DHV Environment and Transportation

Sustainable safe road design

A practical manual

A manual produced for the World Bank
and the Dutch Ministry of Transport,
Public Works and Water Management

September 2005

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FOREWORD

Every year more than a million people die in road crashes around the world, and about 70 percent of these deaths occur in developing countries. Pedestrians represent 65 percent of road crash deaths and 30 percent of them are children. In addition, a staggering 20 to 50 million people are injured or disabled each year in road crashes in developing countries, often pedestrians, motorcyclists, bicyclists and non-motorized vehicles occupants. This human tragedy is doubled by the catastrophic impact of loss of revenues and cost of medical care, as entire families can slip into deep poverty, wiping out the gains accumulated over years, and impacting, in turn, their communities. The emergencies created by road crashes also consume precious medical capacities in the health sector, and reduce the overall access to health care.

This silent epidemic is rapidly getting worse in developing countries. Research conducted by the World Bank [1] estimates that global road fatalities will increase by more than 65 percent between 2000 and 2020, unless intensified safety interventions are implemented. In Europe and Central Asia fatalities are forecast to increase by nearly 20% between 2000 and 2020,

These deaths and injuries are preventable as illustrated by the contrasting trends across regions. Road fatalities are forecast to decrease by nearly 30% in industrialized countries, defined as the G-7 countries, together with the Euro area countries and Korea, Hong Kong and Singapore. The Netherlands has been leading the way in this trend of improved performance. Its sustainable safety vision has been acknowledged as one of the most innovative and successful approaches to improving road safety in industrialized countries. The value of designing and implementing infrastructure to reduce the probability and severity of crashes has been proven, and measurable safety gains have been achieved.

The transfer of best practice knowledge must be tailored for widespread application. Uncertainty about the applicability of the sustainable safety vision in transitional and developing countries was addressed during the preparation of this Manual. Weak safety design capacity, poor institutional co-ordination and limited budgets presented substantial challenges to the adoption of the holistic approach applied in the Netherlands. The Manual reflects the realities of country environments encountered, and elements of the sustainable safety vision have been confirmed.

This 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 represents a first step in what will be a longer journey to implement safety as a leading and fundamental design criterion for road transport, just as it is for other transport modes. The quality of this Manual, and the gusto with which the ideas were received in the region, suggests that adoption of the sustainable safety vision could have a substantive and lasting impact on road safety in the region.

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[1] Kopits, E. & M. Cropper, (2003) *Traffic Fatalities and Economic Growth*, Policy Research Working Paper 3035, Washington DC

1 INTRODUCTION

1.1 Manual for safe road design

This manual has been created during the project ***"Safe Road Design",*** funded by the World Bank and in cooperation with the Dutch Ministry of Transport, Public Works and Water Management as part of their 'Partners for Roads' programme. The consultancy services are provided by: DHV Environment and Transportation, The Netherlands.

The project is governed by contract no. 7129423, dated 7 May 2004. The date of the commencement of services was 26 May 2004.

"Sustainable Safe Road Design, a practical manual" is a manual to assist when developing national roads outside urban areas. The three core aims are:
1. to provide an overview of relevant safe road design practices;
2. to provide material for future training courses;
3. to guide experts in applying safer road design measures in different countries.

This manual is not a guideline on road design for one specific country. The manual is based on both the Dutch philosophy of sustainable safe roads based on the Dutch standards and guide lines and on the training sessions given in Bulgaria, Estonia, Latvia, Lithuania, Poland, Romania and Turkey in Autumn 2004 and Spring 2005.
Every location, every country and every culture is distinct in its own way and an appropriate solution needs to be found for each location. The information contained in this manual should always be adapted for the specific situation.
Not all weather and geographical conditions are treated separately from each other. It is important to develop country guidelines which consider the specific conditions encountered on the roads.

The manual is written:
1. to give designers guidance to find adequate solutions for a problem area;
2. to provide decision makers with proof of the possible benefits of a specific solution;
3. to use as a reference book;
4. to use as teaching material.

1.2 Road safety policy

The promotion of road safety should be priority for every road authority. Attention is generally focused on situations where a relatively large number of accidents and/or fatal accidents occur. Measures designed to tackle those accident concentrations should be based on thorough, objective analysis of the problems (determination of the origins). While accident analysis and investigations are very important this is a reactive approach to an existing situation. With sustainable road design the approach of road safety is pro-active: prevention is better than cure! An pro-active attitude by the road authority is essential to avoid situations that can result in accidents. This approach was stimulated in the Netherlands a few years ago under the banner of 'sustainable safe traffic'. In such a system road safety is the leading principle in the development of road infrastructure, such that:

- the chance of accidents due to the design is drastically reduced from the start;
- in sofar as accidents still happen, the circumstances are such that the chance of serious injury or fatal accidents is minimised.

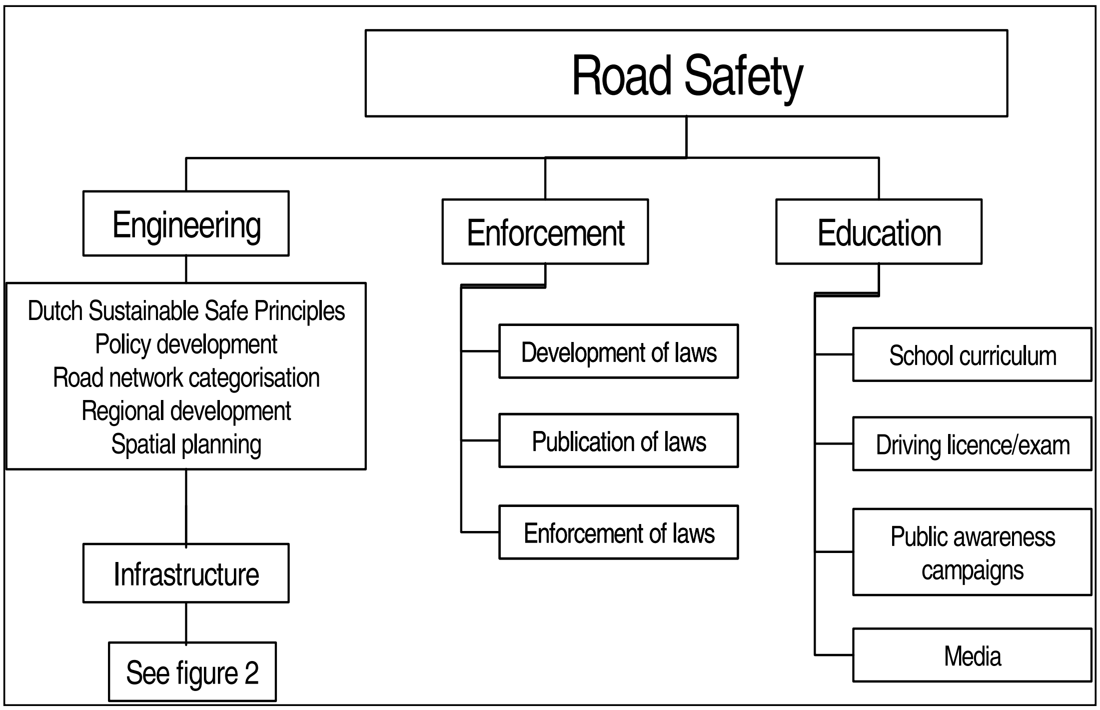


Figure 1: Road safety elements

The principles of sustainable safety are:

- Adjustments for the requirements of town and environmental planning;
- Adjustments for the requirements of safe road design;
- Adjustments for the requirements of mobility;
- Improved education and enforcement of road safety laws.

These four different principles are supplementary to each other and with mutual objectives to increase traffic safety. In any choice related to traffic and transport, safety has to be taken into consideration. Policies in the field of traffic safety have interfaces with various other tasks of public authorities (integrated approach).

1.3 Set up manual

The manual "Sustainable safe road design – a practical manual" contains information on the principles of sustainable road design, looking at the specific engineering implications. This manual focuses on the engineering principles of sustainable road safety, and covers to a lesser degree the principles that education and enforcement play in sustainable safety. The manual focuses only on two-lane roads (single carriageway) outside built-up areas.

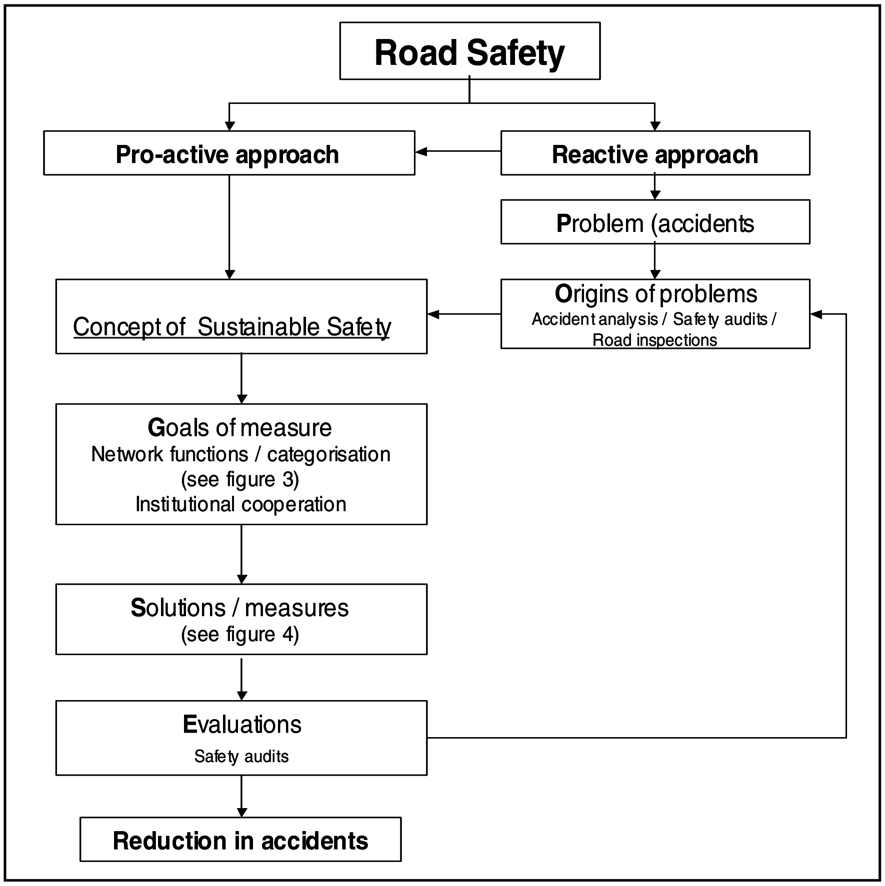


Figure 2: Pro-active and reactive approach to improve road safety through road design

This manual can be used on its own to examine the theory and practice of Safe Road Design. In combination with the manual "Take Over!" in which information about institutional cooperation is provided, a training programme for road designers can be developed.

In chapter 2 the methodology for analyzing a situation is introduced: POGSE (Problem-Origin-Goal-Solution-Evaluation, see figure 2). Chapter 3 is an introduction to sustainable road design- covering the topics of road function and categories. In Chapters 4 – 8

Narrowing distributor road

sustainable road design practice is covered – touching on the elements of engineering, such as cross sections, junctions, alignment, linear villages and pedestrian crossings to improve road safety. In Chapter 9 some practical examples from Lithuania, Latvia, Estonia, Poland, Romania, Bulgaria and Turkey are illustrated.

The process of 'black spot' analysis is carefully outlined in chapter 10 and illustrated with an example from the Netherlands. Chapter 11 outlines use of cost benefit analysis to determine the optimum solution. Education and enforcement, the other two E's important to implementing successful road safety are covered in Chapter 12.

2 SOLVING ROAD SAFETY PROBLEMS: A STRATEGY

2.1 Present practice

Traffic problems are often approached from a specific point of view. The road owner (authority, council) identifies a problem, a group of experts develop a solution and the owner takes a decision. Occasionally, involved parties such as residents, school boards, retail associations or councillors are given the opportunity to put their view forward. The danger of a one-sided approach is that not all aspects of the problem are sufficiently dealt with. Was a cheaper solution possible instead of the expensive traffic regulation system? Has the problem actually been solved? In this manual emphasis will be on road design in relation to road safety with special attention to design standards, accident analysis and cost-benefit analysis. A step-by-step method is described to lead from problem recognition to development of adequate and appropriate solutions.

2.1.1 Policies

Road safety policy is in many countries a spearhead action. For instance: it is based on selecting and analysing black spots, giving special attention to vulnerable road users (pedestrians and cyclists) or predominant accident types (speeding, alcohol). In United Kingdom, Sweden, the Netherlands and Denmark this policy has proven to be very successful in reducing the number of accidents and fatalities. However, for continuing the downward trend in fatalities and injuries it is necessary to develop a more comprehensive approach, based on the interaction between humans, vehicles and the infrastructure. In the Netherlands this approach is known as "Sustainable Safety". In Central and East European countries with high accident rates, due to the strong growth of car ownership and partly inadequate infrastructure, the spearhead policy seems to be the most cost-effective manner to start with.

2.1.2 Approach

The frustrations of interested parties not involved in the process should not be forgotten, nor the interminable discussions afterwards which come too late in the day. A great deal of unnecessary time and money is wasted in this way, certainly if the situation has to be modified afterwards. Unnecessary because there is a better approach to traffic problems:

POGSE

This is a simple aid to quickly and effectively analyse and solve problems. POGSE stands for

- **P**roblem
- **O**rigin (cause)
- **G**oal (objective)
- **S**olution
- **E**valuation.

2.2 Integrated approach

POGSE is a coordinated approach, integrating a number of logical steps to solve the problems of traffic safety. It promotes consultation and active involvement of all parties concerned (the stakeholders) to systematically seek solutions to traffic problems. The starting point is the opinion that all stakeholders – with their traffic behaviour and views on traffic– should play a role in seeking and finding the correct solutions. Communication and cooperation are just as important as traffic science and engineering.

With the POGSE approach all parties involved are assured of the opportunity for maximum input to the decision-making process. The POGSE approach saves time, money and frustration and provides demonstrably better results. In the Netherlands it is applied successfully in various situations, both simple and complex, to solve traffic problems.

The POGSE approach has many advantages. Most important, naturally, is the quality of the decision. The broad approach generally generates points of view that are overlooked in the one-sided approach. With the POGSE approach the various points of view can be carefully weighed up against one another.

The approach, simplified by the steps Problem-Origin-Goal-Solution-Evaluation, summarises the entire decision-making process. Contrary to the conventional approach, involved parties are not confronted with ready-made solutions, but they are given the opportunity to participate and react early on in the process.

2.3 POGSE: step by step

Problem

A problem is mainly related to a location (junction) or a road link. It can be determined on the basis of accident records (see chapter 10: "Analysis of accidents"), but may also follow from complaints of local residents. Insight is needed in the present and future function of the road or road links. (see chapter 3: "Sustainable safe road design: theory"). The trap of confusing the problem itself and the cause of the problem should be avoided (see the next step of the POGSE approach). Consensus of the stakeholders on the real problem and the intended function of the road (link) are required before the next step is started.

