

## **Fewer crashes and fewer casualties by safer roads**

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Contribution to the international symposium 'Halving Road Deaths'  
organized by the International Association of Traffic and Safety Sciences,  
November 28, 2003, Tokyo

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## Summary

Human errors play a vital role in road crashes. This presentation deals with the prevention of human errors by proper road planning, road design and improving existing roads (reconstruction/rehabilitation/resurfacing). Road safety considerations must play an explicit role in decision making in all three areas. Our knowledge about the relationships between road and traffic characteristics and road safety has increased enormously in the last decades, and we can apply this knowledge in decisions related to planning, design and operations. Different procedures are available or will be developed to use this knowledge in actual decision making. In road planning for example, a road safety impact assessment should be made in order to take road safety transparently into consideration.

A minimum safety level should be defined and agreed upon between road authorities. Defining such a level has started in the Netherlands and we call this '*Sustainable safety*'. This concept focuses on three design principles: functionality, homogeneity, and predictability. These principles are introduced briefly in this presentation.

If we implement '*Sustainable safety*', we expect to build a considerably safer road traffic system by reducing human errors, taking into account limits given by human tolerances in crashes and eliminating 'preventable crashes'. Of course, public support needs to be created in order to get this challenging concept implemented and accepted by the population. Integration with other road safety policies is considered crucial.



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# 1. Human error and human tolerance

An 18-year-old youth has just passed his driving test. One Saturday night he is driving his friends home from a disco. The teenager has recently bought a second-hand car. The way home takes them over a winding dyke besides a river. It is raining. The teenager misjudges a bend. He is driving too fast so he cannot adequately correct for the bend. The car drives into the river. Because the youths are not wearing a seat belt, they are thrown out of the car and drown. The following morning a passer-by discovers the crash.

Cause? A young, inexperienced driver, not wearing a seat belt, driving at night in the rain with an inappropriate speed along a road without a barrier, an unexpected sharp bend, bald tyres? All these factors could have contributed to the accident and to the severity of the outcome. Often a critical combination of circumstances is involved (OECD, 1984). Pointing to one single cause, finding one culprit for a crash, does not do justice to the complex reality and – unnecessarily – limits the real opportunities to prevent crashes or the severity of crashes.

Research has shown that the human factor plays a role in practically all crashes. Some have reacted to preventing *human errors* by equipping road users better to carry out the driving task: better education, more public information, and more police surveillance. The insight is slowly beginning to grow that road user mistakes are just a normal part of traffic, and that they should not only be punished for 'bad' behaviour, but that mistakes should be accepted. Furthermore, we know from other circumstances, such as the employment environment or other means of transport (Reason, 1990) that an effective way of eliminating human errors, or at least the chance of limiting them, is by adapting the environment. This is referred to as 'paradigm shift'.

It is not possible to prevent every crash. They will continue to occur also in an adapted environment. The question is then whether the circumstances can be adapted in such a way as to exclude, or practically exclude, severe injury. You can read the following on the website of the EuroRAP programme: "On the racetrack, drivers can walk away from 300 km/h crashes because track and vehicle crash protection work together" ([www.eurorap.org](http://www.eurorap.org)). This concept, as in the visions from Sweden (Vision Zero) – see also [www.vagverket.se](http://www.vagverket.se) - and the Netherlands (Sustainably Safe) – see [www.swov.nl](http://www.swov.nl) and also paragraph 5 - , leads to and forms the second cornerstone of the earlier referred to paradigm shift: the *human tolerance* as a design parameter of the road transport system.

To adjust the present road traffic system to the requirements of human error and human tolerance, an enormous transition is needed. First of all, we do not possess the knowledge of all components to be able to transpose the conceptual ideas to the specific layout of the various components of the system. Furthermore, it is clear that integration is necessary to steer the various system components. This integration is not yet generally accepted, and a holistic approach, in the theoretical sense, is probably a smaller problem than in the steering sense. Finally, it is not to be expected that adapting the present system to one that meets the requirements of human

error and human tolerance will be easy, and ready in the short term. In particular and referring to Holland's road structure, the necessary investments will be considerable. In addition, such expenditure needs public support. It will be necessary to make *Many Small Steps Forward* (so-called incremental change) and decision-making procedures will have to be agreed upon in order to set these Many Small Steps by Many (independent) Stakeholders in the right direction, and to involve efficiency considerations.

## 2. Safety quality of roads

### 2.1. Indicators for safety quality of roads

There are different ways of scoring the safety quality of a road. First of all there is the possibility of expressing the lack of safety in the frequency of crashes occurring, the number of casualties (deaths and injured) thus resulting, and the ensuing costs. First of all, it will have to be kept in mind that crashes are relatively rare occurrences (seen in terms of statistics). Looked at this way, there are frequent accidents hardly anywhere, and the majority of road users are rarely involved.

Another question is that a crash happening does not say enough about the risk being run somewhere. Thus, it is also important to know the extent in which the individual is exposed to a risk, and crashes. In general, crashes are related to 'exposure to risk' (Hakkert & Braimaister, 2002). Exposure to risk is rarely measured directly, but estimated indirectly.

If we want to express the safety of roads, that can be done by dividing the numbers of crashes by the amount of traffic that makes use of that road. This, for example, produces a ratio for road segments of the number of crashes (fatal and/or with injuries) per vehicle kilometre travelled. In the case of intersections, the number of crashes is related to the number of vehicles entering an intersection.

