speed limit: 0 if FNR < 80 Km/h; 1 if FNR = 80 Km/h; 2 if FNR = 100 Km/h;
TYL = access number per Km;
R = heavy vehicles percent;
RKVL = AADT (100 vehicles).
KPIT = investigated section length [Km]
Kalakota K.R., Seneviratne P.N\(^{18}\) proposed

\[Y = 41.32 - 1.23X_1 - 0.54X_2 - 0.67X_6 + 0.03X_1X_2 + 0.03X_2X_6 - 0.0009X_2X_9 + 0.026X_2X_{11} - 0.12X_4X_{11} + 0.009X_5X_9\]

\(Y = \text{Total Accidents/MVM}\)
\(X_1 = \text{heavy vehicles percent};\)
\(X_2 = \text{max flow/ level of service B ratio};\)
\(X_4 = \text{lane width [feet]}\)
\(X_5 = \text{shoulder width [feet]}\)
\(X_6 = \text{cross slope [feet/feet]}\)
\(X_9 = < 580 \text{ m-radius road percent [%]}\)
\(X_{11} = \text{intersections minimum number per mile}\)

3.6 Junctions, intersections and driveways

Accesses and intersections are some of the most frequent causes of risk. When traffic coming from another road is introduced in a road a conflicting traffic flow is created. That includes traffic coming from local, public and private ways.

\(^{18}\) Kalakota K.R., Seneviratne P.N – Accident prediction models for two-lane rural highways – north Dakota State University – 1994
The following text deals with the most important features that influence in safety at intersections and ends with a comparison of different intersection types and some recommendations for intersections between secondary roads and roads of other categories.

3.6.1 Driveways or access points

Driveway density

The separation of points where decisions have to be made, the elimination of unforeseeable events and the control of access from lateral properties are reasons why highways have a higher level of safety than other roads.

In the following the word access makes reference to a point where traffic is introduced from others streets, including local, public, private and commercial roads.

By access control roads can be made safer. Access control means to space, reduce or eliminate the variety of events to which the driver has to respond. It is one of the most important factors in accident reduction. It is possible to reduce the number of accesses to a road, for example, by building or using a lateral road or street to which adjacent properties have access. Further away this lateral road has access to the main road. This modus operandi has considerable influence on the safety level of roads with elevated traffic density. The adequate choice of the spacing between accesses and of the position of intersections have also a significant impact on capacity.

There are studies\textsuperscript{19,20} that mention that the accident frequency augments rapidly when the density of accesses rises. That indicates that one should reduce the number of accesses.

\begin{flushright}
\end{flushright}
Often it is not possible or practical to eliminate the accesses, although reducing the conflict level in access points can moderate the negative effects of accesses. For example by:

- Reducing the number of accesses
- Eliminating left turns
- Providing lateral (parallel) roads/streets
- Providing lanes for turnarounds
- Providing acceleration/deceleration lanes

As dangerous as lateral accesses are left turns, so the engineer should try to reduce the number of left turn possibilities. This does not mean that one should eliminate all left turns completely but reduce the number and make the remaining safer.

Another excellent solution is the construction of grade separated left turn possibilities instead of crossing the oncoming traffic.

Several studies have been conducted to prove the speculation that there is a relation between access point/driveway density and accident occurrence.

Within the framework of a study conducted by the Committee on access management (Transportation Research Circular 456)\(^\text{21}\) the following function to describe the relation was found:

\[
\text{Accidents/MVkm} = 1,199 + 0,0047 \cdot X + 0,0024 \cdot X^2
\]

where:

\[X = \text{access point per km}\]

The corresponding figure for different densities of access points is shown below.

\[\text{Accidents/MVkm} = 1,199 + 0,0047 \cdot X + 0,0024 \cdot X^2\]

\(^{21}\) Committee on access management: “Driveway and street intersection spacing”, Transportation Research Board, Transportation Research Circular 456, Washington, D.C., 1996
To describe the accident modification function one has to set $X_{\text{after}}$ for access point per km after modification and $X_{\text{before}}$ for access point per km before modification and divide both. The corresponding formula is:\(^{22}\)

$$\text{AMF}_{DD} = \frac{1,199 + 0,0047 \cdot X_{\text{after}} + 0,0024 \cdot X_{\text{after}}^2}{1,199 + 0,0047 \cdot X_{\text{before}} + 0,0024 \cdot X_{\text{before}}^2}$$

The resulting values are in the subsequent table:

---

22 Ezra Hauer: "Access and Safety", Professor (Emeritus), Department of Civil Engineering, University of Toronto, Toronto, April 15, 2001
The values in the table can be used to calculate the influence of a modification in access point density on accident frequency.

Another study by Muskaug\textsuperscript{23} ended with an estimate for accident rate for six ADT classes. The study deals only with injury accidents. Hauer\textsuperscript{22} fitted the data into a function:
Accidents/ MVkm = 0.2 + (0.05 - 0.005 \cdot \ln [ADT]) \cdot DD

where:

**ADT** = Average Daily Traffic

**DD** = Driveway Density

The subsequent graphical presentation shows Hauers fit for the six ADT classes mentioned before:

![Graphical representation of accidents per MVkm for different access point densities](image)

Figure 17  Accidents per Mvkm for different access point densities

As in the previous model, one can determine the AMF by dividing the Accidents/ MVkm after and before. The formula is:

\[
\text{AMF}_{DD} = \frac{(0.2 + (0.05 - 0.005 \cdot \ln [ADT]) \cdot DD_{after})}{(0.2 + (0.05 - 0.005 \cdot \ln [ADT]) \cdot DD_{before})}
\]

The resulting values for an ADT of 2000 veh/day are in the subsequent table:

---

The Norwegian study by Muskaug is considered by an international expert panel as the best available study on “safety effects of driveway density on rural two-lane highways”. Furthermore Muskaug’s study is consistent to the results of other studies.\textsuperscript{24} 

3.6.2 At-grade intersections

Intersection skew angle

The Interactive Highway Safety Design Model (IHSDM)\textsuperscript{25} defines the skew angle of an intersection as the derivation of an intersection angle of 90° or in other words the absolute value of the difference between 90° and the actual angle between the major legs and minor legs of an intersection. This absolute value is always within a range from 0° to 90°. The nominal or base condition of intersection skew angle is 0° of skew that can be found at a rectangular intersection where major and minor legs cross at 90°: from a traffic safety point of view, this intersection angle is recommended. The value of the AMF for intersection skew angle is the same independently if the minor leg is STOP-controlled or YIELD-controlled.

For a four-leg intersection where the angles of the intersection legs to the left and the right of the major road differ, they are averaged. For example, if one leg forms a 50° angle and the other intersects at 20° degrees, then the average would be 35° [\text{SKEW} = (20+50)/2 = 35°]

Figure 18 Skew angles for different intersection forms

\textsuperscript{25} Interactive Highway Safety Design Model (IHSDM): “Crash Prediction Module Engineer’s Manual”, September 30, 2004
Sign controlled (STOP-controlled and YIELD-controlled)

The IHSDM distinguishes between three-leg STOP-controlled (YIELD-controlled) intersections and four-leg STOP-controlled (YIELD-controlled) intersections. Intersections with more than four legs (multi-leg) have not been addressed in the initial version of the IHSDM accident prediction algorithm.

The reduced equation to calculate the AMF for intersection skew angle (AMFSKEW) for a three-leg STOP-controlled intersection is:

\[
AMF_{SKEW,3LEG} = \exp (0.0040 \cdot SKEW)
\]

The reduced equation to calculate the AMF for intersection skew angle (AMFSKEW) for a four-leg STOP-controlled intersection is:

\[
AMF_{SKEW,4LEG} = \exp (0.0054 \cdot SKEW)
\]

in both:

\[
SKEW = \text{intersection skew angle as described previously}
\]

The value for all way STOP-controlled intersections is:

\[
AMF_{SKEW,STOP} = 1.00
\]

These AMF apply to total intersection accidents.

Traffic light controlled (signalised)

Three-leg signalised intersections (just as multi-leg signalised intersections) have not been addressed in the initial version of the IHSDM accident prediction algorithm. The model only provides an AMF for four-leg signalised intersections. This value is:

\[
AMF_{SKEW,LIGHT} = 1.00
\]

for all cases of skew angle.

Intersection traffic control

The nominal or base condition for STOP-controlled intersections in the IHSDM is an intersection with STOP signs only on the minor leg(s). Minor-road YIELD controlled intersections are treated identically to minor-road STOP-controlled intersections in the accident prediction algorithm. In this case is:

\[
AMF_{MINOR,STOP} = 1.00
\]
The other possible traffic control is that all ways are STOP-controlled. Lovell and Hauer\(^{26}\) studied accidents on intersections from the US and Canada and found that an all-way STOP-controlled intersection experiences 47% fewer accidents than a two-way STOP-controlled intersection. As a result they set the AMF (applies to total intersection-related accidents) for all-way STOP controlled intersections to:

\[
AMF_{ALL, STOP} = 0.53
\]

One could think that therefore all-way STOP-controlled intersections are related to fewer accidents and thus conversion from minor-road to all-way STOP-controlled intersections will always reduce accident occurrence.

The expert panel recommended that all-way STOP-control should only be used when the established warrants are met. This is necessary to discourage indiscriminate use of all-way STOP-control. All-way STOP control is most appropriate for lower-speed roadways with relatively equal traffic volumes on all legs of the intersection.

**Intersection Left-turn lanes**

The table below shows the values of the AMF for left-turn lanes that are specified for use in the IHSDM. AMF\(_{LTL}\) depends on the intersection type, the type of traffic control on that intersection and on the number of approaches (legs) on which left turn lanes are installed. If there are no left-turn lanes on any major legs to the intersection (nominal or base condition) AMF\(_{LTL}\) is set to 1,00. The AMFs in the subsequent table are based on FHWA-RD-02-089 and other sources evaluated by the IHSDM expert panel\(^{25}\).

All AMFs apply to total intersection-related accidents.

<table>
<thead>
<tr>
<th>Intersection type</th>
<th>Intersection traffic control</th>
<th>One approach (leg) on which left turn lanes installed</th>
<th>Both approaches (legs) on which left turn lanes installed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three-leg intersection</td>
<td>STOP-controlled</td>
<td>0,56</td>
<td>N/A</td>
</tr>
<tr>
<td>Three-leg intersection</td>
<td>Signal-controlled</td>
<td>0,85</td>
<td>N/A</td>
</tr>
<tr>
<td>Four-leg intersection</td>
<td>STOP-controlled</td>
<td>0,72</td>
<td>0,52</td>
</tr>
<tr>
<td>Four-leg intersection</td>
<td>Signal-controlled</td>
<td>0,82</td>
<td>0,67</td>
</tr>
</tbody>
</table>

Table 3. AMFs for Installation of Left-turn Lanes on the Major Legs of Intersections

\(^{26}\) J. Lovell and E. Hauer: "The Safety Effect of Conversion to All-Way STOP Control", Transportation Research Record 1068, Transportation Research Board, 1986
**Intersection Right-turn lanes**

The table below shows the values of the AMF for right-turn lanes that are specified for use in the IHSDM. AMF\(_{RTL}\) depends on the intersection type, the type of traffic control on that intersection and on the number of approaches (legs) on which right turn lanes are installed. If there are no right-turn lanes on any major legs to the intersection (nominal or base condition) AMF\(_{RTL}\) is set to 1.00. The AMFs in the subsequent table are based on FHWA-RD-02-089 and other sources evaluated by the expert panel.\(^{25}\)

All AMFs apply to total intersection-related accidents.

<table>
<thead>
<tr>
<th>Intersection type</th>
<th>Intersection traffic control</th>
<th>One approach (leg) on which right turn lanes installed</th>
<th>Both approaches (legs) on which right turn lanes installed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three-leg intersection</td>
<td>STOP-controlled</td>
<td>0.86</td>
<td>N/A</td>
</tr>
<tr>
<td>Three-leg intersection</td>
<td>Signal-controlled</td>
<td>0.96</td>
<td>N/A</td>
</tr>
<tr>
<td>Four-leg intersection</td>
<td>STOP-controlled</td>
<td>0.86</td>
<td>0.74</td>
</tr>
<tr>
<td>Four-leg intersection</td>
<td>Signal-controlled</td>
<td>0.96</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Table 4. AMFs for Installation of Right-turn Lanes on the Major Legs of Intersections

**Roundabouts**

Roundabouts are relatively easy to understand because of their simplicity and uniformity in functioning. Apart from that they provide a comfortable possibility to turn to the opposite direction (U-turn) and to find the right exit (by driving another round). At roundabouts exists the possibility of the subsequent incorporation of an additional leg, always if there is enough clearance.\(^{27}\) (up to 4 legs)

In most western European countries as Great Britain, France, Spain, Germany, Switzerland, Norway, Portugal, The Netherlands etc. roundabouts have established themselves and in some cases they are already quiet widespread.

\(^{27}\) Eduardo Fernández de Villalta Ferrer-Dalmau: “Intersection morphology and design”, in CARRETERAS magazine, Spain, Nov.-Dec. 2004
According to Ourston et al.\textsuperscript{28} the most important operational element of a modern roundabout is the YIELD-control at the entry, which allows the circulating traffic to keep always moving. This operational procedure works also well with heavy traffic. And since no weaving distance is necessary the roundabouts keep compact.

But there are more features that characterise this kind of intersection and make it at the same time the safest at-grade intersection type. Those characteristics of modern roundabouts are:

\begin{itemize}
  \item The path of entering traffic aims at the centre of the central island and is deflected slowly around it, which leads to speed reduction, increased awareness and thus to accident reduction.
  \item To control entry speed and deter left turns all approaches are provided with splitter islands.
  \item Low number of conflict points at a roundabout compared with other junction types
  \item Separation of conflict points
  \item One-way operation of circulating carriageway
  \item Availability of enough sight distance at the approaches.
  \item Crosswalks are not allowed across the circulatory roadway.
  \item Parking inside the roundabout is not allowed.
\end{itemize}

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{skew_angles}
\caption{Skew angles for different intersection forms, (Source \textsuperscript{28})}
\end{figure}

\textsuperscript{28} Leif Ourston and Joe G. Bared: “Roundabouts: A Direct Way to Safer Highways”, in PUBLIC ROADS online magazine, Volume 58, No. 2, Autumn 1995
A further safety-advantage of roundabouts is that the only movement at the entry and exit is a right-turn. That reduces accident frequency and severity compared to intersections where left-turns are allowed (left-turn head-on accidents) or legs are arranged in a perpendicular way. (crossing traffic can lead to right-angle accidents)

Generally can be said that roundabouts reduce accident frequency as they spread around the world.

When converting different junction types into roundabouts several countries conducted “before-after-studies” to show the effect of this measure in accident reduction. In general quite large reductions were found, with exception of accidents involving two-wheelers, where the reductions were rather small.

According to a study conducted in 1994 in the Netherlands they achieved a 95% reduction in injuries of vehicle occupants as many conventional intersections were replaced by modern roundabouts. Other countries found similar results in accident reduction.

The following table illustrates the results of several international studies regarding accident reduction.

<table>
<thead>
<tr>
<th>Country</th>
<th>Mean Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All Accidents</td>
</tr>
<tr>
<td>Australia</td>
<td>41 - 61%</td>
</tr>
<tr>
<td>France</td>
<td>57 - 78%</td>
</tr>
<tr>
<td>Germany</td>
<td>36%</td>
</tr>
<tr>
<td>Netherlands</td>
<td>47%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>25 - 39%</td>
</tr>
<tr>
<td>United States</td>
<td>37%</td>
</tr>
</tbody>
</table>

Table 5. Mean accident reductions in various countries

An important characteristic of roundabouts regarding accident frequency is the number of legs, as a British study clearly illustrates. Table 6 shows, as was to be expected, that the accident frequency increases with the number of arms.

---

<table>
<thead>
<tr>
<th>Nº of legs</th>
<th>Nº of sites</th>
<th>Accident frequency</th>
<th>Severity (% o fatal and serious accidents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>326</td>
<td>0,79</td>
<td>9,3</td>
</tr>
<tr>
<td>4</td>
<td>649</td>
<td>1,79</td>
<td>7,1</td>
</tr>
<tr>
<td>5</td>
<td>157</td>
<td>3,66</td>
<td>7,1</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>5,95</td>
<td>5,2</td>
</tr>
<tr>
<td><strong>All</strong></td>
<td><strong>1162</strong></td>
<td><strong>1,87</strong></td>
<td><strong>7,2</strong></td>
</tr>
</tbody>
</table>

Table 6. Accident frequency at U.K. roundabouts by number of arms 1999 - 2003

---

<table>
<thead>
<tr>
<th>Country</th>
<th>Reference</th>
<th>Nº. of roundabouts in study</th>
<th>Accident frequency</th>
<th>Total Nº of accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Quoted in NCHRP 264 (1998)</td>
<td>290</td>
<td>0,60</td>
<td>174</td>
</tr>
<tr>
<td>Australia¹</td>
<td>Arndt and Troutbeck (1995)</td>
<td></td>
<td>4,00</td>
<td>-</td>
</tr>
<tr>
<td>France</td>
<td>Guichet (1997)</td>
<td>12.000</td>
<td>0,11</td>
<td>1.320</td>
</tr>
<tr>
<td>Denmark</td>
<td>Jorgensen (1990)</td>
<td>63</td>
<td>1,0 to 1,25</td>
<td>71</td>
</tr>
<tr>
<td>New Zealand</td>
<td>Harper and Dunn (2003)</td>
<td>95</td>
<td>0,51</td>
<td>48</td>
</tr>
<tr>
<td>The Netherlands²</td>
<td>Schoon and Van Minnen (1994)</td>
<td>16</td>
<td>0,75</td>
<td>12</td>
</tr>
<tr>
<td>The Netherlands²</td>
<td>Van Minnen (1993)</td>
<td>46</td>
<td>0,23</td>
<td>11</td>
</tr>
<tr>
<td>Switzerland³</td>
<td>Spacek (2004)</td>
<td>32</td>
<td>0,85</td>
<td>27</td>
</tr>
<tr>
<td>UK</td>
<td>Maycock and Hall (1984)</td>
<td>84</td>
<td>2,36 to 4,38</td>
<td>283</td>
</tr>
<tr>
<td>UK</td>
<td>Current</td>
<td>1.162</td>
<td>1,77</td>
<td>2.057</td>
</tr>
<tr>
<td>US⁴</td>
<td>NCHRP Synthesis 264 (1998)</td>
<td>11</td>
<td>1,50</td>
<td>17</td>
</tr>
</tbody>
</table>

Sites in overseas 396 **0,603** 239
European sites 13.403 **0,282** 3.780
All sites 13.799 **0,291** 4.019

1 Estimated for double lane roundabouts; includes property damage only accidents
2 Casualties per roundabout per year
3 Estimated
4 Single lane roundabouts in Maryland and Florida

Table 7. Accident frequency at roundabouts in different countries²⁹

Table 7 shows accident frequencies from several countries as well as medium accident frequencies for Europe, overseas and for all sites. The medium accident frequencies for all sites and for Europe are very similar, due to the fact that the biggest samples come from European Countries.

In 1999 Luis Serrano Sadurní and Fernando Gutiérrez Parra³³ conducted a before-after study to analyse the influence of the implantation of roundabouts in traffic accidents.

³³ Luis Serrano Sadurní and Fernando Gutiérrez Parra: “La influencia de la implantación de glorietas en los accidentes de tráfico”, Asociación Técnica de Carreteras, RUTAS magazine, p.33-37, Madrid, Mar.-Apr. 1999
They classified three types of cases where intersections have been converted into roundabouts:

- Intersections without traffic light. Each leg of the intersection would be an approach to the future roundabout. This case is called: “intersection → roundabout” they studied 12 cases

- Intersections with traffic light. Each leg of the intersection would be an approach to the future roundabout. This case is called: “intersection with traffic light → roundabout” they studied 4 cases

- Sites where a roundabout is situated at present but where no intersection has been in the past. This case is called: “nothing → roundabout” they studied 6 cases

The changes in accident occurrence when contemplating accidents from 1996-1999 are shown in the subsequent table:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type 1: Intersection → Roundabout</th>
<th>Type 2: Intersection with traffic light → Roundabout</th>
<th>Type 3: Nothing → Roundabout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nº of accidents</td>
<td>-61,20%</td>
<td>-66,70%</td>
<td>+10,50%</td>
</tr>
<tr>
<td>Nº of fatal accidents</td>
<td>-48,62%</td>
<td>-72,90%</td>
<td>-73,92%</td>
</tr>
<tr>
<td>Nº of injury accidents</td>
<td>-72,04%</td>
<td>-73,59%</td>
<td>-61,47%</td>
</tr>
<tr>
<td>Nº of implicated veh.</td>
<td>-70,00%</td>
<td>-65,54%</td>
<td>-18,13%</td>
</tr>
</tbody>
</table>

- Sign: reduction + Sign: augmentation

Table 8. Comparative table of results commensurate with accident severity

Observing the table one can perceive a general reduction in accidents. A positive value (or an augmentation in accidents) means here that there are now accidents where no intersection has been in the past and therefore no accidents.
Additionally, investigators tried to relate accident occurrence on roundabouts with the characteristic of the intersections. The Swedish researchers Brüde and Larson\textsuperscript{34} developed a model that takes the number of legs (3-leg or 4-leg), the maximum local speed limit (70 km/h or 50 km/h) and the number of entry lanes (1 or 2) into account.

Collision Rate CR = 0.1353 \cdot 0.86^{3\text{leg}} \cdot 1.88^{\text{speed}70} \cdot 1.20^{2\text{lanes}}

The 3 dummy variables represent:

- the number of arms
  \((3\text{leg} = 1 \text{ if there are 3 arms, 0 with 4 arms})\)

- the maximum local speed limit
  \((\text{speed}70 = 1 \text{ if the maximum local speed limit is 70km/h, 0 if 50km/h})\)

- the number of entry lanes
  \((2\text{lanes} = 1 \text{ if there are 2 entry lanes, 0 if there is just 1 entering lane})\)

Injury accidents in \([\text{acc./ 10}^6 \text{ veh. entering the junction}]\) are given by:

\[A = 0.8178 \cdot CR^{1.6871}\]

Table 9 shows the possible results for Collision Rate CR and number of Injury accidents per \(10^6\) vehicles for the Swedish model. As was to be expected, 3-leg roundabouts with a local speed limit of 50 km/ h and just one entering lane have the lowest injury accident rates in contrast to 4-leg roundabouts with a local speed limit of 70 km/ h and two entering lanes, which have the highest injury accident rates.

Just by way of illustration: Converted these results for average daily traffic (ADT) instead of \(10^6\) veh. entering the junction the second part of the table shows the yearly accident rate and its reciprocal value for a constant ADT of 15.000 vehicles per day.

\textsuperscript{34} U. Brüde and J. Larson: "What roundabout provides the highest possible safety from a traffic safety point of view?", VTI meddelande 864 and 865 Nordic Road and Transport Review N\textsuperscript{o} 2, 2000
### Comparison of intersection types

The accident frequency and severity varies with the intersection type. The difference in accident rate is attributed to speed differences and differences in number and type of the conflict points.

<table>
<thead>
<tr>
<th>ADT</th>
<th>15.000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injury acc./year</td>
<td>one injury acc. every</td>
</tr>
<tr>
<td></td>
<td>0,4689</td>
</tr>
<tr>
<td></td>
<td>2,1 years</td>
</tr>
</tbody>
</table>

Table 9. Results for Swedish accident model by Brüde and Larson

---

Comparison of intersection types

The accident frequency and severity varies with the intersection type. The difference in accident rate is attributed to speed differences and differences in number and type of the conflict points.
The following figures elucidate those differences:

Figure 20  9 conflict points of a 3-leg intersection and 6 conflict points of a 3-leg roundabout

Figure 21  32 conflict points of a 4-leg intersection (Standard intersection) and 8 conflict points of a 4-leg roundabout
Conflicts can be divided into three basic categories, in which the degree of severity varies, as follows:

- Queuing (Diverging) conflicts. These conflicts are caused by a vehicle running into the back of a vehicle queue on an approach. These types of conflicts can occur at the back of a through-movement queue or where left-turning vehicles are queued waiting for gaps. These conflicts are typically the least severe of all conflicts because the collisions involve the most protected parts of the vehicle and the relative speed difference between vehicles is less than in other conflicts.
- Merge and diverge conflicts. These conflicts are caused by the joining or separating of two traffic streams. The most common types of crashes due to merge conflicts are sideswipes and rear-end crashes. Merge conflicts can be more severe than diverge conflicts due to the more likely possibility of collisions to the side of the vehicle, which is typically less protected than the front and rear of the vehicle.

- Crossing conflicts. These conflicts are caused by the intersection of two traffic streams. These are the most severe of all conflicts and the most likely to involve injuries or fatalities. Typical crash types are right-angle crashes and head-on crashes.

Traffic operation improves with fewer conflict points. Thus 3-leg roundabouts are safer than 3-leg intersections etc.

A study conducted in 1994 by Schnüll et al. deals with the safety comparison of the basic junction forms crossroad and staggered junction on roads outside build-up areas. The aim of their research work was to develop recommendations for the areas of use of the basic junction forms crossroads and staggered junction. Some of the results of the accident investigation are summarised in the subsequent table.

