Influence of infrastructure design on road safety

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1. Causes of road accidents

It is seldom easy to assess a simple accident cause. Let me give an example. 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 him over a winding road. The teenager misjudges a bend. The car leaves the road and hits a lighting pole. Because the youths are not wearing seat belts, they are thrown out of the car. They die.

Cause? A young, inexperienced driver, not wearing a seat belt, driving at night along a road without a barrier, an unexpected sharp bend, bald tires? All of these factors could have contributed to the accident and to the outcome. Often a critical combination of circumstances is involved (OECD, 1984). Pointing to one single cause, finding one culprit for an accident does not do justice to the complex reality and - unnecessarily - limits the real opportunities to prevent accidents. Research reports in the United States and the United Kingdom (cf. Rumar, 1985) have concluded that 95% of accidents are due to human error (observation, decision making and response), 30% result from faults in road design and 10% are the result of mechanical defects (Figure 1)

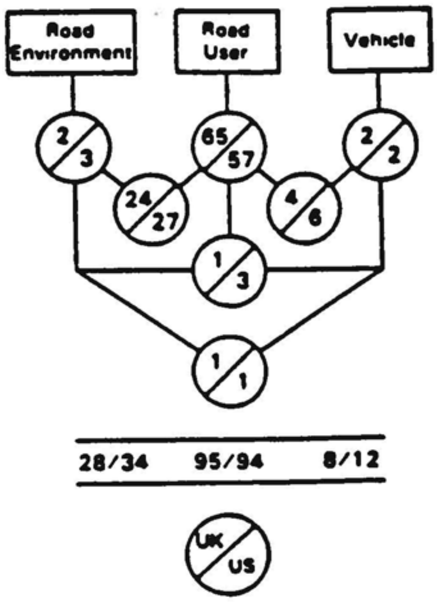


Figure 1. Percent contribution to traffic crashes as obtained in British and US in-depth studies (Rumar, 1985)

Often, and unfairly, the resultant conclusion is that road accidents can only be prevented through education, information and police enforcement. Such a conclusion is erroneous and researchers have warned often enough about drawing such a conclusion. Is it not the case that road improvements, for instance, are intended to prevent human error? Information about the 'single' cause of accidents does not logically lead to a conclusion about the most effective way of preventing accidents. It is also possible to draw erroneous conclusions if one relies on police reports in which the question of guilt is settled. One of the people involved in the accident has always violated the law in some way: traffic regulations are so strict. However, again, this does not say anything about the most effective or efficient way of preventing accidents.

It is advisable to use a so-called phase-model of the accident process when analysing road accidents and formulating countermeasures. Figure 2 shows an example of a simplified model.