In *Table 1*, the risks are given for various road types in the Netherlands. There appear to be large differences in risk. The can be largely explained by the road and traffic circumstances: which vehicle categories use the road, what their driving speeds are, how their driving directions are separated, and what the intersection solutions look like.

Road type	Speed limit (km/h)	Mixed traffic	Intersecting / oncoming traffic	Injury rates per million kilometre
Residential areas	30	Yes	Yes	0.2
Urban street	50	Yes	Yes	0.75
Urban artery	50/70	Yes/no	Yes	1.33
Rural road	80	Yes/no	Yes	0.64
Express road or road closed to slow moving vehicles	80	No	Yes	0.3
Motor road	100	No	Yes/no	0.11
Motorway	100/120	No	No	0.07

Table 1. *Injury rates in the Netherlands in 1986 on different road types.*

Expressing the ratio between crashes and traffic volume in one number assumes a linear relation. This relation, referred to in North American literature, as Safety Performance Functions (SPF) appears normally not to

be linear, but shaped as in *Figure 1* (Hauer, 1995). If a SPF is not linear, the use of a ratio is only limited, if not incorrect.

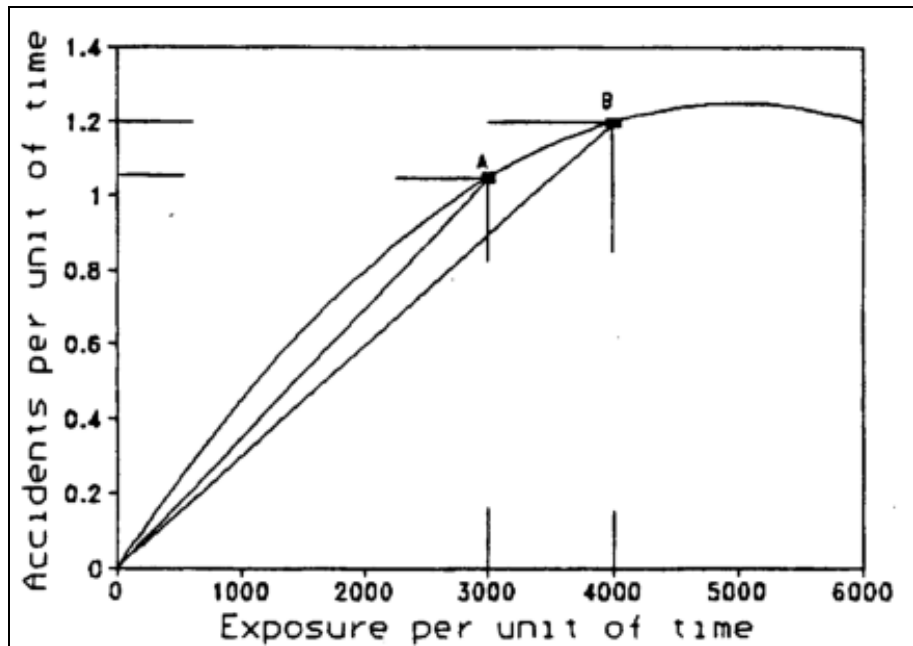


Figure 1. *Safety Performance Function and accident rates. From: Hauer (1995).*

The significance of this ratio not being linear is of great importance, not only scientifically, but also for the road safety implications of certain measures that influence traffic volumes of roads in a network. The question of optimising is here relevant. In other words, certain traffic volumes on roads in a network can be searched for, that can be regarded as the 'optimal safety load' of a network. It is not difficult to see that sticking to fixed ratios can lead to wrong conclusions. In the American Interactive Highway Safety Model (IHSDM) ([www.tfhrc.gov](http://www.tfhrc.gov)), 'a road safety evaluation software program that marshals available knowledge about safety into a more useful form for highway planners and designers', there is a so-called Crash Prediction Module in which 'base models' are used as part of the crash prediction algorithm (Harwood et al., 2000). IHSDM refers to rural two-lane roads. These models distinguish between road segments and intersections (of various types).

Apart from various parameter estimates in SPF for different road types, the geometric features and traffic management measures also influence the ultimately expected number of crashes. This is given in the Accident Modification Factors (AMF). In the previously mentioned IHSDM model, AMF has been developed for: lane width, shoulder width, shoulder type, horizontal curves, grades, driveway density, two way left turn lanes, passing lanes, and roadside design. At grade-separated intersections, the following are taken into consideration: skew angle, traffic control, left and right turn lanes, and intersection sight distance. AMF continuously indicates the extent to which a deviation of an assumed basis value in the 'base model' leads to more or less crashes.

This approach, that for example is also used in Canada, is actually an attempt to make an estimate of the safety consequences of adjustments in the layout of our roads and their traffic in an integrated and quantitative way. Of course, the results of such models can never be transferred to another jurisdiction, meaning that every jurisdiction has to estimate its own parameter values.

## 2.2. Road safety engineering

Road safety engineering deals with prevention of crashes and the reduction of the severity of crashes by planning, design or traffic management. So, road safety engineering consists of two elements: safety conscious planning and safety conscious design. *Safety conscious planning* already deals with safety in the planning phase of new areas, new settlements, new roads and streets. Of extreme importance for road safety is how new road networks will be linked to the existing road network. Another important safety aspect is the so-called access management (limitations!), referring to the entry of a roadway of traffic from other roads, roads to companies and other private properties (use of service roads).

*Safety conscious design* incorporates safety features in the design of new roads and streets, and the improvement of existing roads in such a way that 'preventable crashes' do not occur. The concept of 'preventable crashes' is based on three principles: apply effective measures, are beneficial to a society (in economic terms), and which fit in a vision (in order to create synergy between different interventions (Wegman, 2001).