<table>
<thead>
<tr>
<th></th>
<th>Crossroads</th>
<th>Crossroads equipped w. signals w. left-turn filter and turned off at night</th>
<th>Crossroads equipped w. signals + left-turn filter + not turned off at night</th>
<th>Partial Grade Separated</th>
<th>Staggered Junction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Accident Rate</td>
<td>0,93</td>
<td>1,31</td>
<td>0,86</td>
<td>0,94</td>
<td>0,84</td>
</tr>
<tr>
<td>[acc./10^6 veh.]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accident Cost Rate</td>
<td>80,40</td>
<td>36,80</td>
<td>38,60</td>
<td>37,20</td>
<td></td>
</tr>
<tr>
<td>[DEM/10^6 veh.]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accident of Medium Seriousness</td>
<td>86,000</td>
<td>41,000 - 44,000</td>
<td>41,000 - 44,000</td>
<td>41,000 - 44,000</td>
<td>41,000 - 44,000</td>
</tr>
<tr>
<td>[DEM/acc.]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 10. Characteristic accident values for different intersection types (Schnüll et al. 1994)

The investigation for determination of the causes of accident imply that, due to the system by which they operate, crossroad have a significantly accident higher risk than staggered junctions and other junction forms.

For this reason crossroads should be used only on roads with low traffic volume and low traffic speeds and should be avoided where possible. Crossroads with rather high traffic volume and high speeds should be equipped with traffic lights or other junction types such as roundabouts or staggered junctions should be used.

Compared to crossroads staggered junction have also a higher performance (sum of all vehicles driving into the junction) supposing an average turning-off fraction. Crossroads: 12,000 veh/ day and staggered junctions 15,000 veh/ day.

Schnüll et al.\textsuperscript{35} investigated a large number of assessment criteria such as characteristic accident values, performance, environmental compatibility and Cost-effectiveness and came to the result that staggered junctions in contrast with crossroad have in principle only advantages. But they also mention that a comparative assessment with respect to the basic junction forms partial grade separated, roundabout and crossroad equipped with traffic lights should be performed.

Another study by Eckstein et al.\textsuperscript{36} conducted in 2002 also compared the safety of junction types. They came between others to the following findings:

− Accident cost rates of junction depend on basic type (junction design) and traffic control
− Accident cost rates of junctions are independent of traffic volume
− Junctions influence safety of neighbouring road sections
− Small roundabouts have the lowest accident cost rates and therefore the best safety level
− Small roundabouts are followed by half cloverleaf junctions (the crossing road is grade separated)

\textsuperscript{36} K. Eckstein and V. Meewes: Sicherheit von Landstraßen-Knotenpunkten, Institut für Straßenverkehr Köln, Nr. 40, Köln 2002
T-intersections are safer than crossroads but since two T-intersections are needed to dissolve one crossroad it can not generally be said that the sum of two T-intersections is safer than one crossroad (in contrast to Schnüll et al.35)

Traffic lights increase the safety level only when used with more than two phases

STOP/YIELD-controlled T-intersections and crossroads have the lowest safety level. Traffic lights with two phases do not increase the safety level.

The table below points out which intersection type is recommendable for intersections between secondary roads and roads of other categories.
<table>
<thead>
<tr>
<th>Primary road: slip roads</th>
<th>Secondary road</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Two lanes (2x2)</td>
<td>Single lane (2x1)</td>
</tr>
<tr>
<td></td>
<td>Roundabout, or</td>
<td>Roundabout, or</td>
</tr>
<tr>
<td></td>
<td>all way stop/yield controlled with traffic light and possibly speed reduction measures</td>
<td>all way stop/yield controlled possibly with traffic light and/or speed reduction measures</td>
</tr>
<tr>
<td>Secondary road:</td>
<td>Two lanes (2x2)</td>
<td>Single lane (2x1)</td>
</tr>
<tr>
<td></td>
<td>Roundabout, or</td>
<td>Roundabout, or</td>
</tr>
<tr>
<td></td>
<td>all way stop/yield controlled with traffic light and possibly speed reduction measures</td>
<td>all way stop/yield controlled possibly with traffic light and/or speed reduction measures</td>
</tr>
<tr>
<td></td>
<td>Roundabout, or</td>
<td>Roundabout, or</td>
</tr>
<tr>
<td></td>
<td>all way stop/yield controlled with traffic light and possibly speed reduction measures</td>
<td>all way stop/yield controlled possibly with traffic light and/or speed reduction measures</td>
</tr>
<tr>
<td>Local road</td>
<td>Avoid as much as possible</td>
<td>Roundabout, or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All way stop/yield controlled possibly with speed reduction measures</td>
</tr>
<tr>
<td>Bicycle lanes</td>
<td>Split level junction</td>
<td>Split level junction, or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Roundabout/traffic light</td>
</tr>
<tr>
<td>Public transport lanes</td>
<td>Split level junction</td>
<td>Split level, or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Guarded level crossing</td>
</tr>
</tbody>
</table>
**Roundabout**

A roundabout is the safest form of intersection (all legs on the same level).

Roundabouts are normally used in the following situations:

- Intersections between two secondary roads;
- On accentuated locations like city-borders and change of road categories.

**Traffic safety on Roundabouts**

A roundabout (single lane) is the safest form of intersection, because:

- The real speed of the drivers is very slow. The lower the speed, the lower the chance on accidents or hospital injured/deaths.
- On a roundabout there is a reduction of possible conflict situations. Each connecting road is one well-organized situation.

A single lane roundabout is safer than a roundabout with two lanes. This goes especially for just material damage on the collided objects and less for the injured (hospital/deaths) as a result of an accident.

From the point of view of traffic safety single lane roundabouts are preferred to two lane roundabouts.

**Stop/yield controlled intersections**

The design of stop/yield-controlled intersections must support the right of way. Because of this reason and reasons of traffic safety the following design elements are necessary:

- A left turn lane on the main road
- A lane separation island on the side road
- A maximum of one single lane for through traffic per direction
- A maximum of one single lane on the side road.
Traffic safety on stop/yield controlled intersections

The amount of traffic explains more than half of the variation in accident ratings on stop/yield-controlled intersections. The influence of the amount of traffic on side roads is more than the amount of traffic on the main road.

When stop/yield controlled intersections with three legs are compared with stop/yield controlled intersections with four legs it seems that three legs intersections are more safe than four legs intersections.

The lane separation on the side roads shouldn't be too high because of the chance on collisions.

Intersections with traffic lights

Stop/yield controlled intersections are normally provided with traffic lights because of problems with the capacity or flow of traffic. A traffic light could also be used just because of traffic safety.

Traffic safety on intersections with traffic lights

A stop/yield controlled intersection with traffic lights are used on a secondary road when a roundabout is not possible because of a lack of space. For traffic safety reasons the traffic lights have to be operated for 24 h a day.

3.6.3 Grade-separated intersections

The capacity of an at-grade crossing should be controlled by the characteristics of the main road. In some cases rather the vehicles that approach from the minor legs control the number of vehicles that can pass through the junction. Apart from the mentioned capacity problems those intersections provide many opportunities for vehicle conflicts and therefore they are likely to have an elevated number of accidents.

One out of a number of possible solutions to the problem is the conversion into a grade-separated intersection. From the safety point of view the provision of grade-separated intersections is very advantageous but the initial construction costs when compared to at-grade intersections are rather large. Therefore the planning engineer should carefully weigh up and use the following conditions to justify his decision. A grade-separated intersection should be provided:

- If a free movement of the through traffic is desired
- If an existing traffic bottleneck is to be eliminated
If an existing accident black spot is to be eliminated

If the economic losses due to traffic delays are considerably high (on a long term consideration the initial construction costs can be inferior to the costs for fuel, tyres, oil, repairs and accidents, as well as the time costs of the road-users)

If topographic difficulties make the construction of an at-grade intersection more expensive than a grade-separated intersection

### 3.6.4 Lighting of junctions/ intersections

In 1976 Rockwell, Hungerford, and Balasubramanuan conducted a study to investigate the performance of drivers approaching for intersection treatments of special reflectorised delineators and signs, or illumination. A significant finding from observing 168 test approaches was that the use of roadway lighting significantly improved driving performance and earlier detection of the intersection, whereas signing, delineation and new pavement markings showed marginal changes in performance.

In 1996 Bauer and Harwood found that at rural, four-leg, STOP-controlled intersections, lighted intersections had 21% fewer total and injury accidents than unlighted intersections. However, no similar effect was observed for total intersection accidents, and an effect in the opposite direction, indicating that lighted intersections had more accidents than unlighted intersections, was observed for urban four-leg STOP-controlled intersections. These results were based on accidents for all times of day (daytime plus nighttime).

A study by Blower, Campbell, and Green (1993) indicates that truck accidents in Michigan are more frequent at night and in rural settings; the combination of the two is deemed to imply less lighting.

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These are only a few out of a great number of studies that indicate that intersection lighting influences positively in accident occurrence.

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Section 4  Human factor

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4 Human factor

Despite rural roads are ranking highest concerning the number of people killed the danger associated with them is clearly underestimated by drivers (Ellinghaus & Steinbrecher, 2003).

A study originally published by Treat et al. (1977) revealed that human factors are to be blamed for the majority of accidents (see figure 1).

![Diagram of accident causation factors](image)

Figure 1: Proportion of accident causation factors according to Treat et al. (1977)

While the statistics suggest that the roads are hardly to be blamed for accidents, analysis on a site basis reveal that human errors occur in specific sites more often than in other sites.

The majority of accidents at these sites is due to a mismatch between environment (the road) and human characteristics. This is depicted by the high proportion of accident causation factors as interaction between environment and human (see figure 1).

The following pages give an overview of how road environments interact with human properties and how both factors have to be taken into account in order to design safer rural roads.

4.1 Models of driving behaviour: an overview

The following chapter gives a short overview of different driver and driving behaviour models. The aim is to make the reader familiar with the most important terms. While
details of some models are explained further in the text, others will only be mentioned here. A more detailed discussion of the influence of different models can be found in Michon (1985) and Ranney (1994).

Figure 2: Overview of different driver behaviour theories

Hierarchical (Michon, 1985) and control loop models (Durth, 1974) serve as a framework for other theories. A widespread hierarchical model developed by Michon (1971, 1979, cited from 1985) and Janssen (1979, cited from Michon, 1985) sees driving as hierarchical problem solving task that comprises three different levels. These levels can be divided by the specific task requirements on each level, the time frame needed to carry them out, and the cognitive processes involved. The hierarchical task model of Michon finds its equivalent in the distinction between different performance or behaviour levels proposed by Rasmussen (1986). Rasmussen distinguished between knowledge-based, rule-based, and skill-based levels of a task in general. Both models can be combined as proposed by Donges (1982, cited from 1999) (see figure 3).
Figure 3: Combination of performance levels according to Rasmussen (1986) and the hierarchical model according to Michon (1985), modified from Donges (1982, in 1999).

The left section in figure 3 represents the different task levels proposed by Rasmussen, while the right section represents the model by Michon. The strategic or navigational level comprises all processes concerning trip decisions, like where to go, when to go, what roads to take, and what modes of transport to use. Decisions on this level are rare and take longest in comparison to the other levels. Due to their nature they are processed in a more or less aware mode, but become habits in case of constant repetition. On the manoeuvring level decisions are made within seconds. Typical manoeuvres are overtaking, turning, or gap acceptance. Behaviour on the manoeuvring level is both influenced by motivational and situational variables. Other terms used to describe the manoeuvring level are tactical or guidance level. Finally, decisions on the control level are made rather automatically within a very short time range as stimulus response reactions. Typical tasks on this level are lane keeping or gear shifting. These are both conducted without conscious information-processing by experienced drivers. The terms operational or stabilisation level are used concurrently.

Whether a task is situated on the knowledge-based, rule-based, or skill-based level, depends to a great amount on the familiarity with the task and the environment. Higher order processes situated on the knowledge-based level in general require more cognitive resources than lower level processes. Higher and lower levels of processing are usually referred to as controlled or automatic processing according to Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977).
The knowledge whether the behaviour under observation is situated on the automatic or the control level is very important as the strategies to change this behaviour depend on these levels. Only controlled processes can be modified by awareness campaigns, while behaviour on the automatic level needs constant reshaping.

The following figure 4 gives a flow chart of how decision making and problem solving might be arranged in driving. Note that higher order processes are only used when lower order processes do not lead to the desired output.

Figure 4: The generic error-modelling system (GEMS) as proposed by Reason, (1990).

The crucial point for rural road design is that people in general rather rely on pre-programmed behavioural sequences found on the skill-based level, than revert to higher-order processes. This is because the latter processes require more resources. Similar, rule-based behaviour will be preferred to knowledge-based behaviour as “…humans, if given a choice, would prefer to act as context-specific pattern recognizers rather than attempting to calculate or optimize” (Rouse, 1981, cited from Reason, 1990, p. 65 ).
4.2 Information-processing and perception

Attention, mental models and expectations

Human perception and information processing is influenced by two concurrent systems, a bottom-up and a top-down pathway.

In short, top-down processing means that the driver has formed some kind of hypothesis on what to expect in a given situation. Bottom-up processing in contrast means that attention is guided by stimuli in the environment without higher order cognitive functions.

Processes involved in top-down processing are attention, experience, motivation and expectations. Expectations in turn are formed from past experiences. The more similar the new situation is to a past situation, the stronger these expectations will be for the current situation. These expectations in turn help the driver to direct attention to locations where he assumes to find relevant information. The totality of expectations related to a specific situation form a mental model or internal representation of the whole situation. Other terms in relation to mental models are schemata or scripts. All represent implicit or explicit knowledge of situations or actions.

Due to its nature, top-down processing requires more time than bottom-up processing. Nevertheless it still increases efficiency and effectiveness in human behaviour due to its simplification in comparison to nature. Second, the use of mental models is automatic rather than conscious and therefore needs less resources in working memory. Top-down processing further guides attention to relevant stimuli and therefore allows an efficient allocation of attentional resources. Finally it allows the driver to actively search and infer missing information.

This advantage can easily become a disadvantage when the current situation is misinterpreted, e.g., on the basis of inappropriate expectations and misguided attention. Therefore internal representations can be the underlying cause behind faulty actions or faulty assumptions themselves (Hacker, 2005; Norman, 1981; Reason, 1990). Further, the stable nature of internal representations makes them hard to be changed by single actions.

Concerning top-down processes it should be taken care that the road characteristics are in line with the drivers expectations (top-down). In order to change wrong mental models, feedback has to be provided in case of inappropriate behaviour.
On the other hand perception is a bottom-up process, meaning, amongst others, that environmental stimuli guide attention as well. Whether attention will be attracted to a stimulus or not, depends on the physical characteristics of this stimulus. As the focus of attention is very narrow due to the characteristics of the eye (see below) the stimuli will first be perceived by peripheral attention. Peripheral attention is captured more easily by moving objects. Stationary objects with low luminance contrasts will be hardly detected by human vision.

Therefore it has to be taken care that non-relevant information does not capture attention (bottom-up) in locations that are supposed to be dangerous while on the other hand relevant information has to be designed to attract attention.

The relevance of expectations and mental models for rural road design is in fact already tackled in the engineering concept of “consistency” (e.g., concerning curvature). Consistency in this context means that the driver expects the following road section to be similar to the preceding road section, unless indicated by some environmental cue. Besides being used in design guidelines for rural roads (e.g. RAS-L: FGSV, 1995), consistency is an important aspect of safety. Lamm et al. (2006) successfully applied the following three criteria to assess the safety level of rural roads:

- design consistency as indicated by the design speed,
- operating speed consistency as indicated by differences in \( V_{85} \) between successive elements,
- and consistency in driving dynamics, mainly based on side friction.

Accidents often occur when the drivers expectations do not match the road situation, that is, the road is not consistent.

**Visual perception: the eye and the useful field of view (UFOV)**

Most information needed for driving is taken up predominantly visually. Understanding vision therefore helps to understand and explain safe or unsafe behaviour on rural roads.

In the retina of the human eye, two different light receptor cells (rods and cones) with different characteristics are to be found. The uneven distribution of these cells in the retina is the reason for an approximately linear degradation of many visual functions with eccentricity from the fovea. Referring to this degradation, often the terms foveal, parafoveal (near but not in the fovea) and peripheral or ambient vision are used.
Object identification, which requires deep processing, is only possible in foveal vision and in a very narrow cone around the point of fixation. In contrast to foveal vision, peripheral vision allows a broad area to be scanned without identifying objects. It can be seen as alerting system for saccades (very fast eye movements) to bring the object of interest into foveal vision. Peripheral vision is further very important for the correct perception of speed. These different visual systems are related to two different pathways of information processing in the brain (Milner & Goodale, 1995).

Both the areas of foveal and peripheral vision are limited and subject to change. To describe these changes and the areas affected, different terms are in use:

- functional field of view (FFOV)
- useful field of view / of vision (UFOV)
- visual field
- tunnel vision

UFOV can decrease because of different reasons. One of the reasons is changes in demand or workload (see below). Related to demand, some authors see complexity to be the reason behind diminishing UFOF size (Miura, 1990; Recarte & Nunes, 2000). Decreased UFOV size due to higher speeds is as well reported (e.g., Land & Horwood, 1995). The importance of peripheral vision for speed perception could be shown by Cavallo & Cohen (2001) who found that correct speed estimation is significantly reduced when the size of the visual field and thus peripheral vision is diminished. Recarte and Nunes (2000) used the spatial distribution of fixations to describe these changes. However, when discussing effects on peripheral vision it is important to note that the terms introduced above are not used consistent between authors.

Within this framework of perceptual processes further characteristics of human perception have to be taken into account when dealing with secondary rural road safety. Some of them are summed up as follows (for further aspects see e.g., Bruce, Green, & Georgeson, 1996):

- The human eye needs time to adapt to different light conditions. The time for rods and cones to adapt from brightness to darkness takes longer than vice versa and might take up to 30 minutes for rods (von Campenhausen, 1993). This is relevant when entering tunnels or alleyways in daylight.

- The human eye needs time to accommodate from near to far and vice versa. This accommodation is relevant when drivers direct their attention from inside the car (e.g., speedometer) to outside the car. Accommodation is faster from near to far than vice versa.
- Human information processing capabilities are limited. When the amount of information is too high, relevant information might not be perceived by the driver.
- The human eye is only sensitive for light of a very narrow bandwidth and high contrasts. Given contrast sensitivity it has to be assured that visual information can be perceived in the environment and background where it is presented.
- Foveal vision is very restricted but identification of objects is only possible when they are fixated.
- Human perception depends on the context and is relative to other stimuli as shown by psychophysics (Weber, Fechner, Stevens, overview e.g., in Goldstein, 2005).

A theory, which stresses the importance of visual perception, was developed by Gibson (1986). This theory of direct perception highlights the importance of characteristics present in the environment and the influence of ecological invariants. Time-to-collision (TTC) or Tau and time-to-line-crossing (TLC) (Godthelp, Milgram, & Blaauw, 1984) are examples of such invariants. Further, Gibson assumes that information is directly picked up from the inherent properties of the objects. These properties are called affordances. Affordances convey a meaning to the onlooker in the sense of being … able (e.g., climbable). They thus serve as cue to prompt the respective behaviour at the same time.

Contrary to Rumars model (1985), Gibson uses a mere bottom-up approach. Both agree however, that perception is an active process. While Rumar stresses the importance of cognitive factors, Gibson sees movement as the crucial aspect in information acquisition. Movement of the body and the eye help to perceive the property of objects and environments. Therefore, the human body as a whole becomes the organ of perception, and not the eye alone. Through movement, information of depth, distance, or speed is conveyed to the driver. This information is perceived directly from the rate of change in the texture or the so called optic flow field. The optic flow field can be imagined as a bunch of vectors created by changes in light due to movement. The focus of the flow field specifies the direction where the observer is heading. Warren et al. (1991) showed that circular heading when negotiating a curve is also derived from the optic flow field.

But even without movement, objects convey information through their texture and occlusion of their contour by other objects (examples are given in Bruce et al., 1996). While human perception becomes effective through the use of this information, it can be a source of error itself as is shown by optic illusions.
With perception being the basis for action, environmental design to support wanted behaviour is crucial in designing safer roads.

The following principles derived from characteristics in visual perception should be known by road designers:

- highly textured environments usually diminish speeds
- roadside objects should follow road geometry in order to support the drivers expectations
- the perceived characteristics of road elements are more important for behaviour than the real characteristics. By applying visual elements the perceived characteristics can be changed.

In case mere perceptual measures are not possible due to environmental constraints, road designers can still revert to traditional measures like posting speed limits on signs and enforcing compliance with cameras. In fact there are several studies that indicate that these measures reduce speed and accidents (for an overview see Elvik & Vaa, 2004).

### 4.3 Driving as a self-paced task: Motivational models

While the models on the role of perception in driving rather highlight common characteristics of the whole driver population, motivational models take into account interactions between general mechanisms and individual differences.

The unifying assumption of motivational models is that they stress the self-paced nature of the driving task. Two concepts that could thus be called “motivational” are risk and workload. Closely related is the concept of behavioural adaptation.

**Risk Models**

The central aspect for risk models is the distinction between subjective and objective risk. Klebelsberg (1982) defines objective risk as the measurable probability of having an accident, while subjective risk is the estimated risk by the driver through the perception of the road environment. According to Klebelsberg, situations are unsafe as soon as subjective risk is lower than objective risk. This is because drivers adjust their behaviour according to subjective, not objective risk.

The concept of subjective risk as relevant mechanism for driving behaviour was further developed by Wilde (1988; 1994). Originally called theory of risk homeostasis (RHT) it was later termed the theory of target risk. In short, the theory states that accident rates...
per unit time remain equal, despite objective improvements, as drivers adjust their behaviour so that their target level of risk remains more or less constant. Elvik & Vaa (2004) sum up the shortcomings of the theory but at the same time agree with other researchers that the theory has identified important mechanisms, which should be taken into account when explaining accident causation mechanisms. A theory applicable on the individual level was developed by Näätänen & Summala (1976). Behaviour can be seen as the outcome of the comparison process between accepted and perceived risk.

**Workload Models**

Due to the shortcomings of risk theories, Fuller (2005) developed a theory based on the comparison between task demand and human capability. The resulting outcome of this comparison is the amount of workload a driver experiences. In general workload is lowest and performance is best at medium levels of demand. Both under- and overload caused by a mismatch between demand and capability are detrimental on performance, although compensation due to additional effort invested is possible (see e.g. de Waard, 1996).

According to Fuller (2005) driving is safe as long as capability exceeds demand. Besides being a function of the objective environmental characteristics, the demand of the driving task at a given time or location, depends on the speed level selected by the driver. The demand of a difficult situation can be substantially decreased by lowering the speed. In order to keep workload at a medium, optimal level, the situation has to convey the necessary information to the driver in advance.

The effects of early versus late presentation of appropriate information on workload are depicted in figure 5

*Figure 5: Hypothetical differences in speed and workload in curves with good (left) and inappropriate design (right) (modified from Fuller 2005)*
In the left image early information leads to early, smooth speed reduction and a subsequent steady level of workload. In the right image, curve characteristics are perceived too late, leading to a high and sudden decrease in speed, which in turn results in a massive increase in workload.

Despite figure 5 suggests otherwise different forms of demand, capability and workload are distinguished. This distinction is mainly based on Wickens (e.g., 1991) who distinguished resources according to the task characteristics, the senses used to take up and process the information and finally the modality with which the resulting action is carried out. Depending on these categories human resources are regarded as being independent. Therefore it is often better to present critical information auditory and not visually as the visual system in driving is usually subject to very much other visual information.

For the assessment of workload different techniques are in use. Which workload measurement technique is used depends first of all on the quality of the measures as described by O’Donnell and Eggemeier (1986, cited from de Waard, 1996; Wickens, 1992) and the requirements and restrictions of the experimental situation. Usually the following five techniques are distinguished:

- self-report measures
- primary task measures
- secondary task measures (dual task paradigm)
- physiological measures
- visual occlusion.

As the most important contributor to the amount of workload in road safety is the amount of demand (not the capacity of the single driver) the road characteristics have to be assessed with equal care. The following characteristics are a selection of the most important elements contributing to demand on rural roads:

- vertical and horizontal alignment
- deduced parameters like curvature and consistency
- road furniture, including lines
- surrounding vehicles
- environmental conditions at the time of the assessment.

Demand and workload assessment together with the five measurement techniques of workload as explained in the report are shown in figure 40 as part of a general safety assessment procedure for rural roads.
Due to the self-paced nature of the driving task and interactions between parameters, the exact amount of demand is hard to determine. Nevertheless, some approaches provided good results in determining demand. Wagner & Richter (1997) and Wagner (2000) proposed a procedure based on video ratings. They combined several criteria rated in advance as useful by engineers and psychologists. The criteria selected were divided into three groups:

- **Information-uptake**: amount; variability; contrast; spatial and temporal density; visual guidance.
- **Road quality**: surface; orientation possibilities and compatibility with expectations; early perception of danger.
- **Sensorimotor aspects of car driving**: hand; foot; coordination and automatic processing of motor response.

The resulting scale (ANSITAX) was presented to different expert groups and resulted in high reliability, both between groups and within groups at different times. Joint assessment by psychologists and engineers proved successful in a study conducted in Switzerland, too (Allenbach, Hubacher, Huber, & Siegrist, 1996).
**Behavioural adaptation**

Behavioural adaptation describes the phenomenon that people adapt their behaviour to changing situational demands. In 1990 the OECD (1990) defined behavioural adaptation as: "... those behaviours, which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change; Behavioural adaptations occur as road users respond to changes in the road transport system such that their personal needs are achieved as a result, they create a continuum of effects ranging from a positive increase in safety to a decrease in safety" (p. 23). Summaries of studies dealing with behavioural adaptation can be found in the OECD report (1990). Whether the net outcome is positive or negative depends on the amount of not intended factors due to behavioural adaptation as shown in figure 7.