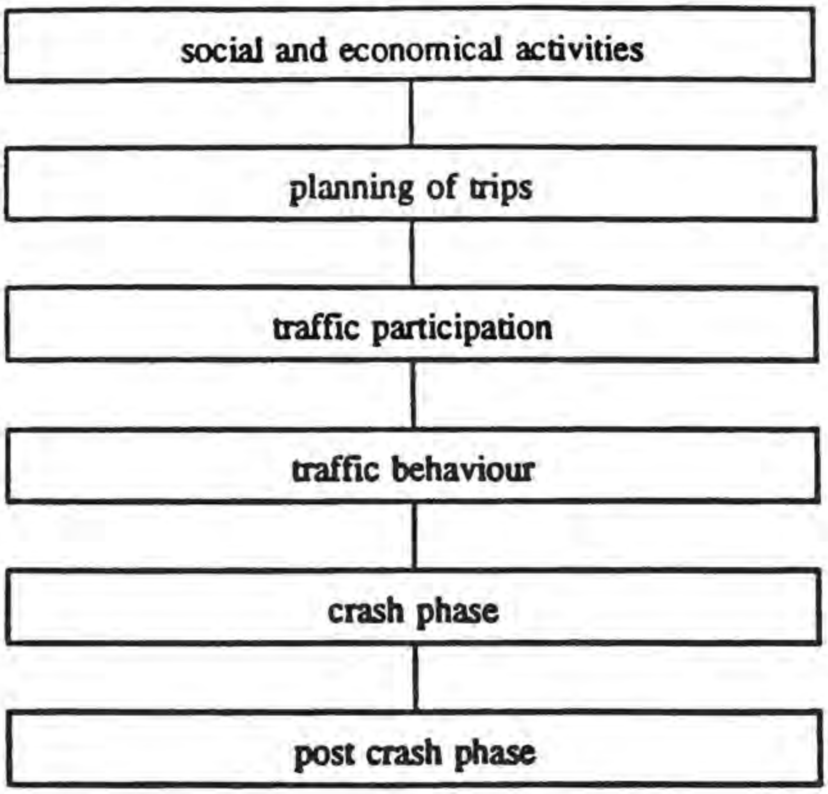


Figure 2. Phase model of the accident process

There are many opportunities to intervene in this process. The earlier the intervention, the more structural, preventive and effective it will be. In the end the road users themselves will have to prevent accidents and behaviour always plays a part in this. Others, though, (road authorities, road safety organisations etc.) can influence circumstances such that the risk of human errors is reduced. Preventing accidents or lessening the seriousness of the outcome is not only the responsibility of the individual road user but also of collective decision makers (authorities, private organisations, industry etc.).

Furthermore, people should realise that when it comes to decisions about road infrastructure and about the vehicles that use it, there are more arguments involved than road safety considerations alone: these include physical planning and land use policy, transport and traffic policy, environmental considerations, public health policy, etc (OECD, 1984). This means that road safety is just one of the criteria used in decisions of this kind. It very often happens that road safety is not considered to be the main objective, though decisions are made that may have consequences for road safety. Road safety is one facet of these other areas of policy. This may mean that, unfortunately, insufficient or no importance is attached to road safety, something that can happen consciously or unconsciously (par. 6).

2. Road design to prevent human errors

Proper road design is crucial to prevent human errors in traffic and less human errors will result in less accidents. To prevent human errors *three safety principles* have to be applied in a *systematic and consistent manner* as much as possible:
- preventing unintended use of roads, i.e. use that is inappropriate to the function of that road;
- preventing large discrepancies in speed, direction and mass, thus reducing in advance the possibility of encounters with implicit risk;
- preventing uncertainty amongst road users, by enhancing the predictability of the road's course and of the behaviour of other road users.

The first safety principle: preventing unintended use of roads, calls for first establishing the intention of every road. Roads are built with one major function in mind: to enable people and goods to travel from one place to another. We call this traffic function. Within this traffic function a distinction can be made between the following aspects:
- the *flow function* enabling high speeds of long distance traffic and, many times, high volumes;
- the *distributor function*: serving districts and regions containing scattered destinations;
- the *access function* enabling direct access to properties along a road or street.

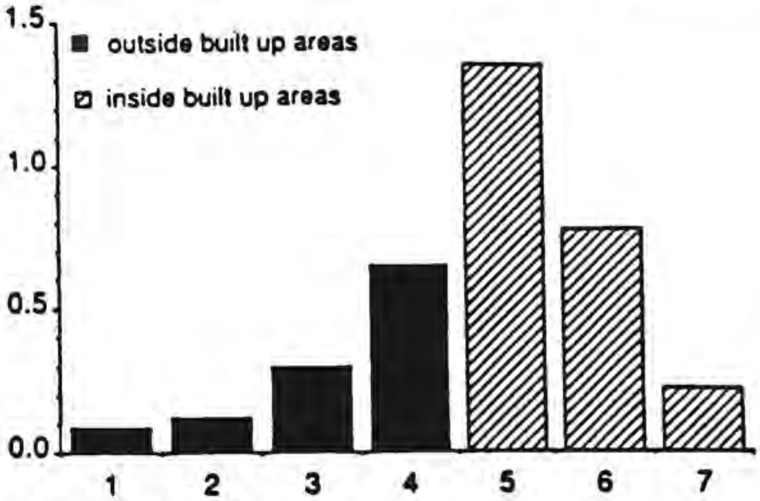
Beside a traffic function, streets and roads in built-up areas should allow people to stay in the vicinity of their house safely and comfortably for their social contacts or outdoor activities, should encourage children to play there etc. We call this function the *residential function.*

In the present situation, most roads are multifunctional, i.e. they perform a mixture of the different traffic functions and the residential function as well. But residential and traffic functions do not tolerate each other. The road user generally has to guess what to expect from the traffic situation, and is presumed to guess what others expect from him. This leads inevitably to a large number of conflicts. One thousand times it goes smoothly, until one time, an error is made.