Road safety engineering should build a solid base for other road safety activities, such as legislation and enforcement of that legislation. Especially speed limits and enforcement of these limits are crucial. Safety of cars and safety of roads should be complementary to each other.

## 2.3. Safety conscious planning

In the context of safety planning, *land use planning* can be described as the planning of the relative location of different types of land use and of the way they are connected. Land use planning deals with the spatial allocation of urban functions and the design of urban structures (Hummel, 2001c). The spatial organisation of land use types in an area determines: the number of generated trips, the modal choice, the length of trips and the route choice. The chosen urban structure determines: travel distances, the general road network design and the functional classification in a road network. So, land use planning can have a major influence on both mobility and safety. Important land use decisions with a possible influence on road crashes are: spatial allocation of origins and destinations, urban density, patterns of urban growth, general shape of the network, size of residential areas and provisions for the different transport modes.

If we accept the three dimensions of road safety (Rumar, 1999): exposure, crash risk and injury risk, *land use planning* could address all three. These safety principles are based on the 'Sustainable safety' vision, as described in paragraph 5:

- minimize exposure
- promote efficient land use

- provide efficient networks where the shortest routes coincide with the safest routes
- promote alternative modes
- minimize crash risk
  - promote functionality, by preventing unintended use of each road
- minimize injury risk
  - reduce speeds

In the context of *route management* (Hummel, 2001b) the following safety principles are at stake:

- minimize exposure
  - provide efficient networks where the shortest/quickest routes coincide with the safest routes
- minimize crash risks
  - promote functionality, by preventing unintended use of each road
  - provide homogeneity, by preventing large differences in vehicle speed, mass, and direction of movement
  - provide predictability, thus preventing uncertainty amongst road users by enhancing the predictability of the road's course, and enabling the behaviour of other road users to be anticipated.

In the framework of *access management* (Hummel, 2001a) we are dealing with:

- minimize exposure
  - provide compact urban form
  - provide efficient networks
- minimize crash risks
  - the same provisions as in route management
- minimize injury risks
  - reduce speeds

The influence of access management on road crashes is often overlooked. It is a very important item leading the Federal Highway Administration to the statement: 'One thing is very clear, the most important geometric design element in reducing crashes is access control' (FHWA, 1992).

In the literature, the foundation is to be found of the idea that land use planning is important for road safety. However, expressing the relations quantitatively is not possible. An important explanation for this is that the application of certain land use planning concepts does not, on their own, determine safety. The actual layout of roads and streets, and the behaviour of road users are always decisive. However, land use planning defines the conditions for the road designers, and they are thus determinant. If the safety effects of decisions in land use planning are considered in a very early stage of land use planning, developments can be directed in a safer direction. Deficiencies in the land use planning can cause unsafe structures and shapes. To prevent those deficiencies, road safety should be a major consideration in an early stage of land use planning, route management and access management.

A matter of a completely different order is how to apply these planning principles in existing urban structures. The principles remain valid but, the applications require much creativity, considerable budgets, and involve

many compromises in making existing structure safer (IHT, 1990; OECD, 1990; DTLR, 2001; DUMAS, 2001).

A starting point of all safety activities in existing areas should be the functional road hierarchy or a categorization of road networks (SWOV, 1992). With the proper integration of land use and transportation planning, local roads and streets provide land access, while through traffic and high driving speeds are discouraged. On the other hand, the roads at the upper end of the hierarchy, such as arterials and motorways are planned to optimise traffic flow and speed, while severely restricting or eliminating all direct access to adjacent lands. Multi-functionality leads to contradictory design requirements and also to higher risk, as could be explained with the figures in *Table 1*. Combinations of functions, combined with use of different transport modes in the same physical space and relatively high speeds and speed differences lead to relatively high risks.

An example of a road categorization plan is giving in *Figure 2*.

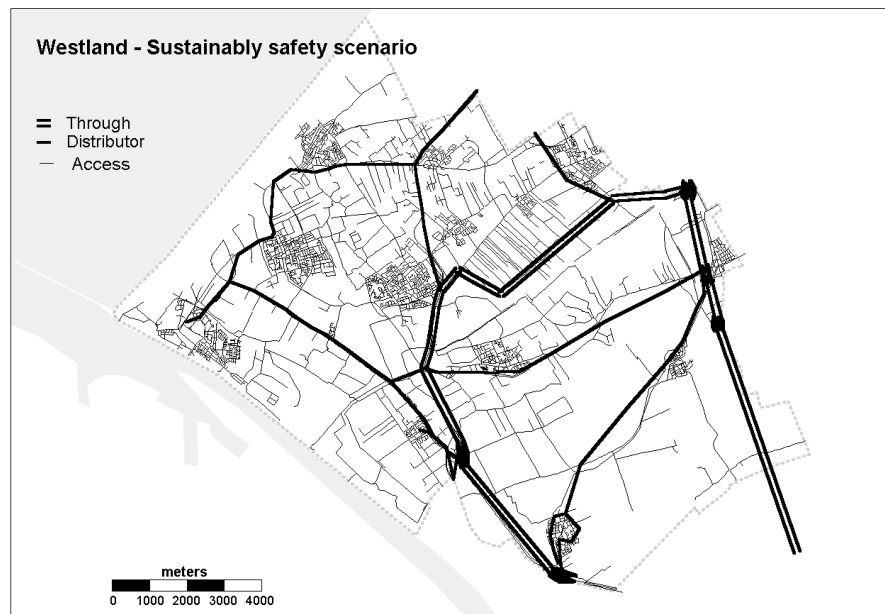


Figure 2. *Categorized road network: an example for an area in the Netherlands.*

#### 2.4. Safety conscious design

A categorized road network (based on mono-functionality) is a sound starting point for safe road design. Discrepancies between function, design and use lead to higher risks. Planners and designers have to create such an environment for the road users *that the design characteristics are consistent with the road's function and elicit the appropriate behaviour*. A second design adage should be: *design characteristics need to be consistent along a particular stretch of road*. Road design creates an expectation by road users as to the appropriate behaviour along a particular stretch of road. Since people are known to be relatively slow in adapting to a new situation, inconsistencies in design along the same road may easily lead to inappropriate behaviour and thus to errors.