![Diagram of behavioural adaptation](image)

**Figure 7:** Behavioural adaptation: resulting final outcome in safety.

One could argue similar to RHT that behavioural adaptation implicates that sole engineering measures would not result in a reduction of accidents. In fact there are publications supporting this assumption. When comparing data from a 14 year period (1984-1997) of 50 US states it was found that the downward trend in fatalities is due to demographic factors, an increase in passive safety and improvements in medical technology (Noland, 2003). Improvements in infrastructure did sometimes even have negative effects suggesting behavioural adaptation. Infrastructure included total lane miles, average number of lanes, lane width and percentage of each road class. Curvature, shoulder width, separation of lanes and presence of roadside hazards are not included but it is implicitly assumed that newer roads are built in a safer way. Noland (2003) concludes that "Results strongly refute the hypothesis that infrastructure improvements have been effective at reducing total fatalities and injuries." (p. 599).

Rothengatter (2002) states however, that adaptation in fact occurs but that the effects are not strong enough to eat up positive impacts of safety measures. Somewhat contrary Dulisse (1997) points out that the effects of behavioural adaptation are
sometimes even underestimated due to methodological shortcoming (for example inclusion of drivers who wore seat belts even before wearing was made compulsory).

The different findings concerning the amount of behavioural adaptation can be explained by the multiple factors that influence the occurrence of behavioural adaptation. These factors were summarized in a model developed by Weller & Schlag (2004) (see figure 8). Similar aspects are named by Bjørnskau (1994; cited from Elvik & Vaal, 2004).

![Figure 8: Process model of behavioural adaptation (Weller & Schlag, 2004).](image)

According to this model, the implemented measure has first to provide the objective possibility to change ones behaviour in an unsafe way. Second the driver has to perceive this possibility. Whether the change is perceived depends on the communication of the measure through media information or advertisements on one hand and on direct feedback to the driver on the other hand. To result in adaptation the change in behaviour further has to be perceived as being positive for the driver (utility maximization). This function is different between different driver groups (e.g., age groups) and different within the same driver group as well (e.g., driver while being in a hurry or not). Independent of this chain of action (objective enhancement, subjective enhancement, utility maximization), there is a second path that leads to adaptation, namely direct change of genuine psychological variables. These changes are a direct outcome of changes in the environment (or the car) and the following changes in the nature of the driving task. When the driving task becomes more easy due to changes in
the alignment (straight instead of curved), workload might decrease and speed might be increased as a consequence. In fact workload is seen as being equally important as risk to explain driving behaviour.

4.4 Application in rural road design: self-explaining roads

Research results on information-processing and perception as described in the preceding chapters, were applied in the development of a high successful road design concept, the self-explaining road or SER concept.

In short, the term self-explaining already implicates the meaning of SER design: roads designed along SER principles should elicit appropriate behaviour solely due to their perceived design and without further need on the side of the driver to consciously elaborate the required behaviour. Obviously, how this is achieved in detail requires further explanation.

Before application in the field of traffic, principles of self-explaining design were developed by Donald A. Norman in his book “The design of everyday things” (1998).

According to these principles road design should follow cultural standards or physical analogies as stored in mental models. Only where this mapping principle is not self-explaining a conceptual model has to be provided with the help of additional cues like signs. These cues should follow the principle of visibility to allow the driver to correctly predict the outcome of his actions. Visibility first of all means that information:

- has to be physically visible and mentally recognizable (for everyone)
- has to be presented at locations and in a way that are in accordance with human expectations
- must guide behaviour in a self-explaining way: no explanation needed.

However, visibility in Norman’s sense exceeds this meaning as visibility of behavioural outcomes is included, too. It is related to feedback, which communicates the appropriateness of behaviour to the driver. Affordances in the sense of Gibson have to be provided by the design without additional information.

Despite the term self-explaining suggests otherwise, behaviour associated with a specific design or design element has to be learned in the first place. In case unknown objects or new design elements are encountered the behaviour elicited is determined by the degree of similarity to the original object. While some roads are highly self-
explaining, like motorways, rural roads seem to lack this quality. Therefore, implementing self-explaining road design will lead to substantiate changes in the perceived characteristics of rural roads. Some of these characteristics will not be self-explaining the first time they are encountered. In this case the appropriate behaviour has to be learned. The ways how this learning is done have to be known in order to be successful. In general the following four principles are applicable:

- Explicit or purposeful learning due to information and education.
- Observational learning in the sense of Bandura (for a summary on Bandura, see Gerrig & Zimbardo, 2005; Schlag, 2004).
- Contingency management; refers to the way feedback is given, both in time and type (for a review see as well Schlag, 2004).
- Stimulus control (antecedent to behaviour).

Especially the last three principles will contribute to learning the appropriate behaviour, concurrently. In contrast to the first one, no special effort is required from road authorities, except that the principles are applied consistently throughout the whole road system.

These principles were developed amongst others as consequence to human error research in driving. Some conclusions, which were derived from this line of research, were published by Hale et al. already in the nineties (Hale, Stoop, & Hommels, 1990). Theeuwes & Godthelp (1995) and Theeuwes (2000) further elaborated these principles. They were summed up by Theeuwes (2000, p. 21) as follows:

- Roads should consist of unique road elements (homogeneous within one category and different from all other categories).
- Roads should require unique behavior for a specific category (homogeneous within one category and different from all other categories).
- Unique behavior displayed on roads should be linked to unique road elements (e.g., woonerfs: obstacles—slow driving, freeway: smooth concrete—fast driving).
- The layout of crossings, road sections, and curves should be linked uniquely with the particular road category (e.g., a crossing on a highway should physically and behaviorally be completely different from a crossing on a rural road).
- One should choose road categories that are behaviorally relevant.
- There should be no fast transitions going from one road category to the next.
- When there is a transition in road category, the change should be marked clearly (e.g., with rumble strips).
- When teaching the different road categories, one should not only teach the
  name of, but also the behavior required for, that type of road.

- Category-defining properties should be visible at night as well as in the
daytime.

- The road design should reduce speed differences and differences in direction
  of movement.

- Road elements, marking, and signing should fulfill the standard visibility
criteria."

### 4.5 Formulation of the driver model and description of its safety concept

So far the underlying behavioural background factors were treated as being
independent. However, this is not necessarily the case. As illustrated in figure 8 the
three factors named so far are influenced indirectly by long- and short-lasting personal
characteristics. Further, workload and subjective feeling of risk are likely to be related
although they represent different aspects in driving. The relationship between these
factors might further interact with the situation.

Based on the Ripcord Iserest WP8 research, a model of driver and driving behaviour is
proposed that assumes three main factors and an additional feedback loop which
influence behaviour and thus safety:

- **Part A**: Affordances and cues are used as long as they are present and as long
  as they are known and perceived by the driver,

- **Part B**: Expected and actual level of workload and risk are used in a
  homeostatic process to regulate behaviour whenever the two other
  mechanisms are not sufficient and

- **Part C**: Perceptual invariants are used for the short-term regulation of driving
  based on visual perception

- **Part D**: Feedback.

This model is shown in Figure 9 and will be explained in the following.
Part A: Affordances and cues

The driver perceives the road and the road environment ahead and its inherent properties. These properties convey a message to the driver that can be enough to be effective in regulating driver and driving behaviour. In fact this is what is the aim of self-explaining road design (see e.g. Theeuwes, 2000; for a summary see Weller et al., 2005). The question is of course how road and environmental properties regulate behaviour in detail. Environmental properties and suggested behaviour are associated through knowledge in the furthermost sense. This knowledge is learnt and does not have to be explicit. Learning of the association between property and behaviour is achieved through a multitude of ways by (for summaries see e.g. Funke & Frensch, 2006; Koch, 2005; Schlag, 2004):

- Classical conditioning,
- instrumental learning through operant conditioning,
- social learning,
- implicit and
- explicit learning.

Classical conditioning uses innate associations between a certain stimulus and a subsequent behaviour. When the stimulus is shown together with another stimulus (for some time and in a predefined way), this new stimulus will afterwards elicit the behaviour without the original stimulus. Operant conditioning means that a positive or negative consequence follows an act performed by a person before. The close and consistent relationship between a certain antecedent (stimulus) and a certain behaviour is called contiguity and the relationship between a behaviour displayed and a certain
consequence is called contingency. Without contiguity the intended behaviour will not become associated with the stimulus. Without contingency the behaviour will not be associated with its consequences (Schlag, 2004). These consequences are rewards or punishments in the furthermost sense of the words. Whereas punishment and reward in traffic safety could be monetary they usually are given constantly in the form of positive or negative feelings (feeling of safety/danger; feeling of comfort/discomfort; etc.) or to a far lesser extent conflicts and accidents. Social learning means that someone learns from watching someone else doing something and the consequences of this behaviour. Implicit learning is difficult to define (for a summary see e.g. Frensch, 2006) but usually means that the fact that something is learnt at all is not conscious. Implicit learning is the contrary to explicit learning. Explicit learning is done whenever learning is done on purpose.

The second question is, how the properties of the environment elicit this knowledge. In psychology there are different theories on how this is done. Two concepts which are useful in our context are the concept of affordances and the concept of cues. The term affordances was created by Gibson (1986) within his theory of direct perception (for a summary of Gibsons theory of affordances see e.g. Jones, 2003). According to Gibson, objects have properties which become affordances in relation to the properties of an individual (here: the driver). An affordance conveys a meaning to the onlooker in the sense of being … –able, for example being climbable. Similar, road elements convey a meaning to the driver: the element is drive-able within a certain speed and attention range. This is what we call the “suggested” range of speed and attention. However, the direct approach to perception is not the only possible way how to explain this range of possible behaviours. They can as well be explained by behaviouristic theories that are to a large extent based on conditioned responses. Here, characteristics of the road or environment serve as discriminative stimuli. These discriminative stimuli give a hint to the driver which consequences to expect when showing the respective behaviour. Knowledge and anticipation of these consequences will then result in the respective behaviour being shown in the case of expected positive consequences or not shown in the case of negative consequences (avoidance behaviour). A road sign for example can almost be called the “archetype of the discriminative stimulus” (Fuller & Santos, 2002, p. 49). However, this does not mean that a certain behaviour is elicited automatically.

There are some predispositions for that: first of all, the sign (or any other discriminative stimulus) has to be perceived which might be impeded by different filters (see e.g. Rumar, 1985). Second the wanted behaviour has to be associated with the respective
discriminative stimulus which is not necessarily the case. The reason for a lack of association can be a lack of feedback or inconsistent or unreliable information conveyed by the stimulus. The third prerequisite is that the driver perceives his behaviour to be under his own control, which is called self-efficacy. Taken all these prerequisites together, it is to be preferred when the whole situation serves as “integrated” discriminative stimulus (Fuller, 1984). In both cases (single elements or whole situation) the appropriate behaviour can be associated that closely to the stimulus that the stimulus literally prompts or triggers the behaviour (stimulus control or top-down control of behaviour). In this case the discriminative stimulus can be called “cue” (Posner, 1980). Here no or hardly any cognitive processing is necessary. The processing is done automatically and thus is much faster and much less consuming of resources than controlled processing (Schneider, Dumais, & Shiffrin, 1984; or Weller et al., 2005, for a summary). While this is useful on one hand it can lead to errors itself (besides the ones already named above). This is the case when the wrong affordances or misleading cues are present in a situation which subsequently automatically leads to inappropriate behaviours.

**Part B: Expected and actual level of workload and risk**

However, affordances or cues do not necessarily have to be present or they might not be known to the driver. In this case the driver has to “guess” which behaviour is appropriate. This is done by comparing the expected level of workload and risk with the preferred workload and risk level. Which of these two parameters is actually used is topic of ongoing discussions. In literature evidence for both parameters is found (e.g. Fuller, 2005; Wilde, 1994; Wilde, 2001). In our studies we found a very strong correlation between rated demand and rated risk which makes it likely that drivers do not really distinguish between those two variables (see Ripcord-Iserest Deliverable 8 for details). Differences will be found however, when drivers are asked to rate the objective risk of an accident (Fuller, 2005). In our research we found that drivers in this case take into account their assumptions of how other drivers will behave, which will not influence their personal behaviour. Regardless of the discussion concerning the relevance of the respective parameters, it is much more important to understand how this process is done. Workload is the effect of situational demand on the driver, depending on the driver’s resources. At this point it is important to notice that situational demand in driving depends on the characteristics of the road and the speed with which this road is driven. This means that workload will differ in the same situation
for the same driver when this driver is forced\(^1\) to drive through the situation with different speed. Further, workload depends on the capabilities or resources of the driver. These capabilities differ both between drivers but within drivers as well.

They depend on the current **motivation** and the current **state** of the driver as well as on longer-lasting **traits** and organic variables like **age** or **driving experience**. When different drivers or the same driver at different occasions are forced to drive the same road with the same speed, they will experience different levels of workload. Usually however, driving is a self-paced task, which means that the driver can choose his preferred speed. This is done in order to assure medium levels of workload and risk. In reality workload and risk oscillate around this optimal level which is called homeostasis. This homeostatic regulation is done pro-active based on expectations concerning the road ahead and re-active as a result of feedback to the current workload and risk situation. In case of pro-active regulation the driver generates **expectations** concerning workload and risk ahead of the current position. The entity of expectations concerning a situation forms a **mental model** (for a summary see Weller et al., 2005). Expectations and mental models in turn are a vital part of self-explaining road design (for a summary see e.g. Matena et al., 2006). The formulation of a mental model is done by combining the following variables:

- the perceived road ahead with
- the information from the road just passed and
- the individual knowledge of how situations usually develop.

These three input parameters can at the same time result in wrong assumptions. This is the case when

- the road ahead is perceived as less demanding than it actually is, when
- the road ahead (static and dynamic situation) differs fundamentally from the road just passed (e.g. in the case of design inconsistencies) or
- the individual knowledge is inappropriate.

The following figure 10 sums up the processes described above.

---

\(^1\) The term “forced” is used here to indicate that the driver usually does not do this. However, it can be achieved in experimental sessions or even when the situation does not have enough degrees of freedom (e.g. due to other cars).
Part C: Perceptual invariants

Finally, speed and path are regulated by perceptual invariants (for a summary, see Bruce, Green, & Georgeson, 1996; Weller et al., 2005). These perceptual invariants are Tau and Tau dot (Lee, 1976) and the deduced variables TTC (Lee, 1976) and TLC (Godthelp, Milgram, & Blaauw, 1984; Van Winsum & Godthelp, 1996). These perceptual invariants are used by the driver to remain within the boundaries of the “lane-tube” (Summala, 1996). A simplified way how drivers use Tau and Tau dot to regulate distance and speed is shown in the following figure 11.
In contrast to the two aforementioned mechanisms, perceptual invariants can be calculated without having to know the properties of the individual driver. However useful this might be, perceptual invariants are only used for the short-term regulation of behaviour and therefore are not enough to explain the entity of the complex behaviour regulation on rural roads.

**Part D: Feedback**

Last not least, the selected behaviour itself (be it speed, path or attention) and its consequences influence future behaviour through feedback. This actual behaviour changes the actual experienced workload and risk and might thus influence the future preferred level of workload and/or risk as well as the expectations concerning future workload. The actual behaviour influences as well the perceived road ahead through a change in the perceptual invariants. Further the experiences made with the current behaviour serve as knowledge-base for future situations and might therefore influence directly the perception of the road ahead (e.g. former neutral stimuli become cues
through experience, see above). Of course, inappropriate behaviour is enforced as well in case of missing or wrong (here: not negative) feedback. As is well-known from aggression research: if people know that they are doing something wrong but no consequence follows, they perceive this lacking feedback as positive reinforcement strengthening the wrong behaviour.

References


December 2007


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5 Secondary Road categorisation

In the previous section 1 the need of a clear and standardised definition for "secondary road" was explained, for a road with the following physical characteristics:

1. Single carriageway, two lanes
2. Paved road
3. Outside Urban Areas

In this section the road categorisation and an interpretation of secondary road for European Member States is described, in order to make a comparison between the new suggested term and the actual situation in the EU countries, mainly based on functional characteristics. The road categorisations of eight countries have been compared: for these countries three functional categories have been distinguished: flow/connection road, collection road and access/residential road. Such countries are expected to be representative enough to make a uniform description of secondary roads. The purpose of a uniform classification of secondary roads is useful for proposing the same safety measures on the same type of road. This uniform classification contributes the Self Explaining Roads. The basic information of the categorisations is taken from the RIPCORD-ISEREST Work Package 3. It is difficult to make a uniform categorisation and definition of secondary roads for all countries. There are many different roads and these cannot be ‘matched’ one-to-one.

The definition of a secondary road can be further implemented with the following 2 functional characteristics:

4. Connect towns and villages
5. Mainly Collection function

5.1 Road Categorisation (from the R.I.-project)

In the table below the functional road categorisation of the eight countries is presented in a summary format. A short description of the secondary road (collection) of each country is given. All the received road categorisations are based on a functional design.
Table 13  Road categorisation of eight European countries.

<table>
<thead>
<tr>
<th>Type of road</th>
<th>The Netherlands</th>
<th>Germany</th>
<th>Norway</th>
<th>Belgium (Flanders)</th>
<th>Belgium (Walloon)</th>
<th>Portugal</th>
<th>Hungary</th>
<th>Greece</th>
<th>Czech</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>SW120</td>
<td>AI</td>
<td>Part of H1</td>
<td>Autosnelweg Grootstedelijke wegen</td>
<td>RGG I</td>
<td>IP</td>
<td>Motorway</td>
<td>group A</td>
<td>D</td>
</tr>
<tr>
<td></td>
<td>Part of SW100</td>
<td>Part of AII</td>
<td>Part of H2</td>
<td>RGG II</td>
<td>Part of IC</td>
<td>Motor road First category main road</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Part of H3</td>
<td>RGG III</td>
<td></td>
<td>Second category main road</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td>Part of SW100</td>
<td>Part of AII</td>
<td>Part of H1</td>
<td>Hoofdweg Interwijkenwegen Verzamelwege</td>
<td>RESI I</td>
<td>Part of IC</td>
<td>Connecting road</td>
<td>group B</td>
<td>S</td>
</tr>
<tr>
<td></td>
<td>GOW80</td>
<td>AIII</td>
<td>Part of S1</td>
<td>RESI II</td>
<td>EN</td>
<td>Access road Stations access road</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GOW70</td>
<td>AIV</td>
<td>Part of A1</td>
<td>RSR I</td>
<td>Part of ER</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GOW50</td>
<td></td>
<td>Part of S2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tertiary</td>
<td>Part of ETW 60</td>
<td>Part of AV</td>
<td>S3</td>
<td>Lokale straten</td>
<td>RESI III</td>
<td>Part of ER</td>
<td>service and living roads Local distributor roads</td>
<td>group C</td>
<td>special purpose roads</td>
</tr>
<tr>
<td></td>
<td>ETW 30</td>
<td></td>
<td>A2</td>
<td>RSR II</td>
<td>EM</td>
<td></td>
<td></td>
<td>group D</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A3</td>
<td>RSR III</td>
<td></td>
<td></td>
<td></td>
<td>group E</td>
<td></td>
</tr>
</tbody>
</table>
5.1.1 The Netherlands

A sustainable safe road network has a functional layout, based on three main road types. The two 'extreme' types are 'flow roads' (stroomweg/SW), for traffic dispersion, and ‘access roads’ (erftoegangsweg, ETW), for access to the destination. The third type, the distributor roads ‘gebiedsontsluitingsweg'/GOW), are for a good link between the two categories mentioned before, both literally and figuratively. All distributor roads and part of the access road together are the secondary roads. A part of SW100 are categorised as Secondary road, because some of these roads have two lanes without a median barrier. The part of ETW60 is due to roads, which have mainly an access function, but these roads are connecting some villages with each other.

5.1.2 Germany

In Germany new design guidelines for rural roads are about to being published which will introduce a system of standardises, self-explaining road types.

The information provided below bases on the current guidelines which will be replaced by the new guidelines soon. Currently, a secondary road can be either of the following categories:

- Part of category AII - interregional/regional roads,
- Category AIII - interurban roads,
- Category AIV - collector roads.

5.1.3 Norway

The motor traffic road, which is basically a two-lane undivided motorway (part of H1) is here categorised to the Secondary road. The suburban (H2) and urban main roads (H3) are not categorised to the Secondary road. These roads are mostly inside built-up area and have another road design than the criteria of the Secondary roads.

Collector roads and access roads (S1, S2 and A1) are secondary roads that serve less important transport functions. The difference between main roads and collector roads refer to traffic volume and to the size of the communities they serve. There is a designated main road network in Norway of 7,000 kilometres, serving as connections between main population centres. Collector roads have through traffic, whereas access roads should normally be designed not to have through traffic, that is an access road should only serve traffic that needs to access properties along the road. The bulk of access roads are residential roads with very low traffic volume, often less than 100
vehicles per day. Many of these roads have a speed limit of 30 km/h and have speed humps to keep speeds down. These roads inside built-up area (S3, A2 and A3) are not categorised to the Secondary road.

### 5.1.4 Belgium

Belgium consists of three regions, each with different road categorisation. In this case only the Walloon and Flemish region will be described. For the purpose of the categorisation of secondary roads the Brussels city region is not interesting.

For the Walloon region two types of road categories are considered to fall under secondary roads. “Le reseau interurbain (RESI)”, a medium distance connection with higher level of access to adjacent properties, is characterized by: harmonious cohabitation between all road users; mixing of all road users; evacuation of the traffic to the highways. For the definition of a secondary road the road categorisation RESI I+II will be used.

A RESI-I road connects two urban centres of medium importance. A RESI-II road enters the built-up areas or is situated in the transition zone between the rural and the urban areas. In Flemish region a secondary road is comprised of either a connect road or a collect road on the local level. The selection of the Secondary roads is a responsibility of the provinces, and was integrated in the making up of their provincial town and country policy plans (‘provinciale ruimtelijke structuurplannen’). The same principles as for the Main roads and the Primary roads by the Flemish authorities where applied. Some roads that according to these principles should normally be Primary roads have been selected as Secondary roads because the road environment didn’t allow the traffic flow and the road infrastructure that corresponds with a Primary road.

### 5.1.5 Portugal

*Complementary Itineraries* (IC) and *National Roads* (EN) roads connect the main network (IP roads) to midsized urban areas and these roads form the main arteries of major metropolitan areas. The national authorities are responsible for the National Road Network and for the Regional Road Network roads. Regional Roads (ER) establish inter-municipal connections. Some IP and IC roads belong to the Motorway Network. Roads restricted to motorized traffic have full access control. Most of these roads are IP or IC. The remaining IC and most EN and ER roads have a maximum speed limit of 90 km/h. Small stretches of EN and ER roads through small villages have a 50 km/h maximum speed limit. These roads IC, EN and ER are the secondary roads.
that follow the description above. The local roads (EM) in urban or rural areas with access function belong to the municipal network and the motorways (IP) are out the Secondary road categorisation.

5.1.6 Hungary

The connecting roads connect localities with each other and to the main road network and perform the role of collector-distributor roads. They carry traffic to main roads. The access roads connect localities to the national road system ensuring the operation of the public transport, and their accessibility for passenger and goods traffic. Roads leading to and connecting the national road network with the stations of various transport modes, the railway stations and the ports (bus-terminal, railway station, port, ferry dock, airport etc.) of the different transport modes. On these roads outside built up area there is a speed limit of 90 km/h and inside built up area a limit of 50 km/h.

5.1.7 Greece

The function Group B (connection) is the group of roads that includes roads located within the limits of cities or residential areas, with limitations concerning the service of roadside properties and whose main function is connection. The general speed limit is determined through the definition of the traffic mode (rural roads speed limit: 100 km/h), but depending on the alignment or certain conditions (traffic density, accident frequency, road conditions), a lower speed limit can be set for individual roads or road sections by the traffic authority, which is independent from the road authority responsible for road design. In Greece six functional grading (I to VI) consists; grading I and II have characteristics of roads with a flow function. The grading III have the characteristics of connection and IV to VI like access roads.

5.1.8 Czech

Czech has four function groups, only the function group A (flow and connection roads) and group B (collection roads) will be used for the definition of secondary roads. Beside of the four function groups Czech have three road categories. The road categories are rural roads (motorway and road), urban road and special purpose roads. The secondary roads will be found in the rural roads. The rural roads have two main categorisations: motorways (D) and roads (S). The S-roads are the secondary roads. The S-roads, where all types of vehicles and road users are allowed, are divided into three classes:
- **1st class road** – mainly designed for long distance and international traffic. The quality level is C, which means traffic flow is stable.

- **2nd class road** – their main function is to connect the regions. The quality level is D, which means traffic flow is still stable.

- **3rd class road** – their main function is to connect towns/cities and to enable the connection of these towns to the road network. The quality level is E, which means the capacity of traffic line is reached.

The speed limit for the secondary roads in the rural area is 90 km/h.

### 5.1.9 Italy

The Italian regulations (D.M. 05/11/01) provides for a functional classification of a road network.

This classification is hierarchical in type and includes four levels of network:

- **primary with throughway and traffic flow function**;
- **main with distribution function**;
- **secondary with function of local network entrance**;
- **local with access function**.