Multifunctionality leads to contradictory design requirements. Therefore, in a sustainably safe infrastructure every road is appointed only one specific function. This concept comes down to the removal of all function combinations by making the roads *monofunctional*, i.e. by creating three categories of roads: pure through roads, pure distributor roads and pure access roads.

And the different traffic functions can not be combined because different functions lead to contradictory design requirements.

The application of this philosophy is most successful on motorways and in special 'woonerven' or 30 km/h-zones. This is demonstrated by the fact that these types of roads and streets show a relatively low accident risk, while arterial roads inside the built up area and rural roads demonstrate a high risk (Figure 3). In general terms: high driving speeds, many inconsistencies, many differences in direction and speed, different types of road users occupying the same space explain the greater risk figures for these roads.



1. Motorway: 100-120 km/h
2. Motorroad: 100 km/h
3. Arterial rural road: 80 km/h
4. Local rural road: 80 km/h

The most elementary classification for the built up area is subdivided into:

5. Arterial roads with a speed limit of 50 km/h (sometimes 70 km/h)
6. Residential streets with a speed limit of 50 km/h
7. "Woonerf" and residential street (approx. 8 km/h to 30 km/h)

Figure 3. Injury accidents in the Netherlands (1986) per million vehicle kilometres.

The function of a road should explicitly be defined in a traffic policy plan or in a plan dealing with land use planning or town planning (Brindle, 1984). Then, it is the task of the road designer to design according to the functional requirements. This design deals with road construction, with traffic engineering measures, road safety devices and, lastly, with traffic rules and regulations. To design new road lay-outs according to these principles is relatively simple. To translate these principles to existing situations is far more complicated. Schemes as from the Guidelines for Urban Safety Management (IHT, 1990a) could be helpful in this.

It turns out that *road classification* enables the roads to fulfil their various functions satisfactorily and solves the problems of contradictory design requirements of different functions. In Figure 4a and 4b two examples are given of road classification. A so-called *grid-system* (Figure 4a) could be considered as an unsafe system: all roads perform the same function, the same speeds are possible on all roads, safety devices are needed on all junctions, etc. In Figure 4b a hierarchy of roads is depicted. By using this hierarchy many aspects of traffic can be directed, thus improving the quality of traffic flows, of safety, of the environment, of the amenity, etc.

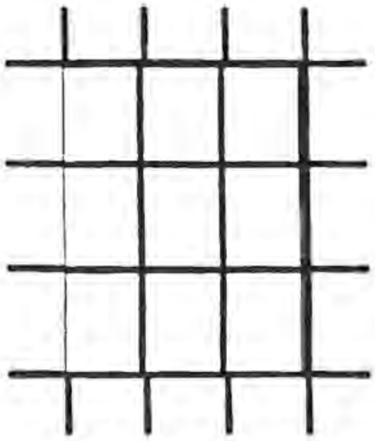


Figure 4a. Grid system

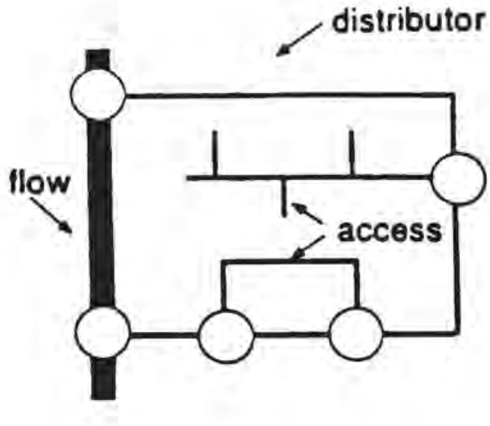


Figure 4b. Road hierarchy

It is impossible to discuss the design of all road categories in this paper. The following books contain interesting information on the relationship between infrastructure design and road safety (TRB, 1987, TØI, 1989, ITE, 1993). However, in a recent report (Ruyters, et.al., 1994) in the European Union the following observation has been made: " The unavailability and the non-accordance of road design standards for the road network in Europe increase risks and therefore contribute to the actual size of the road safety problems on this continent. As the cross-bordering traffic increase, it becomes even more valid from a road safety point of view for harmonizing road design standards on the level of the European Union". This leads to the warning not to rely being easy going on international literature reviews, and just to copy handbooks and textbooks from abroad.