However, these design philosophy and characteristics are not part of the normal design practices yet, and application of them in existing situations is a challenging task. An outline of road design practices is as follows. Roads are designed with several criteria in mind, such as travel time, comfort and convenience, safety, the environment, energy consumption, costs, and town and country planning. Some criteria are dealt with in qualitative terms, while quantitative norms are adopted for others. Most of the criteria mentioned interact: some combinations of criteria even produce conflicts. The art of designing a road is predominantly the art of giving the right weight to the various criteria, in order to find the most satisfactory solution.

Safety is usually one of the criteria that are taken into account as a matter of course: at every stage in the design process, the designer is expected to take decisions with safety in mind. But decisions are rarely taken for safety reasons alone. At the end of the process, therefore, it is difficult to judge the extent to which safety has been taken into account.

In general, safety can be considered at four levels (Ruyters et al., 1994):

1. Safety achieved through specific attention paid during the detailed road design process. However, road designers do not have always the right knowledge and awareness needed to give safety enough consideration.
2. Safety achieved through compliance with road design norms and standards. However, although standards, guidelines etc. are written with safety in mind, the authors almost never have quantitative knowledge of the link between engineering decisions and their safety consequences.
3. The level of safety than can be achieved through road classification. However, in practice, correct application of road classification has proved to be a major problem.
4. The (explicit) degree of safety offered by the conceptual transport system satisfying the need for mobility.

Road design standards play a vital role in road design, but major problems exist in this field: not all countries have road design standards for all types of roads, road authorities do not apply their own standards, some space for interpretation is possible, road safety arguments are treated fairly implicitly and – at least in Europe – there is no compatibility between the different countries. The non-availability and non-compatibility of road design standards for the road network in different countries increases risks and therefore contributes to the actual scale of the road safety problem.

It is good to observe an enormous increase of our knowledge in this field during the last decade. A good example is the attempt in Norway to draft a *Trafikksikkerhetshåndbok* (Road Safety Handbook), *The Traffic Safety Toolbox* by the Institute of Transportation Engineers ([www.ite.org](http://www.ite.org)) and *A Road Safety Good Practice Guide* (DTLR, 2001). A very comprehensive and ambitious approach is the development of the *Interactive Highway Safety Design Model* ([www.tfrc.gov](http://www.tfrc.gov)), by the Turner-Fairbank Highway Research Centre from the Federal Highway Administration in the United States. This model consists of several modules (crash prediction module, design consistency module, intersection review module, policy review module, traffic analysis module). All these modules are part of the 2003 release. One module is still under development: the driver/vehicle module. This has turned



out be a complex and complicated module, leading us to a second problem, to be mentioned here.

Design standards are traditionally based on 'basic assumptions' regarding, for example, reaction times, eye heights, friction coefficients between tyres and the road surface, deceleration and acceleration of vehicles, etc. On the basis of assumptions on these factors and the choice of the design speed, the stopping distances, sight distances, overtaking distances, lane width, bend curvature etc. can be calculated and incorporated in the design guidelines.

But we have to admit that we still face a major problem in talking about safety on our roads. Traffic engineers and road designers do not know exactly how and why road users behave as they do, and how they could influence behaviour through design. Behavioural scientists and engineers need to work together more closely to improve understanding of road behaviour and to change it in the right directions. Both in Europe (van der Horst & Hagenzieker, 2002) as in the United States (NCHRP-project 17-18/31 on: [www.trb.org](http://www.trb.org)) a growing interest can be observed for developing Human Factor Guidelines for road systems.

### 3. Assessment of the safety quality of a road network and roads and streets

#### 3.1. Procedures to assess safety quality of existing roads

Traditionally, there are two methods of determining the safety quality of roads: the black spot approach and the road safety inspections. In the so-called *black spot* approach, parts of the road network are selected (mainly intersections) in which, in the past, there was a concentration of crashes. Although no international agreement seems to have been made about the definition, the concept is mainly the same: a selection of locations, a diagnosis of the crashes that have occurred in order to establish accident patterns, a selection of the appropriate measures, and then an evaluation of the measures taken. Their usefulness in reducing the number of crashes has been queried the last years. If the approach had been successful, it would have become a victim of its own success: after all, no black spots would have remained. But, there is even doubt about that. Elvik (1997) published an article in which the conclusion has been drawn that there has been no statistically significant effect of the black spot approach. A problem with evaluation studies of improvements emanating from black spot treatments is, that there hasn't always been a control for 'confounding factors', such as regression-to-the-mean and accident migration. A plausible explanation for this unexpected effect hasn't anyway been given yet. Neither, since the Elvik results, has any other study been presented that places matters in another perspective.