Road classification is as follows:

<table>
<thead>
<tr>
<th>TYPE OF ROAD</th>
<th>POSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOTORWAY</td>
<td>A</td>
</tr>
<tr>
<td>MAIN RURAL RD.</td>
<td>B</td>
</tr>
<tr>
<td>SECONDARY RURAL RD.</td>
<td>C</td>
</tr>
<tr>
<td>TRAFFIC FLOW URBAN RD.</td>
<td>D</td>
</tr>
<tr>
<td>URBAN OF QUARTER</td>
<td>E</td>
</tr>
<tr>
<td>LOCAL</td>
<td>F</td>
</tr>
</tbody>
</table>

Position:

- RURAL
- URBAN

The main function of a road is that of the network it belongs to. While secondary functions are the main ones of the contiguous classes in the hierarchical order.

Then the main function of the secondary rural roads (C) is the entrance, while the distribution and the access stand for the secondary functions.
The secondary rural roads show the following geometric and traffic characteristics:

- speed limit: 90 Km/h;
- number of lanes in one direction: 1;
- design speed range: 60-100 Km/h;
- lane width: 3.75m (C1) e 3.50m (C2);
- minimum shoulder width: 1.50m (C1) e 1.25m (C2);
- level of service (according to H.C.M.): C;
- service flow: 600 car equivalent/hour;
- parking control: allowed at the lay-by;
- public transport control: stops at relevant places at the carriageway side;
- pedestrian flow control: at the shoulder;
- accesses: allowed.

The classification of rural roads can be summarized as follows:

<table>
<thead>
<tr>
<th>TYPE OF ROAD</th>
<th>ITALY</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRIMARY</td>
<td>GROUP A</td>
</tr>
<tr>
<td></td>
<td>GROUP B</td>
</tr>
<tr>
<td>SECONDARY</td>
<td>GROUP C</td>
</tr>
<tr>
<td>TERTIARY</td>
<td>GROUP F</td>
</tr>
</tbody>
</table>

### 5.2 The definition of a Secondary road (categorization)

In Table 1 the roads of the eight European countries are categorised to the primary, secondary and tertiary road categorisation. All secondary roads are described for each country above. There are many differences between secondary roads. In that way the secondary road are distinguished in three functional categorisations; flow/connection, collect and access (see Table 14).
(*) the general speed limit for rural roads is currently 100km/h.

Table 14  Characteristics of secondary roads of the eight countries.

<table>
<thead>
<tr>
<th>Type of secondary road</th>
<th>Country</th>
<th>National name of secondary road</th>
<th>Characteristics: speed limits</th>
<th>Characteristics: Road administrator</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLOW (Connect)</td>
<td>The Netherlands</td>
<td>SW100</td>
<td>100 km/h</td>
<td>Province</td>
</tr>
<tr>
<td></td>
<td>Germany</td>
<td>All (*)</td>
<td></td>
<td>Usually State Authorities</td>
</tr>
<tr>
<td></td>
<td>Norway</td>
<td>S1</td>
<td>80 km/h</td>
<td>Usually State Authorities</td>
</tr>
<tr>
<td></td>
<td>Belgium (W)</td>
<td>RESI I</td>
<td>&lt;= 90 km/h</td>
<td>Province</td>
</tr>
<tr>
<td></td>
<td>Belgium (F)</td>
<td>Hoofdwegen</td>
<td>&lt;= 90 km/h</td>
<td>Province</td>
</tr>
<tr>
<td></td>
<td>Portugal</td>
<td>IC</td>
<td>&lt;= 100 km/h</td>
<td>National Road Authorities</td>
</tr>
<tr>
<td></td>
<td>Hungary</td>
<td>Connecting road</td>
<td>&lt;=90 km/h</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Greece</td>
<td>Group BI</td>
<td>&lt;= 100 km/h</td>
<td>Region</td>
</tr>
<tr>
<td></td>
<td>Czech</td>
<td>1st class road</td>
<td>90 km/h</td>
<td>State</td>
</tr>
<tr>
<td>DISTRIBUTOR (Collect)</td>
<td>The Netherlands</td>
<td>GOW80</td>
<td>80 km/h</td>
<td>Province/Municipalities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GOW70</td>
<td>70 km/h</td>
<td>Municipalities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GOW50</td>
<td>50 km/h</td>
<td>Municipalities</td>
</tr>
<tr>
<td></td>
<td>Germany</td>
<td>AIV</td>
<td></td>
<td>Usually County Administration</td>
</tr>
<tr>
<td></td>
<td>Norway</td>
<td>S2</td>
<td>&lt;= 70 km/h</td>
<td>Country road</td>
</tr>
<tr>
<td></td>
<td>Belgium (W)</td>
<td>RESI II</td>
<td>70 km/h</td>
<td>Walloon Government</td>
</tr>
<tr>
<td></td>
<td>Belgium (F)</td>
<td>Interwijkenwegen</td>
<td>70 km/h</td>
<td>Province</td>
</tr>
<tr>
<td></td>
<td>Portugal</td>
<td>EN</td>
<td>&lt;= 100 km/h</td>
<td>National Road Authorities</td>
</tr>
<tr>
<td></td>
<td>Hungary</td>
<td>Connecting road</td>
<td>&lt;=90km/h</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Greece</td>
<td>Group BIII</td>
<td>&lt;= 70 km/h</td>
<td>Region</td>
</tr>
<tr>
<td></td>
<td>Czech</td>
<td>2nd class road</td>
<td>90 km/h</td>
<td>Regional Government</td>
</tr>
<tr>
<td>Access</td>
<td>The Netherlands</td>
<td>ETW60</td>
<td>60 km/h</td>
<td>Municipalities</td>
</tr>
<tr>
<td></td>
<td>Germany</td>
<td>AV</td>
<td></td>
<td>Municipalities</td>
</tr>
<tr>
<td></td>
<td>Norway</td>
<td>A1</td>
<td>80 km/h</td>
<td>Municipalities</td>
</tr>
<tr>
<td></td>
<td>Belgium (W)</td>
<td>RSR I</td>
<td>70 km/h</td>
<td>Municipalities</td>
</tr>
<tr>
<td></td>
<td>Belgium (F)</td>
<td>Verzamelwegen</td>
<td>70 km/h</td>
<td>Municipalities</td>
</tr>
<tr>
<td></td>
<td>Portugal</td>
<td>ER</td>
<td>&lt;=90 km/h</td>
<td>National Road Authorities / Municipalities</td>
</tr>
<tr>
<td></td>
<td>Hungary</td>
<td>Access road</td>
<td>&lt;=90 km/h</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Greece</td>
<td>Group BIV</td>
<td>&lt;= 60 km/h</td>
<td>Municipalities</td>
</tr>
<tr>
<td></td>
<td>Czech</td>
<td>3rd class road</td>
<td>90 km/h</td>
<td>Regional Government</td>
</tr>
</tbody>
</table>
Following the criteria a secondary road will be defined as:

- Single carriageway, two lanes
- Paved road
- Outside the urban area
- Connect towns and villages
- Mainly collection function

Below some examples (pictures) are presented of the Dutch situation:

<table>
<thead>
<tr>
<th>Function of Secondary Road</th>
<th>Old situation</th>
<th>New situation with some measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connect</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 15 Function of secondary road in the Dutch situation (Reference: www.crow.nl)
The photographs in the first column are secondary roads, which have the old road design. The photographs in the latest column are secondary roads, which have the new road design following the policy “Duurzaam Veilig” (sustainable safety).

5.3 A stepwise approach to road categorisation

Traffic can be seen as a system of infrastructure, legislation and regulations, vehicles and road users. To reduce the number of fatalities and injured involved in road accidents in Europe, it is important to apply a system approach when it comes to road safety issues. Within this system all elements must be geared to one another. This means that there is a connection between function, geometric design, regulations and use.

To increase road safety it is important to adjust the geometric design and the use of a road to the following principles of road safety:

- prevent unintentional use of the infrastructure;
- prevent intersections with major speed - and direction differences;
- prevent insecure behaviour of road users.

These three road safety principles are inverted to three general pillars:

1. the functionality of the road network;
2. the traffic homogeneity;
3. predictability of the road user behaviour.

Ad 1) Homogeneity

By applying the right geometric design and regulations, two road safety targets can be accomplished:

1. an equal traffic flow
2. low speed driving on intersections

Ad 2) Predictability
To achieve predictable road user behaviour it is essential to take into account the recognizability and simplicity of traffic situations and the willingness of road users to accept the traffic regulations.

Ad 3) Functionality

A sustainable safe road network has a functional layout, based on three main road types within secondary roads. Each type of road indicates a certain behaviour of road users. The functional use of a sustainable safe road network is connected with route decision, types of vehicles, flow and accessibility, and volumes. Ascribing a function to a road is named ‘categorisation’. This section contains a step-by-step plan to categorize a road network.

5.3.1 Categorizing a road network

When road authorities categorize their road network it is important to keep in mind that the set up of this network needs to be logical. Starting point of this principle are the three main road types within secondary roads:

- ‘flow roads’: …..
- ‘connecting roads’: ….
- ‘access roads’: …..

5.3.2 Step-by-step plan

When new roads are built or current roads are adjusted, road safety often is not a major determining factor. Factors like available space, budget, function, required flow and expected problems do also play a part in this process. The categorisation of the road network can be considered as a desirable situation, based on the several wishes that have been collected in an earlier stage of the process. To categorize a road network the following steps must be completed, according to the Dutch approach:

- to determine preconditions and starting points;
- to develop desirable situations;
- to combine and match desirable situations;
• to apply practical solutions;
• to adjust desirable situations;
• to compare desirable situation ‘sustainable safe road network’ to other fields of activities;
• consideration and choice making.

The step-by-step plan is visualised in figure 1.

**Step 0; determine preconditions and starting points**

The main goal of this step is to determine preconditions and starting points for all involved fields of activities, which forms the basis for the desirable situation of a ‘sustainable safe road network’. The fields of activities involved determine the structure of the traffic system. Early stage teamwork may have a positive influence within this process. The comparison with the desirable situations of other fields of activities (step 5) forms the motivation for considering and selecting varied issues.
Step 1: develop desirable situations

Step 1 deals with the desirable situations of various modes of transport and the desirable situation of residential (access) areas. Starting point for the development of these desirable situations is ‘a sustainable safe road network’. Desirable situations are drawn up for pedestrians, bicycling, slow-motorized transport, public transport and motorized transport. The functional requirements of a sustainable safe road network play an important role in the process of development.

Step 2; combine and match desirable situations

As soon as the desirable situation have been formulated, they must be combined, which requires the following efforts:

1. categorize the road network;
2. check the categorized road network;
3. combine the categorized road network with desirable situations of other fields of activities.

Categorize the road network

Firstly, the desirable situation of motorized transport is projected on the desirable situation of residential areas. This confrontation provides insight into bottlenecks: situations where flow meets access. To solve these bottlenecks the scheme below must be followed:

<table>
<thead>
<tr>
<th>Question</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Are there any alternative ‘flow’-routes?</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>2. Can the traffic exchange be concentrated on the intersections?</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td>3. Can the access areas be transferred?</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
</tbody>
</table>
Check the categorized road network

When the road categorisation is completed, two checks are necessary: a check on the consistency of the categorized road network and a check on the functional traffic volume on access roads.

A consistent categorized road network should not contain transitions between flow and access roads. Concerning the traffic volume on access roads: the volume should be limited. In case of high volumes the quality of residential areas may end up in a crush. Besides, high volumes could form a barrier for non-motorized transport (pedestrians and bicyclists). Road authorities can determine a maximum value, to protect the quality of the environment. When access roads need to process more vehicles than desired, a choice must be made:

- reduce the traffic volume by using alternative distribution roads;
- categorize the road as a connecting or flow road and adjust the functional lay-out.

Combine the categorized road network with desirable situations of other fields of activities

By adding the remaining desirable situations to the categorized road network, an overall picture is created. This overview clarifies the issues of various modes of transport on intersections and road sections. On the basis of the practical requirements, a combination of these modes of transport, will lead to a certain geometric design.

Step 3; (Re)design roads in conformity with functional categorization

After combining the desirable situations, the requirements for the lay-out of road sections, intersections and transitions need to be applied, such road-with, speed limits, etc. Subsequently, it is important to verify possible problems caused by the practical application of the requirements.

Step 4; adjust desirable situations

In some situations the geometric design of road sections, intersections and transitions will not fit the practical requirements. In these cases possible adjustments to the
desirable situations have to be considered. Due to this, maybe other practical solutions need to be applied. The consequence is a return to step 2.

When the road authority concludes that all road sections, intersections and transitions fit the practical requirements, a sustainable safe road categorisation is accomplished.

**Step 5; compare desirable situation ‘sustainable safe road network’ to other fields of activities**

The previous steps result in a desirable situation based on the view of a sustainable safe road network. This step contains the comparison with the desirable situations of other fields of activities, like urban planning, environmental quality, funds, etc.

**Step 6; consideration and choice making**

In many cases, the confrontation of desirable situations (step 5) leads to contradicting issues. At this point, politicians are committed to make choices. The consequence could be that other fields of activities obtain priority. The result may be the allotment of another type (category) to roads. Subsequently, other practical solutions must be applied; otherwise road safety may be at risk.

The final result is an overall picture of the road categorisation, based on the principles of a sustainable safe road network. The establishment of this road categorisation must be taken into practice and applied in various related documents.
Section 6  Self-Explaining Roads

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6  Self-Explaining Roads

6.1  Definition of Self-explaining Road (SER)

Currently, road design is hardly adapted to human capabilities. The crucial question is how the occurrence of errors in traffic can be reduced.

The SER concept advocates a traffic environment that elicits safe driving behaviour simply by its design. In order to support safe driving behaviour and appropriate speed choice, drivers should be enabled to recognise the type of road they are on. Therefore, it is important that the way people subjectively categorise these roads matches the function and use of roads.

Self-Explaining roads are roads with a design that evokes correct expectations from road users (Theeuwes & Godthelp, 1992) [14].

Another example of the most simply and accurate definition of self-explaining road has been determined in FHWA (2001; 2005) based on (CROW 1997) [4]:

The concept of self explaining roads, also known as self-enforcing (FHWA2001), or self-organising (FHWA 2005) roads is based on the idea that roads with certain design elements or equipment raise certain expectations of road users regarding their own driving behaviour and the attitude of other road users and thus induce appropriate speed or steering maneuvers.

A self-explaining road is a road designed and built in such a way as to induce adequate behaviour and thereby avoid driving error.
In order to obtain Self-Explaining Roads, it is important that the design of the infrastructure is adjusted to the way the road environment is categorised in the ‘heads’ of its users (Theeuwes & Diks, 1995b) [13].

In Review Of The Road Safety To 2010 Strategy, Jeanne Breen Consulting, 2004 [20], the SER has been described as:

"Some of the physical measures force the road user to reduce speed". That means it is necessary to design the road environment in order that drivers are persuaded to reduce speed voluntarily. This technique is called the ‘Self Explaining Road’. In essence the ‘Self Explaining’ Roads (SERs) concept advocates a traffic environment that elicits safe behaviour simply by its design. By designing a road environment that accords with actual speed limit drivers could be persuaded to choose that appropriate driving speed more or less automatically.

This represents a new approach to speed reduction and traffic management particularly within the village environment by influencing driver behaviour through ‘softer’ engineering options such as changing road surfacing and the removal of visually intrusive signs and lines. Such schemes are also significantly cheaper than schemes employing ‘harder’ engineering measures such as ramps, speed humps, and tables.
It must be stressed that this approach is unorthodox and very much in its infancy. Much more research will be necessary before adopting the ‘self explaining’ road for large-scale traffic management schemes. However, the principle of self-enforcing driver behaviour as a result of an appropriately designed environment is an important aim of speed management policy."


“The new design guidelines should be based on a new design principle: roads ought to be standardized and self-explaining. Standardization of roads means that there will be types of uniform road layouts, which can easily be distinguished. The meaning of self-explaining in this context is that roads are designed in such a way that road users can recognize subconsciously how they are expected to behave. Both targets can be reached by defining a limited number of sets of design options, taking operational aspects into account, and by defining a close relationship between these sets and the function of the road. The main point is to establish a new guidance figure in order to define the right combinations of different types and sizes of design elements. Up to now, the guidance figure for road design has been the design speed. But the design speed only defines the minimum radius of a curve with a maximum cross slope under defined circumstances. The design speed does not determine the type and width of cross sections, the type of intersection or the operation mode. Neither is there a strong relationship between the design speed and the required sight distance, the length of a straight section, the inclination or the cross slope. This is the reason why a design class, as it is called, has been defined as a new guidance figure “
6.2 SER Criteria

Because expectations play an important role, it is crucial that the design of roads be adjusted to these expectations. Purely by their design, roads should elicit safe behaviour (Alexander & Lunenfeld, 1986; Theeuwes, 1998; Theeuwes & Godthelp, 1995). By taking into account the constraints and the limitations of the driver, road design can reduce the number of errors that occur in traffic. The type of road that elicits safe behavior simply by its design has been referred to as a self-explaining road (Theeuwes & Godthelp, 1993) [15]. Along similar lines, Alexander and Lunenfeld (1986) [1] developed the concept of positive guidance, referring to road environments that are in line with the expectations of the road users.

On theoretical grounds, Theeuwes and Godthelp (1993, 1995) [15] [16] identified some criteria that will increase the self-explaining character of roads. When developing the “road of the future,” one should start with a few easy recognizable and distinguishable road categories. These types of roads should be designed in such a way that high speed differences and directional differences are not possible.

Four categories can be distinguished

- freeways,
- highways connecting larger regions,
- rural roads connecting residential and shopping areas,
- small roads going from door to door (in Europe are called woonerfs).

For these four categories, self-explaining roads should fulfill the following tentative criteria:

- Roads should consist of unique road elements (homogeneous within one category and different from all other categories).
- Roads should require unique behavior for a specific category (homogeneous within one category and different from all other categories).
- Unique behavior displayed on roads should be linked to unique road elements (e.g., woonerfs: obstacles—slow driving, freeway: smooth concrete—fast driving).
- The layout of crossings, road sections, and curves should be linked uniquely with the particular road category (e.g., a crossing on a highway should physically and behaviorally be completely different from a crossing on a rural road).
- One should choose road categories that are behaviorally relevant.
• There should be no fast transitions going from one road category to the next.
• When there is a transition in road category, the change should be marked clearly (e.g., with rumble strips).
• When teaching the different road categories, one should teach but also the behavior required for, that type of road.
• Category-defining properties should be visible at night as well as in the daytime.
• The road design should reduce speed differences and differences in direction of movement.
• Road elements, marking, and signing should fulfill the standard visibility criteria.
• Traffic control systems should be uniquely linked to specific categories (e.g., on freeways, systems that regulate traffic flow; on rural roads, systems that restrict driving speed).

Another way for road hierarchy (The Dutch road hierarchy):

• Flow: to go from place of departure to destination – through -roads – roads with a flow function for through traffic without interruption. For these roads no speeds at above 100-120 km/h with complete separation of traffic streams.
• “Distributor (Collector) Roads: To avoid that traffic flow on connector (flow) roads is disturbed by too many intersections, roads of this type work as buffers by “collecting” and channeling traffic from several access roads to a road of a higher level.”
• Access: to enter and leave an area – distributor roads – with the needs of moving traffic continuing to pre-dominate, local distributor roads – giving equal importance to motorised and non-motorised local traffic but separating users wherever possible. Roads with a connecting function for car traffic to and from large urban districts, villages and rural areas with traffic interchange at limited sections. Speeds should not exceed 50km/h within built-up areas and 80km/h outside. Separate paths for pedestrians and cyclists, dual carriageways as standard, with stream separation on the full length and speed management on major crossings and right of way.

Residential access: to reach an individual dwelling, shop, or company – where the needs of non-motorised users predominate – residential access roads. Roads with an access function for vehicles with constant traffic interchange, comprising the vast majority of roads. For these roads no speeds over 30km/h in towns and villages. No speeds of over 40km/h at crossings and entries in rural areas, otherwise 60km/h may be acceptable. Where a road performs a mixture of functions, the appropriate speed is normally the lowest of the speeds appropriate to the individual functions.
6.3 Design Instructions (Principles)

Road design should follow cultural standards or physical analogies as stored in mental models. Only where this mapping principle is not self-explaining a conceptual model has to be provided with the help of additional cues. These cues should follow the principle of visibility to allow the driver to correctly predict the outcome of his actions. Visibility first of all means that information:

- has to be physically visible and mentally recognizable (for everyone)
- has to be presented at locations and in a way that are in accordance with human expectations
- must guide behaviour in a self-explaining way: no explanation needed.

However, visibility in Norman’s sense exceeds this meaning as visibility of behavioural outcomes is included, too. It is related to feedback, which communicates the appropriateness of behaviour to the driver. Affordances in the sense of Gibson have to be provided by the design without additional information.

Despite the term self-explaining suggests otherwise, behaviour associated with a specific design or design element has to be learned in the first place. In case unknown objects or new design elements are encountered the behaviour elicited is determined by the degree of similarity to the original object. While some roads are highly self-explaining, like motorways, rural roads seem to lack this quality. Therefore, implementing self-explaining road design will lead to substantiate changes in the perceived characteristics of rural roads. Some of these characteristics will not be self-explaining the first time they are encountered. In this case the appropriate behaviour has to be learned. The ways how this learning is done have to be known in order to be successful. In general the following four principles are applicable:

- Explicit or purposeful learning due to information and education.
- Observational learning in the sense of Bandura (for a summary on Bandura, see Gerrig & Zimbardo, 2005; Schlag, 2004).
- Contingency management; refers to the way feedback is given, both in time and type (for a review see as well Schlag, 2004).
- Stimulus control (antecedent to behaviour).
Especially the last three principles will contribute to learning the appropriate behaviour, concurrently. In contrast to the first one, no special effort is required from road authorities, except that the principles are applied consistently throughout the whole road system.

A key point of departure for positive design is that it openly recognizes that drivers use the total information provided by their environment—not just posted speed limits—and strives to take advantage of these opportunities to provide drivers with the information they need to operate their vehicles safely and appropriately. On this subject, European counterparts have developed a potentially valuable alternative. European designers use an "environmental reference speed" when designing a roadway, beginning the design process by tightly specifying the desired operating speed of a roadway, and then using this intended operating speed as the roadway’s design speed, providing posted speed limits that match (FHWA, 2001; Lamm et al., 1999) [6] [7]. Roadways are thus designed to be self-explaining and self-enforcing, conveying a single and consistent message to the driver on safe operating behavior.

The concept of self-explaining roads requires that

- Roads with the same function, the same traffic mix and the same speed limit look similar in order to be **recognisable**
- Roads with different functions, different traffic modes or speed limits are **distinguishable**
- Desired driving behaviour can be easily interpreted by road users or even be **induced**

As a result of a literature study, Van Schagen et al. (1999) concluded that motorists used the following features when they arrange and structure the road network in a subjective way:

**On urban roads**

- Road width
- Roadside environment

**On rural roads**

- Number of carriageways/lanes
- Road width
- Edge marking
- Axis marking
- Narrowing-illusion marking
Alignment
Distance between road and vegetation
Sort of road surface
Condition of road surface

One of the conclusions of this review is that not all of these features are relevant for the possibilities of improving the recognition of road types. Moreover some of these features can not be changed for existing roads (e.g. alignment).

Within the framework of these previous studies of categorising, Van Schagen et al. (1999) examined which requirements road features had to meet in order to increase the recognition of road types and to emphasise the distinction between types. They arrived at three requirements:

- The first and most important requirement is that the feature must be **continuously visible**. The road user must be continuously able to determine on which road type he/she is driving.
- The second requirement is that the feature has to be **practically applicable** and **feasible**. As an example, using a different colour for street lighting or lampposts would probably lead to a clear distinction between different road categories at any time: but there is street lighting on a minority of roads only. As a result, the implementation of street lighting on rural roads would not be cost effective and therefore not feasible.
- The third requirement is that a feature must **not** itself have a **negative safety effect**, and should be visible during less favourable conditions such as darkness and snow.

Based on these requirements (continuously visible, applicable & feasible and no negative safety effect), Van Schagen et al. (1999) and Aarts et al. (in preparation) examined the extent to which the features included in the operational requirements, were suitable for making the various road types recognisable. They concluded that the following features could be relevant for promoting the recognition of self-explaining road types:

1. Marking in the longitudinal direction
2. Driving direction separation
3. Width of lanes
4. Adjacent cycle lanes
5. Road surface/extent of roughness
6. Characteristics of the shoulder (width, obstacle distance, reflector posts)
7. Roadside environment (land use, for instance: urban characteristics such as buildings, parked cars, exits)

8. Intersections and transitions type (not continuously visible)

In AASHTO’s (2002) [3] Roadside Design Guide, the central authority on the design of safe roadsides, the application of the forgiving roadside concept has been refined to the point where roadside design is an integral part of transportation design criteria.

Design options for reducing roadside obstacles, in order of preference, are as follows:

- Remove the obstacle.
- Redesign the obstacle so it can be safely traversed.
- Relocate the obstacle to a point where it is less likely to be struck.
- Reduce impact severity by using an appropriate breakaway device.
- Shield the obstacle with a longitudinal traffic barrier designed for redirection or
  - use a crash cushion.
- Delineate the obstacle if the above alternatives are not appropriate. (pp. 1–2)

This self-explaining roads concept means choosing distinctive features, such as surfacing, lane width, presence or lack of cycle paths, width of pavements, etc. On a driving simulator, researchers singled out two aspects to which drivers seem particularly receptive: cycle paths and road width.

Along the same lines, the report stresses the need to adapt roads to their environment, particularly when they pass through residential areas. They could include chicanes, noisy markings, narrowing of the road, traffic islands, mini-roundabouts, noisy or coloured surfaces, gateways at the entrances of villages, etc. Several studies have concluded that layouts like this could cut the number of serious accidents by 30% to 50%.