Consensus of stakeholders

Origin (cause)

When agreement regarding the nature of the problem is achieved; it is possible to proceed to the following phase: indicating possible causes. Opinions can differ drastically here between the stakeholders. Car drivers, for example, can be inclined to point to irresponsible cyclists' behaviour, while vice versa there are complaints about speeding by car drivers. At this stage, clear, independent research is indispensable. It is essential for all opinions to be considered, as more than one cause can lead to the identified problem. Also with this step, agreement on the cause(s) of the problem is a requirement before proceeding to the next step.

All stakeholders should be convinced

The analysis may concern:

- accidents (black spot analyses, see chapter 10);
- complaints (local residents, drivers, school boards, other pedestrians);
- traffic data (speeds, volumes);
- confusing road lay out;
- evaluation of measures (reconstruction or else) taken in the past (see the last step of the POGSE in this chapter).

Goal (objective)

Once problems and causes have been analysed and established, a common objective needs to be formulated. For example: within a certain period the number of accidents at a junction have to be halved, or cyclists are not to be mixed with fast speeding traffic on a particular road link. In every case, the description of the objective needs to include the highest achievable return.

If an agreeable objective cannot be specified, there is a danger of remaining on a too general level like "Improving the road safety". Make sure the objective can be measured by defining a quantified improvement. In the evaluation the results of the measures taken (the solution) will be checked or audited against the goals identified in this step. When a specific, common goal is agreed, possible solutions can be identified and implemented, which is the next step.

Solution

This step is to devise possible solutions, in which the traffic expert has an important role. The input or basis for optional solutions are the conclusions of the previous steps (the goal in particular). The stakeholders may propose alternative solutions to facilitate discussions and decisions. The final choice is made considering the following:

- which solutions have the best effect (comes nearest to the goal or goals)?
- what is the cost?
- are other works foreseen to combine with specific measures?

A cost benefit analysis (see chapter 11) may provide more insight when comparing and discussing possible solutions. All stakeholders should be convinced that the final choice would provide the benefits appropriate to the identified objective or goal. If so implementation (design, construction, installation) can proceed.

Evaluation

Evaluation is the continuous monitoring of the effects of measures, followed by comparison with the set goals. Monitoring means collection and analysis of traffic data and accident data,

complaints. Experience shows that implemented measures do not immediately lead to an improvement of the situation; it may even worsen initially. Evaluation is also very important to gather experience and knowledge about safety measures within certain circumstances.
Comparison with the set goals means: an answer to the question whether results are as expected (do the results comply with the goals).

An evaluation period of three years is generally observed before definite conclusions are drawn. If found that the benefits are not satisfactory, the POGSE approach should be repeated, most probably leading to a refinement of the initial solution.

3 SUSTAINABLE SAFE ROAD DESIGN: THEORY

In the early 1990's, in the Netherlands Sustainable Safety was developed as a vision towards a safer road traffic system. The aim of Sustainable Safety is to avoid burdening in a future generation with the consequences of road traffic accidents resulting from current and future mobility demands. The means are available to substantially reduce the costly and largely avoidable road casualty problem. 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 deaths and injuries every year.

3.1 Safety concept

The starting point of the concept of ‘Sustainable safety’ is to considerably reduce the probability of accidents through improvements in infrastructural design. In addition, where accidents still occur, the process that determines the severity of these accidents should be influenced, so that serious injury is minimized.

The concept is based on the principle that “man is the reference standard” (the human factor will always be present), 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 as effectively as possible;
- and a road user who is adequately educated, informed and, where necessary, controlled. The ability and vulnerability of man should be the reference standard and road safety problems should be addressed at all levels.

The key to achievement of a sustainable, safe traffic system lies in the systematic and consistent application of safety principles.

3.2 Safety principles

The Sustainable Safety starting point of man, with his cognitive and physical limitations as a reference standard, is elaborated in an *integrated* vision of the elements of 'man', 'vehicle', and 'infrastructure'. In sustainable safe road traffic, the entire traffic and transport system is adjusted for the limitations and capabilities of road users. The objectives are prevention of of accidents; and that the consequences of accidents are kept to a minimum. The infrastructure should prevent collisions of moving objects with large differences in direction, speed, and mass and should also inform the road user what behaviour is expected. Road users are educated and informed properly; their behaviour is tested regularly.

Sustainable safety is based on a systematic approach where all elements of road safety and the transport system are geared to one another. Traffic has to be regarded as a system with infrastructure, regulations, vehicles, and traffic participants as the main elements.

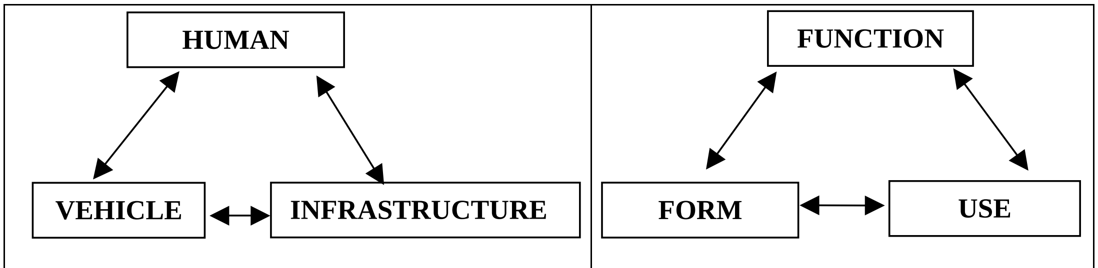


Figure 3: Systematic approach to Sustainable Safety

At the highest level it is the interaction between man, vehicle, infrastructure and legislation. At the next level it is the relation between function, form and usage (see figure 3).

- *Function:* relates to the use of the infrastructure as intended by the road authority;
- *Form*: relates to the physical design and layout properties of the infrastructure;
- *Usage:* relates the actual use of the infrastructure and the behaviour of the user and legislation relates to regulatory requirements for the use of the infrastructure.

All these elements must be attuned to one another within the concept of sustainable safety. That tuning is a matter of coordination between performance, formula, regulations and usage. In summary a sustainable, safe traffic system comprises:

- a road environment with an infrastructure adapted for the limitations of the road user;
- vehicles equipped with technology to simplify the driving task and provided with features that protect vulnerable and other road users;
- road users that are well informed and adequately educated;
- legislation and enforcement safe driving practice.

The essence of the sustainable, safe approach is that prevention is better than a cure (as opposed to intervention afterwards). Each category of road requires a design compatible with its function, while at the same time ensuring optimum safety. To meet the latter requirement, all road categories should comply with the following three safety principles:

- *Functionality:* preventing unintended use of the infrastructure: the traffic will be distributed over the road network as was intended and the various roads are used by the types of traffic for which they are designed;
- *Homogeneity:* avoiding significant differences in speed, driving direction and mass of vehicles. Differences in speed and mass between transport modes using the same link or junction at the same time is reduced to a minimum;
- *Predictability:* avoiding uncertainty among road users; as far as possible predictable traffic situations; road users anticipate the layout of the road correctly.

Functionality
The functionality of the road system is important such that actual use matches with intended use, as designed by road authorities. Roads, within the road network, have different functions (see paragraph 3.5) clear distinction between the roads with a through function or an access function needs to be made. In other words ‘through traffic’ or long-distance traffic does not belong on roads with an access function, and local traffic does not belong on roads with a through function. This requirement has implications for design of roads in the network. Roads with an access function should not offer time-saving, alternative routes (rat runs) to through traffic (that is: traffic travelling to or from a location outside the immediate area); and roads with a through function should not offer direct access to homes, schools, offices, factories, sports facilities, etc.

The requirements for functionality are:
- realization of as many connected residential areas as possible; make residential areas as large as possible without division by through roads;
- minimum journey time along unsafe roads, let the main part of every trip be traveled over the safest type of road;
- trips as short as possible;
- shortest and safest route should coincide.

Sustainable safety makes demands on functionality that requires individual road user to choose a route that is safe, for both themselves and for others. This means that a ‘through’ journey may not go through a residential area. Driving along an unsafe road for too long is also not desirable. A large residential area is safe for internal traffic; and prevents too many crossings-over by slow traffic of the surrounding through roads. An area that is too large leads to too much internal traffic; one that is too small leads to too many junctions with the surrounding through roads.

Homogeneity
The severity of road accidents is usually determined by the factors of speed, direction, and mass of vehicles. Worldwide the safest roads are the motorways, based on the number of casualties per kilometre driven as the safety indicator. Although driving speeds are the highest they are relatively uniform and is little variation in direction (e.g. no crossing traffic) and vehicle mass (no pedestrians, cyclists, mopeds or slow moving vehicles). The 30 km/hr zones and residential areas, are also relatively safe despite considerable variation in the direction and mass of traffic participants. In these cases the increased safety is attributable to low driving speeds and small speed variations between different road users.

Speed is one of the core issues in road safety. Higher driving speeds lead to greater collision speeds and thus to more severe injuries. Higher driving speeds also provide less time to process information and to act on it, and the braking distance is longer. Thus the possibility of avoiding a collision is smaller. In short, fast speeds lead to a higher incident of accidents, also with a more severe outcome. However, we do not sufficiently know the exact relation between speed and road safety. We also do not sufficiently know the conditions that influence this relation to calculate the effects of concrete speeding measures.
It is not straight forward to determine the number of crashes in which too fast speed is the main cause. There are often various factors involved. In addition, speed can contribute to there being

an accident because it was faster than the speed limit, or faster than that relevant to the circumstances at that time. This second aspect is especially difficult to quantify objectively.

Consequently the police rarely register speed as cause of the crash. However, in-depth studies internationally report a share of 20-35% and speed is identified as a very important road safety factor.

The roads that fall between through roads and access roads require special attention, since they are the most dangerous. These are the roads with a distributor function, where vehicles travel at fairly high speeds and there is a great deal of intersecting traffic. Safety improvements on these roads require the separation of motorised and non-motorised traffic (e.g. separate foot and cycle paths). This reduces variations in traffic speeds and mass. At locations where motorised and non-motorised traffic intersect, lower maximum speeds should be introduced, or traffic movements should be controlled (e.g. traffic signals, roundabouts etc.). At junctions, roundabouts are preferable. Traffic signals can cause large variations in driving speeds (e.g. when drivers ignore red lights) although these are smaller than speed variations at uncontrolled intersections.

The homogeneity requirements are mainly the result of accident analyses. Making certain conflicts impossible and separating different vehicle types could prevent many accidents. Accident severity decreases considerably with lower speeds and obstacle-free zones. The requirements for homogeneity are:

- avoid conflicts with oncoming traffic;
- avoid conflicts with crossing-over traffic, particularly slow moving vehicles at junctions;
- separate vehicle types;
- reduce speed at potential conflict points;
- avoid obstacles along the carriageway.

Predictability

To prevent uncertainty among road users, roads should be constructed and marked/signed to make obvious what sort of behaviour is expected. In other words the road must be "self-explanatory". To facilitate clear distinction between the road categories, the number of road classes should be restricted and their design and layout as uniform as possible within each category. Road users will then have a better idea of what sort of driving behaviour is expected of them, and be better able to anticipate the driving behaviour of other road users. With “self-explanatory” roads, road users will know at which speed to drive, whether to expect traffic from side roads, and whether cyclists are likely to be on the road.

The requirements for recognition and predictability are:

- avoid unpredictable behaviour by clear designing, marking and signing;
- make road categories recognizable;
- limit the number of design elements each category and make them uniform.

The homogeneity requirements aim at orderly traffic surroundings: unification of measures, road signs and signposting. For Sustainable-safety, the limitation of the number of road categories produces the largest contribution to the recognition. This assumes that the differences between the categories are large, and within each category are small.

In a sustainable, safe traffic system the human takes the central role. Humans are (largely) unpredictable and influencing their behaviour cannot be sustained over the long term. They are therefore incorporated in sustainable safety as a reference against which other system elements are measured.

3.3 Road functions

A sustainable safe road network has three traffic functions:

- ***flow function***: vehicle movement rapid and uninterrupted – ***through roads*** *(national roads);*
- ***distributor function****:* for the distribution and collection of traffic to and from different districts and residential areas – ***distributor roads*** *(regional roads);*
- ***access function***: provide entrance: vehicles reach and depart from an individual dwelling, shop or company while ensuring the safety of the street as a meeting place, as for cyclists and pedestrians – ***access roads*** *(local roads).*

Presently, roads and streets often have more than one traffic function, creating unsafe conditions. The concept of sustainable, safe road transport comes down to the removal of all function combinations by making the road mono-functional, i.e. by creating categories of roads: pure through roads, pure distributor roads and pure access roads. Multi-functionality leads to contradictory design requirements, and also to higher accident risks.
Together, the three road categories make up a road network. Junctions are intended for switching traffic from one road to another road. Road links are intended for traffic flow. An exception to this is the road link in access roads, where stopping and turning is allowed. Through roads should not have junctions but split level interchanges to guarantee a continuous flow function.

Besides a traffic function, streets and roads in urban areas should allow people to move around the vicinity of their house safely and comfortably, and this residential function and this function can be combined with the access function. A residential function for areas means that pedestrians, playing children, cyclists and parked cars can use the same area. The roads in these areas should be designed in such a way that the residential function is immediately recognizable, and prohibits driving speeds of more than 30 km/hr within urban areas or 60 km/hr within rural areas. The possibility of conflicts between slow and fast traffic may still exist, but the lower speed allows good anticipation and avoidance of hazards. Furthermore, any accident that does occur should have less serious consequences.

3.4 Recognizable road categories

In a sustainable, safe traffic system road users know what traffic behaviour is expected related to the road category, and what to expect from other road users. Emphasizing the recognizability of each category increases predictability. The mechanism that ensures the right level of predictability consists of two steps:

1. road users must be able to recognize the road category by a small number of design elements;
2. based on education and experience, road users should know which possible traffic situations are associated with the present road category.

The aim of this mechanism is to lower the workload (or mental load) of drivers. This will have a positive influence on the performance of the driving task. A small set of the operational requirements should ensure the predictability of the traffic situations. Such a set consists of continuous longitudinal road elements:

- longitudinal lane/direction road markings;
- separation of directions;
- pavement, irregularity of the surface;
- presence of vehicle breakdown facilities and obstacle-free zones (emergency lane on motorways);
- applied junction types within a road category.

Ideal situation

The situation described in the paragraphs above is an ideal one and nowhere in the world (including the Netherlands) has this been achieved yet. Experiences with implemented safety features are now being gained, and are subject to continuous evaluation and adjustment. Any road authority wanting to adhere to the principles of sustainable road safety will realise that changes can be made only gradually. The ideal situation will only (if ever) be reached after a long period of time (decades).

There is, therefore, no certainty yet about what conclusions can be drawn regarding the precise influence of each of the mentioned road features on the level of anticipation of the road user. Furthermore, this project studies existing road situations. It only answers the question regarding which existing road features, in not yet sustainable safe situations, influence road user behaviour. For the design of sustainable safe road surroundings, it would be appropriate to know what the influence is of adapted or new road features in sustainable safe surroundings.