There are still two questions to be answered. First of all, there is the question of whether registered crashes in the past are still good predictors for those in the future. With such a question as starting point, the *SafetyAnalyst* programme ([www.safetyanalyst.org](http://www.safetyanalyst.org)) has chosen a combination of safety performance functions (SPF) and the application of the so-called Empirical Bayes (EB) method (FHWA, 2002). This method combines two sources of information: the expected number of accidents, estimated by means of a safety performance function and the registered number of accidents. Another example of this approach (based on crashes in the past) is an approach in which a 'standardized number of crashes' is determined for a road type, with which individual roads will be compared. If, on a road, more crashes occur (than the norm), then there is reason for action. This approach is the basis idea behind the EuroRAP programme (Lynam et al., 2003). The idea behind this is that a greater number of accidents than the 'norm' will appear to be interesting for crash reduction activities.

A second comment on the black spot approach has emerged from efficiency considerations: we are not actually interested in a screening of the roads for unsafety in the past, but for improvement possibilities in the future. That is why, in the *SafetyAnalyst* programme, the concept of 'sites with promise' will be introduced, based on cost-effectiveness considerations.

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At this moment in time, it cannot be exactly predicted what the possibilities will be for the various methods being currently developed. But it is certain that, in comparison with the traditional black spot approach, improvements are necessary and seem possible.

A second method can be summarized as (visual) *road safety inspections*. Here also, traditionally many possible implementation forms have been applied. There are many simple implementation forms in which personnel of the road authority drive around, make a note of striking matters, and often immediately take simple measures. There are also more advanced methods in which, for example, use is made of a video. This leads, in the EuroRAP programme to a 'Road Protection Score' (Lynam et al., 2003). Little has been reported about the effectiveness of such inspections, in terms of accident reduction. In this context is the attempt being carried out in New Zealand to reach a more objective methodology (Wilkie, s.a.). In his article, Wilkie claims to have found a correlation between the results of the ratings of a 'quantitative method of assessment' and the accident history of a particular stretch of road. A further exploration of such methods is highly recommended because the methods are relatively simple, which is why they are attractive for a road authority and, if they are effective, they are nearly always cost-effective.

Apart from the methods mentioned here, there are ways of working that attempt to establish the extent in which the actual road design differs from that which has been agreed upon in the design guidelines, or what is considered a desirable and safe design. The IHSDM program contains a module, the Policy Review Module, in which can rapidly be determined if a road (or road design) differs from that in the so-called Green Book of the American Association of State Highway and Transportation Officials (AASHTO). An attempt is being made in the Netherlands to develop an instrument for determining the sustainably safe character of existing roads and new designs (Dijkstra, 2003).

To summarize, it can be concluded that, during recent years, one can talk about a revision in thinking about the approach of the safety screening of roads; this development can certainly be called promising.

### 3.2. Safety quality of new designs

Several definitions are used to describe techniques to assess the safety quality of new road designs. It is helpful to distinguish two phases. A *road safety impact assessment* (RIA) is a formal procedure for independent assessment of the likely effects of proposed road or traffic schemes ('variants'), or indeed other schemes (e.g. changing speed limits) that have substantial effects on road traffic, upon accident occurrence throughout the road network upon which traffic conditions may be affected by the schemes (ETSC, 1997). A *road safety audit* (RSA) is a formal procedure for independent assessment of the accident potential and likely safety

performance of a specific design for a road or traffic scheme – whether new construction or an alteration to an existing road. The aim is similar and the difference is the scope and timing. The scope of a RSA is usually confined to an individual road scheme. A RIA covers a larger part of the road network than the scheme itself. A RIA precedes and complements the eventual RSA or RSA's. For smaller schemes, the two procedures can be combined by extending the first phase of a RSA (feasibility stage) to include the likely effects of the scheme on accident occurrence in the surrounding network. The aim of a RIA is to take better-informed decisions on a strategic level, in which the road safety impact has been made transparent for the political decision makers. A RIA could go parallel in time with other impact assessments (for example a Strategic Environmental Impact Assessment). A RSA aids to make a safer road design and may affect the scheme site and/or the nearby network. A RSA result is used most of the time by the management of a road authority.

*A Road Safety Impact Assessment (RIA)* procedure tries to include in a quantitative way the safety consequences of changes of traffic over a road network due to infrastructural projects (new roads, new road lay outs, etc.) or a major change in general operating conditions by using a scenario technique (Wegman et al, 1994). This technique uses the fact that different categories of roads (with different road and traffic characteristics) have different road safety records dependent on traffic volumes. This relationship between traffic volumes and crash risks are known as Safety Performance Functions. Added to or included in these models are the so-called accident modification factors in which the safety effects of different road characteristics are modelled. The results of a RIA shall be considered in the planning process alongside other information relevant to the decision-making on which of the variants shall be selected.

The *Road Safety Audits (RSA)* process is designed to pro-actively improve road safety through formal independent review of designs for constructing new roads, for traffic operation plans and also for modifying existing roads. The essential elements are: a formal and independent process, carried out by an expert ('trained auditor'), restricted to road safety issues. Many audit procedures distinguishes five stages: feasibility, draft design, detailed design, pre-opening and in-service. Auditors (or a team of auditors) in many cases use checklists or prompts. Checklists are available from all over the world.

How to establish the effectiveness of applying RIA or RSA? The aim of a RIA is not necessarily to reduce the number of casualties. The aim is to take 'informed decisions' and to weigh quantitatively road safety information to other important aspects in a scorecard. So, decision makers have to profit from a RIA-result and the quality of the decision-making process should be qualified as better with the RIA-results than without them.