Elements of self-explaining roads should be continuously visible, practically applicable and must have no negative effect on road safety. As the results of the literature survey show, the effects of different road features identified differ in their impact.
From the eight road features cited in Van Schagen’s study, four (markings, driving direction separation, width of lanes, adjacent cycle lanes) refer to road markings and the width of the driving lanes. These features are usually continuously visible and emboss the patterns of road types in the road users’ minds. The presence or absence of guardrails and markings not only have impacts on the appearance of the roads but also on driving speed, lateral position and overtaking behaviour.

The influence of the road surface on driving speed has been dealt with in some studies. The usage of rougher materials like bricks or cobblestones in rural road design like they are applied in the Netherlands, however, seems not to be an option for all European countries due to maintenance and safety reasons. The influence of different compositions of asphalt on driving speed and their feasibility in this respect has to be investigated further.

It seems that roadside design, apart from the characteristics of the shoulder like roadside slopes and the width of obstacle free zones, has not been paid much attention in current design guidelines although its influence on driving behaviour is obvious. Roadside vegetation, marker posts and other elements on shoulders like curve warning signs and guardrails underline the appearance of the road. When applied correctly, drivers’ concentration can be raised and driving speed reduced by the design of the roadside.

The effects of the various reported effects of road features on traffic behaviour are summarised in the table below (Tab. 1). For each feature, the expected effects on the average driving speed, the number of overtaking movements or the percentage of offenders, and the lateral position are all given.
<table>
<thead>
<tr>
<th>Type of road surface</th>
<th>Average speed</th>
<th>Number of overtaking movements and % offenders</th>
<th>Lateral position (a = towards road axis r = towards roadside)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rougher surface (e.g. cobble stones instead of asphalt)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Renewal of asphalt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Separator</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Larger physical hindrance (strips or flaps)</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Double axis with reflectors and broken v. DR old</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Strips between double axis</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Marking in the longitudinal direction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No marking</td>
<td></td>
<td></td>
<td>r</td>
</tr>
<tr>
<td>Addition of axis line on an unmarked road</td>
<td>+</td>
<td>a</td>
<td></td>
</tr>
<tr>
<td>Edge line</td>
<td></td>
<td>+/−</td>
<td></td>
</tr>
<tr>
<td>Axis line replaced by edge line</td>
<td></td>
<td>-</td>
<td>r</td>
</tr>
<tr>
<td>Width of driving lane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marking in the lateral direction (split chevron)</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Driving lane widths &lt; 3m</td>
<td></td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Driving lane width &gt; 3,75 + emergency lane</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reflector posts</td>
<td>+/−/***</td>
<td>a/ r</td>
<td></td>
</tr>
<tr>
<td>(Non-compulsory) cycle lane</td>
<td>Urban area</td>
<td>0</td>
<td>r</td>
</tr>
<tr>
<td></td>
<td>Rural area</td>
<td>0</td>
<td>a</td>
</tr>
<tr>
<td>Buildings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roadside Vegetation</td>
<td>Continuous</td>
<td>+</td>
<td>r**</td>
</tr>
<tr>
<td></td>
<td>Spread</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Outside of bend</td>
<td>+**/−</td>
<td>a</td>
</tr>
<tr>
<td></td>
<td>Inside of bends</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Obstacles/parked vehicles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presence of other road users</td>
<td>Slow traffic</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oncoming vehicles</td>
<td>r</td>
<td></td>
</tr>
</tbody>
</table>

* The shorter the distance between building/obstacle and road, the slower the speed.
** except right-turn bends.
*** straights and left-turn bends slower / right-turn bends faster

**Tab. 1** The effect of different road features on driving speed, the number of overtaking movements and the percentage of offenders, and the lateral position of motorists. The relevance of this table is that these elements can help in making a road more self-explaining or self-enforcing. E.g., if the measured speeds are too high for the desired function one could consider to change axis lines to edge lines (as is done in the NL for 60 km/h-roads), of course as a uniform measure for all roads of this category"
Other studies have concluded that road safety in Europe would improve substantially if speed limits were generally tighter.

### Dutch guidelines for designing safer roads: Requirements relating to roads

<table>
<thead>
<tr>
<th>The category / the type of the road</th>
<th>The maximum speed</th>
<th>The division of the road</th>
<th>Intersections</th>
<th>Roads to the lands</th>
<th>Bicycle lane</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flow Road</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>120 km / h</td>
<td>2x2 or more</td>
<td>Multilevel</td>
<td>No</td>
<td>Free lying</td>
</tr>
<tr>
<td></td>
<td>100 km / h</td>
<td>2x1 (or 2x2)</td>
<td>Multilevel</td>
<td>No</td>
<td>Free lying</td>
</tr>
<tr>
<td><strong>Distributor (collector) Road</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>80 km / h</td>
<td>2x1 lub 2x2</td>
<td>One-level</td>
<td>No</td>
<td>Free lying</td>
</tr>
<tr>
<td></td>
<td>70 km / h</td>
<td>2x1 or 2x2</td>
<td>One-level</td>
<td>No</td>
<td>Free lying</td>
</tr>
<tr>
<td></td>
<td>50 km / h (*)</td>
<td>2x1 or 2x2</td>
<td>One-level</td>
<td>No / Limited</td>
<td>Free lying / strip on the lane</td>
</tr>
<tr>
<td><strong>Access Road</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>60 km / h</td>
<td>1x2</td>
<td>One-level</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>30 km / h (*)</td>
<td>1x2</td>
<td>One-level</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

(*) urban
The review of the essential features of recognisability according to category and type of the road

<table>
<thead>
<tr>
<th>The category / the type of the road</th>
<th>Marking</th>
<th>Marking the edge of the surface</th>
<th>The separation of traffic directions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Road 120 km/h ASW sign(^1)</td>
<td>solid line</td>
<td>energy-consuming barrier or the wide lane of separation</td>
<td></td>
</tr>
<tr>
<td>100 km/h(^2) AW sign(^2)</td>
<td>solid line</td>
<td>double line with the green lane or energy-consuming barrier or the lane of separation</td>
<td></td>
</tr>
<tr>
<td>80 km/h general limit, unnecessary sign</td>
<td>broken line</td>
<td>double line or the lane of separation</td>
<td></td>
</tr>
<tr>
<td>Distributor Road 70 km/h the sign order the limitation</td>
<td>broken line or kerb</td>
<td>double line or lane of separation</td>
<td></td>
</tr>
<tr>
<td>50 km/h general limit, unnecessary sign</td>
<td>broken line or kerb</td>
<td>double line or lane of separation</td>
<td></td>
</tr>
<tr>
<td>Access Road 60 km/h the sign of the zone</td>
<td>broken line or the lack of marking</td>
<td>the lack of separation of directions</td>
<td></td>
</tr>
<tr>
<td>30 km/h the sign of the zone</td>
<td>broken line or kerb or the lack of marking</td>
<td>the lack of separation of directions</td>
<td></td>
</tr>
</tbody>
</table>

1) the sign of the highway (ASW - AutoSnelWeg - the Highway)
2) the sign of the quick movement route (AW - AutoWeg - the route only for cars)

In order to apply the strategic principles of the Traffic Road Safety it is necessary to make selections on the individual stages (levels) of analyses and projecting. From this analysis appears picture of desired function of the road (categorization). The choice determined on higher level defines a way of proceeding on lower levels.
There is also important to consider the psychology of the road traffic (the point of view of the road traffic users) in projecting and connect it with infrastructure and surroundings (the point of view of the roads administrators). The equipment of the road forces the definite behaviour of the traffic user, although not always in accordance with desired behaviour.

Readers interested in more detailed design instructions for self-explaining roads can find them in Ripcord – Iserest Report:

"Road categorisation and design of self explaining roads"

6.4 Structured Roads, examples from Poland

Figure 1 Crossroads 50 and local road near Mlodzieszyn

Figure 2 Crossroads 50 and local Road near Leontynow
Figure 3  Crossroads 14 and local road in Glowno

Figure 4  Crossroads 14 and local road near Strykow
Figure 5  Interchange on A2 highway and 703 road near Stary Gostkow

Figure 6  Flyover over A2 highway near Wartkowice
References


[8] Rozporządzenie Ministra Transportu i Gospodarki Morskiej z dnia 2 marca 1999 r. w sprawie warunków technicznych, jakim powinny odpowiadać drogi publiczne i ich usytuowanie (Dz. U. Nr 43, poz. 430


Section 7  Safety Analysis

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7 Safety Analysis

Safety analysis is a wide argument, dealt with in several Ripcord-Iserest workpackages: this section proposes a resume of the most relevant approaches for Secondary Roads, with the references to the other project deliverables where such approaches are more detailed.

The relevance of a safety analyses would be to find out ways to improve safety: this can be done ex ante (before) or ex post (afterwards). Instruments helpful in the ex ante analyses for Secondary Roads are Road Safety Audits (RSA) and Road safety Impact Assessment (RIA); for the ex post analyses instruments are Accident Prediction Models (APM), Safety Performance Function (SPF), Black Spot Management (BSM), Road Safety Inspection (RSI) and the Secondary Roads Expert System (SEROES).

SEROES is the specific application for local road managers with low accident data availability and, as explained in the previous section 1.1 (figure 2), is the natural completion of the handbook and vice-versa. The last part of this section is dedicated to this tool, while the first part is to be intended as a general information about the state of the art of safety analysis and a technical background referred to the tool itself.

The following paragraphs are dedicated to an overview of RSA and RSI, an introduction of the Safety Performance Function and an overview of some APMs models with their calibration problems.

7.1 Road Safety Audits

(for a comprehensive approach, please refer to the Ripcord-Iserest Deliverable D4, from which the following part has been taken)

Taking into account the common practice, one can define a road safety audit as a formal systematic road safety assessment of a road scheme carried out by an independent, qualified auditor who reports on the project’s accident potential for all kinds of road users.

The comparison of different approaches in several countries indicated the need for a clear differentiation between road safety audits on the one hand and road safety inspections on the other. The boundary between these two instruments sometimes appears blurred and can therefore lead to misunderstandings. In contrast to road safety inspections which are sometimes called road safety audits of existing roads, the original road safety audit refers to examinations conducted in the planning and the
design stages of road projects (which include new projects but also re-design projects) before or shortly after a road is opened to traffic or the measure is completed.

Mostly three different parties are involved in the audit process: the client, the designer and the auditor. The roles and responsibilities of the different parties can sometimes differ.

**Client:** The organisation responsible for the project which is sometimes also called the project manager, or project sponsor. Often the road authority or local stakeholders are the clients but also private investors can be responsible for road projects.

**Designer:** A person or team commissioned by the client to develop the road schemes. The design team can be part of the client’s organisation.

**Auditor:** A person or team commissioned (or approved) by the client to carry out the audit. In order to ensure an unbiased judgement, the auditor ought not to be involved in the design process or in the operation of the road. It is recommended that the auditors are independent from the designer's organisation.

---

**Figure 1: Accident Cost Rate and Curvature Change Rate**
(taken from the deliverable D4)

Auditing is no simple check whether the design is according to the standards. The audits are more focused on real safety issues affecting road users rather than design
issues. The auditor therefore has to check if the road infrastructure is safe from the point of view of all road user groups, including vulnerable and impaired road users. In late audit stages (before and after traffic opening) it is advisable that the auditor actively uses the road infrastructure as a pedestrian, cyclist and motorist. A site inspection at different daytimes (rush hour, dusk/dawn/night) can be necessary.

The most important questions the auditors have to answer during the inspection are: “who can be hurt here, how seriously and why?”

The demands regarding the qualification of auditors are high. Auditors do not only have to be able to read plans but also to detect their deficiencies and the safety implications emanating from those deficits. For that reason auditors need to be experienced in road design as well as in road safety engineering and road users’ behaviour.

Another important requirement is the participation in basic training courses, and the participation in further training programmes, such as regular seminars and workshops. The continuous further training of auditors is necessary in order to assure that the auditors keep up their knowledge.

The following basic requirements for setting up audit procedures can be formulated:

**The earlier the better!** It is easier to make changes in the schemes in early phases of the road design process when the deficits only exist on paper. Deficits which are not rectified in the first phases are less likely to be rectified later.

**The more often the better!** The types of the typical deficits differ between audit stages due to different levels of detail and the topics which are relevant in the planning stages.

**Qualification is essential!** The education of auditors and designers largely affects the quality of the schemes. Training courses have to ensure the high quality of auditors.

**Keep knowledge up to date!** Regular meetings and courses for auditors and for designers help to disseminate the latest knowledge on safety research and to increase the quality of road design and road safety audits. Such meetings should be an integral part of the further education of road safety auditors.

**Evaluation increases the quality!** Regular evaluations of audit results help identifying frequently occurring deficits. Training courses, audit checklists and guidelines should be adapted according to these findings. These evaluations should be integrated into the RSA process.
7.2 Road Safety Inspection

(for a comprehensive approach, please refer to the Ripcord-Iserest Deliverable D5)

Road Safety Inspection (RSI) is a periodical controlling instrument of the existing road network (including roadsides), independently of number of accidents. RSI allows the implementation of remedial measures before accidents occur.¹

RSI should be performed by a team of road safety experts, taking into account:

- accident analysis – accident map
- analysis of the traffic conditions
- analysis of the constructional elements
- inspection – on-site visit
- analysis of road surface (pavement rating - ruts, friction, …)
- analysis of road maintenance measures
- analysis of road environment
- possible remedial measures (short-medium long term)

The main current problems in defining a common understanding of RSI are the existence of great number of RSI approaches across Europe, the lack of a standardised RSI approach within the Countries, the absence of a legal basis for RSI in most Countries, as well as no standardised RSI reporting in most countries.

At the present, the “common understanding” on RSI includes the following definitions

- Preventive tool
- Independent of the occurred number of accidents
- Regular inspection
- Covering the whole existing road network
- Carried out by trained traffic expert team

¹ source: High Level Working Group on Road Infrastructure Safety, 2003
7.3 Safety Performance Function

Introduction

The improvement of road safety is an important task of infrastructure engineering. There are numerous opportunities to improve the safety of existing or future traffic facilities whereby basically different approaches and procedures have to be distinguished.

The most of the existing safety analysis procedures base on the evaluation of the current and past accident occurrence and mainly they are used in order to solve an actual safety problem like black spots or dangerous junctions. That means all results are derived from real data or at least from investigations of local road authorities. Often critical spots are in the focus of safety inspections. But there are also procedures for the evaluation and analysis of road networks which base on real accident data. Other procedures like safety audits are already involved during the planning process in order to avoid design faults which may affect negatively the safety of the future facility. However, all these mentioned procedures have in common that they consider current situations or experiences of the past.

A Safety Performance Function (SPF) works with an accident prediction model. Such forecast models take parameters of the road, traffic and environment into consideration aiming at a prediction which is most accurate as possible. Numerous research studies have worked out that especially the design of roads and their traffic conditions influence the road safety. Therefore, the most SPF include prediction models which base on such input values. But furthermore, also the consideration of human factors came into the focus of scientists. Investigations have shown that the general design of roads mainly influences the behaviour of drivers and mostly accidents are caused by driver’s faults.

The most frequent accident cause is speeding and usually these accidents are characterised by sever consequences. Inappropriate driving behaviour has various causes; it depends on the skills, experiences, and motivation etc. of the driver but also the geometric design of roads may lead to driving faults if e. g. the alignment is inhomogeneous. For these reasons it is necessary that a safety performance function should also consider these facts.

Approach

The goal of the development of the safety performance function within the RIPCORD-iSEREST project was to combine both engineering and psychological approaches. This was made in order to include various aspects of accident causations. The most of the
existing approaches only base on the connection between traffic conditions, geometric properties and road safety. The influence of human factors usually is not taken into account.

Pre-analysis have shown that mainly selected geometric parameters of the horizontal alignment highly correlate with the accident occurrence. Such parameters are the curve radius, curvature change rate, and road / lane width. Furthermore, the traffic conditions and especially the traffic volume have an important impact.

From investigations of driver behaviour it is known that the driven speed correlates with the alignment whereby the impact of consecutive and single elements has to be distinguished. Usually single elements are single curves with small radii which abruptly discontinue the alignment. Such singularities cause high speed differences which may lead to critical situations or even to accidents.

In the field of psychology many studies have been working on the development of integrated user behaviour models which describe the entire process of perception, information processing, and action.

Due to the complexity of human behaviour the development has not been finished so far. But important key results of these research works have influenced also investigations on practical approaches for road design guidelines. Mostly guidelines include speed forecast models for the determination of safety relevant design parameter such as superelevation or required sight distances.

For the development of the safety performance function the general idea of speed forecast models has been integrated in order to consider experiences from driver behaviour investigations. Therefore, the mentioned two different types of road section are distinguished: single curves and sections with similar alignment. Pre-studies have pointed out that not a small radius is the ultimate cause of accidents; rather it is the speed difference.

That means, even though a single curve is characterised by a small radius it does not mean it’s dangerous. In combination with the neighbouring elements it may become safety relevant if it consequences in high speed differences.

These conclusions were integrated in the SPF development so that finally two different sections types were defined:

- Transition areas: single curves which discontinue the alignment and cause speed difference more than 10 km/h
- Sections with similar alignment which are characterised by an almost constant speed profile.
This differentiation considers various aspects: on the one hand the impact of road geometry and on the other hand the influence of driving behaviour on road safety.

Based on the mentioned road section classification correlation models have been developed which includes the connection between geometric parameters and accident occurrence. The model includes as

- Accident parameters:
  - Accident rate: describes the risk to get involved in an accident
  - Accident cost rate: describes the severity of accidents

- Alignment parameters:
  - Transition areas: curve radius, speed difference, road width, ADT
  - Section with similar alignment: curvature change rate, road width, ADT.

For the various geometric parameters exist different regression models for certain traffic volumes and road widths, respectively.

**Application**

The application of the safety performance function requires several road data in high quality. Since the prediction models based on the relation between road geometry and accident occurrence, precise information especially about the horizontal alignment have to be available. Furthermore, data about the traffic condition and the design of cross sections are required. In detail the following information are needed:

- Horizontal alignment
  - Tangent: length
  - Curve: radius, length
  - Clothoid: parameter, length (optional)

- Cross section
  - Road width

- Traffic condition
  - Average daily traffic (ADT)

The SPF is not appropriate for the analysis of single road or short stretches. It has been developed in order to evaluate road networks or at least parts of road networks. The following listed conditions describe the field of application of the SPF for the analysis of road networks:

- Outside urban areas,
- Secondary rural roads only (paved single carriageway with two lanes),
• Outside intersection and junctions

All in all the analysis as well as the final evaluation of the investigated road network follow four steps:

1. Input of data
2. Detection of section types
3. Calculation of estimated accident rates and accident cost rates
4. Calculation of safety potentials

**Input**

As an important precondition the data and information of road alignment (horizontal geometry), cross section design and traffic conditions must be available and clearly defined regarding the position within the road network. The structure of these data depends mainly on the used road network structure which is different from country to country. A classical way to do so is the structure by network nodes which usually correspond to junctions or intersections of classified roads. Between two nodes a node section is defined and represents uniquely in that way a certain road stretch. Each node section has its own hectometres. Based on this structure geometric design elements are described as element type (radius, tangent, clothoid), node section (from node, to node), start/ end (from hectometre, to hectometre), parameter (radius), and direction (left, right).

**Detection of sections**

In order to apply the prediction model the horizontal alignment of the investigated roads has to be classified regarding their effects on driving behaviour and road safety. In general two different types of sections are distinguished: section with similar alignment and transitions (mostly single curves). To detect these section types each single element and consecutive elements must be analysed. In a first step based on the cumulated deviation angle and the curve radius single curves are detected which discontinue the alignment and correspond to high speed differences. As result a temporary classification is built. In a second step a speed prediction model is used to combine detected section if they are similar. This second step avoids mainly short section lengths which influence negatively the calculation of accident parameters. Finally a well detailed classification of the horizontal alignment is available for the safety analysis. Both section types are attributed to different geometric parameters: section with similar alignment are described by the curvature change rate, single curves are described by the radius. Furthermore, for each section type the road width and the traffic volume is allocated.
Calculation of accident parameter

There are different correlation models for the defined section types in order to consider their different impact on road safety. The following listed parameters are required for the application of the correlation models:

- Section type (section with similar alignment or transitions (single element))
- Road width
- Road class
- Traffic volume (ADT)

In general there are two different calculated results for each detected section: accident rates and accident cost rates. Both indicators are important accident parameter which should be always used to evaluate existing roads concerning their safety performance. The predicted accident parameter depends on the input values mentioned above.

Finally for each detected section an accident rate (risk to get involved in an accident) and an accident cost rate (severity of accidents) is calculated.

Both have the meaning that from the statistical point of view these geometric constellations have a certain impact on road safety. It does not mean the may a section is already noticeable. Perhaps, there happened no accidents in the last years but the analysis result show that it must be expected that accidents may happen.

This is the main difference to the analysis of real accident data which usually show the current safety problems. A SPF shows a statistically possible accident occurrence.
Figure 2: Accident Cost Rate and Curvature Change Rate

ACR = -0.0007CCR² + 0.4529CCR + 3.247
0 gon/km < CCR < 360 gon/km

\[ R^2 = 0.91 \]

Figure 3: Accident Cost Rate and Reduction of Speed

ACR = 0.0012dV³ - 0.1551dV² + 4.8542dV - 5.2093
5 km/h < dV < 35 km/h

\[ R^2 = 0.63 \]
Calculation of safety potential

The results of the SPF are calculated and predicted accident parameters which represent the relation between infrastructure values (geometry, traffic) and road safety. Just based on these calculated values it is going to be impossible to evaluate a road network concerning its safety performance. First, these results mean that on an investigated road section could be the accident risk and accident severity like this. It does not mean whether the result is safety critical or not. In order to evaluate the results a reference value is needed. Since accident occurrence is influenced by many different parameters a representative reference value like basic accident rates or basic accident cost rates are appropriate. Such basic accident parameters are calculated for road networks based on real accident data. They represent the average of accident risk or accident severity which is typical for the investigated area.

The safety potential is defined as the difference between calculated (predicted) accident parameters and basic accident parameters:

$$\Delta SP = ACR - bACR$$

$$\Delta SP > 0 \rightarrow \text{safety potential available} \rightarrow \text{further investigation}$$

$$\Delta SP \leq 0 \rightarrow \text{no safety potential} \rightarrow \text{no investigation}$$

whereas:

SP safety potential, ACR accident cost rate by SPF, bACR basic accident cost rate for the investigated area

If the predicted accident cost rate is higher than the basic accident cost rate the investigated stretch is above the average so that a potential to improve the safety situation is available. If it is less or equal than the basic accident cost rate the investigated road stretch is not noticeable or even below the expected average of accident occurrence.

A further distinction of available safety potentials (SP>0) is possible if the range above the basic accident parameter is further grouped: e. g. bACR+5%, bACR+10% etc. But this decision has to be done for each case and is different from area to another area. The evaluated results can be displayed within a map as shown in Figure 4.
A safety performance function forecasts an accident occurrence based on statistic models which include correlation between infrastructure and accident parameters. From numerous research studies is known that especially the road geometry and the traffic conditions have an important impact on road safety. Furthermore, the driver itself as human being influences the accident risk as well. Therefore, modern safety performance functions consider beside the impact of infrastructure also human factors.

The developed SPF takes both aspects into account. Based on a driving behaviour related approach the existing alignment of roads is analysed and classified into two different sections types: sections with similar alignment which cause an almost constant speed profile and transitions which are characterised by high speed differences. This distinction considers the behaviour of drivers derived from studies about speed behaviour. Both sections types are represented by different geometric values: sections with similar alignment by curvature change rate, transitions by curve radius and predicted speed difference, and independently by road width and ADT.

The SPF requires accurate data of the alignment in order to analyse the geometric properties as described. After the section detection based on the various statistic models the accident rate and accident cost rate is calculated. In final step the safety potential is derived by using basic accident parameters which are a representative average of accident occurrence in the investigation area. If the difference between the predicted accident parameters and the basic accident parameters is above zero an improving potential is available.
The developed SPF is appropriate for the analysis of road networks or parts of road networks. It cannot be applied for single roads. For this kind of analysis other methods are available like safety inspections or safety audits. Concerning ‘classical’ safety analysis the results given by a safety performance function show possible safety potential based on the predictions. Such an analysis is feasible for prevention work. In contrast other safety analysis procedures investigate the existing accident occurrence and therefore they show existing safety potentials. They are appropriate to react on current problems (Figure 5).

![Safety Performance Function vs. Safety Analysis](image)

### 7.4 Accident prediction models (APM) overview

(A comprehensive APM approach, can be found in the Ripcord-Iserest Deliverable D2 – section 3 “Accident prediction models for rural roads).

Accidents prediction models stand for a valuable tool for road safety management, that is the activity aiming at implementing reliable safety procedures.

Of the factors related to road planning, safety is taking on an ever increasing importance. In the past, but even recently, benefits users could be given were basically in terms of travel time decreasing and major travel comfort. But owing to high social costs brought about accident rate, benefits analysis does take into account safety improving actions.

A.P.M. are mainly resorted to for evaluating the will-be effects of actions on accident rate values.
Their working out is quite recent, for, the first models date back to the middle 70s. This shows that prior to that period, safety was not considered in the evaluation of improving effects. From that time on the scientific literature enriched itself with numerous prediction models.