The influence of the design and the environment on driver anticipation is important.

In the Netherlands the debate on developing one set of standards has led the Dutch Road Administrations to agree on the following:

- through road:
  - physical separation (between opposing traffic directions);
  - emergency lane;
  - priority road (main road);
  - continuous edge lines (0.20 m wide);
- distributor road:
  - non physical driving direction separation, two (dis)continuous centre lines;
  - priority road;
  - discontinuous edge lines (3 m line ,3 m gap, 0.15 m wide);
- access road:
  - no centre line marking;

- separate cycle path, priority junctions if effectiveness can be proven;
- no edge line, if effectiveness can be proven discontinuous line (1 m line, 3 m gap, 0.10 m wide).

3.5 Road categories

The layout of a road should be appropriate to its function. This is presently explicitly the case for motorways and urban access roads. However, the layouts of roads especially meant to distribute traffic often have too great a diversity. On through roads in rural areas, it is physically possible to drive at high speeds, on distributor roads the speed limit is low (particularly at junctions), and on access roads the speed is even lower. The layout should 'automatically' enforce the desired speed.

3.5.1 Through roads (rural)

The through road is divided in two types (table 1, figure 4), but each type has the essential characteristics of this category (the layout of each type as distinctive as possible):

- type I : motorway (freeway);
- type II : motor road (trunk road).

Table 1: Essential characteristics of through roads

Type I: motorway (freeway)	Type II: motor road (trunk road)
speed limit 100 or 120 km/hr	speed limit 100 km/hr
design speed 120 km/hr	design speed 100 (90) km/hr
split level interchanges	split level interchanges
physical separation	physical separation
at least 2x2 lanes	at least 2x1 lanes, maximum of 2x2
emergency lane	emergency bays and/or semi hard shoulder
complete marking	complete marking

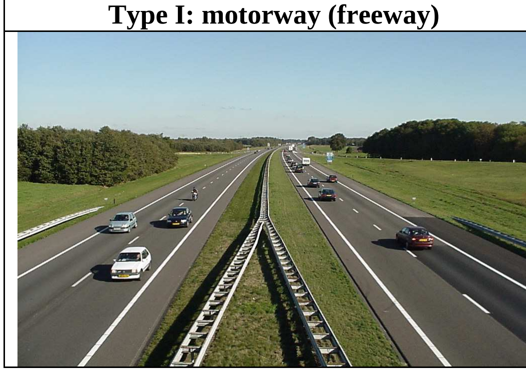
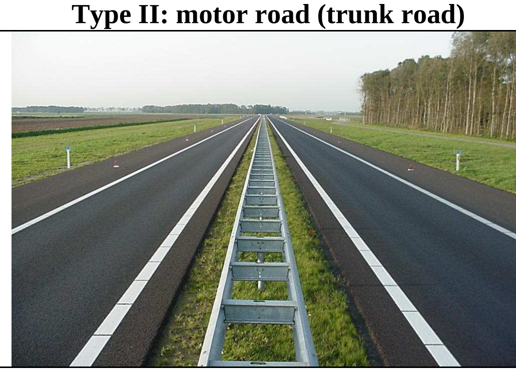
Type I: motorway (freeway)	Type II: motor road (trunk road)
	

Figure 4: Examples of through roads outside built-up area

The construction of a motor road or trunk road with a physical carriageway separation is expensive. The Dutch Road Administrations agreed on a phased solution. The picture shows an example: two continuous lines fill up with a green surface. This design is (unfortunately) quite similar to a distributor road (see chapter 3.5.2). To recognize this design as a through road is difficult.

Two continuous lines filled up with green surface

3.5.2 Distributor road (rural)

The distributor road is also divided in two types (table 2, figure 5) and each type has the essential characteristics of this category (the layout of each type as distinctive as possible):

- type I : dual carriageway;
- type II : single carriageway.

Table 2: Essential characteristics of distributor road

Type I: dual carriageway;	**Type II: single carriageway**
speed limit 80 km/hr; design speed 80 km/hr; physical carriageway separation; priority road, 2x2 lanes; closed to (light-) mopeds and bicycles; a parallel cycle path or service road exists; junctions designed as roundabouts or priority crossroad with traffic lights; limited number of connections to access roads; Emergency bays or semi-surfaced shoulder; discontinuous edge line;	speed limit 80 km/hr; design speed 80 km/hr; non physical driving direction separation; priority road, 1x2 lanes; closed to (light-) mopeds and bicycles; a parallel cycle path or service road exists; junctions equipped with speed reducing provisions or designed as roundabout ; limited number of connections to access roads; Emergency bays and semi-surfaced shoulder; discontinuous edge line;

Type I: dual carriageway	**Type II: single carriageway**

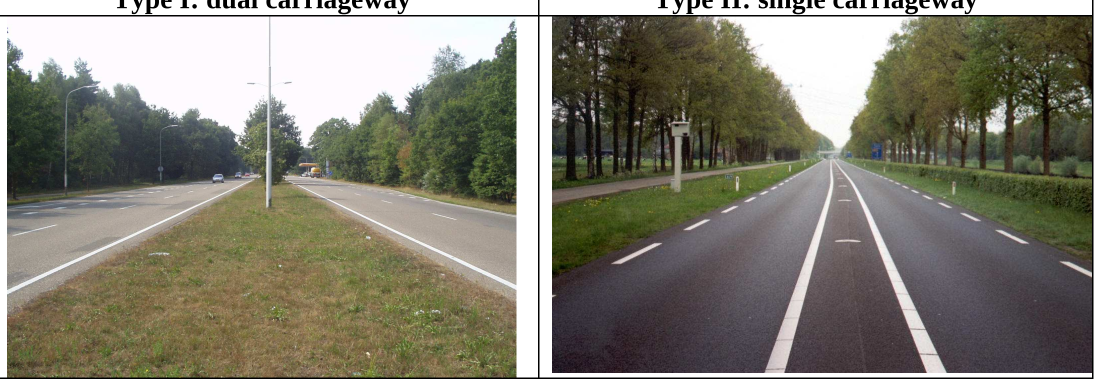


Figure 5: Examples of distributor roads outside built-up area

3.5.3 Rural access roads

The surfaced width of access roads varies between 2.50 and 6 metres. The lane width (in the middle of the carriageway) for motor vehicles is between 2.50 and 3.50 metres. The surfaced width is the sum of the widths of the above and the widths of two non-compulsory cycle lanes (discontinuous line; no cycle symbols/pictograms). The access road is also divided in two types and each type has the essential characteristics of this category (figure 6):

- type I : vehicle lane with separate cycle path(s), priority junctions are possible;
- type II : single lane for all road users; at level, no-priority crossroads.

Junctions of access roads and distributor roads are in the form of a roundabout or a three or four-arm crossroads. Distributor roads have raised plateaus 100 metres before and after the crossroad junction. Junctions of access roads could alternative have a raised plateau.

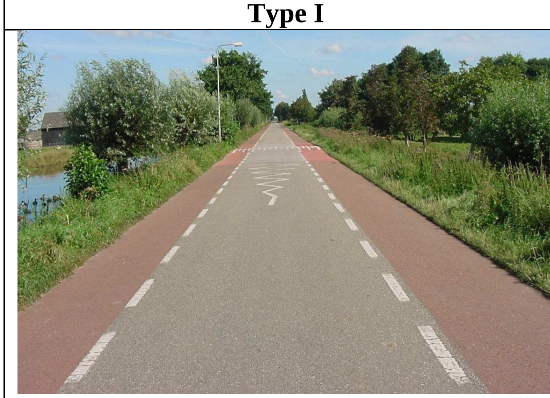
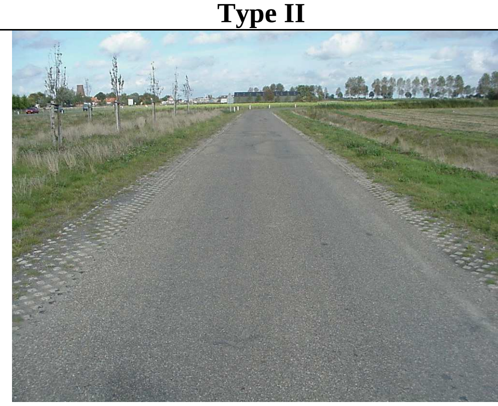
Type I	Type II
	

Figure 6: Examples of access roads outside built-up area

The access road, type 1 has cycle lanes (discontinuous line, red surface) and raised plateaus (to reduce speeds to 60 km/hr). The type II road has no markings and semi-surfaced shoulder.

3.6 Network classification

In almost every country the existing road network will turn out to be a result of semi-structured developments in the past. For example, it is evident that certain villages have been united to form one big town, and in many cases when doing this, connecting roads between the villages became part of the urban area of the new town without losing their original function. So, it is imaginable that such a development led to roads whose function, design and usage are not attuned to each other. In practice this will often be the case. Now the question presents itself: how to change from an existing road network to a sustainable safe road network within realistic costs?

When designing new roads and reconstructing existing roads, road safety is an important issue, together with those of the physical space, the budget, the function of the road, the flow capacity, and environmental. In the sustainable safety concept, categorizing should be considered as a

'optimum target' that previously has to be considered with other 'targets' like accessibility, environmental problems and physical planning. In this way all parties benefit from an early cooperation between the different policies. The desire for a sustainable safe road system by categorizing the road network therefore can be realized step-by-step.
Such a step-by-step plan can be considered as an iterative process when not all conditions for one separate step can be fulfilled. In this case it will be necessary to return to a former step. By doing so, the categorized road network is achieved. After establishing an overall picture of the network, choices can be made and brought into practice in the transport plans / designs.

At the highest level the infrastructure network is established, where each road network has to fulfil three fundamental functions to allow each road user to:

- be able to go from origin to destination (flow function);
- be able to enter and leave an area with multiple destinations (distributor function);
- be able to access properties alongside a road or street (access function).

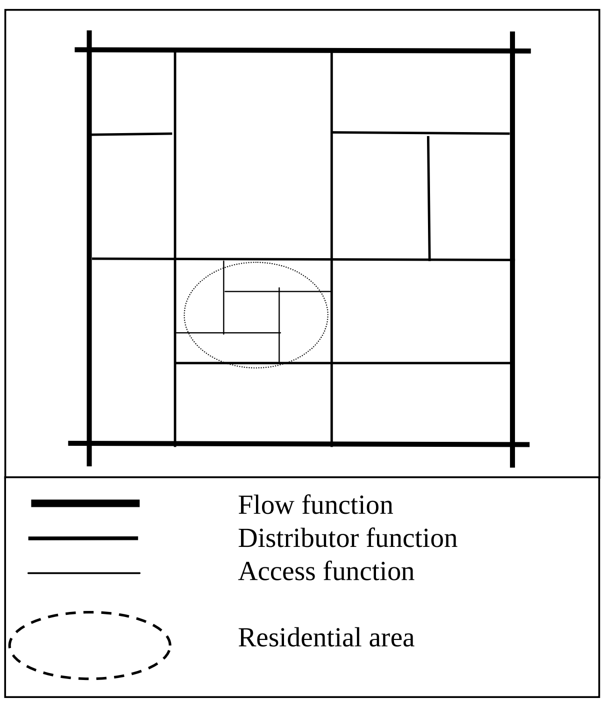


Figure 7: Categorisation in a road network according to Sustainable Safety

This produces a road network with three categories (figure 7):

1. Through-roads (flow function): enabling high speeds for long distance traffic and, often, high volumes;
2. Distributor roads (exchange between flow and access): serving districts and regions containing scattered destinations;
3. Access roads (access function): enabling direct access to properties alongside a road or street.

Roads and streets, generally, fulfil more than one function. and this combination of functions results in higher accident risks. That is why, in a sustainable safe road network, each road should only have one function. Together, these three functions form a road network that (greatly simplified) looks like that depicted in figure 7.

On a detailed road design level, the sections of roads have a different purpose than that of the Junctions or intersections (see table 3). Intersections are for traffic exchange (allowing changes in direction etc.) whilst road sections facilitate traffic flow. Exceptions to this are the road links of access roads where traffic modes are not separated, speeds are low, and all types of road users share the roadway. Main roads with a flow function (motorways or freeways) do not have junctions, but are fully grade separated intersections with free flowing links.

Table 3: Purpose of road links and junctions on different road categories.

Road type	***Road elements***	
	Road link	***Junction***
Through road	Flow	Flow
Distributor road	Flow	Exchange
Access road	Exchange	Exchange

The first step is to categorize the roads, which means that every road must be given a certain function. Thereafter, the proper design should be defined on basis of the design criteria. When giving a function to a road, it is important to build up a logical road network based on the three categories of roads: flow function (through roads), distribution function (distributor roads) and access function (access roads).

Sustainable safety begins with preparation of a categorizing plan by all those road authorities that are responsible for the construction and maintenance of roads (figure 8). The initial step is to agree on the function that individual roads have to fulfill. The purpose of these categorizing plans is to reduce the number of road classes in the road network hierarchy to 3 outside the built-up area (and 2 within the urban area). These roads would eventually have to be given a layout that makes them unique and identifiable to the road users (the concept of “self-explanatory” roads).

Distributor road, dual carriageway, one lane

The expertise of different kinds of people has to be combined, so that a framework can be established for the function of every road to be built in the future. In this plan, every road in an area is designated one category only, and the functional requirements for that road category are already specified. Then as a critical operation it is essential that the roads and streets are designed in such a way that they optimally meet the corresponding functional requirements.