Then, what is the effectiveness of a RSA? In general, the literature suggests that RSA process is effective and cost-effective (safer roads, better and more transparent design practices, enhancement of road safety engineering, better informed decision-makers, reduced need for remedial work after new schemes are built, etc). However, the studies were not very convincing, dividing the world in 'believers' and 'non-believers'. A convincing approach on establishing RSA-benefits has been issued in Australia just recently

(Macaulay & McInerney, 2002). The development of their method was based on the so-called Safety Risk Manager. That tool allows an assessment of the risk of a wide range of hazards and their associated treatments. This method has been applied in a limited amount of design stage audits. The results are very encouraging (in almost all cases Benefit-cost ratios > 1.0) and the majority of audit findings in this pilot required only very low-cost responses. Austroads concludes 'that the findings confirm the current belief that the audit process is a valuable and beneficial process in maximising the safety of the road network and minimising road trauma'.

## 4. Safety effects of improving roads

### 4.1. Rural roads

Each year, about 60% of all fatalities in OECD Member countries are on rural roads, and this share has increased over the last decades (OECD, 1999). As much of 80% of all crashes on rural roads falls into three categories: single vehicle crashes, especially running of the roads (35%), head-on collisions (25%) and collisions at intersections (20%). Driver behaviour and road infrastructure are the key contributing factors to these types of crashes. Rural crashes are scattered over the entire rural road network. The rural road system itself has inherent characteristics that significantly contribute to the high number of crashes and the high risks, according to the OECD-report. Inappropriate and excessive speeds are a key factor in rural road crashes because the actual speeds on rural roads are relatively high under circumstances where these high speeds cannot be safely maintained. Rural roads require constant speed adaptation to the regularly changing situations and circumstances, thus increasing the opportunities for human errors and leading to higher risks for crashes. The OECD-report therefore concludes that reducing inappropriate and excessive speed together with safe road design and roadside design are the key elements to improve rural road safety (aside from this, fatigue and alcohol/drug use are also key factors in rural safety). Equally important, speed variation caused by the presence of buses, heavy trucks agricultural vehicles, mopeds and bicyclists generate higher crash risks than on other types of roads.

The main type of rural road crash occurs most often in horizontal curves rather than on adjacent tangent sections. Design consistency seems to be the key concept to address this problem (Lamm et al., 1999). See also the Design Consistency Module in IHSDM ([www.tfhrc.gov](http://www.tfhrc.gov)). Flattening horizontal curves is an effective, but expensive crash-reduction measure, only cost-effective on higher-volume roads. Less expensive measures are therefore recommended, such as removing (or protecting road users from) roadside hazards, flattening side slopes, improvement skid resistance, increasing the super-elevation, paving the shoulders and eliminating pavement edge-drops. As low-cost measures could be considered (upgrading edge and centre line, adding reflective markers or upgrading the advance warning. Rumble devices can also be effective, as could be roadside markings. However, a Finnish study (Kallberg, 1991) found that care must be taken not to provide too much visual guidance on roads with relatively low design standards as it may lead to speeds, which are inappropriate for the road.

Forgiving roadside concepts and roadside improvements in general can significantly reduce the severity of crashes, there is a very high potential for improving overall safety by treating or removing roadside obstacles (Ogden, 1996, OECD, 1999).

In relation to head-on crashes, prevention can be accomplished by physically separating opposing traffic with soft and hard solutions. Physical space in a cross-section is needed. A rather drastic approach that is

accomplishable on rural roads is narrow physical separation by means of double centre lines, double centre lines with physical features glued to the surface, or by harder physical means such as kerbstones, cable barriers, guardrails or concrete barriers. These physical barriers could have influence on traffic operations (emergency services, surface maintenance, winter maintenance). In order to cater for overtaking conflict-free overtaking opportunities could be created for regular overtaking lanes. The so-called '2 + 1-concept' in Germany turns out to be a relative safe solution (Palm & Schmidt, 1999). Another opportunity is a combination of an increasing lane width and shoulder width, allowing for overtaking not crossing the centre-line ('the Swedish solution').

In considering intersection collision, roundabouts have a very good safety record in comparison to three- and four-way intersections. If such a solution is not cost-effective or is waiting for reconstruction-activities, channelization could be considered.

In addressing the issue the issue of speed variance, separating slow and fast traffic will contribute to the overall safety of rural roads. For the Netherlands for example, this means separated facilities for cyclists/mopeds and for agricultural vehicles.

#### 4.2. Urban areas including traffic calming

The proportion of fatal road crashes in urban areas varies from 15% to almost 50% in OECD countries (OECD, 2002). Between half and three-quarters of all injury crashes occur in urban areas. Road crashes in urban areas are often scattered randomly in an area, besides those crashes concentrated at 'black spots'. To illustrate this: about 75% of all crashes occur on traffic arteries, which form 25% of the road length in urban areas in the Netherlands. The other 25% occur in residential streets, scattered all over the area. Our vulnerable road users such as pedestrians, cyclists, young and older road users meet key-problems. This is the result of a complex mix of factors (ETSC, 1999) but underlying all other problems is the fact that the modern traffic system in our metropolitan areas, cities and villages has its origin in history and was not designed for modern traffic. Furthermore, adaptation of our roads and streets to more and more cars and traffic has been done mainly from a car-user perspective. The struggle between cities and cars started in many countries already in the 1950s and 1960s. Jane Jacobs and Colin Buchanan, the Radburn-principle, the SCAFT-guidelines are the eye-catching names to address the problems of the dominant position of motorized car traffic and the problems related to that at a very early stage. Road crashes were not seen as the dominant problem. It was the struggle between an efficient road traffic system and the liveability of the citizens in cities and villages. In the 1970s road crashes started to be considered as a problem, in close connection with liveability and amenity. Two answers were formulated to make our streets and roads in urban areas safer: more separation of different traffic modes (as was applied successfully in new areas) and integration (OECD, 1979). It soon became clear that from a road safety point of view, traffic calming in residential areas had to be area-wide rather than applying it to an individual street only. Low traffic volumes and a low density of traffic violations make police enforcement inefficient. Physical speed reducing measures were introduced to support a speed limit of 30 km/h.