We limit ourselves to two interesting types of roads to illustrate modern road design philosophy: rural/interurban roads and residential streets.

4. Rural roads

Using Dutch accident statistics four crash types produced 95% of all casualties on interurban/rural roads (Oei, 1993):

	%
- single vehicle/getting off the road/hit fixed object	32
- collisions with intersecting vehicles	24
- two vehicles/rear end collisions	20
- two vehicles/head on collisions/overtaking	19

There is no reason to believe that these figures should be substantially different in other European countries, but that could be verified of course. Characteristics of these accidents are rather well known, sometimes interacting, seldom one single cause and they could easily be derived from accident statistics: at night, on curves, involve alcohol, speeding, failure to yield, failure to obey traffic devices, age of involved drivers, etc.? Road safety professionals are trained to analyze accidents and to propose countermeasures to combat these causes. Different procedures could be used to carry out these road safety analyses (Catshoek & Slop, 1994): road safety inspection, black spot treatment and road safety impact assessment inc. road safety audits. Textbooks and handbooks are available how to come from problem analysis to countermeasures.

The rather traditional starting point of road design is design speed and correlated characteristics (stopping distances, friction coefficients, and sharpness of horizontal and vertical curvature, steepness of grades, width of lanes etc.). Based on these assumptions road alignment design and cross section design could be made.

But we have to admit that we still have to face two main problems talking about safety on rural roads. The first one relates to the fact that function of a road and road design are not attuned leading to human errors and higher accident risks (par. 2). The second problem deals with lack of knowledge: as traffic engineers we do not know exactly how and why the road user behaves like he does, and how we could change behaviour by proper design. Psychologists and engineers have to cooperate more to understand road user behaviour and to change it properly for example by means of proper road design.

To illustrate this view an example is given of horizontal curves on two lane roads (Brenac, 1994). Statistical studies show high accident rates on horizontal curves (1.5 to 4 times higher). Furthermore, sharper horizontal curves tend to have higher rates than curves with high radii. But, the accident rates are only relatively high when the average curvature of the whole alignment is low. High accident rates are observed at a bend when it follows a long straight line. Moreover, some studies show that internal factors (depending on the design of the curve itself) also have important effects, especially at bends having a small or medium average radius of curvature: the main defect is irregularity of the curvature inside the bend. Results of behavioural studies indicate the scanning-pattern of the drivers, when they detect a bend and after that when they negotiate a bend. When for some reason an unsafe bend on an existing road could not be reconstructed (now) several measures are possible to reduce risks by signing and marking. More homogeneous rules through the different (European) countries are needed in this field.

So, safe design of curve geometry is more than deriving a right curvature from a design speed. This conventional concept is not sufficient (Brenac, 1994). Introducing, in diverse forms, the expected actual speeds is positive but not sufficient. The introduction of *consistency rules* concerning the succession of the different elements of the horizontal alignment (radius of a curve following a straight line, compatibility of radii of two near curves) seems necessary from the safety point of view. We could expand this example to other design elements as well. *Consistency seems to be a key word in modern road design to create predictability and so to prevent human errors and accidents*.

Lamm (1994) developed an interesting 'design-consistency concept' in which three criterion play an important role:

- alignment consistency, expressed by the absolute difference of the 85th-percentile speeds between successive (horizontal) design elements should fall into certain ranges;
- harmonizing design speed and operating speed, expressed by the absolute difference of the observed 85th-percentile speed and the design speed;
- adequate dynamic safety, expressed by the difference between geometric assumed side friction and side friction demand.

'Good', 'Fair' and 'Poor' design levels could be derived from research in which design elements and corresponding speeds are correlated with actual accidents in curves. Generally spoken, research results in this area can not be copied simply to other jurisdictions but have to be validated.