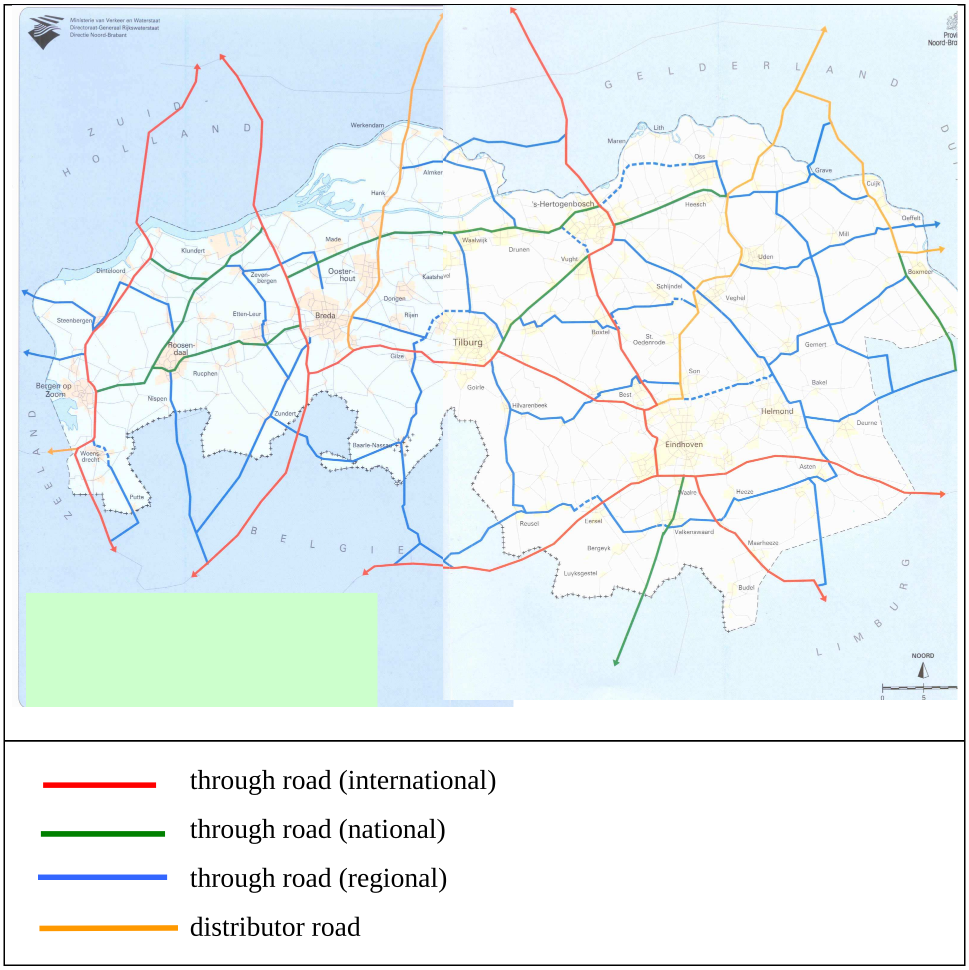


Figure 8: Example of road categorizing plan of a Dutch province Noord Brabant

3.7 Capacity

For the appropriate selection of cross sections, the following recommendations are given:

- if the expected traffic volume is greater than 25,000 vehicles/day, than four lane median separated standard cross sections should be provided;
- for traffic volumes between 15,000 and 25,000 vehicles/day either the intermediate cross section 2+1 (see chapter 4) is appropriate;
- for traffic volumes less than 15,000 the intermediate cross section 2+1 may be adequate, but a single carriageway with two lanes and two way traffic is also possible;
- in general the cross section is not normative but the level road junction or the grade intersections.

Indicative capacities of motorways (120 km/hr) and motor roads or trunk roads (100 km/hr) are shown in the table.

Table: Indicative capacities of motorway and motorroad

Road category / type	Number of lanes	Capacity (pve/hr/dir)
Motorway	1	2,160
	2	4,650
	3	7,250
	4	9,700
Motor road	1	1,575
	2	4,000

4 SUSTAINABLE SAFE ROAD DESIGN: CROSS SECTION

Design details of rural roads with single carriageway and two way traffic are given for:
- the cross section (chapter 4);
- the junctions (chapter 5);
- the alignment (chapter 6).

The specific safety problems for linear villages are mainly conflicts between transit traffic, local traffic and especially vulnerable road users (pedestrians). The purpose of chapter 7 is to present solutions for design principles.
The need for pedestrian crossings near bus stops for instance is depending on the number of crossing pedestrians, the road width, the traffic volumes and the speeds. Chapter 8 gives some design principles and examples of measures.

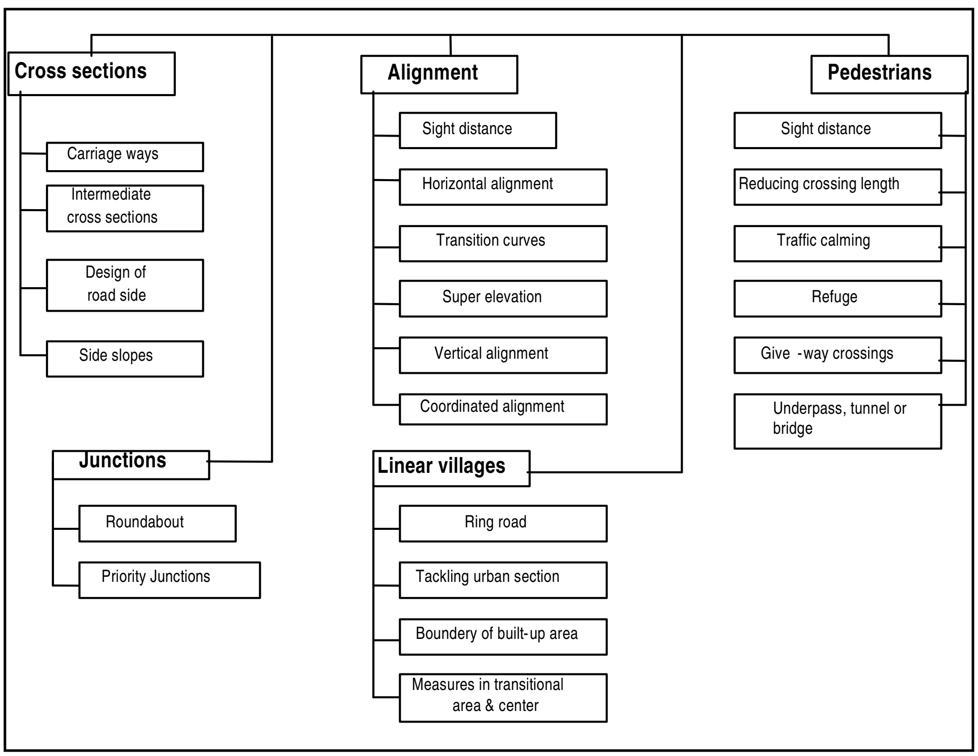


Figure 9: Road design topics

4.1 Cross section

The main elements of a road cross section are:
- the pavement with the vehicle lanes, edge strip and markings;
- the emergency zone and obstacle free zone;
- the embankment and cutting slopes (and ditches).

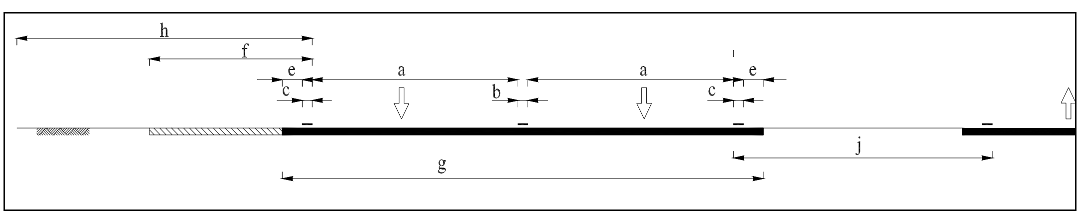
The width of the cross section is determined by:
- the pavement related to the number of lanes;
- the required width of the edge strip;
- the shoulders and earthwork slopes and depth;
- segregated parallel facilities (cyclists and pedestrians);
- the ditches.

The choice between type I and type II for the distributor road (see paragraph 3.5) is determined by the required capacity of the road link. The maximum capacity of road type II (single carriageway, two way traffic) is ideally an average of approximately 2,800 pve/hr (pve = passenger vehicle equivalent). Relative to the distribution of the two way traffic, the capacity can be as much as 3,200 pve/hr. The capacity is, however, determined by the 'weakest' link in the chain of road links and junctions. In the event of a (expected) higher traffic volume than approximately 2,800 (3,200) pve/hr, the capacity of the regional access road should be increased by introduction of a section of 2 lanes per direction (road type I, dual carriageway).

Depending on his speed, the driver of a vehicle should keep a certain distance from other road users and the fixed objects next to or above the lane. Naturally, the space needed also depends on the dimensions of the vehicle. The spatial requirements comprise several components:
- the traffic space, consisting of:
  - the physical dimensions of the design of the vehicle;
  - the horizontal and vertical deviations due to vehicle manoeuvring;
- the space profile, consisting of:
  - the traffic space;
  - the object distance, the distance that drivers keep from fixed objects for fear of collisions.
- the safety zones, consisting of:
  - the emergency zone;
  - the obstacle free zone.

4.1.1 Distributor road type I

The Dutch cross section of the distributor road type I is illustrated in figure 10.



a (lane) = 3.10 m	f (emergency zone) = 2.40 m
b (separation line) = 0.15 m	g (pavement width) = 7.25 m
c (edge line) = 0.15 m	h (obstacle free zone) = 4.50 m - 6.00 m
e (edge strip) = 0.30 m	j (median = 3.90 m

Figure 10: Normal cross section distributor road type 1, dual carriageway

Distributor road, dual carriageways, two lanes

The distributor road type I with at grade junctions should preferably only be applied under the following circumstances:

- speed limit 80 km/hr;
- dual carriageways by means of a (narrow) median;
- separation of cyclists, tractors and other automotive machinery with a limited speed;
- preferably at grade separated crossings for slow traffic;
- no connections of access roads.

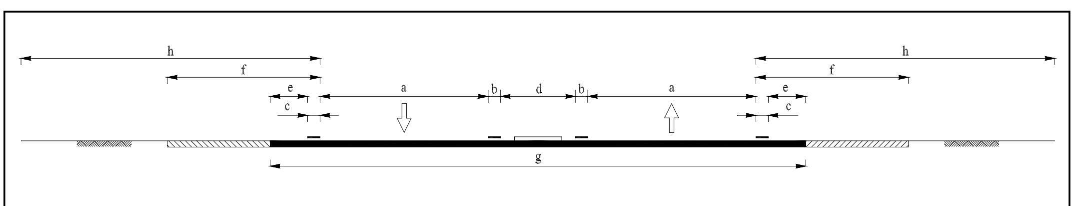
4.1.2 Distributor road type II

Distributor road, design in the past

The cross section in the Netherlands applied in the past for distributor roads outside built-up area is illustrated in the photograph. In practice this profile entails primarily the following problems:

- a relatively large number of serious accidents as a result of head-on collisions (primarily as a result of overtaking manoeuvres);
- a relatively large number of run off road accidents (single vehicle accidents).

A high number of (very) serious frontal accidents take place on single carriageways with two-way traffic. These accidents occur not only as a result of conscious overtaking manoeuvres, but also as a result of 'unconscious' or unintentional sideways movement.



a (lane) = 2.75 m	e (edge strip) = 0.30 m
b (separation line) = 0.15 m	f (emergency zone) = 2.40 m
c (edge line) = 0.15 m	g (pavement width) = 7.50 m
d (driving direction separation) = 0.80 m	h (obstacle free zone) = 4.50 (6.00) m

Figure 11: Normal cross section of distributor road, type II

Separation of the two lanes of traffic in opposite directions (separating the driving directions); prohibition and prevention of overtaking all contribute considerably to decrease the risk of these serious accidents. The preferred solution consists of two continuous separation lines, between which reflectors or typical small sized obstacles are installed diagonally to the centre line with retro-reflective strips (figure 11). It is also possible to create a slightly convex elevation between the separation lines in a different colour and texture.

In principle, prohibition or prevention of overtaking (ideal situation, photo 1) applies to distributor road type II for road safety reasons. The slow (agricultural) traffic then uses a service road or a parallel road. When this is not the case, the following options are available:

- prohibition of overtaking, but overtaking of slow motorised traffic is permitted (see photo 2);
- construction of passing lay by at regular intervals to allow slow vehicles to pull off the road (see photo 3);
- prohibition of overtaking on curves without an overview (see photo 4).

Photo 1: prohibition of overtaking

Photo 2: Overtaking of slow traffic permitted

Photo 3: passing lay by at regular intervals

Photo 4: prohibited overtaking non-overseeable curve

The lane width for all categories in various countries is more or less 3.50 m. Such a width is in the Netherlands only applied on motorways (120 km/hr), in accordance with European legislation. For more minor roads, depending on the circumstance, narrower lanes are applied:

- 100 km/hr : 3.10 m to 3.25 m;
- 80 km/hr : 2.75 m to 3.10 m.

4.2 Intermediate cross sections

In Germany and Sweden, for example, extensive research has been conducted into possible intermediate cross sections. The following cross sections have been included (figure 12):

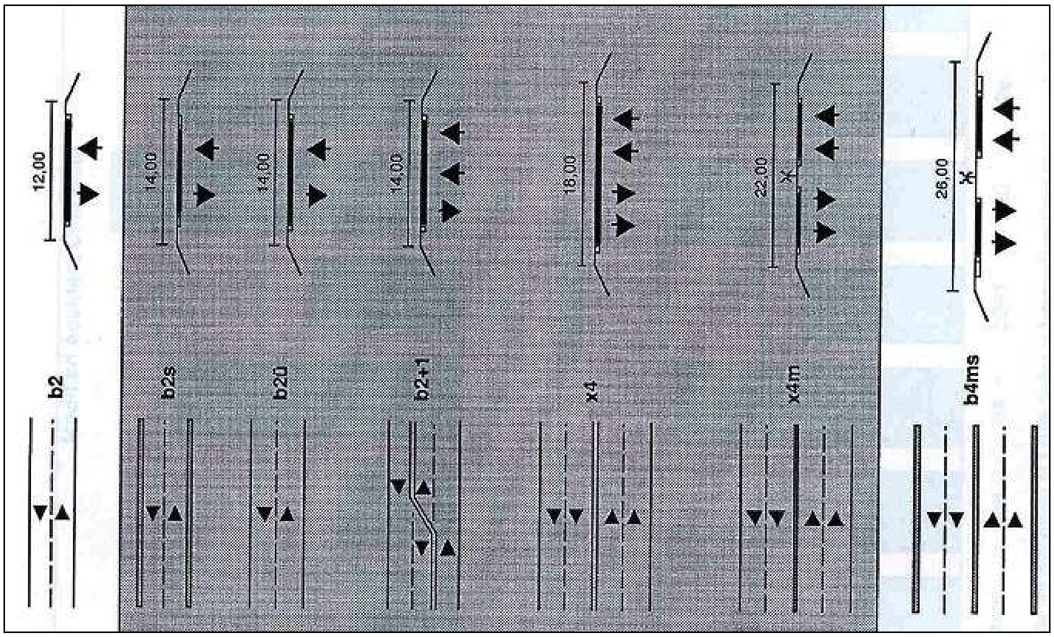
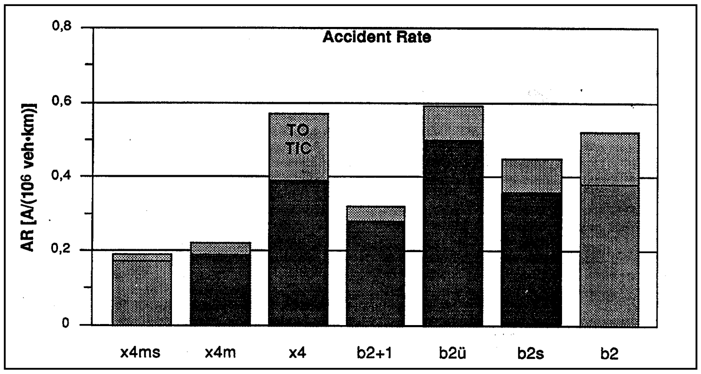


Figure 12: Intermediate cross sections

- 2 lanes, two-way traffic with normal lanes and normal edge strips (b2);
- 2 lanes, two-way traffic with hard shoulders, which are also intended to simplify overtaking and evasive manoeuvres (b2s);
- 2 extra-wide lanes (b2ü), two-way traffic where overtaking manoeuvres can be executed without or with negligible crossing of the axis line;
- 3 lanes where the central lane is allocated alternatively to one of the two directions (b2+1);
- 4 lanes, two-way traffic without a median (x4);
- 4 lanes two-way traffic with a (narrow) median but without emergency lanes (x4m);
- 4 lanes two-way traffic with a median and emergency lanes (b4ms, motorway).