In nearly all models, the road to be modernised undergoes analyses in its geometric configuration and traffic volume. In some models for predicting accident rate near intersections, traffic volume of confluent roads is also surveyed.

For models indicating the pavement maintenance frequency or the use of improving innovative techniques, prediction models will also include variables of the road surface condition.

Moreover, there are models considering operative speeds for single sections or mean speeds for road portion with homogeneous characteristics. Their use will imply speed or travel times recordings.

Even if the models structure and the type of variables may seem so differentiated, the modes they can be used is similar. Once the values of the past situation have been determined, a first accident rate calculation will be effected by means of formulas provided by models.

Then the comparison of calculation results and accident rate data of roads under examination will allow the model calibration. At this stage, calibration coefficient will be determined. These are corrective coefficients of formulas determining accident rate values which are used to consider exogenous variables ignored by the model and diversities between the context models were determined and the one they were applied.

Later, a further accident rate calculation, using the same formulas but corrected by calibration coefficients, will be effected according to variables of the road considered, be this last, a new road to be built or requiring improving actions.

**Prediction models variables**

Prediction models in literature evidence that independent variables used as input belong to the following categories:

1. geometric characteristic of the road
2. road surface conditions
3. composition and traffic volume
4. speed

The major geometric characteristics are:

- lane width
- carriageway width
- shoulder width, paved or unpaved,
roadside hazard rating: RHR. In a scale of value 1 through 7, a score is given according to the road conformation and particular situation on its side. The score 1 refers to the least hazard situation. The score 7 implies the highest accident hazard.

- Degree of curvature (degree/100 ft)
- Length of the stretch considered
- Dangerous curves density in the stretch considered.

Variables in the models indicating the road surface condition are as follows:

- PSI (present serviceability index)
- Skid number at 40 miles per hour
- Time proportion when pavement is wet
- And others

The most considered traffic variable is the annual average daily traffic: AADT, while the only variable considered for composition is trucks.

The operative speed is usually referred to the speed variable (instantaneous on the considered spot). Other models take into account the average speed in the considered stretch. Some model refer to speed standard deviations as well.

Output variables of models can be distinguished in two categories:

- accident density:
  - predicted number of total accidents per year on a particular roadway segment
- accident rate:
  - expressed in acc./10^6 vehicles-miles

Output variables in prediction models besides the whole accidents may also refer to a subset of theirs depending on particular modes:

- estimate of accident rate including all accidents
- estimate of single-vehicle, head-on, opposite-direction sideswipe, and same-direction sideswipe accidents
- estimate of wet accident rate

**Brief description of some prediction models**

The following table shows some models available in literature, with the indication of the independent variables categories in the model and R^2 value.
<table>
<thead>
<tr>
<th>MODEL</th>
<th>Authors/E.</th>
<th>Independent variables categories</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1</td>
<td>Griffin</td>
<td>x x X</td>
<td>0.58</td>
</tr>
<tr>
<td>1/2</td>
<td></td>
<td></td>
<td>1984</td>
</tr>
<tr>
<td>2/1</td>
<td>Griffin</td>
<td>x X</td>
<td>0.456</td>
</tr>
<tr>
<td>2/2</td>
<td>C. V. Zegeer, D. W. Reinfurt, W. W. Hunter, J. Hummer, R. Stewart e L. Herf</td>
<td>x X</td>
<td>0.461</td>
</tr>
<tr>
<td>2/3</td>
<td>Griffin</td>
<td>x X</td>
<td>0.18</td>
</tr>
<tr>
<td>2/4</td>
<td>Griffin</td>
<td>x X</td>
<td>0.19</td>
</tr>
<tr>
<td>2/5</td>
<td>Griffin</td>
<td>x X</td>
<td>0.25</td>
</tr>
<tr>
<td>3/1</td>
<td>R. Lamm, A.K. Guenther e E. M. Choueiri</td>
<td>x</td>
<td>0.33</td>
</tr>
<tr>
<td>3/2</td>
<td>R. Lamm, A.K. Guenther e E. M. Choueiri</td>
<td>x</td>
<td>0.35</td>
</tr>
<tr>
<td>3/3</td>
<td>R. Lamm, A.K. Guenther e E. M. Choueiri</td>
<td>x</td>
<td>0.73</td>
</tr>
<tr>
<td>3/4</td>
<td>R. Lamm, A.K. Guenther e E. M. Choueiri</td>
<td>x</td>
<td>0.30</td>
</tr>
<tr>
<td>4/1</td>
<td>A. Vogt e J. G. Bared</td>
<td>x X</td>
<td>0.655</td>
</tr>
<tr>
<td>5/1</td>
<td>Taylor, A. Baruya and J.V: Kennedy</td>
<td>x X X</td>
<td>0.77</td>
</tr>
<tr>
<td>5/2</td>
<td>Taylor, A. Baruya and J.V: Kennedy</td>
<td>x X X</td>
<td>0.80</td>
</tr>
<tr>
<td>6/1</td>
<td>Bester</td>
<td>x x</td>
<td>0.278</td>
</tr>
<tr>
<td>6/2</td>
<td>Bester</td>
<td>x x</td>
<td>0.224</td>
</tr>
</tbody>
</table>

One can notice that there are mean-low R2 values. However, models including also the speed variable do explain most accidentality. Speed is a variable tightly connected with the human factor. The introduction of such a factor in models is a way of making them more reliable. The following relates to forms for each model in the table.

### MODEL 1 (1984)

<table>
<thead>
<tr>
<th>Authors:</th>
<th>Griffin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contents:</td>
<td>Wallman and Astrom (2001) found that slipperiness had a significant effect on driving speeds – vehicle speeds reduced by as much as 7km/h for slippery surfaces when compared with good driving conditions. They also report models originally presented by Griffin (1984) for high and low-speed roads.</td>
</tr>
</tbody>
</table>
### Formulation:

**1/1**

\[
WAR = -21.7 + 0.0009 \text{ ADT} + 2.34 \text{ ACC} - 0.40 \text{ SN} + 286 \text{ TW} + 1.32 \text{ LN}
\]

where:
- \(WAR\) = wet accident rate [number accidents/mi * year];
- \(\text{ADT}\) = average daily traffic [veh/day];
- \(\text{ACC}\) = access (a standardised subjective scale of roadway congestion) [adimens];
- \(\text{SN}\) = skid number at 40 miles per hour;
- \(\text{TW}\) = proportion of time wet [adimens];
- \(\text{LN}\) = lanes of traffic [adimens].

**\(R^2\):** 0.58

**Observations:** Wet pavement accident per mile per year; for high speed road.

### Formulation:

**1/2**

\[
WAR = -0.75 + 0.0001 \text{ ADT} - 0.053 \text{ VM} + 0.54 \text{ V} + 0.69 \text{ ACC} - 0.025 \text{ SN}
\]

where:
- \(\text{VM}\) = mean traffic speed [km/h];
- \(\text{V}\) = standard deviation of the speed distribution [adimens].

**\(R^2\):** 0.46

**Observations:** Wet pavement accident per mile per year; for low speed road.

### MODEL 2 (1988)

**Authors:** C. V. Zegeer, D. W. Reinfurt, W. W. Hunter, J. Hummer, R. Stewart e L. Herf

**Bibliography:** “Accident effects of slideslopes and other roadside features on two-lane roads” - Transportation Research Record 1195

**Contents:** The purposes of the study were to develop one or more methods for quantifying roadside hazard, define factors that influence run-off-road accidents, and estimate the accident benefits of various roadside improvements.

**Formulation:**

\[
RA/M/Y = 0.0019 (\text{ADT})^{0.8824} (0.8786)^{W} (0.9192)^{PA} (0.9316)^{UP} (1.2365)^{H}
\]
Where:

RA/M/Y = related accidents (single-vehicle, head-on. Opposite-direction sideswipe, and same-direction sideswipe accidents) per-mile, per-year,

W = lane width [feet],

PA = average paved shoulder width [feet],

UP = average unpaved (gravel, stabilized, earth, or grass) shoulder width [feet],

H = median roadside hazard rating [adimens].

TER1 = 1 if flat terrain, zero otherwise, and

TER2 = 1 if mountainous terrain, zero otherwise.

R²:

0.456

Observations:

This model was developed using average roadside recovery distance (RECC) in place of roadside hazard rating.

Formulation:

\[
RA/M/Y = 0.0076 \times (ADT)^{0.8545} \times (0.8867)^W \times (0.8927)^{PA} \times (0.9098)^{UP} \times (0.9715)^{RECC} \times (0.8182)^{TER1} \times (1.2770)^{TER2}
\]

where:

RECC = the average roadside recovery distance as measured from the outside edge of the shoulder [feet]

R²:

0.461

Formulation:

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

where:

AS = single-vehicle accident rate [accidents/ 100 MVM],

SS = median (50th percentile) sideslope measure, where SS=1 if sideslope is 3:1 or steeper, or zero otherwise,

ADT = average daily traffic (50 to 10,000 veh/day),

W = lane width (8 to 13 feet),

PA = average paved shoulder width [feet],

SW = total shoulder width (paved plus unpaved), 0 to 12 in feet,

RECC = median (50th percentile) roadside recovery distance from the
outside edge of the shoulder to the nearest roadside obstacle or hazard (0 to 30 feet)

**Observations:**
This is the resulting model for the single-vehicle accident rate (AS) using two categories of sideslope.

**Formulation:**

\[
AS = 731.16 (0.839)^W (0.99995)^{ADT} (0.975)^{RECC} (0.909)^{SW} (1.373)^{SS1} (1.349)^{SS2} (1.238)^{SS3} (1.164)^{SS4} (1.091)^{SS5}
\]

where:
- SS1 = 1 if sideslope = 2:1 or steeper, or zero otherwise,
- SS2 = 1 if sideslope = 3:1, or zero otherwise,
- SS3 = 1 if sideslope = 4:1, or zero otherwise,
- SS4 = 1 if sideslope = 5:1, or zero otherwise,
- SS5 = 1 if sideslope = 6:1, or zero otherwise.

For slideslope of 7:1 or flatter, the last five terms of the equation would become 1.0.

**Observations:**
This model indicates that the rate of single-vehicle accidents decreases steadily for slideslope categories of 3:1, 4:1, ...to 7:1 or flatter.

**Formulation:**

\[
AR = 129.99 (1.319)^{SS} (0.849)^W (0.983)^{RECC} (0.999984)^{ADT} (0.958)^{SW}
\]

where:
- AR = rollover accidents per 100 million vehicle miles,
- SS = 1 if sideslope is 4:1 or steeper, or zero otherwise.

**Observations:**
In this model the rollover accident rate (AR) is used as the dependent variable.
### MODEL 3 (1995)

<table>
<thead>
<tr>
<th>Authors:</th>
<th>R. Lamm, A.K. Guenther e E. M. Choueiri</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bibliography:</td>
<td>“Safety module for highway geometric design” - Transportation Research Record 1512</td>
</tr>
<tr>
<td>Contents:</td>
<td>Precedent studies of the same authors demonstrated that the most successful parameter in explaining much of the variability of accident rates is the degree of curve.</td>
</tr>
<tr>
<td>Formulation:</td>
<td>Federal Republic of Germany</td>
</tr>
<tr>
<td>3/1</td>
<td>$ACCR^* = -0.29 + 0.37 \text{ DC}$</td>
</tr>
<tr>
<td>where</td>
<td>$ACCR = \text{estimate of accident rate including run-off-the-road (acc./10}^6 \text{ vehicles-miles), only}$</td>
</tr>
<tr>
<td>$\text{DC} = \text{degree of curve (degree/100 ft.) range: 0° to 25°}$</td>
<td>$R^2$: 0.33</td>
</tr>
<tr>
<td>Observations:</td>
<td>Lane width &gt; 11 feet.</td>
</tr>
<tr>
<td>Formulation:</td>
<td>Federal Republic of Germany</td>
</tr>
<tr>
<td>3/2</td>
<td>$ACCR^* = -0.50 + 0.55 \text{ DC}$</td>
</tr>
<tr>
<td>$R^2$:</td>
<td>0.35</td>
</tr>
<tr>
<td>Observations:</td>
<td>Lane width &lt; 11 feet.</td>
</tr>
<tr>
<td>Formulation:</td>
<td>United States of America</td>
</tr>
<tr>
<td>3/3</td>
<td>$ACCR = -0.55 + 1.08 \text{ DC}$</td>
</tr>
<tr>
<td>where</td>
<td>$ACCR = \text{estimate of accident rate including all accidents (acc./10}^6 \text{ vehicles-miles)}$</td>
</tr>
<tr>
<td>$\text{DC} = \text{degree of curve (degree/100 ft.) range: 0° to 25°}$</td>
<td>$R^2$: 0.73</td>
</tr>
</tbody>
</table>
### Observations
- **Observation 1:** Lane width = 12 feet.

### Formulation
- United States of America
  \[ \frac{3}{4} \text{ACCR} = -1.02 + 1.51 \text{DC} \]

- **R²:** 0.30

### Observations
- **Observation 2:** Lane width = 10 feet.

---

### MODEL 4 (1998)

#### Authors:
A. Vogt e J. G. Bared

#### Bibliography:
PUBLICATION NO. FHWA-RD-98-133

#### Contents:
This model was developed with negative binomial regression analysis for data from 619 rural two-lane highway segments in Minnesota and 712 roadway segments in Washington.

#### Formulation:
\[
4/1 
Nbr = \text{EXPO} \exp(0.6409 + 0.1388\text{STATE} - 0.0846\text{LW} - 0.0591\text{SW} + 0.0668\text{RHR} + 0.0084\text{DD}) \left( \prod_{i=1}^{WHi} \exp(0.0450 \text{DEGi}) \right) \left( \prod_{i=1}^{WVi} \exp(0.4652 \text{Vi}) \right) \left( \prod_{i=1}^{WGi} \exp(0.1048 \text{GRi}) \right)
\]

where:
- **Nbr** = predicted number of total accidents per year on a particular roadway segment,
- **EXPO** = exposure in million vehicle-miles of travel per year = \(\text{ADT \times 365 \times L \times 10^{-6}}\),
- **ADT** = average daily traffic volume (veh/day) on roadway segment,
- **L** = length of roadway segment (mi),
- **STATE** = location of roadway segment (0 in Minnesota, 1 in Washington),
- **LW** = lane width (ft), average lane width if two directions of travel differ,
- **SW** = shoulder width (ft), average shoulder width if two directions of travel differ,
- **RHR** = roadside hazard rating (from 1 to 7),
- **DD** = driveway density (driveways per mi) on roadway segment,
- **WHi** = weight factor for the \(i\)th horizontal curve in the roadway segment [adimens] = horizontal curve length/roadway segment length,
DEGi = degree of curvature for the \( i \)th horizontal curve in the roadway segment (degrees per 100 ft),

\[ \text{WV}_j = \text{weight factor for the } j\text{th crest vertical curve in the roadway segment} \]

\[ \text{[adimens] = crest vertical curve length/roadway segment length,} \]

\[ V_j = \text{crest vertical curve grade rate for the } j\text{th crest vertical curve within the roadway segment in percent change in grade per 100 ft} = \frac{|g_{j2} - g_{j1}|}{l_j} = \frac{\text{roadway grades at the beginning and end of the } j\text{th vertical curve (percent)}/}{\text{length of the } j\text{th vertical curve (in hundreds of feet)}} \]

\[ \text{WG}_k = \text{weight factor for the } k\text{th straight grade segment [adimens]} = \]

\[ \text{straight grade length/roadway segment length,} \]

\[ G_{Rk} = \text{absolute value of grade for the } k\text{th straight grade on the segment (}). \]

\[ R^2: \quad 0.655 \]

### MODEL 5 (2002)

**Authors:** Taylor, A. Baruya and J.V. Kennedy

**Bibliography:** TRL Report TRL511

**Contents:** The report describes a more extensive investigation of the relationship between speed and accidents on rural single-carriageway roads in England. The study involved: site selection; the collection and analysis of data from 174 road sections; the application of statistical techniques to group the sections; and statistical modelling to relate accident frequency to factors such as traffic flow, vehicle speed and other characteristics of the road.

**Formulation:**

**5/1 LEVEL 1 MODEL**

\[ AF = (3.281 \times 10^{-7}) \, Q^{0.727} \, L^{1.000} \, V^{2.479} \, G_i \]

where:

- \( AF \) = accidents per year;
- \( Q \) = AADT flow (vehicles per day);
- \( L \) = link length (Km);
- \( V \) = mean speed (miles/hour);
- \( G_i = 1.000 \) for Group 1 (low quality roads)
- \( = 0.539 \) for Group 2 (low than average quality roads)
### Safety Handbook for Secondary Roads

#### Formulation:

**LEVEL 2 MODEL**

\[
AF = \left(3.152 \times 10^{-7}\right) Q^{0.728} L^{1.039} V^{2.431} G_i e^{(0.121 DS + 0.286 DX)}
\]

where:

- \(AF\) = accidents per year;
- \(Q\) = AADT flow (vehicles per day);
- \(L\) = link length (Km);
- \(V\) = mean speed (miles/hour);
- \(G_i\) = 1.000 for Group 1 (low quality roads)
  - = 0.558 for Group 2 (low than average quality roads)
  - = 0.391 for Group 3 (higher than average quality roads)
  - = 0.285 for Group 4 (high quality roads)
- \(DS\) = sharp bend density [adimens];
- \(DX\) = crossroad density [adimens].

#### Observations:

**ROAD QUALITY:**

- **Group 1:** Roads which are very hilly, with a high bend density and low traffic speed. These are low quality roads.
- **Group 2:** Roads with a high access density, above average bend density and below average traffic speed. These are lower than average quality roads.
- **Group 3:** Roads with a high junction density, but below average bend density and hilliness, and above average traffic speed. These are higher than average quality roads.
- **Group 4:** Roads with a low density of bends, junctions and accesses and a high traffic speed. These are high quality roads.
### MODEL 6 (2003)

<table>
<thead>
<tr>
<th>Authors:</th>
<th>Bester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bibliography:</td>
<td>&quot;The effect of road roughness on safety&quot;, TRB 2003 Annual Meeting</td>
</tr>
<tr>
<td>Contents:</td>
<td>A South African study (Bester, 2003) found that a road surface’s Present Serviceability Index (PSI), which is a measure of ride quality or road roughness, and pavement width, affect accident rates</td>
</tr>
<tr>
<td>Formulation:</td>
<td></td>
</tr>
</tbody>
</table>

\[
6/1 \quad TOT = -0.295 - 0.12 \text{showid}^2 + 0.71 \text{topog}^2 + 0.933 \text{psi} - 0.648 \text{topog} \times \text{psi}
\]

where:

- TOT = total accident rate [accidents/MV*Km];
- showid = shoulder width [m];
- topog = 1 for flat terrain, 2 for rolling, 3 for mountainous;
- psi = present serviceability index [adimens].

\[ R^2: 0.278 \]

| Formulation: |  

\[
6/2 \quad SIN = 0.275 - 0.055 \text{showid}^2 + 0.41 \text{topog}^2 + 0.70 \text{psi} - 0.0496 \text{pavwid} - 0.43 \text{topog} \times \text{psi}
\]

where:

- TOT = single vehicle accident rate [accidents/MV*Km];
- showid = shoulder width (m);
- topog = 1 for flat terrain, 2 for rolling, 3 for mountainous;
- psi = present serviceability index [adimens];
- pavwid = total paved width (m).

\[ R^2: 0.224 \]
Prediction models calibration

Models include a wide range of variables under examination. One can also notice that each model has a limited number of variables compared to the possible ones. In general the lower the number of ignored variables the higher is the performance of the prediction model. Ignored variables represent variables out of the model. Some of these variables can be easily recognised because are used in other models but do not appear in the model under consideration.

Moreover, there are other variables which are ignored in all models present in literature.

For, no model include variables concerning:

- climate (except for Griffin’s model where accidentality is calculated in wet pavement conditions)
- visibility (night darkness, daily dazzling, mist, fog)
- local people’s habits
- travel aims
- presence of pedestrians, cyclists, and animals on the carriageway
- age of the fleet of vehicles and others.

These variables are to be considered out of the whole set of models worked out so far.

The construction of prediction models taking also into account such variables is extremely laborious if not impossible.

In other cases the poor performance of prediction models is due to differences in data collection modes. At times output variables in prediction models do not match accident data registered on roads under investigation. This is the very case of the Italian situation where since 1991 serious accidents only (with dead and/or wound) were registered on highways, leaving apart accidents with only damage to things.

In order to consider both the ignored effects caused by variables external to the single model or the whole set of models, and distortions in data collection, it is necessary that the accident rate calculation by mathematical formulas, be followed by calibration.

Assumed:

- \( \text{NC}_{ij} \) the number of accidents predicted by models for the spot “\( i \)” of the road (or of the regional network) under investigation and the time (elapsed) “\( j \)”.
- \( \text{NO}_{ij} \) the number of accidents registered at the same spot “\( i \)” and same time “\( i \)”,

by the relation:
\[ NO_{ij} = C_{ij} NC_{ij} \]

It is possible to calculate \( C_{ij} \).

Mean values \( E(C_{ij}) \) for each “i” and “j” considered are the calibration coefficients to the road (or for the regional network) under investigation.

The predictable number of accidents on the spot “r” of the road (or of the regional network) and over the time (future) “s” will be given by:

\[ N_{rs} = E(C_{ij}) NC_{rs} \]

The above procedure is the simplest calibration model. Other procedures require the categorisation of some variables and for each category resulting from the calibration coefficient determination. Some more variables require the construction of regression lines of coefficients depending on some variables.

In short, calibration allows it to globally consider ignored effects correlated to unconsidered variables, and to adjust distortions caused by data collection differences.

**Prediction models choice**

The authority that in the first stage of the road improvement for major safety needs to predict accidents both in the current situation and the design one, faces a great variety of APM models. The choice of the model to be used will be the most reliable one, that is the one providing a better matching between calculated values and observed values. Of course, the comparison will be effected according to data in the past.

The first stage of choice will imply the investigation of:

- Geometric characteristics of the road section
- Traffic travelling on the road
- Pavement condition
- Speeds (average or punctual).

A first selection of models will be effected according to these estimations.

Models whose formulation include the most significant variables for the type of road and the particular situation to be analysed, will be preferred.

Variables considered being equal, one will choose models with higher value of the determination coefficient \( R^2 \) that measures the variations proportion owing to
independent variables influence, compared to the total amount of deviations $R^2$. It is therefore, a reliable model in both explaining phenomena and predicting events.

Following to the model selection, it will be applied by calculating the accidents number. Later calibration will take place. Calibration coefficients, which represent the ratio between observed values and theoretical values calculated, will make the model more reliable as well. The more their value is close to the unit, the higher the model flexibility in describing the situation and predicting the events. The calibration coefficient value may stray from the unit, even if a model with a high $R^2$ value reported in literature has been used. This happens when the model was constructed in a context and reality other than those investigated. In this case exogenous variables influence plays a paramount role. The model will be rejected and then, of those available single out a different one providing a calibration coefficient value closer to the unit.

**APM Limits**

A first limit of prediction models relates to the fact that it is a mathematical model, then it needs to simplify the complex of relations leaving apart some variables (exogenous variables). Usually, less significant variables are left out. That is those with lesser influence on the dependent variable value. But at times, some variables are neglected because they are difficult to be measured or statistically determined.

Limitations in using APM may depend on:

- calibration difficulty
- poor explanation of accidentality.

Calibration difficulties may derive from the following circumstances:

- data collected and results of calculations are not homogeneous. This is the Italian situation where the number of localised accidents the statistics national Board took a census of, considers only accidents with damage to things (with no dead and/or wound). To apply the prediction model, it is necessary to determine the total accidents number by resorting to other statistical sources such as data from insurance companies on the ratio number of accidents with damage only to things, and total number.

- Many accidents are not accurately localised. In highways it is indicated the kilometre stretch where the accident took place. But this datum does not suffice to classify the accidents among those occurred on a curve or a straight or near a junction.

- Difficulties in applying the model come from the lack of data of independent variables to be considered as input variables. Geometric characteristics are
generally known for main roads, where the cross section is uniform for long stretches. On secondary roads, in most cases, cross section dimensions keep uniform only for short stretches, they vary according to the terrain orography and/or the construction or restoration period.

- Owing to the lack of a road cadastre it is difficult to trace back to cross dimension values for each road section. It is also difficult to trace back to the planimetric curvature radii. The only way to determine them is to have access to the project longitudinal profile.

- Other difficulties arise from the traffic data collection. In Italy, at present, on highways the census sections are too far one from the other, hence along whole stretches the traffic between two important road junctions with intersections and busy travelling is unknown. To assign a capacity value the only way is the application of the network equilibrium models. Secondary roads have a more unstable situation. Traffic investigation is carried out by local road authorities by special recordings.

Said difficulties in retrieving data do increase the error possibility in estimating the context where the accident takes place, thus making the prediction model less reliable.

Another APM limit is the poor capacity to explain accident rate in certain circumstances.

One experienced that when ADT values are below 1500÷1800 vehic/day and accidents per kilometre does not exceed 1÷2 accidents every 5 years prediction models relations cannot be applied. In fact, in these cases $R^2$ has mean-low values and accidents assessment carried out “ex post” are not correlated to the model theoretical results. This occurs basically because for moderate accident numbers, random and the human behaviour play a major role, so causes due to geometric conformation and environmental conditions evaluated in models, take second place.

Actions for higher APM reliability

The prediction model limits investigation makes up the base to improve their use.