Nowadays a more general term is used: traffic calming. Application of this principle started in residential streets, but these days we use the same ideas to make main traffic arteries safer. Traffic calming on traffic arteries aims at an appropriate speed for motorized traffic and to provide safe and attractive facilities for the vulnerable and soft transport modes.

In two large-scale pilot projects in the Dutch cities of Rijswijk and Eindhoven it was found that traffic calming indeed substantially reduced the number of injury accidents, not only in the 'woonerf' areas (homezones), but also in 30 km/h-zones. The reduction percentage reported were about 25%, and this same figure was also found in a recent meta-analysis on the effects of speed reducing measures in residential streets (Elvik, 2001). We have enough knowledge and expertise to design safe residential areas and to redesign existing residential areas (van Schagen, 2003). We have experiences from all over the world: Tempo-30 zones in Germany, 'silent roads' in Denmark, etc. From the 'human tolerance' perspective we learned that collision speeds between cars and vulnerable road users have to be lower than 30 km/h. And because the implementation of 'woonerfs' was costly and not more effective than 30 km/h-zones, it was decided just to implement 30 km/h-zones. In the beginning the size of the 30 km-schemes was limited. Later, due to the wish of local road authorities to reduce investment costs, traffic calming measures were only required when entering a 30 km/h-zone, at intersections, and at sites that are considered risky (in front of a school for example). In the Netherlands between 1985 and 1997, 10-15% of the urban residential roads were converted to 30 km/h-zones (Koornstra et al., 2002). The average saving of accidents in these zones is quoted as about 40%. Between 1997 and 2002 ( 5 years) the proportion of roads converted has increased to 50%. These last 5 years, the 30 km/h-treatments are not that comprehensive as in the period before. The interesting observation can be made that traffic calming is not an incidental treatment anymore, but all Dutch local authorities do implement these schemes and their character is more and more low-cost (in order to increase the treated road length). At the same time, the gradually growing length of cycle facilities and the increase of the number of roundabouts have accomplished a substantial improvement of safety. Roundabouts are the safest type of intersection in the Netherlands and their amount is growing every year. SWOV estimated a crash reduction of up to 70% is possible compared with the traditional 4-leg intersection.

As years passed by, the scope and considerations with respect to traffic calming broadened, emphasising urban-wide measures to reduce motorised traffic and to promote other transport modes. Urban safety management comprises a wide variety of interventions and measures (e.g. IHT, 1990, DUMAS, 2001). However, implementation of these interventions seems not to be taken on a large scale. The knowledge is there, pilot projects have been carried out. A further analysis of this lack of progress is appropriate. Integration with other policy fields in order to reach other goals as well, with the same interventions should be considered. It can be concluded from the Dutch experiences that to create a so-called 'delivery mechanism' for urban safety management, the role of local politicians and of public participation could not easily be overestimated (van Schagen, 2003).



## 5. New paradigm to further reduce road crashes

### 5.1. Introduction

In the history of road safety policy, different accents have been based on different paradigms over the years (OECD, 1997). In a SWOV-report (Mulder & Wegman, 1999), the sequence of policy accents is described; they evidently follow a pattern (SWOV, 1992). Early in the 1990s, SWOV was asked the question as to how road traffic in the Netherlands could be considerably safer: not 1000 deaths a year, but not more than 100 a year. Two lines were open. According to the first line, a considerable improvement had to be achieved by conducting the current improvement activities 'more and better'. The second line was that such an improvement would be achieved by adopting the vision that safety should also be a design principle for the road traffic system (as was for other transport systems). In the end, the conclusion was that the first line could lead to considerable improvements, but that additional ideas would be necessary to make the road traffic considerably safer. This originally led to the idea of an 'inherently safe road traffic' (based on ideas from the energy production and distribution). In order to obtain sufficient public support, the vision was renamed 'sustainably safe'. The *Sustainable Safe vision* is based on two leading ideas, as explained in paragraph 1: how do people try to prevent errors as much as possible and how to ensure that the collision conditions are such that the human tolerance is not exceeded and severe injury is practically excluded.

### 5.2. Sustainable safety: the vision

The aim of 'sustainable safety' is not present a burden for future generations of the road crashes consequences of today's and future mobility demands given that means are available to reduce substantially the costly and largely avoidable road casualty problem. From this perspective, it was chosen to 'borrow' from the well-known Brundtland-report on sustainable development, the adjective sustainable for safety as well: *no longer do we want to hand over a road traffic system to the next generation in which we tolerate that road transport inevitably leads to thousands of killed people and ten thousands of injured in the Netherlands, every year*. So, the starting point of 'sustainable safety' is to drastically reduce the probability of crashes in advance by means of infrastructural design. In addition, where crashes still occur, the process that determines the severity of these crashes should be influenced, so that serious injury is virtually excluded.