With regard to the single-lane cross section with an pavement width of a maximum of 8,00 m (b2) and the cross section for motorways(b4ms) accident analyses have assessed the various cross sections as follows (figure 13):

- in comparison with the 2+1 profile (b2+1), single carriageways with two normal lanes and a normal edge strip (b2), single carriageways with two lanes and hard shoulders (b2s) or two extra-wide lanes (b2ü) clearly provide less safety;
- single carriageways with 4 lanes (x4) exhibit a far less favourable value for the accident rate than the 2+1 profile and the dual carriageways (x4m);
- dual carriageways with two lanes (2x2) without an emergency lane (x4m) have a low accident rate; which are significantly lower than for the single carriageway section.



Accident rate (AR) = number of accident per 1 milj. vehicle kilometers

Figure 13: Accident rate intermediate cross sections

Traffic flow

Analysis of results from traffic flow/speed surveys indicate the following:

- The speed on roads with single carriageways hardly differs from that of roads with 2+1 lanes (maximum speed 100 km/hr). On roads with extra-wide lanes (b2ü), however, the speeds are considerably high.
- The wide edge strips and extra wide lanes positively influence the dispersion of platoons of vehicles. Critical overtaking manoeuvres are numerous. With a 2+1 cross section, both traffic flows are separated and critical situations therefore rarely occur.
- The introduction of a safety barrier in an existing single carriageway with 4 lanes results in a slightly lower speed, but has no negative effect on traffic flow.
- The safety barrier in an existing single carriageway with 4 lanes, where the left-hand lane is narrowed from 3.50 m to 3.00 m, gave a similar result. Negative effects on the traffic flow could not be established.
- It was impossible to make any general statements concerning the capacity of the specific cross sections studied on the grounds of the interaction observed between traffic volume and speeds. The traffic volume at the test locations was determined by the adjacent road links with the 'old' cross sections.

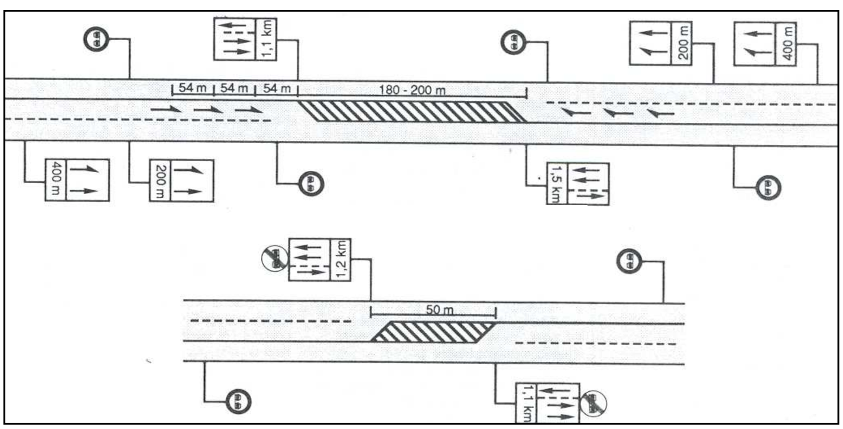


Figure 14: **Design of cross section with 2+1 lanes in Germany**

A solution was sought in Germany for the problems on single carriageways with a cross section with 3 lanes, where the central lane is allocated alternatively to one of the two driving directions

(2+1 lanes, figure 14). As said before, this profile is almost twice as safe at a maximum speed of 100 km/hr compared to a traditional single carriageway with two lanes.

In many Central and East-European countries the width of the pavement is approximately 12.50 m (figure 15). The width of the hard shoulders varies in practice between 1.50 m and 2.50 m.

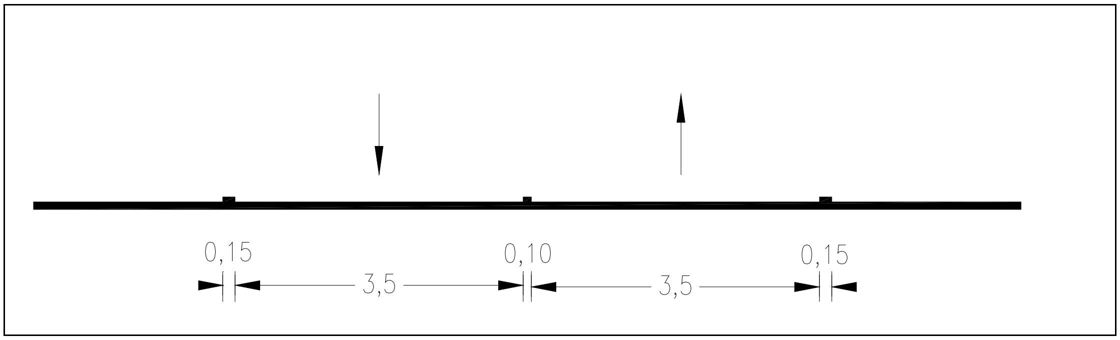


Figure 15: Cross section of many national and regional roads in East Europe (single carriageway with wide edge strip)

With this cross section all traffic is (necessarily) permitted, even often the slow (agricultural) traffic. This causes problems in respect of the (quality of) traffic flow and road safety. A solution with 2+1 lanes (figure 14) can be introduced relatively easily in situations with the cross section according to figure 15. In the cross section according to figure 15, multiple use is made of the hard shoulders for overtaking manoeuvres. It is quite common for 3 and sometimes even 4 vehicles to be alongside each other in the cross section. In The Netherlands hard shoulders (emergency lanes) are only constructed for motorways.

4.3 Design of roadside

The shoulders are an integral part of the road design and have also a function related to road safety and traffic flow:
- preventing broken down or stationary vehicles from blocking the lane;
- providing correction space for run off road vehicles.

With many run off road accidents only one vehicle is involved, (single-vehicle accidents);
- fixed object accidents: accidents where the vehicle collides with a fixed object, any object fixed in the ground, such as signposts, light posts and trees;
- single vehicle accidents: accidents where there is no collision with another road user or with a fixed object, such as vehicles that end up in the ditch or roll off the side slope.

The proportion of registered run off road accidents on single carriageways outside built-up area, in relation to the total number of accidents on these roads, is considerable, naturally, to reduce run off road accidents, the best way is preventing vehicles from leaving the travel lane. In reducing the number of single-vehicle accidents, three objectives can be identified:
1. preventing drivers running off the road;
2. when a driver runs off the road, minimise the risk of accidents;

3. reduce the severity of the accidents.

Table 4 is an overview of measures to increase the safety of shoulders. The order is based largely on the costs of measures. Protecting an (unavoidable) danger zone with a guardrail, barrier or impact attenuator is the last resort as a measure. This applies to a far higher degree to residential access roads than to the main road. A barrier or impact attenuator is certainly a relatively collision-friendly object, but always poses a certain risk of injuries.

Table 4: Measures to reduce run off road accidents

N	Objective		Nature of the measure
1	*Keep vehicles from encroaching on the roadside*	a	Enforcing the speed limit or reducing the maximum speed.
		b	Constructing a profiled, acoustic edge line.
		c	Widening the edge strip at the cost of the lane width
		d	Constructing a semi-paved edge strip where the pavement is relatively narrow.
		e	Applying a profiled road surface (‘rumble strips’) in the edge strip.
		f	Installing or improving guidance by means of markings, particularly with relatively sharp horizontal curves.
		g	Improving the horizontal alignment and/or the super elevation.
		h	Improving the skid resistant of the pavement.
2	*Minimize the risk of crashing into a object or overturning if the vehicle travels beyond the edge of the shoulder*	a	Ensuring that the shoulder connects to the pavement at the same level.
		b	Improving the load-bearing capacity and skid resistance of the shoulder surface (semi paved) in the emergency zone.
		c	Widening the shoulder to a minimum of the width of the emergency zone, but if possible to the width of the obstacle free zone.
		d	Removing or relocating obstacles outside the emergency zone, but preferably outside the obstacle-free zone.
		e	Constructing less steep and rounded off side slope
3	*Reduce the severity of the crash*	a	Improving the design of the roadside hardware by means of collision-proof supports.
		b	Installing guardrails, barriers or crash cushions, where collision with facilities constitutes less of a risk than driving into the danger zone.

4.3.1 Design of shoulders

When a vehicle runs off the road, the outcome depends greatly on the design of the shoulder. The driver must be presented with the most advantageous situation (obstacle-free zone) to get the vehicle safely under control. Vehicles run off the road to both the left and the right. Frequently drivers first swerve out of the travel lane, slightly to the right, and then, due to over steering, cause a frontal collision with traffic coming from the other direction or go off the road to the left.

To provide optimum benefit from the obstacle-free zone, the construction of the emergency zone has to fulfil a number of requirements. Drivers who have to make an emergency stop or who run off the road for some reason must be able to bring their vehicle safely to a halt in the shoulder and/or return safely to the road. The safety requirements for the construction of the shoulder are:

1. the shoulder surface has to connect to the pavement at approximately the same level;
2. the shoulder has sufficient load-bearing capacity, especially in the emergency zone and lay-by, but also in the obstacle free zone;
3. the shoulder surface offers sufficient skid resistance;
4. the super elevation is not too steep;
5. the management and maintenance of the road and shoulder to be routine and simple;
6. the appearance of the shoulder has to be ‘green’.

Figure 16 shows the proportion of accidents involving collision with trees relevant to the total number of accidents for single-lane national highways, depending on the distance from the pavement of trees. According to figure 17, 10 to 15% of these accidents still occur at a distance of 6 m. It should be remembered that tree accidents are generally very serious. The greater the obstacle distance, the smaller is the risk of collision. Objects within the obstacle free zone constitute a danger zone. Possible measures, in order of priority, are:

- removing or relocating the objects by placing them outside the obstacle free zone;
- replacing the support of the obstacle with a collision-friendly support giving them a breakable or slide construction;
- placing the obstacles as close to each other as possible and protecting these danger zones with, for example, a safety barrier.

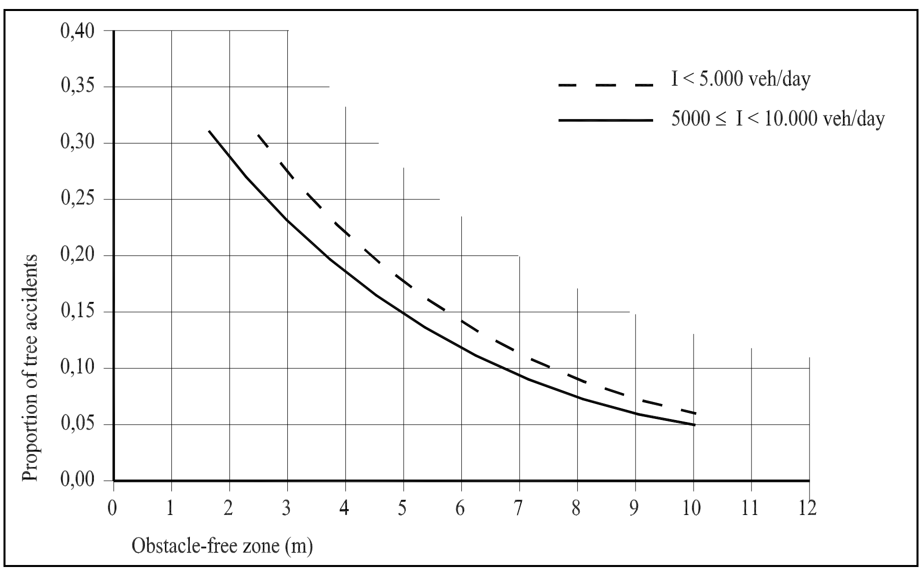


Figure 16: Proportion of tree accidents of the total number of accidents

The following design elements are important for limiting the risks to drivers and passengers:
- the edge strip;
- the emergency zone and lay-by;
- the obstacle free zone.

Edge strip

The objective of the edge strip is to offer drivers good facilities for correcting (slight) course deviations. The frequency of slight course deviations, where the vehicle goes slightly over the edge line, is high and depends on the width of the lane and the speed. The width of the edge strip is normally 0,30 to 0,60 m. To reduce the number of accidents where the car runs off the road, it is better to opt for a relatively wide edge strip than for a relatively wide travel lane. On the other hand, the edge strip should not be too wide thus encouraging (illegal) overtaking manoeuvres.

Rumble strips within the edge strip

In the US, it is proven that tiredness, inattention, drowsiness and distraction also contribute significantly to causing run off road accidents (proportion 40% to 60%). The recommendation is to construct the edge strip in addition to the edge line in such a way that it 'guides' and 'warns' the drivers. Options include the colour and texture of the road surface and applying rumble strips (see example). This recommendation particularly applies to long, straight road links and locations with monotonous landscape surrounding.

Emergency zone

Through roads and distributor roads fulfil an important network function. To guarantee the traffic flow, there has to be space next to the road for vehicles stranded due to breakdown or accidents to park away from the traffic flow. Drivers of passenger cars will avoid the shoulder if it looks unreliable with regard to evenness and load-bearing capacity. Furthermore, pedestrians (passengers) can wait for the emergency services relatively safely in the emergency zone. The zone is measured from the inside of the edge line, at 2.00 to 2.50 m, and constitutes part of the obstacle free zone. The load-bearing capacity of the emergency zone deserves attention for two reasons:

Stabilized or semi-hard shoulder

- the emergency zone or lay-by is part of the obstacle-free zone, where most vehicles that run off the road end up;
- drivers will only 'park' their vehicles here if the shoulder surface connects to the pavement approximately at the same level and is reliable in terms of load-bearing capacity.

The emergency zone should preferably be stabilised. A stabilised shoulder or semi-paved (see example) has a positive effect on preventing run off road accidents. For road safety and road management reasons (shoulder damage), with the pavement width less than 7.00 m, it is particularly important to stabilise the shoulder.

Obstacle-free zone

The design of the shoulder determines to a large extent the risk of run off road accident. This risk depends primarily on the width of the obstacle free zone. The wider the clear zone, the safer it will be. If the shoulder is well designed, the driver who runs off road should have the opportunity to stop reasonably safely or regain control of the vehicle and return to the road. The consequences of such incidents, however, depend highly on:

- the object distance;
- the load-bearing capacity and friction coefficient of the shoulder;
- the mass and nature of the fixed objects;
- the shoulder geometry.

Distributor road: obstacle free zone

The width of the obstacle-free zone should be geared to the distance within which the majority of run off vehicles could to rest on flat weight-supporting (grass) shoulders without obstacles or could return to the carriageway. The best situation for safety on e.g. a distributor road can be achieved with an obstacle-free zone of approximately 6 m.