First the need for improving accident data collection:

- Outputs of prediction models in the international literature are composed of the number of total accidents. In countries like Italy where only serious accidents data are collected (with dead and/or wound), one should extend data collection to accidents with damage to things only. This will enable a homogeneous comparison between the number of accidents observed and the number of the accidents calculated.
The accident should be located on the road in a more accurate way. The indication of the kilometric stretch is not enough. One should add also the number of hectometres. GPS use can help space location.

The accident time and day, how it happened (head-on, run-off, pedestrian running down a.s.o.) the seriousness (number of involved vehicles, number of the dead and the wound) climate and visibility conditions should be systematically specified. The registration method should be the same among the different police bodies in charge of the road surveillance.

A further step relates to road geometry and traffic data collection.

Italy started to organise its own road cadastre. Once this job is accomplished, it will account for a good instrument to estimate and predict accidentality.

Traffic data should be collected at closer range, so that each network section, between two road junctions O-D or intersections, could be assign a capacity value

A final series of measures concerns the model structure improvement. One noticed that models with higher R2 include speed as independent variable (Taylor et al., 2002). Speed is one of the few variables (but the only one) connected with the human factor and easy to be measured at the same time. Then, models already including this variable are to preferred.

Hence, researchers are expected to introduce speed among independent variables to upgrade future models.
7.5 Expert System Overview

SEROES, the Secondary ROads Expert System, offers to the registered user measures to improve secondary roads (paved rural roads) safety.

Most road safety measures are known to have a positive effect on accident reduction. Due to interactions with the surroundings, other road users or other elements of the road some measures don’t have any effect on safety or their effect is even negative.

To find out which measures are more effective in accident reduction or accident severity reduction investigators in Europe and all over the world have conducted statistical analyses on different measures.

This knowledge is summarised in the “Handbook of Road Safety Measures” by Rune Elvik and Truls Vaa, which gives a systematic overview of the current knowledge concerning road safety measures and their effect.

SEROES was developed based on Elviks and Vaas work. It is further based on the D 9.1 report of the RIPCORD-ISEREST project, which deals primary with studies that relate road safety relevant elements in a quantitative way with accident occurrence but mentions also other research work which describes this relation in a rather qualitative manner.

The software is directed to road authorities and administrators responsible for (secondary) roads infrastructure and is thought to serve as a base of decision making.

The system could be especially useful for small and medium road administrations of European countries, with limited financial possibilities and a lack of detailed accident data.

To work with SEROES the user only needs to describe an existing road safety problem in terms of incident site, accident type and cause of the accidents using pull-down menus and afterwards study the offered measures regarding their effect and costs. The application can be found under www.seroes.com and www.seroes.eu.
The following figure shows interactions between SEROES and Road Authorities.

**ROAD AUTHORITIES**

**Incidentality analysis**
- Incidentality data analysis of the single infrastructure or of the Road network
- Localization of Black spot or stretch with high accident density and choice of action priority
- Determination of the accident types to tackle at each critical point
- Determination of the accident causes

**Determination of the possible safety measures**
- Description of the measure
- Effects on incidentality
- Intervention cost

**Evaluation and choice of proposed safety measures**
- Benefit-cost or multicriteria analyses
- Choice of safety measure to be adopted
- Operational planning to implement adopted measures

**Implementation of safety measure**
- Analysis of the real implementation cost

**Accomplished safety measures monitoring**
- Analysis in terms of rate variation on incidentality

Figure 6: Interactions Road Authorities and SEROES
How to start with SEROES

SEROES can be used without much experience in road safety and the collecting and processing of data necessary for a deeper analysis. The first steps are described below.

1. To begin the user has to visit one of the above mentioned web-pages; afterwards the first step is to open an account. To do that the Request a user option within the Options menu has to be called.

2. Once the registration form has been filled in and the confirmation about the activation of the account, the user name and the password has been received the new user can sign in.

3. Information about the product, the partners, the project etc. can be found in the options menu.

4. To actually start SEROES the Expert System Access option within the Seroes menu has to be called.

5. If any problems arise during the registration process the Help option can be used (PDF) or an email to the administrator can be written.
Structure and Functioning

The application is structured into various menus for users and an additional menu for administrators. The additional administrator tool will be described further down. The most important menus are Options and Seroes.

Options is an informational menu. Under Options the user can find any kind of information regarding the partners that participated in the development, the RIPCORD-ISEREST project partners, the application, related products, the registration form etc.

Under Seroes the actually access to the application can be found. The application SEROES can be subdivided into two main blocks: The Input and the Output.

**Input:** The user has to describe the road safety problem he would like to solve. This description has to be carried out within 3 steps. In every step it has to been chosen between various options. Depending on the characteristic feature chosen in the previous step, the options in the next step are limited so that only logical sequences are eligible. The sequence of 3 steps goes:

- **Incident Site:***
- **Accident Type:***
- **Cause:**

![Figure 8: Example for Input](image-url)
Output: Once the Input is finished the application offers one or several measures as a solution. For each of the measures the following information will be provided:

- Objective
- Description
- Effect on accidents (sign means accident reduction, sign means accident increase)
- Cost Range (€/Km)
- Get Information

In most cases the user can additionally choose between the effects on different types or severities of the accidents. All information is stored in a database, which is expandable and can be modified.

![Figure 9: Example for Output](image-url)

Administrator tool

SEROES has an additional menu for administrators. Within this menu are the subsequent options which allow the administrator(s) to modify the content of the database and to govern users:

- Scene Definition
- Incident Site
Scene Definition

The centre-piece of the administrator tool is the scene definition menu item where the administrator can define new proceedings (scenes) by connecting a new set consisting of an incident site, an accident type, a cause and a measure from the database and thus enlarge the system.

Incident Site

At present there are three different incident sites to choose from. In case it appears appropriate to add other incident sites, this can be done by using this part of the administrator tool. Subsequently the new incident site can be connected within the scene definition menu with the other components.

Accident Type

Currently there are several different accident types defined. Within the accident type menu item new accident types can be added and accident types that are not anymore in use can be deleted. Within the scene definition menu the new accident types can be connected with the other components.

Cause

The same way as before new causes of accidents can be added. A number of accident causes is already defined. By using the cause menu item the administrator(s) can easily add new causes and connect them subsequently to other the components.

Measures

Each measure is composed of a Name, an Objective of the measure, a Description of the measure, a Type of accident affected, a Best Estimate for the accident reduction potential, a Confidence interval for this reduction potential, a statement if the best estimate is statistically significant or not and a Cost Range.
To define a new measure the first step is to fill in the text in the name, objective and description fields.

In the second step a type of accident affected has to be chosen from a pull-down menu, subsequently the numbers for Best Estimate and Confidence Interval have to be filled in. Afterwards the administrator has to choose Yes or Not from another pull-down menu for the Significance and finally fill in the Cost Range. Additional information regarding the measure can be provided in a separate field.

The second step can be repeated for another type of accident affected by the same measure to differentiate for example between the effects of the measure on injury accidents and property damage only accidents.

**Type of accident affected**

Using the same procedure as in incident site, accident type, a cause the list of possible types of accidents affected by a measure can be expanded or reduced too. Subsequently the new type of accidents affected can be used within the measures menu item to describe the effect of a measure on this new type of accident affected.

**Users**

The user menu item provides an easy tool to administer the users. Users can be registered to the system, deleted from the system or their user data can be modified.

**Library of documents**

With this tool the administrator(s) can upload documents which afterwards are visible to all users.
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A-3.2 Solution examples

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Annex B Backgrounds: existing road safety handbooks, manuals, instructions and recommendations

B.1 José Maria Pardillo Mayora

B.2 Rune Elvik and Truls Vaa

B.3 C.R.O.W. Handbook Road Design


B.5 Tasmanian Department of Infrastructure

B.6 Forschungsgesellschaft für Straßen- und Verkehrswesen

B.7 PIARC Road Safety Manual

B.8 US Highway Safety Manual - Two-lane highways prototype chapter

B.9 World Bank - Safe Road Design - A Practical Manual

B.10 EURO-RAP and its documents

B.11 Fuller, R., & Santos, J. A. Human Factors for Highway Engineers

B.12 Decision Support Safety Tool (DST) - Overview
ANNEX A: The problems confronted on the two-lane roads and the general applications for the solutions in Turkey

A-1-Situation of the Highway Network in Turkey

General Directorate of Highways is responsible for the motorways, State and Provincial Roads, whereas, Municipalities are in charge of inner city roads and Provincial Special Administrations are responsible for the village roads in Turkey. As of January 1st 2006, the road length under the responsibility of General Directorate of Highways is 31.371 km as State Roads and 30.568 km as Provincial Roads, if we add 1.775 km as motorways into the figure then our total road network reaches to 63.714 km. The length of the dual carriage ways totals to 10.286 km of which 1.775 km as motorways, 7.917 km as State Roads, 594 km as Provincial Roads.

A-2- Accident Data

A-2.1. Dead, injured and materially damaged car according to the results of traffic accidents (between 2001-2005)

<table>
<thead>
<tr>
<th></th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>WITH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FATALITIES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of</td>
<td>3 487</td>
<td>3 387</td>
<td>3 093</td>
<td>3 446</td>
<td>3 600</td>
</tr>
<tr>
<td>Accidents</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of</td>
<td>4 386</td>
<td>4 169</td>
<td>3 966</td>
<td>4 428</td>
<td>4 525</td>
</tr>
<tr>
<td>Dead</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| WITH INJURY |      |      |      |      |      |
| Number of   | 62 991| 62 463| 64 042| 73 600| 83 788|
| Accidents   |      |      |      |      |      |
| Number of   | 116 202| 116 045| 117 268| 136 229| 154 094|
| Injured     |      |      |      |      |      |

MATERIALLY DAMAGED

| Number of Accidents | 376 482| 374 108| 388 532| 460 338| 533 795|
| Amount of Damage in YTL | 271.409.766| 322.412.230| 535.208.719| 747.921.168| 1.006.146.641|

Total figures (General Directorate Of Security + Gendarme)

(*) This figures include only victims at-accident site, numbers belong to hospitalization and within 30 days are missing.

A-2.2. (divided and undivided roads) Dual carriageway way and single-carriageway roads (km and %)
BREAKDOWN OF THE ROADS

- SINGLE CARRIAGEWAY ROADS
  - 53,428
  - 84%

- MOTORWAYS
  - 1,775
  - 3%

- DUAL CARRIAGE WAYS
  - 8,511
  - 13%
A-2.3. - The accident types and the rates according to the occurrence forms of the traffic accidents with dead and injury (between 2001-2005)

<table>
<thead>
<tr>
<th>Incident Type</th>
<th>2001</th>
<th>RATE (%)</th>
<th>2002</th>
<th>RATE (%)</th>
<th>2003</th>
<th>RATE (%)</th>
<th>2004</th>
<th>RATE (%)</th>
<th>2005</th>
<th>RATE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIDEWISE COLLISION</td>
<td>13.958</td>
<td>22,02</td>
<td>14.296</td>
<td>22,67</td>
<td>14676</td>
<td>24,71</td>
<td>17 168</td>
<td>26,06</td>
<td>20 414</td>
<td>26,42</td>
</tr>
<tr>
<td>COLLISION TO PEDESTRIAN</td>
<td>14.554</td>
<td>22,96</td>
<td>14.491</td>
<td>23,00</td>
<td>14105</td>
<td>23,75</td>
<td>15.143</td>
<td>22,40</td>
<td>16 098</td>
<td>20,83</td>
</tr>
<tr>
<td>RUN-OFF</td>
<td>9.389</td>
<td>14,81</td>
<td>9.237</td>
<td>14,67</td>
<td>7104</td>
<td>11,96</td>
<td>8.530</td>
<td>12,62</td>
<td>9 771</td>
<td>12,64</td>
</tr>
<tr>
<td>REAR-END COLLISION</td>
<td>5.042</td>
<td>7,97</td>
<td>5.501</td>
<td>8,73</td>
<td>5702</td>
<td>9,60</td>
<td>6.628</td>
<td>9,81</td>
<td>7 921</td>
<td>10,25</td>
</tr>
<tr>
<td>OVERTURN</td>
<td>7.073</td>
<td>11,16</td>
<td>6.763</td>
<td>10,74</td>
<td>5109</td>
<td>8,60</td>
<td>6.068</td>
<td>8,98</td>
<td>7 198</td>
<td>9,32</td>
</tr>
<tr>
<td>COLLISION TO FIXED OBJECT</td>
<td>5.473</td>
<td>8,64</td>
<td>5.345</td>
<td>8,48</td>
<td>5011</td>
<td>8,44</td>
<td>5.519</td>
<td>8,17</td>
<td>6 377</td>
<td>8,25</td>
</tr>
<tr>
<td>HEAD-ON COLLISION</td>
<td>5.250</td>
<td>8,28</td>
<td>4.714</td>
<td>7,48</td>
<td>4894</td>
<td>8,24</td>
<td>5.125</td>
<td>7,58</td>
<td>5 888</td>
<td>7,62</td>
</tr>
<tr>
<td>COLLISION TO IMMOBILE VEHICLE</td>
<td>1.991</td>
<td>3,14</td>
<td>2.056</td>
<td>3,26</td>
<td>2003</td>
<td>3,37</td>
<td>2.161</td>
<td>3,20</td>
<td>2 635</td>
<td>3,41</td>
</tr>
<tr>
<td>MAN FALLING FROM THE VEHICLE</td>
<td>358</td>
<td>0,56</td>
<td>363</td>
<td>0,58</td>
<td>365</td>
<td>0,61</td>
<td>412</td>
<td>0,61</td>
<td>481</td>
<td>0,62</td>
</tr>
<tr>
<td>COLLISION TO ANIMAL</td>
<td>230</td>
<td>0,36</td>
<td>190</td>
<td>0,30</td>
<td>355</td>
<td>0,60</td>
<td>337</td>
<td>0,50</td>
<td>415</td>
<td>0,54</td>
</tr>
<tr>
<td>SUBSTANCE FALLING FROM THE VEHICLE</td>
<td>63</td>
<td>0,10</td>
<td>54</td>
<td>0,09</td>
<td>70</td>
<td>0,12</td>
<td>52</td>
<td>0,08</td>
<td>74</td>
<td>0,10</td>
</tr>
<tr>
<td>TOTAL</td>
<td>63.381</td>
<td>100,00</td>
<td>63.010</td>
<td>100,00</td>
<td>59394</td>
<td>100,00</td>
<td>67.593</td>
<td>100,00</td>
<td>77 272</td>
<td>100,00</td>
</tr>
</tbody>
</table>

When taken into consideration according to the occurrence of the accident:
Sidewise strikes and collisions occupy the first place. This indicates the existence of the geometrical problems on the junctions and the violation of the right of way on the junctions.

Second place goes to the collisions to the pedestrians. This is due to the insufficiency of the security measures and due to the lack of necessary respect of the drivers and pedestrians for the rules.

Excessive velocities of the vehicles are the causes of the other run-off, rear collisions, overturning.

Reduced speed of the heavy vehicles on the two-lane roads leads to the accumulation of the vehicles and to the accidents due to the changing of the lane (violation of the lane) of the impatient drivers. (Turkey has about up to 50 % heavy percentage on the main road corridors.)
A-2.4.- Accident Types and rates of the accidents with fatalities and injuries according to the geometrical particularities of the roads (between 2001-2005)

<table>
<thead>
<tr>
<th></th>
<th>2001</th>
<th>RATE (%)</th>
<th>2002</th>
<th>RATE (%)</th>
<th>2003</th>
<th>RATE (%)</th>
<th>2004</th>
<th>RATE (%)</th>
<th>2005</th>
<th>RATE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STRAIGHT ROAD</td>
<td>47.009</td>
<td>85</td>
<td>46.815</td>
<td>85</td>
<td>48.279</td>
<td>86</td>
<td>54.721</td>
<td>86</td>
<td>61.496</td>
<td>85</td>
</tr>
<tr>
<td>HORIZONTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WITH CURVE</td>
<td>8.151</td>
<td>14</td>
<td>7.931</td>
<td>14</td>
<td>7854</td>
<td>13</td>
<td>8.910</td>
<td>14</td>
<td>10.813</td>
<td>14</td>
</tr>
<tr>
<td>WITHOUT SLOPE</td>
<td>41.715</td>
<td>75</td>
<td>40.828</td>
<td>74</td>
<td>42.493</td>
<td>75</td>
<td>47.596</td>
<td>74</td>
<td>53.903</td>
<td>74</td>
</tr>
<tr>
<td>VERTICAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JUNCTION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>YES</td>
<td>17.681</td>
<td>32</td>
<td>19.208</td>
<td>35</td>
<td>19.246</td>
<td>34</td>
<td>22.760</td>
<td>35.5</td>
<td>26.848</td>
<td>37</td>
</tr>
<tr>
<td>NO</td>
<td>37.479</td>
<td>67</td>
<td>35.538</td>
<td>64</td>
<td>36.887</td>
<td>65</td>
<td>40.871</td>
<td>64</td>
<td>45.461</td>
<td>62</td>
</tr>
</tbody>
</table>

In the breakdown of the accident figures according to the road geometry; it can be considered that it is necessary to take measures for reducing the speed because the favourability of the road geometry causes speed acceleration on the straight road without slope.
### Motorized vehicle numbers according to the years (BETWEEN 2001-2005)

<table>
<thead>
<tr>
<th>Year</th>
<th>Total</th>
<th>Car</th>
<th>Minibus</th>
<th>Bus</th>
<th>Lorry</th>
<th>Truck</th>
<th>Motorbike</th>
<th>Special Purpose Vehicles</th>
<th>Tractor</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>8 521</td>
<td>4 534</td>
<td>239 381</td>
<td>119 306</td>
<td>833 175</td>
<td>562 063</td>
<td>1 031 221</td>
<td>22 939 1 179 068</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>956</td>
<td>803</td>
<td>241 700</td>
<td>120 097</td>
<td>875 381</td>
<td>567 152</td>
<td>1 046 907</td>
<td>23 666 1 180 127</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>8 655</td>
<td>4 600</td>
<td>245 394</td>
<td>123 500</td>
<td>973 457</td>
<td>579 010</td>
<td>1 073 415</td>
<td>24 468 1 184 256</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1 70</td>
<td>140</td>
<td>343</td>
<td>239 381</td>
<td>119 306</td>
<td>833 175</td>
<td>562 063</td>
<td>1 031 221</td>
<td>22 939 1 179 068</td>
</tr>
<tr>
<td>3</td>
<td>843</td>
<td>343</td>
<td>241 700</td>
<td>120 097</td>
<td>875 381</td>
<td>567 152</td>
<td>1 046 907</td>
<td>23 666 1 180 127</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>10 236</td>
<td>5 400 714</td>
<td>318 957</td>
<td>152 380</td>
<td>1 260 009</td>
<td>647 295</td>
<td>1 218 710</td>
<td>27 979 1 210 314</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>358</td>
<td>11 145</td>
<td>5 772 745</td>
<td>338 539</td>
<td>163 390</td>
<td>1 475 057</td>
<td>676 929</td>
<td>1 441 066</td>
<td>30 333 1 247 767</td>
</tr>
</tbody>
</table>

1. Field vehicles are included.
2. It contains load vehicles with heavy tonnage such as trailers, scavenger trucks, towing machines.
3. Figures are as of the end of December 2005. TÜİK,
A-3-Solutions

A-3.1. The places of the accident black spots
A-3.2 Solution examples

Accident Black Spots determined theoretically by 'Rate-Quality Control' are reinserted, ascertained on the site. Accident information belonging to the spot is compiled. 'Collusion diagram's' showing the accident occurrence types are prepared. Photos are taken. Project and surveys are conducted. Benefit and cost calculations are carried out for countermeasures. For every spot an economic and an ideal solution are tried to be advised. Some examples of improvement on two-lane roads commonly used in Turkey can be listed as follows;

1- Construction of double carriageway,
2- Construction of climbing lane,
3- Improvement of horizontal curves (increasing the curve radius),
4- Construction of additional lane or shoulders on the horizontal curves,
5- Improvement of Junctions (traffic islands / signalization),
6- Construction of additional lane at bus-stop,
7- Installation of guardrail on mountainous areas or roadside safety.

A-3.3 Accident decrease factors and cost/benefit analysis

Cost/ Benefit Analysis is carried out on the bases of traffic accident reduction effect of the proposal projects. The accident reduction rates of various road safety improvements are given in the following Table;

<table>
<thead>
<tr>
<th>TYPE OF WORK</th>
<th>ACC. REDUCTION FACTORS (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flyover Junction</td>
<td>64</td>
</tr>
<tr>
<td>Double carriageway cons.</td>
<td>40</td>
</tr>
<tr>
<td>Junction construction</td>
<td>48</td>
</tr>
<tr>
<td>Construction of Climbing lane</td>
<td>44</td>
</tr>
<tr>
<td>Signalization</td>
<td>44</td>
</tr>
<tr>
<td>Guardrail</td>
<td>36</td>
</tr>
<tr>
<td>Flashing signal</td>
<td>32</td>
</tr>
<tr>
<td>Overpass</td>
<td>16</td>
</tr>
<tr>
<td>Structures</td>
<td>20</td>
</tr>
<tr>
<td>Lay-by</td>
<td>24</td>
</tr>
</tbody>
</table>
These figures are not depended upon the long-term implementations of work under Turkish condition, but they are rather adaptation of some International studies.

Economic evaluation can be realized by making comparison between the streams of benefits and costs. Costs come through rehabilitation of black spots and benefits arise from decrease in the number of accidents, fatalities, and injuries.

Accident benefits are the decrease in the average repair costs of materially damaged vehicle, the number of deaths and injuries when the current road is rehabilitated.

**Evaluation of Material Damages:** In Turkey the repair cost of the materially damaged car is obtained from General Directorate of Security.

**Evaluation of Personal Damages:** The below mentioned articles are considered for benefits obtained by the decrease in the number of deaths and injuries:

Deaths and injuries are considered as decrease in production due to loss of labour. Loss of labour in work is considered as the bases on the annual average national income per capita.

An approximate of 35 years loss in labour force is assumed in case of a death. Calculation of loss of labour cost in case of death is considered as the multiplication of work labour loss of 35 years by annual work labour value.

In the calculation of the labour force loss for the injured, it is assumed that the 40 per cent of the total injured number will not be able to work 1 month, 30 per cent- 3 months, 20 per cent- 6 months, and the rest will not be able to work forever.

After the determination of benefits that arise from decrease, accidents, fatalities, and injuries, costs and benefits are evaluated for a period of 20 years with a discount rate of 8%. General economic evaluation methods (IRR, NPV, and B/C) are used in these studies.

**A-3.4. Safety audit in the recommended projects**

For the existing roads and the roads which are planned to be constructed, General Directorate of Highways has prepared ‘HIGHWAYS TRAFFIC SAFETY AUDİT MANUAL’ based upon ‘DESİGN MANUAL’ and its applications have been started in 2006.
A-3.5. Assessment of the improved accident black spots

Under the KITGI project (Highways Improvement and Traffic Safety) financed by the World Bank and begun to be implementing in 1997, 317 accident black spots have been improved. 30 Million USD as external resource and 12 Million USD as internal resource have been used. Additionally, resource has been obtained from the national budget for the improvement of black spots. After the finishing of the funds ensured from the World Bank, improvements are still carried out with the funds from National Budget. Economical analysis related to the improvement of the accident black spots are conducted. The Table for the improvement of the said spots are given below:

<table>
<thead>
<tr>
<th>NAME OF THE WORK</th>
<th>NUMBER OF SPOTS</th>
<th>TOTAL COST IN USD</th>
<th>RATE OF DECREASE</th>
<th>BENEFIT / COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>JUNCTION ARRANGEMENT</td>
<td>74</td>
<td>9.558.858</td>
<td>75</td>
<td>4.59</td>
</tr>
<tr>
<td>JUNCTION ARRANGEMENT &amp;</td>
<td>15</td>
<td>981.039</td>
<td>23</td>
<td>1.33</td>
</tr>
<tr>
<td>SIGNALIZATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CURVE IMPROVEMENT</td>
<td>20</td>
<td>1.774.292</td>
<td>95</td>
<td>2.63</td>
</tr>
<tr>
<td>BRIDGE IMPROVEMENT</td>
<td>1</td>
<td>78.759</td>
<td>88</td>
<td>9.28</td>
</tr>
<tr>
<td>CONSTRUCTION OF DUAL</td>
<td>7</td>
<td>1.282.079</td>
<td>77</td>
<td>2.4</td>
</tr>
<tr>
<td>CARRIAGeways</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLIMBING LANE CONSTRUCTION</td>
<td>6</td>
<td>924.001</td>
<td>68</td>
<td>2.21</td>
</tr>
<tr>
<td>CONSTRUCTION OF UNDERPASS AND OVERPASS</td>
<td>12</td>
<td>506.038</td>
<td>66</td>
<td>8.31</td>
</tr>
<tr>
<td>INSTALLATION OF SIGNALIZATION</td>
<td>44</td>
<td>1.010.328</td>
<td>72</td>
<td>16.32</td>
</tr>
<tr>
<td>GUARDRAIL INSTALLATION</td>
<td>22</td>
<td>1.570.412</td>
<td>81</td>
<td>17.98</td>
</tr>
<tr>
<td>TOTAL</td>
<td>201</td>
<td>17.685.806</td>
<td>75</td>
<td>5.92</td>
</tr>
</tbody>
</table>
The above results of 201 black spots are belong to the KITGI Project. It was a country-wide (5Years) black spot rehabilitation project which originally include 317 black spots. The above table is going to be revised soon by taking all the points follow-up into accounts.
ANNEX B Backgrounds: existing road safety handbooks, manuals, instructions and recommendations

B.1 José Maria Pardillo Mayora:
“Procedimientos de estudio, diseño y gestión de medidas de seguridad vial en las infraestructuras” (Procedures of analysis, design and management of road safety measures in infrastructures), Madrid, 2004

Summary

The book consists of 22 chapters that are structured into four parts:

- Basic concepts
- Safety improvements of existing roads
- Road safety in new road projects
- Road safety in planning

In “Basic concepts” the author introduces the reader into the field of traffic accidents and describes methods to estimate the economic damage done by them. It is explained how road user, vehicle, infrastructure and road environment as well as weather conditions influence in accident occurrence.