Concerning the treatment of safety problems at curves on existing roads low cost measures are possible when some internal defects (e.g. irregularity of curvature, too long clotoids) are identified. In this case, slight amendments to the alignment, shoulder reconstruction or pavement treatment are often sufficient. In the other cases, low cost treatments are often limited to signing or equipment of the curve. Vertical, regularly spaced elements of delineation along the outer side of the curve give information directly useful for the perceptive task. Information along the inner side of the curve helps the driver to negotiate a curve.

5. Residential areas

A majority of road accident casualties inside built-up areas take place on traffic arteries, those streets or roads where traffic or flow function dominates. About 20 - 40% of the accidents has occurred in streets with a residential function. It is an exception rather than a rule to find black-spots in residential areas. Accidents are scattered over the entire area. This leads to the conclusion that an area-wide approach to solve road safety problems in residential areas is most appropriate.

Many children and older people, pedestrians and cyclists are casualties of road accidents in residential areas. These road user groups belong to the most intensive users of these areas. Older areas seem to be less save than new ones. No simple explanation can be found for this, but a combination of various factors play a part (more mixed functions of streets in older areas, more through traffic and parking problems, less space to play for children etc.

A literature study of Kraay & Wegman (1980) gives a survey of criteria, which have a positive or negative effect on road safety:
- Residential areas with closely built houses, old residential areas which are not very far from the town centre, display a relatively low road safety level. Areas with many shops and schools, with little playing space for children are relatively unsafe;
- In densely populated residential areas, with many young pedestrians in the streets, the road safety is relatively low.
- Undifferentiated road systems, a poor segregation of traffic categories, many cross-roads, long and narrow streets, involving complex traffic situations, have an unfavourable effect on road safety.
- Busy streets with relatively heavy traffic and many parked cars affect road safety negatively.

Studies from other European countries support these conclusions (Kjemtrup & Herrstedt, 1992).

In Dutch cities and villages, about 4000 residential areas were newly built or reconstructed and reclassified on the basis of this concept. Results of accident investigations indicate that the woonerf-concept lead to a reduction of approximately 50% in the number of accidents. The reduction in the number of injury accidents turned out to be even 70-90%. The woonerf was successful in improving amenity in residential areas and reducing accidents. Although some drawbacks could be notified as well: relatively high construction costs because of the additional engineering measures, the space needed for realisation and under high parking pressure conditions legal obligations could not be fully met. More simple and less costly options showed to perform at least as effective as the woonerf.

It was generally acknowledged (Wegman, 1993 and Wouters, et.al., 1994) that with regard to safety in residential areas two features are essential: reducing speed of traffic and reducing (through) traffic. From accident studies it turned out that the collision speed should remain below 30 km/h, because then the probability of serious injury will be minimal. From this finding it was deduced to set in residential areas the legal limit at 30 km/h. To guide Dutch municipalities to select effective speed-restricting measures a Handbook for 30 km/h measures was developed (Ministry of Transport, 1984). Handbooks are made in many other countries (e.g. Denmark, Germany, UK,). From accident studies we concluded a reduction in injury-accidents of 22%. This relatively low reduction percentage (compared with maximum results achieved) can be explained by the low magnitude of existing problem in many redesigned areas and the lack of quality of implemented countermeasures. A careful design is most important.

6. Road safety impact assessment (inc. safety audits)

In a black spot analysis the aim is to find indications for improving the layout of an accident prone location by studying similarities between characteristics of road accidents on that location. This type of analysis, primarily based on accident data, could be considered as a first generation of accident analysis. Complementary methods were recently developed to be considered as the second generation: analysis of 'black routes' and area-wide approaches. This methods are the start of high cost-effectiveness approach when low-cost engineering measures are taken: marking, signing, signalling, simple road maintenance etc. An important drawback of this black spot analysis is that first accidents have to occur before they could be analyzed and countermeasures could be considered and taken. For this reason another approach seems to become more popular: road safety impact assessment analysis.