Table 5: Width of obstacle free zones

	Through road (120 km/hr)	Distributor road (80 km/hr)	Access road (60 km/hr)
Optimum	13.00 m	6.00 m	2.50 m
Minimum	10.00 m	4.50 m	1.50 m

At a speed of approximately 100 km/hr, 80% to 90% of vehicles that run off road penetrate the shoulder no further than approximately 10 m (table 5). The lower the speed, the less the driver penetrates into the shoulder. For each 10 km/hr reduction in speed a 1.5 m reduction in the penetration distance can be applied. For distributor roads, the width of the obstacle free zone is normally 6.00 m with a minimum of 4.50 m.

4.3.2 Embankment and cutting side slope

A gently embankment side slope with a gradient of 1:7 (vertical : horizontal) or lower is reasonably safe. Figure 17 shows the ratio between the accident risk at a particular side slope gradient and a side slope gradient of 1:7. This is a simultaneous estimation, which means that

the influence of other circumstances, such as traffic volume, lane width and obstacle distance, has also been taken into account.
On a embankment side slope, the risk of accidents increases with steeper slopes. Based on simulations, it has been established that the risk of accidents on a steeply side slope (steeper than 1:3) is great. This slope is always a danger zone, and figure 17 indicates that the accident risk is more than 35% higher than on a 1:7 side slope.

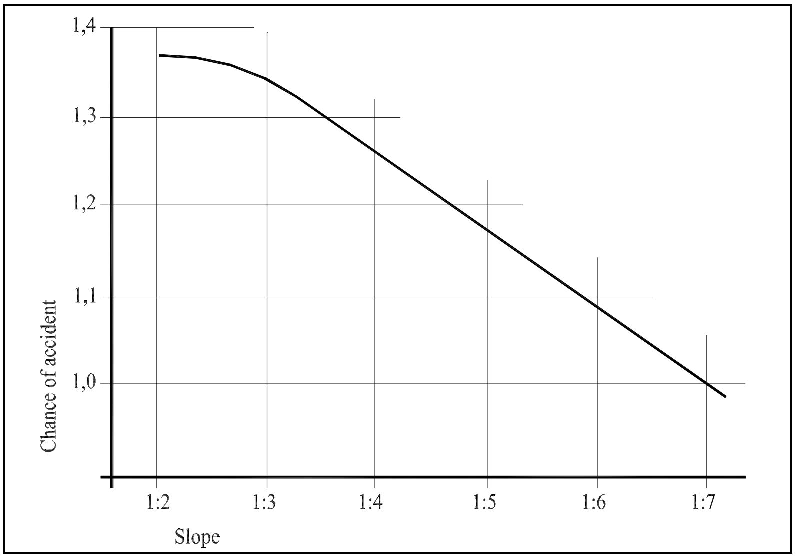


Figure 17: Ratio of single-vehicle accidents rate for a given side slope gradients versus a side slope of 1:7 for two lane rural roads

A slope within the obstacle-free zone should therefore always be less steep than 1:3 (figure 18). The rounding off of the side slope keeps the vehicle in contact with the ground. The radius of that rounding should be a minimum of 9.00 m. The crown line and the toe line of embankment side slopes should always be rounded off.

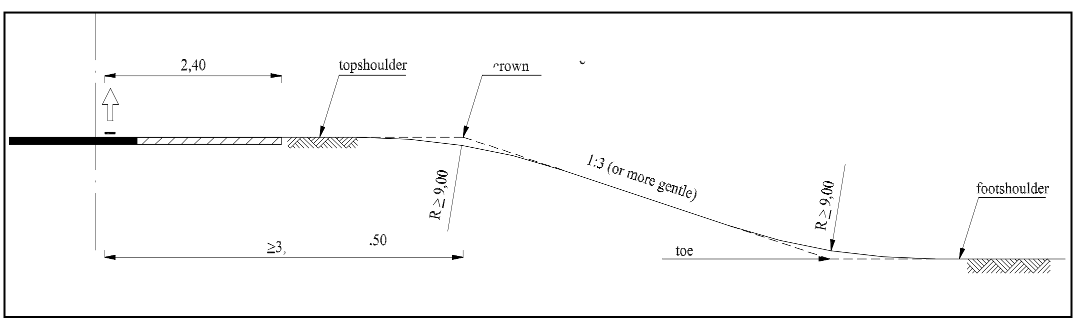


Figure 18: Design of embankment side slope

A cutting side slope has a more favourable effect on the consequences of single-vehicle accidents than an embankment side slope. With cutting side slopes, the vehicle remains reasonably controllable, while the risk of turning over is relatively limited.

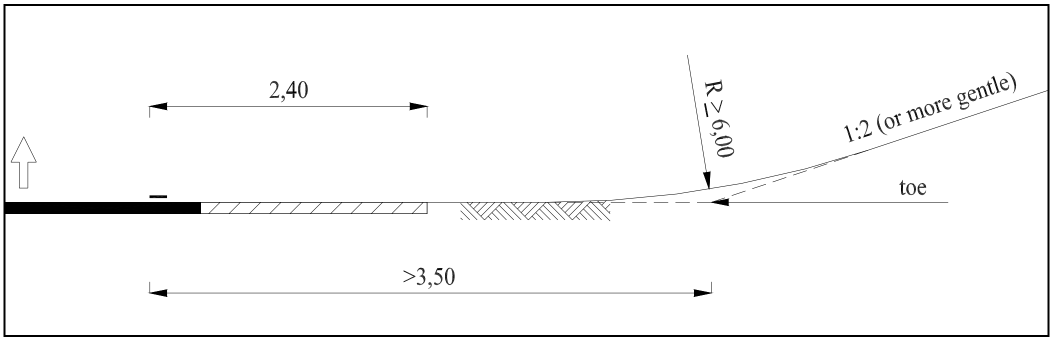


Figure 19: Design of cutting side slope

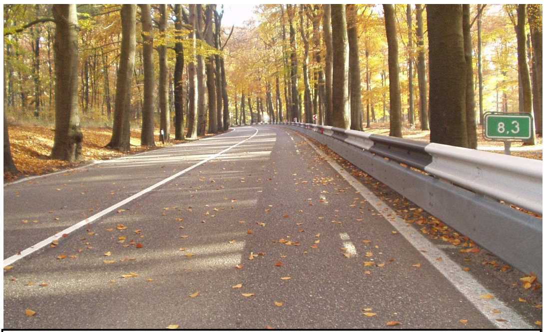
Simulation research has shown that cutting side slopes steeper than 1:2 or side slopes not rounded off at the foot should be treated as a danger zone. The rounding off of the side slope should be a minimum of 6.00 m radius, to prevent the vehicle ploughing into the slope (figure 19).

4.4 Restraint systems

If a motorist travels into the roadside, the probability of a crash occurring depends upon the roadside features such as the presence and location of fixed objects, shoulder edge drop off, embankments, ditches and trees. As said before, the greater the obstacle distance, the smaller is the risk of collision. Objects within the obstacle free zone constitute a danger zone. Possible measures, in order of priority, are:

Distributor road: guardrail protecting danger zones

- removing or relocating the objects by placing them outside the obstacle free zone;
- replacing the support of the obstacle with a collision-friendly support giving them a breakable or slide construction;
- placing the obstacles as close to each other as possible and protecting these danger zones with, for example, a safety barrier.



Distributor road: trees close to the carriageway

Installing guardrails, barriers or crash cushions, where collision with facilities constitutes less of a risk than driving into the danger zone (e.g. ditch, trees, signposting). The goal is reducing the severity of the crash.

In general the following observations are made:
- safety barriers are a cost-effective way of saving lives;
- under typical impact conditions (i.e. impact angles ≤ 25 deg), small and midsize cars involved in guardrail crashes are usually safely redirected with minimal injury to the occupants;
- impacts with concrete or steel barriers are found to be more serious, even at moderate impact angles.

Wooden restraint system: integrated into the environment

A single European performance-based standard is being developed to cover road restraint systems (defined as safety barriers, transitions, terminal and crash cushions). Most of the standards has been ratified by the European Standardization Committee (EN 1317).The European Standards specifies requirements for the impact performance of safety restraint systems including parapets. It defines performance classes for different containment levels, acceptance criteria for impact tests and test methods.

5 SUSTAINABLE SAFE ROAD DESIGN: JUNCTIONS

5.1 General requirements

A junction is a potential danger point in the road network. In the Netherlands, more than half the accidents on single carriageways occur on at grade junctions. Safety measures at the junction are often more cost effective than measures on road links.

A junction has to fulfil a number of general design requirements:
- *recognisable*: if a limited number of junction forms are used, with uniform (main) characteristics, then the road user will recognise the situation as such more quickly and the situation will comply with expectations.
- *visible*: a junction must be visible in time, conspicuous and clearly recognisable and locatable as such. To see something from a distance, it must have at least a certain size to which the road user's attention and perception can be directed. Contrast, colour, shape and movement are important factors here. Finally, the information 'signs' need to be installed in logical, clearly visible places in the field of vision.
- *overseeable:* when approaching a junction the road user must be able to oversee the junction and part of the approaching roads and any traffic on them, in time.
- *comprehensible*: a junction is comprehensible to the road user when perceptions of shape, scope, signposting, marking and traffic regulations can be interpreted quickly, correctly and unambiguously on approach.
- *negotiable*: negotiability of a junction means that the various design elements fit together sufficiently smoothly. The elements themselves must also be easily negotiated.
- *balance*: a balanced junction structure means that the various design elements (including the approach roads) and the traffic measures must form an integrated whole.
- *completeness*: a junction is complete when the traffic at the site of the junction can continue on its way in all possible and intended directions.

In principle there are three basic forms of 'at grade' road junction:
- roundabout (paragraph 5.2);
- priority junction without traffic control system (paragraph 5.3);
- priority junction with traffic control system (paragraph 5.4).

5.2 Roundabout

The roundabout is very suitable as a junction both inside and outside built-up areas and the roundabout is currently the safest 'at grade junction'. Roundabouts both promote the fluid flow of traffic and have a strong speed-reducing effect. Roundabouts therefore make a substantial contribution to road safety. In the view of road safety, capacity, clarity and uniformity, to name a few, the traffic on the roundabout should always have the right of way.

The main safety advantages of roundabouts compared to other junction forms (with or without traffic lights) are:

- The actual speed of the drivers both, with and without right of way, is (very) low. The lower the driving speeds, the slighter the risk of (serious) conflicts or (injury) accidents.
- On a traditional junction the number of potential conflict points is multiple. On a roundabout there is one conflict point for each adjoining road.

A great deal of research has been conducted into the safety of roundabouts (one lane on the roundabout) in Europe. In the Netherlands, where traditional junctions have been converted into roundabouts, the total number of recorded accidents has dropped by almost 50%. The number of victims outside urban areas has decreased by as much as 85%. It has also been concluded that the safety advantage of a roundabout is long-term.

Single lane roundabout

5.2.1 Capacity

The level of service of a roundabout is determined by the volume and processing capacity. The capacity is the maximum number of vehicles that can be processed during a particular period of time, regardless of the waiting time. The capacity of a roundabout is up to a certain point, greater than that of a junction controlled by traffic lights (figures 20 and 21).

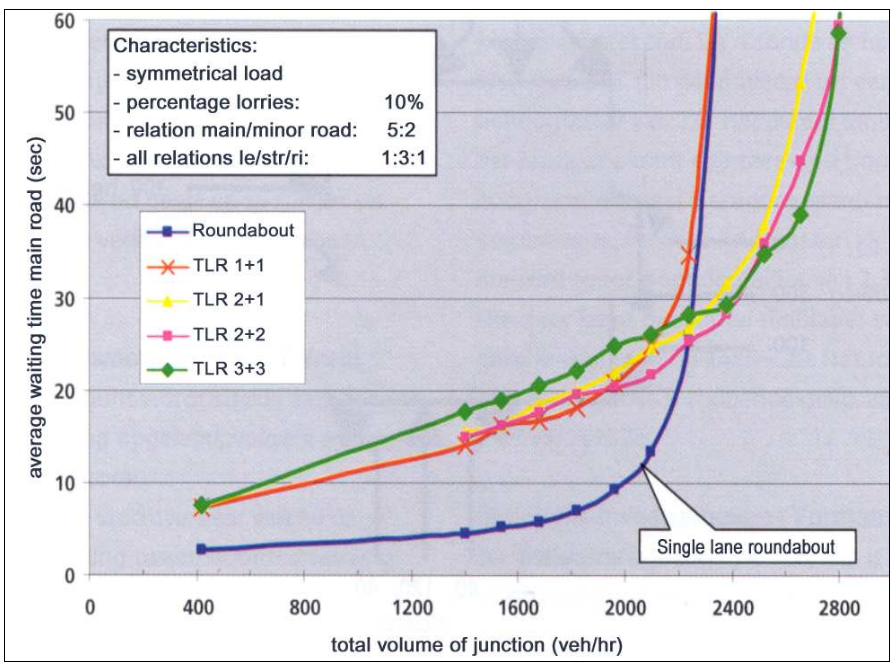


Figure 20: Average waiting time main road

In figure 21 (main road) and figure 22 (minor road), the average waiting time for a single-lane roundabout is compared with a junction with traffic lights by means of micro simulations. The traffic volume in each direction is symmetrical, while the different number of lanes at the junction controlled by traffic lights is taken into account:

- TRL 1+1 : traffic lights regulation, one lane main road, one lane minor road;
- TRL 2+1 : traffic lights regulation, two lanes main road, one lane minor road;
- TRL 2+2 : traffic lights regulation, two lanes main road, two lanes minor road;
- TRL 3+3 : traffic lights regulation, three lanes main road, three lanes minor road.

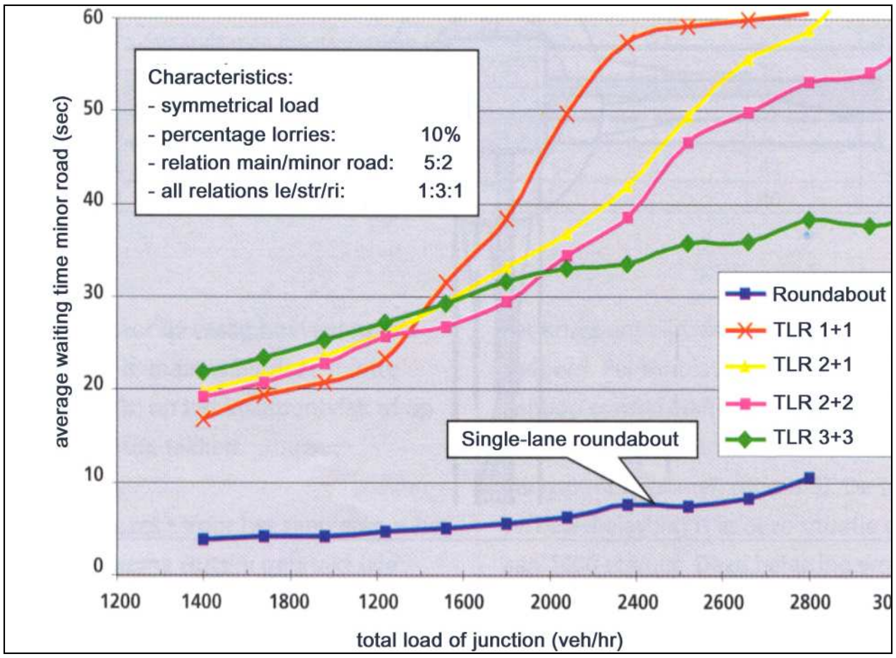


Figure 21: Average waiting time minor road

There are various methods available for assessing capacity in order to decide whether a particular roundabout can be applied. An initial test is extremely global. Depending on that test, more in depth methods can be utilised. In practice, a global test generally suffices. An in-depth method is only recommended when solutions are unclear.
To determine the capacity of the roundabout, the following methods are available:

- rules of thumb;
- calculation rule;
- macroscopic or microscopic calculation models.