The second part “Safety improvements of existing roads” concentrates on programs in road safety improvement and their planning and realisation. It is described how to get relevant information (not only accident data, but also road geometry data, data about police penalties and similar), how to administer it (databases) and statistical methods of their interpretation and evaluation. Further chapters are dedicated to the treatment of high accident concentration locations, preventive measures to reduce accident frequency and severity and adverse weather conditions. Finally one can find advice how to control and evaluate the efficacy of the measures carried out.

How appropriate design influences in road safety is described in the third part of the book. The writer depicts the importance of characteristics such as design speed, geometrical elements, sight distances, traffic signs, road environment and so on and lays special emphasis on the channelling of pedestrian and cyclist flows. Road safety audits on new road projects are described as an important instrument in the planning period. Furthermore is explained what a special road safety annex should include. This part ends with a chapter about the revision of road safety relevant elements by computing means, above all the IHSDM. (Interactive Highway Safety Design Manual)
The last part is dedicated to general terms of road network planning and their impact on road safety. This includes as well urbanism and functional classification of the road network as access control. The last chapter deals with sustainable road safety.

**Conclusions**

The book is kept quite general and might be dedicated to a relatively broad audience. The author covers almost all subject areas regarding road safety, giving an overview of the treated themes, entering in some of the topics deeper.

Both, the author and his book seem to have a rather academic background and consequently this work gives the impression of an introduction in road safety directed to students or persons without or with little knowledge in the road safety field. But exactly this broad topical area makes it interesting for every “expert” too, since the book treats all important fields of road safety and for some possible problems are given practical example solutions. New approaches to analyze road safety as e.g. the integration of the revision of road safety relevant elements during the design process by computing means are also included.

**Measures regarding secondary road safety**

- Analysis of accident concentration stretches and preventive measures
- Alignment, cross-section, signposting, roadsides, intersections, access control, pavement, measures against fatigue…
- Road safety improvement with adverse weather conditions, in new projects, for pedestrians and cyclists…
Summary

The Handbook of road safety measures is composed of 4 parts:

- Part I: Introduction
- Part II: General-Purpose Policy Instruments
- Part III: Specific Traffic Safety Measures
- Part IV: Vocabulary and Index

In the introduction the authors explain the purpose of the handbook and its structure. Then they describe the systematic of the literature search, the classification of the studies and the functioning of meta-analysis – a method used to summarise and weight the results of studies. The writers give an overview of the factors contributing in road accidents and of the basic concepts in road safety research. Finally the authors depict how to assess the quality of an evaluation study and which influence or contribution has research in road safety policy-making.

In general-purpose policy instruments a distinction is made between 14 types of measures. The measures stretch from exposure control over urban and regional planning to provision of medical services. These measures are often characterised by the fact that the improvement of road safety was not the most important objective when conducting them in the first place. All measure types are analysed identically to get an overview and make it easier to compare them. Special attention is turned on the measure’s effect on accidents, the effect on mobility, the effect on the environment and the costs of the measures. Where possible a cost-benefit analysis is carried out.

Part III describes 124 specific traffic safety measures in a structured way. The authors pursue the same methodology as in part II. As an introduction Elvik and Vaa depict the problem and describe the measure as well as the measure’s objective in a detailed manner. Then they make statements of the effectiveness of the measure and the costs. Additionally they try to estimate secondary effects on mobility and on the environment. Where possible they conduct a cost-benefit analysis.
Dependent on the acceptance of a measure and the extent it has been researched, to some measures is paid more attention that to others. The handbook deals with the following categories of measure:

- Road Design and Road Furniture
- Road Maintenance
- Traffic Control
- Vehicle Design and Protective Devices
- Vehicle and Garage Inspection
- Driver Training and Regulation of Professional Drivers
- Public Education and Information
- Police Enforcement and Sanctions

**Conclusions**

In their meta-analysis Elvik and Vaa have analysed more than 1700 road safety evaluation studies. In a systematic survey they examined 25-30 years (in some cases 40 years) of scientific journals, reports, conference proceedings, books and many more to get finally a catalogue of over 100 measures appropriate to improve road safety. However, as the authors themselves said, their work is not a handbook in the typical way. By the name “handbook” the reader would normally expect a kind of manual with instructions for conducting measures. Elvik’s and Vaa’s book is more meant to be a catalogue or encyclopaedia where measures are listed and statements of effectiveness and costs are made. The book was first published in 1997 in Norwegian language, revised in 2001 and then translated into the English. For that reason Norwegian and other Scandinavian evaluation studies are more represented than studies from southern Europe or the German speaking countries. But nevertheless the handbook offers an overview of a large number of measures conducted up to this very moment and gives information about their effects. The findings represent the essence of hundreds of examined studies but even so there still space for discussions. Especially the first part imparts the fundamentals of road safety investigation and gives an appropriate overview for all those who don’t have the authors’ longstanding experience.

**Measures regarding secondary road safety**

Various measures regarding:

- Road design and road furniture
- Road maintenance
- Traffic control
- Police enforcement and sanctions
B.3 C.R.O.W. Handbook Road Design

Guidelines for road construction per type of road category (only outside urban areas)

Summary

The handbook is divided in four different parts:

1. Basic criteria (140 pages)
2. Primary road Highway (stroomweg) (196 pages);
3. Secondary road (gebiedsontsluitingsweg) (264 pages);

The Road Design Handbook for roads outside built-up areas is the result of the revision of the Guidelines for the Design of Non-Motorways (RONA) outside built-up areas, which date from the period 1980-1992. Technical and social developments, particularly surrounding the Sustainable Safety of Traffic concept, motivated the revision.

‘Basic Criteria’ first addresses the origins of the Road Design Handbook and describes the principles of the Sustainable Safety of Traffic concept. Next, the characteristics of the traffic system components – users, vehicles and the road – are explored, followed by the themes of road safety and accessibility. Traffic safety indices are then presented, offering insight into the collection and use of traffic data. Furthermore, traffic capacity and flow are addressed. The space and environment sections describe the statutory and procedural framework, and look at the assessment aspects for spatial and environmental considerations in planning. In addition, the latest insights regarding the integration of roads into the landscape and working with a landscape plan are presented. Finally, ‘Basic Criteria’ leads into the other three parts by drawing a connection between traffic engineering design and the manner in which it is integrated into the environment, and road construction design.

Conclusions

The handbook is intended for designers and offers a tool in the design and (re)organization of roads. For this reason, ‘Basic Criteria’ first discusses the starting points and design principles in general. Each of the other parts then addresses one of the three road categories with regard to the starting points and criteria, specific design, and organizational elements and special subjects.

Measures regarding secondary road safety

- Alignment (horizontal, vertical, sight distance)
• Cross section (lanes, separated driving directions, central reservation, marking, shoulders, slopes and parallel roads)
• Roundabouts (one or two lanes)
• Intersection (with or without traffic lights)
• Traffic signs, marking, safely design of shoulders (obstacle free zone) and lights

B.4 SWOV: The safety handbook (2001)
(only costs and effects of safety measures)
http://www.swov.nl/

Structure and number of pages
1. Policy (10 pages):
   a. Vision on traffic safety
   b. Cost and effects of traffic safety measures
2. Procedures (11 pages):
   a. Introduction
   b. Collecting traffic data
   c. Analysis
   d. Creating plans
   e. Executive program
   f. Evaluation
3. Available information sources (14 pages)
   a. Available instruments (infrastructure, education and enforcing)
   b. Survey websites

Measures regarding secondary road safety (costs and effects)
• Erftoegangswegen (secondary/tertiary roads): Bicycle strokes, plateaus, road marking, effects of speed reducing and less through traffic
• Gebiedsontsluitingswegen (secondary roads): creating parallel roads in combination with reducing junctions on main road, hard to pass separated driving directions, pedestrian and bicycle crossing, overall effect of homogeny speed on main road and speed reduction, safely design of shoulders (including obstacle free zone).
B.5  Tasmanian Department of Infrastructure

“Road Hazard Management Guide”, Australian Road Research Board, 2004

Summary

The Road Hazard Management Guide is divided into two main parts: Keeping vehicles on the road and Dealing with errant vehicles. The first part focuses on delineation and road design elements. In “Delineation” different subchapters are dedicated to those elements that were found to have an influence in path keeping, showing road users the course a road takes. This includes the correct use of centre and edge lines and the safety advantages of audiotactile line markings.

In addition the author expounds on how to use guideposts on one hand and curve warning signs, chevrons and other warning signs on the other hand for the purpose of road keeping. According to the author the operating speed is the factor that most influences in the vehicle’s ability to remain on the road. For that reason elements like lane and shoulder width as well as horizontal and vertical alignment have to be designed in a suitable way. What safety relevant aspects the practitioner has to be aware of is described in “Road design elements”. Furthermore the writer expounds on road surface and its influence in skid resistance, adequate sight distances and the significance of road surface drainage as well as the drainage of the surrounding areas.

The second major part concentrates on desirable breadth of clear zones as the simplest way in “Dealing with errant vehicles”. But since the physical and environmental conditions of road surroundings not always allow providing enough space, a further chapter is dedicated to the different types of hazards and their treatment.

Five broad categories of possible hazards are identified: Embankments, rigid objects, medians, open drains and bodies of water. The author elaborates on the treatment of each of these groups with regard to accident severity. At sides where these hazards cannot be removed or redesigned safety barriers have to be applied. Thus, different types of safety barriers are presented and their appropriate use is described.

Conclusions

Whenever the author depicts the relation between any of the mentioned elements and its influence in accident occurrence, he mentions the design standard belonging to it. (Austroads, Australian standard, New Zeeland standard, Tasmanian Code,
AASHST...) In spite of this strong local relation the guide gives clear advise with practical examples, which are easily transferable to European conditions.

The guide is unmistakably addressed to practitioners and road authorities since most of the work is dedicated to maintenance activities and upgrading of existing roads. The manual distinguishes itself by its well-structured and simple composition (just a few, important topics are mentioned) and due to the fact that it comes rapidly to the point.

**Measures regarding secondary road safety**

The guide is not exclusively addressed to secondary roads but includes a large number of measures applicable to secondary roads as:

- Delineation: Line markings, raised pavement markers, guideposts, warning signs, weather warning systems; Road design elements: lane widths, vertical alignment,…
- Clear zones: Types of hazards and their treatment; Safety barriers and Work zones
B.6 Forschungsgesellschaft für Straßen- und Verkehrswesen
“Merkblätter zum Auswerten von Straßenverkehrsunfällen, Teil 1 und Teil 2”, CD-ROM, Institut für Straßenverkehr Köln (ISK) des Gesamtverbandes der Deutschen Versicherungswirtschaft e.V. (GDV), Köln, 2002

Summary

The CD-ROM consists of 5 main menus:

- Road traffic agency
- Pin maps
- Measures
- Accident types
- Accident parameters

Additionally the CD-ROM is equipped with add-on menus as for example an alphabetical index, terms, abbreviation, material, literature and others.

The road traffic agency in Germany is an administrative authority responsible for the supervision and execution of the road traffic regulations. In the first menu the user can learn of all kind of administrative and legal concerns regarding road safety measures. In several submenus the user gets to know about general legal conditions, the organisational environment or the most important administrative actions and their control. Furthermore it is explained how different public authorities work together when the implementation of a road safety measure is planned. That regards amongst other the cooperation between road traffic agency, road construction agency, police or local authorities.

Finally there are some appendixes that explain which are the agencies and administrations, responsible for affairs as combating traffic accidents, safeguarding the way to school, parking space management, hearings, special exemptions or permissions.

Location based analysis of road traffic accidents – local accident investigation – helps to find accident-conspicuous sites and investigate them more closely. These surveys serve about all the aim of finding out where accidents become more frequent, why there of all sites and what measures seem appropriate to eliminate identified accident sources. For that reason accident pin maps are required.

According to German right the combat against road traffic accidents has to succeed in close cooperation between police, road traffic agency and road construction agency.
The so-called accident commissions serve that purpose. Accident commissions are multidisciplinary panels typically composed up to ten members, including representatives from the police, the road construction and traffic authorities. The police agency is responsible for preparing pin maps for the previous year and the preceding three years.

The second menu is dedicated to pin maps. The user can find out about the basics of manually conducted accident pin maps and can get further information about digitally conducted pin maps. It is explained what data is required, how to recognize sites, line and areas were accidents are frequent, what has to be investigated and what measures can the accident commission take. Furthermore there are several appendixes with explanatory examples.

The next menu – measures - represents certainly the core part of the CD-ROM. The first submenus start again with the accident commissions. It is depicted how the commissions has use the accident type pin maps and what are the different accident categories and types. The measures are arranged in three groups: “inside build-up areas”, “rural roads” and “motorways”.

Apart from that measures for inside build-up areas are subdivided into “thoroughfares” and “development roads” and measures for rural roads into “single-lane roads” and “dual-lane roads”. Further submenus are divided by the location of the accident. Possible locations are: traffic light controlled intersections, intersections without traffic lights, roundabouts, accident accumulation location and accident accumulation line. Then one can choose for each accident location between several basic accident types, where schematic representations help to make a decision.

The aim of all that is to categorise every accident according to road type → accident location and → accident type. As soon as one has decided on the accident type another screen opens and for a number of possible deficits the corresponding measures are offered. Before-after pictures should make the situation and the measures clearer.

Another menu depicts again in a more detailed manner the different accident types, subtypes and sub-subtypes, which is important for the correct identification and classification of the accidents. In the last menu the user gets to know about absolute and relative accident parameters, fixed and adapted accident costs and other characteristic values of accidents as accident densities or accident rates.

Conclusions

To make the accident commission's task easier the Forschungsgesellschaft für Straßen- und Verkehrswesen (Road and Traffic Research Institute) has published the
“Instruction leaflets for the analysis of road traffic accidents, part 1 and part 2”. The German Insurers Traffic Engineering Institute has published recommendations to support the road traffic agencies. This instruction leaflets and recommendations together with an accident type catalogue and the latest accident costs came out on one single CD-ROM. The CD-ROM is easy structured and self-explaining with a great amount of before-after examples using text, images and video for illustration. The measures haven’t been assessed regarding their effect on safety or compared between them. On the other hand unsuited, ineffective or expansive measures are named on the CD-ROM. The compact disc represents an easy-to-use tool for every road authority or consultant.

*Measures regarding secondary road safety*

The submenu “measures” includes measures for single-carriageway rural roads as, for example, regarding:

- sight distance
- intersections
- roadsides
- pedestrians,
- speed violation
**B.7 PIARC Road Safety Manual**


**Summary**

The manual is structured in 4 main parts:

Part I: Introduction to road safety

Part II: Analysis process

Part III: Technical sheets

Part IV: Technical study

The first part is, just as the title suggests, an introduction in the field of road safety. It starts with the scope of the road safety problem where the reader gets familiarised with fatality and injury estimates, economic costs of accidents and their analysis methods.

Further chapters are dedicated to road safety management comprising many interesting fact regarding road safety programs and road safety action plans and to road safety factors, which include the human-environment-vehicle system.

In the second part the authors go through the analysis process of traffic accidents. It starts with an introduction in the data that is used (accident data, geometrical data, traffic data) and goes on with a description of methods for the identification of road safety deficiencies. Afterwards follows a chapter dedicated to the diagnosis of accidents and the locations. The next chapter describes how to set up a system for prioritising the various treatments required, important to use the available budget in the most appropriate way. The last chapter of this part describes how to monitor the measures to ensure the investments are used effectively.

Part three covers the technical relationship between safety and a range of road infrastructure components and human capabilities. The authors pay special attention to horizontal and vertical alignment, sight distances, road surface conditions, the human factor and intersections as well as their influence on road safety. It is also explained how to improve those elements.

The fourth part reviews different aspects of technical studies of safety analysis. For example the reader gets introduced in spot speed studies in order to determine the speed distribution for a certain location or. Furthermore it is said when and how to conduct traffic counts. The last part finishes with studies regarding friction, sight distance, travel time and delay and traffic conflicts.
Conclusions

The manual claims to be designed to give engineers a better understanding of the impact that design elements have on road safety at all design and operation phases. Although it does not exclusively focus on secondary roads most of the recommendation can be applied on them. Especially part three, which expounds the relation between road design elements and safety, gives advice concerning secondary road safety.

Measures regarding secondary road safety

- Various measures regarding Road design (alignment, sight distance, road surface conditions, human factors and intersections)
- Additionally the manual includes a multitude of checklists and work sheets.
**B.8 US Highway Safety Manual - Two-lane highways prototype chapter**
(http://www.highwaysafetymanual.org)

**Summary:**

The manual is a prototype chapter of a larger project managed by the Task Force of the US Transportation Research Board; it is structured in an introduction (part I) and 3 main parts:

- Part II: Methodology
- Part III: Applications
- Part IV: Example Problems

The safety analysis methodology presented in the prototype chapter estimates the safety performance for an existing or proposed rural two-lane highway operating under current or projected traffic demand.

The safety performance measure for two-lane highways is the expected annual accident frequency, which can be calculated for a particular roadway segment, intersection, or entire project applying a base model, a calibration factor and several accident modification factors (AMF’s)

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![HSM safety analysis methodology](image)

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**Figure 1 HSM safety analysis methodology**

HSM: Two-Lane Highway Safety Prediction Methodology

1. Select a roadway segment or intersection
2. Apply base model
3. Apply AMFs
4. Determine predicted accident frequency, accident severity distribution, and accident type distribution
5. Present final predicted values to user
There is a specific section in the part III dedicated to “Safety prediction when site-specific accident history data are not available” ; this section complies with the needs illustrated in the introduction (two lane roads, local road managers without accident data availability)

**Conclusions**

The manual is an actual accident prediction model, based on a division of the selected road into individual homogeneous roadway segments and intersections: The model approaches the effects of each segment as independent of one another and ignores potential interactions between them.
B.9  World Bank - Safe Road Design - A Practical Manual

The manual, produced for the World Bank and the Dutch Ministry of Transport, Public Works and Water Management, aims to transfer best practice knowledge tailored for widespread application; the uncertainty about the applicability of the sustainable safety vision in transitional and developing countries was examined and addressed during its preparation.

The Manual is the result of a strategic alliance between the Dutch program Partners for Roads and the World Bank to test the applicability of sustainable safety principles and concepts in road design in Central and Eastern Europe; it is composed by 12 sections:

- 1 introduction
- 2 solving road safety problems: a strategy
- 3 sustainable safe road design: theory
- 4 sustainable safe road design: cross section
- 5 sustainable safe road design: junctions
- 6 sustainable safe road design: alignment
- 7 sustainable safe road design: linear villages
- 8 Sustainable safe road design: pedestrian crossing (PDF, 329 kb)
- 9 Case studies in different countries: Poland, Latvia, Estonia, Lithuania, Bulgaria, Romania, Turkey
- 10 Analysis of black spots
- 11 Cost benefit and cost effectiveness analysis
- 12 Education and enforcement
B.10 EURO-RAP and its documents

(http://www.eurorap.org)

EuroRAP (European Road Assessment Programme) is an international not-for profit association registered in Belgium. Its members are motoring organisations, national and regional road authorities, and experts who have been elected because of the special contribution they gave to the programme.

The formal objectives of EuroRAP are to:

- reduce death and serious injury on European roads rapidly through a programme of systematic testing of risk that identifies major safety shortcomings which can be addressed by practical road improvement measures;
- ensure assessment of risk lies at the heart of strategic decisions on route improvements, crash protection and standards of route management; and
- to forge partnerships between those responsible for a safe roads system - motoring organisations, vehicle manufacturers and road authorities.

EuroRAP is a sister programme to EuroNCAP, the independent crash test programme that star rates new cars for the crash protection they provide to passengers and pedestrians. EuroNCAP demonstrates that well-designed crash protection can make family cars safer. Similarly, EuroRAP is beginning to show how roads can be made safer, so that the car and road work together to protect life.

The EuroRAP website (section “Library / Technical”) contains several technical reports about risk mapping across Europe, road inspections and many other road safety related items.
**B.11 Fuller, R., & Santos, J. A. Human Factors for Highway Engineers**
Amsterdam: Pergamon (2002).

The book edited by Fuller & Santos is composed of several chapters dealing with the most important current psychological issues of human factors in highway design. The chapters are written by different authors who are all experts in their field. The book serves to increase understanding behind human behaviour on roads and is thus an important supplement for road designers. The book is not specifically addressed to rural roads but can be applied in this field as well.

Content (taken from: http://www.elsevier.com/wps/find/bookdescription.cws_home/622585/description#description)

**The System: Road and Road User.**
Psychology and the highway engineer (R. Fuller, J.A. Santos).
Multiple perspectives (O. Carsten).
Ergonomics of driver's interface with the road environment: the contribution of psychological research (F. Saad).
Learning and the road user (R. Fuller).
A study of subjective road categorization and driving behaviour (N. Kaptein et al.).

**The Driver From A Psychological Perspective.**
Human factors and driving (R. Fuller).
Visual factors in driving (D.R. Mestre).
Perception of road users' motion (J.A. Santos et al.).
Sampling information from the road environment (J. Theeuwes).
Some insights on how to work with human error in traffic behaviour (E.J. Carbonell, B. Martín-del-Río).
Mental workload (D. de Waard).
Learning and driving: an incomplete but continuing story (J.A. Groeger).
Behavioural adaptation and drivers' task control (H. Summala).
Social psychological principles: "the group inside the person (M. O’Connell).

**Special Categories of Road User.**

Young pedestrians and young cyclists (H.H. van der Molen).
The psychology of the young driver (R. Fuller).
Road users who are elderly: drivers and pedestrians (A. Simões, C. Marin-Lamellet).

**Advanced Transport Technology.**

A note on advanced transport technology (R. Fuller, J.A. Santos).
B.12 Decision Support Safety Tool (DST) - Overview

The DST is a practical management tool for the stimulation of a safety-oriented management of (secondary) road infrastructure. This management tool, developed under the Ripcord-Iserest project, aims to assist road authorities and other decision-makers on a local or regional level, by introducing road safety intervention measures in the best possible way. The DST is based on the ‘Verkeersveiligheidsverkenner’ by the SWOV (NL) and the VIB by Mobycon (NL).

The DST helps local and regional road authorities to determine road safety problems, to select appropriate safety intervention measures and to predict the road safety level of a region or municipality and cost effectiveness of road safety projects. The results are shown in terms of accident reduction, cost effectiveness and the total cost of road safety measures. The accident reduction can also be compared to safety goals set by the local, regional or national government.

With the DST the following questions can be answered:

- What is the safety impact of my infrastructural road safety projects?
- How can I reach my road safety targets in a cost-effective way?
- In what way can all road authorities in a region gear all road safety-activities?

The process within the DST can be divided into four different stages:

**Stage 1: Collecting relevant data**

The first step is to collect all the relevant data. The DST has to be filled with the necessary data, such as digital road network data, digital accident data (death and hospital injured) and actual average daily traffic (AADT). Besides these network specific data it is recommended to collect country specific data about safety measures and their costs and effects.

**Stage 2: Preparation of the DST**

After collecting the necessary data these data must be implemented into the DST. The first step is to combine the digital accident data and the actual average daily traffic with the digital road network data. After this combination the road network data should be converted into readable GIS-files for the DST. Besides the implementation of the necessary data the road authority also has to complete the following information before working with the DST:

- the basis year (average year of accident data)?
- the reference year?
- the road safety targets (in death and hospital injured reduction)?

**Stage 3: Work sessions with the DST**
The DST is now ready for work sessions to generate all kinds of safety intervention scenarios. The measures from the Expert System, which are provided with costs and effects, are standard available in the DST. Road managers can implement these measures at road sections and intersections in order to reduce the number of deaths and hospital injured. There is a manual available to guide the user how to start the DST, how to implement the measures into the DST and how to interpret the results. The DST interface is shown in the figure below. The costs of the measures are based on the results of the Expert System eventually completed with country specific costs. The costs/km are calculated with the length of the measure that is applied to the road sections and the costs for a single element is based on the cost for e.g. one roundabout. Finally, the costs of different measures are added up to show the total cost of this scenario.

**Effect calculation of the safety intervention scenarios**

The effects of the measures are based on the results of the Expert System eventually completed with country specific effects. Examples of the effect calculation:

- Sustainable safety areas (60 km/h-areas with different measures): the effect of the measure (reduction percentage) applies to the whole area the measure is applied to;

- Sustainable safety areas in combination with bicycle-lanes:
  - Victims x reduction percentage sustainable safety areas = first result
  - First result x reduction percentage bicycle-lanes = total reduction.

**Stage 4: Deliverable with results**

The work sessions will provide different safety intervention scenarios for road safety improvements in a municipality or region. The results of these scenarios are shown in terms of accident reduction, the total costs of road safety measures and the cost-effectiveness of the scenario. The results are presented in a deliverable with maps, charts and tables accompanied with an explaining text of the results. The deliverable can be used to persuade politicians.