Two primary objectives often predominate in (large) infrastructural projects: realising a high level of service and increased access for important destinations, economically or socially. An additional factor in recent years has been that plans should not place an excessive burden on the environment. The environmental effects of infrastructural projects must therefore be estimated in advance, through Environmental Impact Assessments (EIAs). If the political assessment of a particular project is negative, mitigation of environmental pollution could be agreed upon on the basis of the EIA-results. In a recent OECD-report (OECD, 1994) a distinction has been made between impact assessments at a more strategic decision level (SEIA) and that of an individual project or scheme (EIA).

Road safety is another quality aspect of road traffic which represents an equally important consideration in decision-making on infrastructure. At best, traffic risks are only considered implicitly and quantitatively in current decision making on infrastructural projects, which means that the consequences for road safety are not visible. This can mean that - unintentionally, but also unwittingly - road safety is not given sufficient consideration in decision-making process. It also hampers rational consideration of alternative solutions.

In a Road Safety Impact Assessment (Wegman, et al., 1994) safety impacts are assessed of changes in road infrastructure on two levels:

- the changes of the distribution of traffic over a certain road network due to changes of that network;

- the changes of design characteristics of roads.

On the first, more *strategic level*, a tool has to be developed to optimize network design by using a risk scenario technique. Such a technique could be based on a well known fact that physical features of a road network, together with the traffic volumes on that network are the main explanatory factors of the number of accidents happening on that network. Three steps can be described in the risk scenario technique:
- to prepare the reference material: establishing the categories of road types for a certain jurisdiction and the relevant road safety indicators per road type.
- preparing for a certain region an inventory of all roads, their traffic volumes and locate registered accidents per road type, when possible digitalized using GIS. Compute and validate regional safety indicators.
- for the same region as in step 2, make an estimation of the road network, its traffic volumes and the road safety indicators. Try to establish the road safety effects of changes of the road network and the traffic volumes.

Make an interpretation (impact assessment) of the RIA-result to be used in public discussions and in the political decision process.
"The main objective of safety audits is to ensure that all highway schemes operate as safely as possible: this means safety should be given thorough consideration throughout the whole preparation of the project." This quotation is to be found in the 'Guidelines for: The safety audit of highways', issued by the British Institute of Highways and Transportation (IHT, 1990b). The background of safety audits on a *project level* is to carry out formal checks to ensure that during the design and realisation phase of infrastructural projects road safety aspects have been covered explicitly, soundly based in accident investigation experience (Ross, et.al., 1993). Audits could be applied to existing roads as well as new designs. On existing roads a balance have to be found between normal accident investigations and the use of so-called audit checklists. The essence of an audit is that the (independent!) auditor is able to arrive at a road design which is simple and recognizable for future road users, thereby minimizing potential for error. Four phases are distinguished in the UK-guideline for road safety audits: feasibility/initial design, preliminary design, traffic signs and inspection of the road.

A road safety impact assessment seems to be an useful instrument for assessing those aspects relevant to road safety at an early stage and during all subsequent phases of the road design. It is to be recommended not to start road safety audits before the results are available of the first phase of a RIA: network scenario's.

To summarize the principle characteristics of a RIA:
- does not result in a choice, but offers a supported overview of all sensible alternatives which can be considered in the decision;
- leads to the optimum concrete and operational description of the objectives;
- considers all reasonable alternatives;
- offers an overview of the uncertainties and gaps in know-how which, if relevant to the decision making process, should be solved as a matter of priority;
- leads to an evaluation plan.

7. Sustainable safe road transport system

The number of traffic fatalities in high-motorized countries constitutes a sacrifice that would not be tolerated in any other man-made invention: in comparison with rail and aviation traffic, people involved in road traffic run some 100 to 200 times greater risk per passenger kilometre travelled. Road traffic would also find it impossible to meet standards imposed by society on the working environment, technological-power installations and natural disasters: participation in road traffic per unit of time is no less than 1,000 times more hazardous. In the road traffic system of today, non-professional motorists operate, unequipped with automatic pilot but high-speed vehicles, who are still confronted by all types of surprising traffic situations.