Rules of thumb
A roundabout can usually be utilised if the sum of the approaching traffic flows is less than:

- single lane roundabout, single lane entrances and exits: approximately, 25,000 veh/24 hr;
- two-lane roundabout, single-lane entrances and exits : approximately 30,000 veh/24 hr;
- two-lane roundabout, two-lane entrances and exits : approximately 40,000 veh/24 hr.

The values quoted only apply to situations where there are no cyclists or pedestrians or where they have either no priority or free passage. This rule of thumb ignores differences in the varying traffic volumes at different times of the day, origin and destination relationship and traffic composition. Therefore it is also advisable to carry out a control calculation based on the conflict load.

Calculation rule

A roundabout can be seen as a series of connected T-junctions. The capacity is reached when the volume of flow on one of the approach roads is identical to or greater than the capacity at the conflict point with the entrance of a connecting road. The capacity of an approach road is seen here as a determinant quantity and comprises two components:

- The exiting capacity: the maximum number of vehicles that can enter the roundabout without conflicting traffic. The capacity depends on geometry, weather conditions and the distribution of the traffic;
- The conflict factor: this factor shows the reduction in the exiting capacity due to (possible) conflicting traffic.

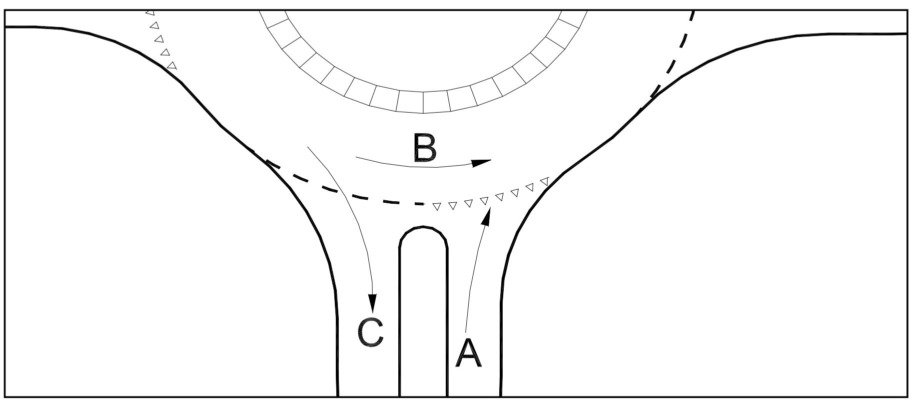


Figure 22: Determining conflicting directions for the capacity of a single lane roundabout

The determining conflict is shown in figure 23 by the letters A and B. Obviously conflicting traffic (C) means traffic turning right just before the entrance of the roundabout. This right-turning traffic influences the capacity. Drivers leaving the roundabout generally don’t indicate, and drivers waiting at the entrance then start wondering if they are waiting longer than necessary. This can be partly prevented by constructing a wide central island (and a more spacious roundabout). The maximum conflict load is (figure 22):

- single-lane roundabout, single-lane entrances and exits : 1,500 pve/hr;
- two-lane roundabout, single-lane entrances and exits : 1,800 pve/hr;
- two-lane roundabout, two-lane entrances and exits : 2,100 to 2,400 pve/hr.

The conflict load is expressed in ‘pve’ (passenger vehicle equivalents). Not only do trucks and buses have larger dimensions; these vehicles also move oft more slowly, which influences the capacity. The ‘pve’ value for trucks and busses is:

- truck or bus on the roundabout : 2 to 3 pve;
- truck or bus on the entrance of the roundabout : 3 to 4 pve.

The processing capacity of single-lane roundabouts, with single-lane approach roads without cyclists with priority can be determined using the formula below. Every connection should be calculated individually using this formula.

$A_{entrance} = 1{,}500 - B_{roundabout} - 0.3 \times C_{exit}$

$A_{entrance}$	*= processing capacity of the entrance in pve/hr*
1,500	*= conflict load*
$B_{roundabout}$	*= volume on the roundabout in pve/hr*
C_{exit}	*= volume of the exit in pve/hr*

Other models

For other basic forms of the roundabout there are no validated methods enabling reliable statements concerning traffic processing.

Assessments can best be estimated using the “Bovy” calculation method. This formula allows you to calculate the capacity for both single and two-lane roundabouts with either single or two-lane entrances. The method allows for obvious conflicting traffic on the roundabout turning right just before the entrance (C in figure 22).

Nomograms are produced using formula (figure 23 and figure 24) that enable assessment of the traffic processing on an approach road. The following should be noted in respect of these nomograms:

- the nomograms have only been validated to a limited extent;
- two lines are drawn in the nomograms:
  - the upper line shows the maximum quantity of traffic that can be processed regardless of waiting times;
  - the lower line shows the practical capacity, based on a waiting time of traffic of a maximum of 20 sec;
- the volume of the entrance is plotted on the vertical axis (pve/hr) (A on figure 22);
- the volume on the roundabout is plotted on the horizontal axis, including a proportion (approx. 30%) of the volume at the exit of the same connection. (B + 0.3C on figure 22);
- in the case of a bypass (e.g free turning right lane) the volume of traffic using the bypass is subtracted from the volume on the entrance;
- at roundabouts with cyclists or pedestrians, there is a refuge with sufficient space to cross in two stages.

The following two conclusions can be drawn from the calculations:

- A two-lane roundabout with single-lane entrances offers a higher capacity to enter in comparison to a single-lane roundabout with a maximum of 400 pve/hr. Determine whether the single-lane exits with a maximum capacity of 1,500 pve/hr can process the volume. The capacity difference decreases proportionately in the event of lower volumes on the roundabout and, ultimately, this difference is nil.
- A two-lane roundabout with two-lane entrances offers a higher capacity to enter in comparison to a two-lane roundabout with single-lane entrances with a maximum of 800 pve/hr. This difference is reached at extremely low roundabout volumes and decreases proportionately to approximately 50 pve/hr in the event of extremely high volumes on the

roundabout. Here, too, determine whether the single-lane exits with a maximum practical capacity of 1,500 pve/hr can process the volume.

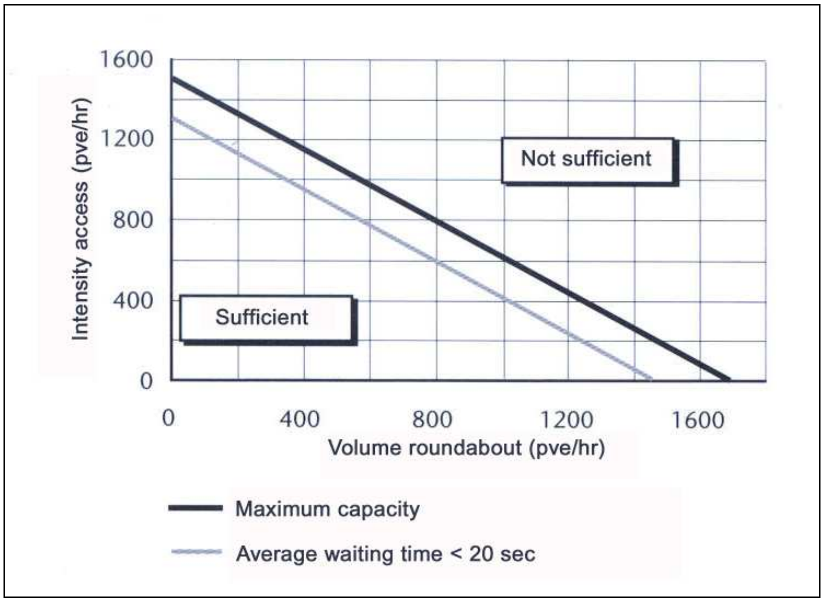


Figure 23: Nomogram capacity of a single-lane roundabout with single-lane entrances (pedestrians no priority)

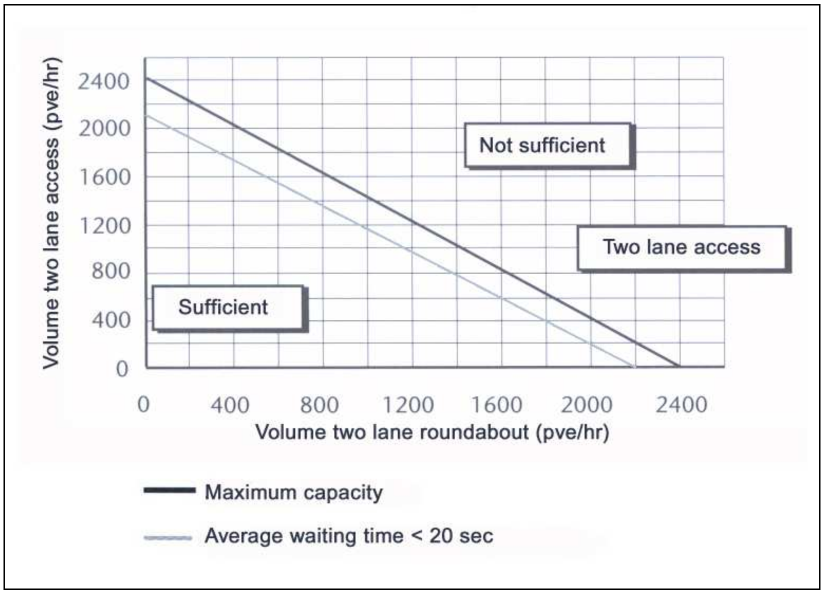


Figure 24: Nomogram capacity on two-lane roundabout with two-lane entrances (pedestrians no priority)

5.2.2 Design of roundabouts

Many road safety aspects play a role in the design of the roundabout. Important aspects are: speed, uniformity, conspicuousness, visibility and recognisability.

- The road user must be informed of the approach of the roundabout in time. Consistent signposting and markers can contribute.
- The advance signposting, on which the roundabout is already recognisably displayed, is a clear signal of the approach of a roundabout.
- To improve the conspicuousness of the roundabout it is advisable to raise the central island. It is not necessary for the approaching motorist to see the oncoming traffic over the central island. The diameter of the elevation must, however, be substantially smaller than the entire central island, to ensure the visibility of traffic on the entrances. The height should be a minimum of 1,10 m (eye level). The design of the island should be collision-friendly.
- Entrances should be connected to the roundabout as radially as possible, therefore limiting the entering speeds and supporting the priority rules. The entrance and exit radii should therefore also be as small as possible.
- In the case of connecting roads with a (very) wide refuge (beneficial to the capacity) it is advisable to increase the diameter of the roundabout to prevent traffic that has to give way from entering the roundabout at too high speed. Up to 30 m, the outer radius of a roundabout is of little influence on the speed and therefore on road safety.
- For through traffic it is important that the bend-out at the roundabout is sufficiently wide. If the connecting roads are not square to each other, then there is the risk of increasing speeds on the roundabout.
- The design of any separate cycle paths should support the priority rules (no priority for cyclists outside built-up area).

There are five design elements that determine the layout of the standard roundabout outside built-up area:

- the outer and inner radius;
- the lane width and the width of the circulatory section;
- the entrance and exit curves;
- the width of the entrance and exit;
- the refuge in the connecting roads.

5.2.2.1 Single-lane roundabout

Figure 25 and table 6 show the standard dimensions for the single lane roundabout and the dimensions of the roundabout for vehicles with a length of 22.00 and 27.00 m.

Outer radius

The outer radius is the distance from the central point of the roundabout to the outside of the pavement. Any separate cycle facilities are outside this pavement. The outer radius is therefore directly relative to the space available for the motorised traffic.

Inner radius

The inner radius is the distance from the central point of the roundabout to the outside of the central island, including the mountable apron. The inner radius therefore more or less determines the visual restriction of the entrances and the negotiability of the roundabout. The inner radius has a major influence on speeds on the roundabout and therefore on road safety.

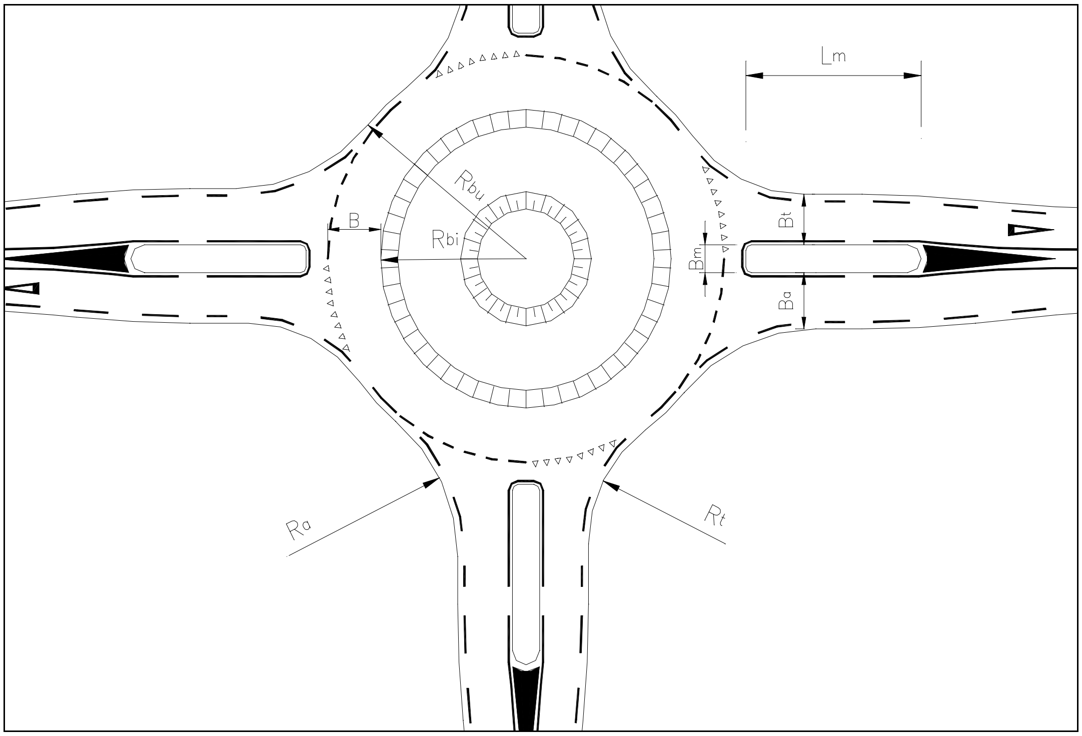


Figure 25: Single lane roundabout outside built-up area

Table 6: Overview of dimensions single-lane roundabout outside built-up area

Design element	Standard (m)	Length of design vehicle 22.00 m	27.00 m
Outer radius (Rbu)	18.00	18.00	18.00
Inner radius (Rbi)	12.75	12.75	12.75
Lane width (B)	5.25	5.25	5.25
Overrun area	1.50	3.00	4.00
Entrance curve (Rt)	8.0[1] / 12.0[2]	12.00	12.00
Exit curve (Ra)	12.00[1] / 15.00[2]	15.00	15.00
Entrance width(Bt)	4.00[1] / 3.50[2]	4.00	4.00
Exit width (Ba)	4.50[1] / 4.00[2]	4.50	4.50
Refuge width (Bm)	3.00	3.00	3.00
Refuge length(Lm)	10-15	10-15	10-15

[1]) without refuge

[2]) with refuge

Lane width

The difference between the outer and the inner radii is the lane width. The lane width must, on one hand, be wide enough for the representative design vehicle to pass and, on the other, not so wide that it encourages excessive speeds.