The concept is based on the principle that 'man is the reference standard' (human error and human tolerance). A sustainable safe traffic system has an infrastructure that is adapted to the limitations of human capacity, through proper road design, vehicles equipped with tools to simplify the tasks of man and constructed to protect the vulnerable human being (crash protection) as effectively as possible, and a road user who is adequately educated, informed and, where necessary, controlled.

The key to arrive at a sustainable safe traffic system lies in the systematic and consistent application of three safety principles:

- functional use of the road network by preventing unintended use of roads;
- homogeneous use by preventing large discrepancies in speed, direction and mass at moderate and high speeds;
- predictable use, thus preventing uncertainties amongst road users, by enhancing the predictability of the course of the road and the behaviour of other road users.

As stated before, the road user as the reference standard represents the central element in a sustainable safe traffic system. He/she must be prepared to accept an infrastructure, vehicles, and rules of behaviour, information and control systems, which may restrict his/her personal freedom, in return for a higher level of safety. If this willingness is not present, resistance will be the result. Freedom restrictions without good arguments should not be offered to the road users. Social marketing techniques could be used here.

The three safety principles (functional use, homogeneous use, and predictable use) require the specification of the intended traffic function of each road and street. Roads should perform one of the three major traffic functions:

- the flow function: enabling high speeds of long distance traffic and, often, high volumes;
- the distributor function: serving districts and regions containing scattered destinations;
- the access function: enabling direct access to properties alongside a road or street.

Besides a traffic function, streets and roads in built-up areas should allow people to stay in the vicinity of their house safely and comfortably. This so-called residential function could well be combined with the access function.

Education could and should play an important role in the transition period from the traffic system of today to a sustainably safe system. Education could concentrate on the whys and wherefores of sustainable safety. Public awareness, public participation and education should create support for implementation and find their place alongside implementation of other key elements of this vision. Without any doubt we shall need in the transition period as in the sustainable safe period education to learn and to motivate people to use the system safely and to deter of undesirable and dangerous behaviour by organising an effective 'deterrent chain' (police enforcement and punishment).

With respect to vehicles, the diversity of vehicles should be kept to a minimum. Furthermore, the various types should be clearly distinguished. When used in the same 'physical space', vehicles should demonstrate the same behaviour – in all respects – or otherwise be provided with separate road facilities. In the sphere of passive sustainable safety provisions lay those that work independently of the driver or passenger: 'built-in' devices like solid passenger compartments of cars with crushable zones and airbags (in addition to the compulsory use of seat belts). Improvements of the front-end design of passenger cars, to reduce injuries to vulnerable road users like pedestrians and cyclists, are relevant as well. In the field of active safety a lot of progress may be expected from devices, which provide relevant information to the road users, improve their observation, or simplify their tasks. An interesting development is the so-called Intelligent Speed Adapter

(ISA). Two real problems have to be solved here: gaining public acceptance and support, and developing an introduction strategy.

### 5.3. Sustainable safety: the implementation

The sustainable safety vision was conceived in the early 1990s. The consistent application of the three principles (functional, homogeneous and predictable use) requires the support and commitment of all stakeholders (all tiers of government, all road authorities and of the road safety community) to implement measures in a coordinated manner. In order to create such a partnership, the key stakeholders had to be involved in developing the vision and its implementation. Furthermore, it has to be understood that large amounts of funding were needed to adapt the Dutch road network to the sustainable safety principles. From the beginning, it was clear that not road safety budgets, but road budgets have to be made available in order to come to full implementation. SWOV-estimates indicated that an annual return of investment of 9 percent could be expected, which represents twice the usual 4 returns from large infrastructure projects (Poppe & Muizelaar, 1996).

Road authorities at all three levels (national, regional, and local) came to an agreement for a so-called 'Start-up programme', covering the period 1997-2002. The central government provided about €240 million, as a grant, about half of the costs. Later, it became clear that regional and local authorities provided a far higher amount of money. SWOV estimated that the regional and the local level invested something in between € 200 and € 250 million a year in improving road safety.

We have strong indications that these investments resulted in a reduction of number of people killed and injured in Dutch traffic. The formal monitoring and evaluation has not been published yet.

The process leading to full support of key-stakeholders has been described in other papers (Wegman & Wouters, 2002). From the introduction process, specific lessons could be learned to be at least supportive of, or were even a prerequisite for successful action:

- The conviction that the current policy was not sufficiently effective in reaching the road safety targets in the Netherlands. Thus something 'new' was needed.
- Road safety experts and the professional world should express themselves in full accordance with the new concept. If experts disagree, policy makers and politicians will feel uncertain and decisions might be postponed.
- The vision has to appeal in both the short term and the long term. Of course, no concept is drawn up for eternity.
- From the start, the vision has to enhance creativity and not resistance. An important element with respect to this: appealing directions and no obvious drawbacks.
- Road safety organisations and lobby groups (stakeholders and 'actors') have to consider the vision as offering them new opportunities.
- Implementation of the vision must be integrated in existing budget streams.

- Structural opportunities to connect the vision to other activities should be looked for and created: drafting guidelines for road design, education curricula for schools, etc.
- Last but not least: intelligent ways to commit stakeholders have to be found.

Sustainable safety is the cornerstone of Dutch road safety policies and forms an integral part of Dutch transport and traffic policies. The Dutch Government is drafting a new policy document on this and discussion on this policy document in Dutch Parliament is expected to take place 2004, if not later. In the meantime two further developments can be observed. Based on the successful action strategy in the past, prolonging the good and effective partnerships between the different tiers of government when it comes to implementation of sustainable safety (until 2010). The second development is to design the *Next Generation of Sustainable Safety*.

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