Are we beyond the stage of astonishment? Are we so used to road hazard, combined with the assumed inability to do anything about it, that we seem to have adopted a somewhat apathetic attitude, which permits too much laxity in the approach towards road hazard? By demonstrating that road hazard can most certainly be effectively combated, and does not have to come with an excessive price tag, this passive acceptance can be tackled, and a sufficient base of support can be created to enable radical measures.

Despite the marked rise in motorised mobility, the absolute number of accidents per year has gradually fallen since 1970. The annual fatality statistic for Dutch traffic is still about 1300, however. The Dutch Government considers this figure to be unacceptably high.
Road safety objectives laid down in a long term traffic safety plan include as a target for the year 2010: a further decrease in the number of fatalities by 50%, compared with the reference year 1985. In view of this, the SWOV Institute for Road Safety Research was asked by the Dutch government to develop, in close cooperation with other research institutes, a scientifically supported, long term concept for the implementation of an essentially safer road traffic system (SWOV, 1993).

The general concept of sustainable development introduced by the UN Brundtland Commission also inspired the vision we evolved in the field of road safety: no longer do we want to hand over a road traffic system to the next generation in which we tolerate that road transport leads to thousands of killed people and tens of thousands of injured people. Instead, we should try to drastically reduce the probability of accidents occurring in advance.

The concept of *'sustainable road safety'* is based on the idea that man is the reference standard. Human beings are capable of many things, but present-day traffic makes excessive demands on their abilities, causing them to make mistakes, sometimes with fatal consequences. Our task is to adapt traffic and transport systems to people, so that they can behave safely, instead of insisting that people adapt to the system - on penalty of death or permanent mutilation. A sustainably safe traffic system has:

- an *infrastructure* that is adapted to the limitations of human capacity through proper road design;
- *vehicles* fitted with ways to simplify the task of man and constructed to protect the vulnerable human being as effectively as possible; and
- a *road user* who is adequately educated, informed and, where necessary, controlled.

It is not possible yet to give a complete picture of a traffic and transport system designed for sustainable safety, because we are still finding things out. But certainly, certain statements can be made about the three parts of the traffic system referred to just now.

If the *functional classification of the roads* is properly carried out, with a matching layout of the roads, the actual use of the roads will also agree.
Pure *through* roads require a design which allows high speeds. Oncoming, crossing and intersecting traffic should not occur. Fixed roadside objects should be kept at a safe distance, or properly protected. Present motorways meet these requirements.

Pure *distributor* roads require a relatively high density of junctions. Slow and fast moving traffic should be kept separate and oncoming traffic must be avoided as much as possible. Driving speed should always be reduced at intersections. The majority of present urban arterial roads and non motorway rural roads fail in this respect.

Pure *access* roads should prohibit driving speeds over 30 km/h, at least inside built-up areas. On these roads, the possibility of conflicts between slow and fast traffic may still exist, but the low speeds allow good anticipation and avoidance of hazard, while furthermore, any accident that does occur should not have a serious consequence.
30-km/h areas are already seen to a limited extent in many towns. Outside the built up areas, nothing has been done to design access roads in accordance with the principles of sustainable safety.

With respect to *vehicles*, it can generally be stated that in order to harmonise with the aforementioned objectives, the diversity of vehicles should be kept to a minimum. Furthermore, the various types should be clearly distinguishable. When used in the same traffic area, vehicles should demonstrate the same behaviour as far as possible, or otherwise be provided with separate facilities.

Also in the field of vehicular improvements, there are gains to be made. In the sphere of *passive* safety, specific sustainable provisions can be mentioned here are those that work independently of the driver or the passenger. These 'built-in' or passive devices could be structural design elements such as solid passenger compartments of cars, surrounded by programmed collapsible elements at the front, the rear, and the sides. Airbags in cars are other modem examples of these passive safety devices. In the field of *active* safety, substantial progress could be made through by the practical application of sophisticated electronic means designed to relieve elements of the driving task or to help drivers in complying with the rules.

In a sustainably safe road transport system, the *road user* represents the central element. He must be prepared to accept an infrastructure, vehicles, rules of behaviour, information and control systems that may restrict his individual freedom, in return for a higher level of safety. If this willingness is not present, resistance will result. Perhaps the principles of '*social marketing*' will need to be applied in order to create a favourable climate (OECD, 1993).

This does not mean that in a sustainable, safe road traffic system, traffic lessons would no longer be necessary. To the contrary, attention should be focused on adequately educating the road user, in all phases of his life. Furthermore, it will always remain essential to discourage certain groups from using the road, for instance those driving under the influence of alcohol.

It is evident that, will a full implementation of a sustainably safe traffic system, major *financial efforts* will have to be invested in the field of the infrastructure. The scope of the required adaptations is so great that this process will take many years. If sustainable safety is implemented at the same rate as, and running in parallel with, the standard maintenance of the infrastructure it is possible to reduce the associated costs considerably. Tentative estimates have lead to the conclusion that the introduction of a sustainably safe traffic infrastructure would cost 10 to 20% more than traditional maintenance procedures.

In this context, it is good to know that, from a *macro-economic perspective*, the savings are considerably higher than the costs of sustainable safety. One fundamental problem, however, is the fact that the savings do not come back to the bodies that provide the means. Those who will benefit from the savings include insurance companies and insured parties who may pay lower premiums, while the government, i.e. the tax payer, or the users of the infrastructure will tend to be responsible for the costs. If this problem is solved, a sustainably safe road traffic system is not only feasible, but also affordable.

This vision has meanwhile been incorporated into the Dutch policy to improve road safety. The basic principles now receive support from all important traffic organizations and also from the Dutch Parliament. This acceptance is prudently being converted now to actual deeds.

8. Conclusions and recommendations

Road accidents usually occur as a result of a critical combination of circumstances and seldom have just one cause. There appears to be many opportunities for preventing human error that brings about road accidents (cf. the so-called phase model of the accident process). It is advisable to use this model when analysing road accidents and formulating countermeasures. This calls for integrated road safety programmes and requires the government to be organised in such a way as to reflect these.

Proper road design is crucial to prevent human errors in traffic and less human errors will result in less accidents. To prevent human errors three safety principles have to be applied in a systematic and consistent manner as much as possible: preventing unintended use of roads, preventing large discrepancies in speed, direction and mass, preventing uncertainty amongst road users. Where these principles have been applied best (motorways and residential streets) low accident risks occur. In general terms: high driving speeds, many inconsistencies, many differences in direction and speed, different types of road users occupying the same space explain the greater risks for arterial roads in urban areas and for rural roads.

The function of a road should explicitly be defined in a traffic policy plan or in a plan dealing with land use planning or town planning. It turns out that road classification enables the roads to fulfil their various functions satisfactorily and solves the problem of contradictory design requirements of different functions.

To illustrate this design approach two examples are given: for rural roads and for residential areas. Starting from an explictely defined function of a road, consistency seems to be a key word in modern road design to create predictability and so to prevent human errors and accidents. Road design manuals and guidelines are recommended to be prepared and delivered to the designer. This offers the best possibility for safe designed roads and streets.

It is to be recommended to make road safety arguments as explicit as possible in the decisionmaking process about infrastructure design on a strategic level and on a project level. A Road Impact Assessment (RIA), inc. a road safety audit, seems to be an useful instrument for assessing those aspects relevant to road safety at an early stage and during all subsequent phases of road design and implementation

The improvement of road safety should be situated in the long-term perspective of development towards 'sustainable safe road traffic'. Even when motorised mobility is growing, a substantial reduction of road casualties seems to be possible. The concept of 'sustainable road safety' is based on the idea that man is the reference standard. The underlying thought in this regard is to drastically reduce the probability of accidents in advance, through the design of infrastructure. And in so far accidents still occur, the process that determines the severity of accident should be influenced such that serious injury is virtually excluded.

By improving road design major steps could be made to prevent human errors and, even when mobility is growing, to reduce the number fatalities and injuries. New ideas of modern road design are available, as indicated in this paper. The concept of 'sustainable road safety' looks promising as a gateway to a next generation of safety measures. This approach starts with our astonishment about accepting the road deaths toll of today and by demonstrating that road accidents can be tackled by radical means. From a macro-economic perspective, the savings are considerably higher than the costs of sustainable safety. A sustainable safe road traffic system is not only feasible, but also affordable.

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