Lane and overrun area of a single lane roundabout

Overrun area

The overrun area is a part of the central island. The width depends on the design vehicle and the combination of the dimensions of the other design elements. Figure 26 shows the cross-section of the roundabout. To keep the roundabout compact, but negotiable for trucks, a overrun area has been included. This overrun area is in principle, only used by (large) trucks. The gradient is 1%, combined with a special transitional concrete element (maximum level difference 0.08 m).

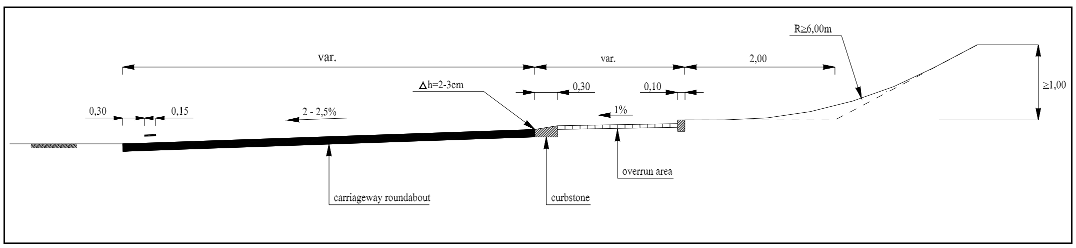


Figure 26: Cross-section of a single-lane roundabout

The standard dimensions quoted for the outer and inner radii should not be taken as absolute. Larger roundabouts can also function quite satisfactorily, as long as the dimensioning of the other design elements corresponds. Figure 27 gives a graphic of the relationship between outer radius, inner radius and lane width.

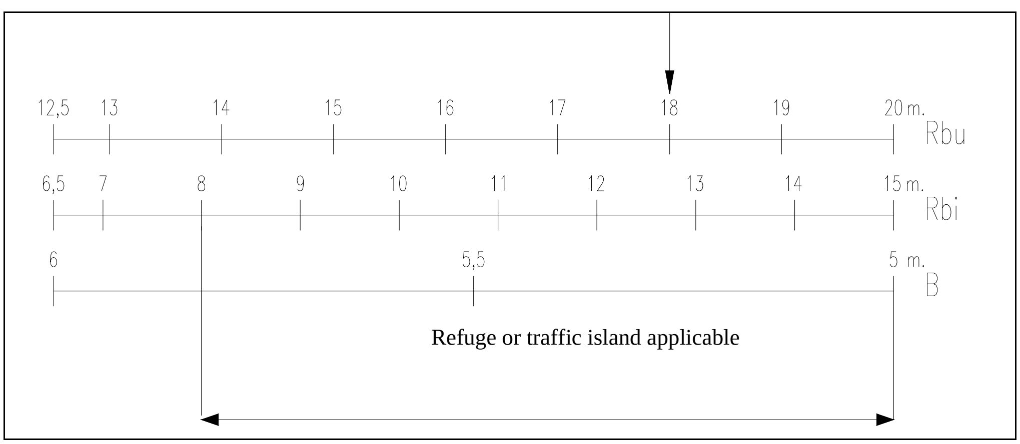


Figure 27: Relations between outer radius, inner radius and lane width for a single-lane roundabout

Curves

Together with the width of the roundabout lane and the width of the entrances and exits, the curves determine the negotiability of the roundabout for the representative design vehicle. In general, it is preferable to make these radii as small as possible. More generous radii need not, however, necessarily lead to higher speeds when negotiating the roundabout. In situations of exceptional large vehicles it can be beneficial to install a mountable apron next to the exit curve.

Width of entrances and exits

The widths of the entrances and exits has little or no influence on speeds when negotiating the roundabout, but do affect:

- the negotiability of the roundabout for buses and trucks;
- ease of crossing for cyclists and pedestrians (the narrower the better);
- the visual restriction of the entrance, together with the diameter of the central island, supporting the priority rules.

Refuge

Refuges or traffic islands can be installed in the connecting roads for the following reasons:

- guiding the drivers between the entrance and exit;
- increasing the capacity of the round-about;
- ease of crossing the lane for cyclists and pedestrians;
- positioning sign posting.

Refuge with cyclist crossing

The use of refuges is directly related to the dimensions of the entrance and exit curves and the radius of the central island. Refuges applied wrongly can cause negotiability problems for trucks and busses. With small roundabouts, the refuges should therefore be omitted. The advantage here is that a more flexible solution is created for heavy traffic.

In rural area the width of the refuge should preferably be 3 m with a length of approximately 15 m. The head of the road marking should be set back from the side of the roundabout by approximately 1 m to improve the roundabout’s negotiability.

Bypass

To increase capacity, one particular traffic flow can be directed alongside the roundabout. This ‘short-cut’ alongside the roundabout between two connecting roads is referred to as a bypass.
Figure 28 shows a representation of bypass forms. The bypass is only useful when the traffic flow in question is sizeable. Only then is the conflict point on the entrance of the roundabout alleviated. The bypass can cause problems when there are parallel facilities alongside the road (bicycle path, parallel road).

5.2.2.2 Multiple-lane roundabout

The multiple-lane roundabout is less safe than the single-lane roundabout due to:
- the more complicated traffic situation on the roundabout;
- the higher speeds as a result of the wider lanes.

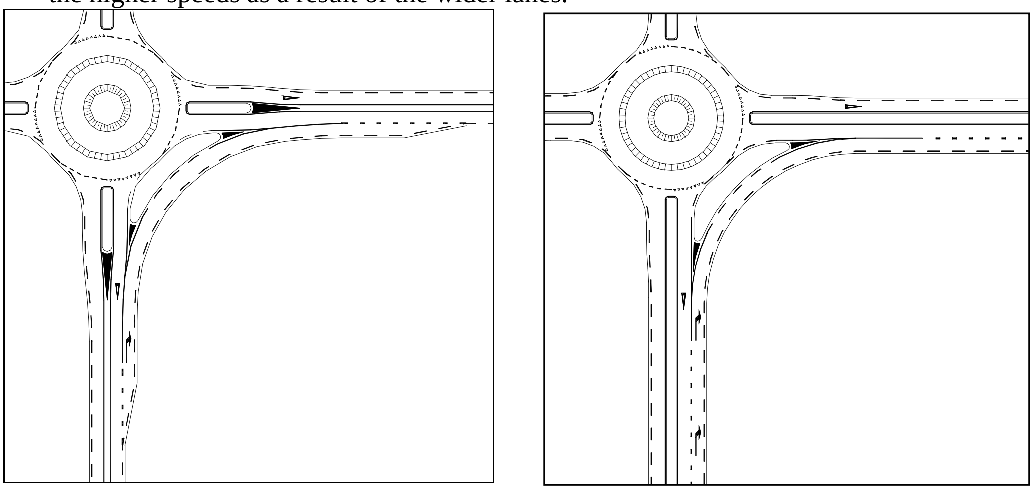


Figure 28: Bypass alternatives

The two-lane roundabout can, nevertheless, be installed safely, and, the two-lane roundabout is safer than priority junctions with traffic lights as long as a number of aspects are kept in mind:
- the entrances should be placed as radially as possible;
- a circular roundabout is preferable to an elliptical roundabout;
- both single and two-lane entrances can be accommodated;
- the exits should, in principle, be single-lane to prevent conflict situations on the roundabout.

The two-lane roundabout, with or without two-lane entrances and exits, should only be adopted when the capacity of the single-lane roundabout is insufficient. This also has advantages when cyclists and pedestrians are crossing. When seeking solutions for the capacity problem it is advisable to progress through the following steps:

Two-lane roundabout with bypass

- take measures to increase the capacity of the single-lane roundabout, such as a bypass. Single-lane roundabouts with two-lane entrances and exits should not be applied;
- a two-lane roundabout with single lane entrances and exits;
- increase the capacity of the two-lane roundabout by applying a bypass;
- a two-lane roundabout with two-lane entrances and single lane exits;

- a two-lane roundabout with two-lane entrances and two-lane exits.

Dimensions of design elements

When dimensioning the various design elements the following principle should be applied:

- the dimensions of the lane widths at the entrance, the roundabout and any exit should be based on the requirement to two trucks driving parallel;
- the dimensions of the central island and the width of the entrances and exits must be related to a speed of 40-45 km/hr.

Figure 29 and table 7 give an overview of the design criteria, assuming a bend out for straight on traffic at the roundabout, is based on the dimensions of the cross-section at the entrance, with a refuge width of 2.50 m and a carriageway width of 7.00 m. The design of the central island is in principle identical to that of the single-lane roundabout. When applying a two-lane roundabout, a median should always be applied in the connecting roads. With an outer radius of 29.00 m, an inner radius of 20.00 m, two lanes in the entrance and a median of 2.50 m the passenger vehicles may negotiate the roundabout at approximately 38 km/hr. The speed for passenger vehicles should not exceed 40 to 45 km/hr.

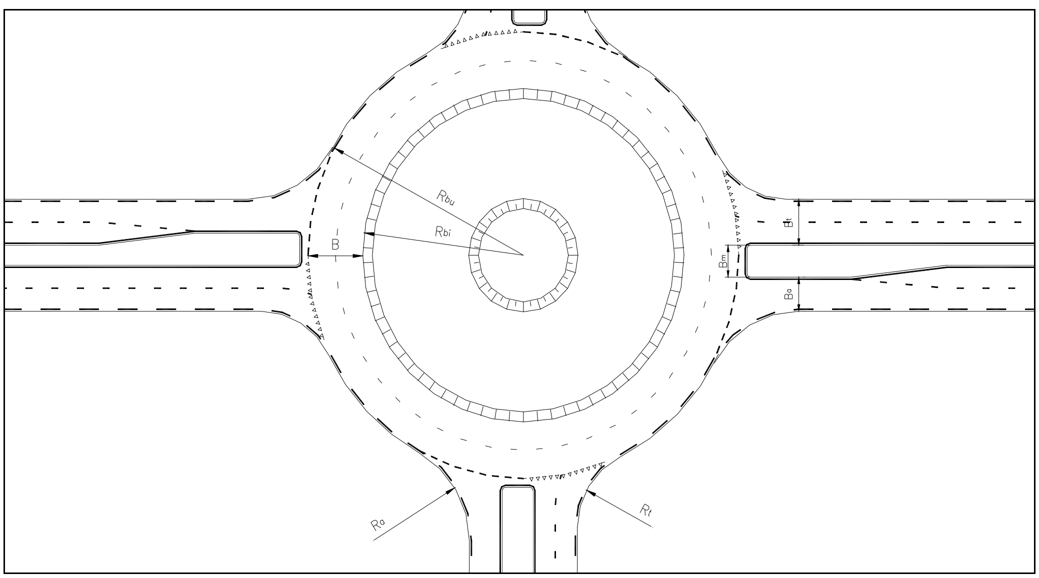


Figure 29: Two lane roundabout, two lane entrance, single lane exit

Table 7: Overview of dimensioning of two-lane roundabout outside built up area

Design element	**Dimensions (m)**				
Outer radius (Rbu)	20.00	25.00	29.00	33.50	38.00
Inner radius (Rbi)	10.00[1]	16.00[1]	20.00	25.00	30.00
Lane width (B)	10.00	9.00	9.00	8.50	8.00
Entrance curve (Rt)	12.00	12.00	12.00	12.00	12.00
Exit curve (Ra)	15.00	15.00	15.00	15.00	15.00
Entrance (single lane)	4.00/3.50[2]	4.00/3.50[2]	4.00/3.50[2]	4.00/3.50[2]	4.00/3.50[2]
Exit (single lane)	4.50/4.00[2]	4.50/4.00[2]	4.50/4.00[2]	4.50/4.00[2]	4.50/4.00[2]
Entrance (two lane)	lane[3]	lane[3]	lane[3]	lane[3]	lane[3]
Exit (two lane)	lane[3]	lane[3]	lane[3]	lane[3]	lane[3]

[1]) test the speed on the roundabout with these dimensions

[2]) depending on whether there is any heavy or exceptional large vehicle

[3]) the width depends on the width of the lanes of the link road at the exit/entrance

The disadvantage of the multiple-lane roundabout as shown in figure 30 is that a lot of weaving conflicts arise between two successive side roads. Any accidents arising from these conflicts are usually not serious because of the limited speeds. The capacity is, however, negatively affected by these conflicts. The disadvantages in respect of road safety and traffic flow can be prevented by prompting the choice of route before entering the roundabout. These conflicts no longer take place on the roundabout itself. This has led to the development of the multiple-lane roundabout with spiral markings. Figure 30 and figure 31 show two examples.

Weaving conflicts on two lane roundabout

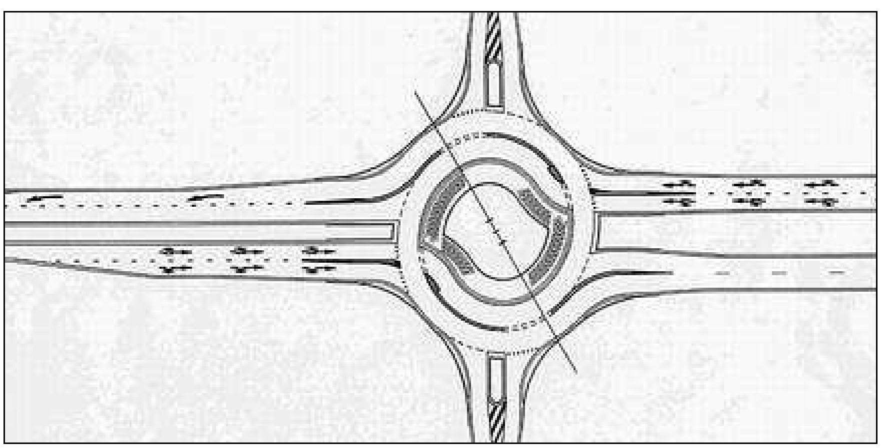


Figure 30: Multilane roundabout 'egg'

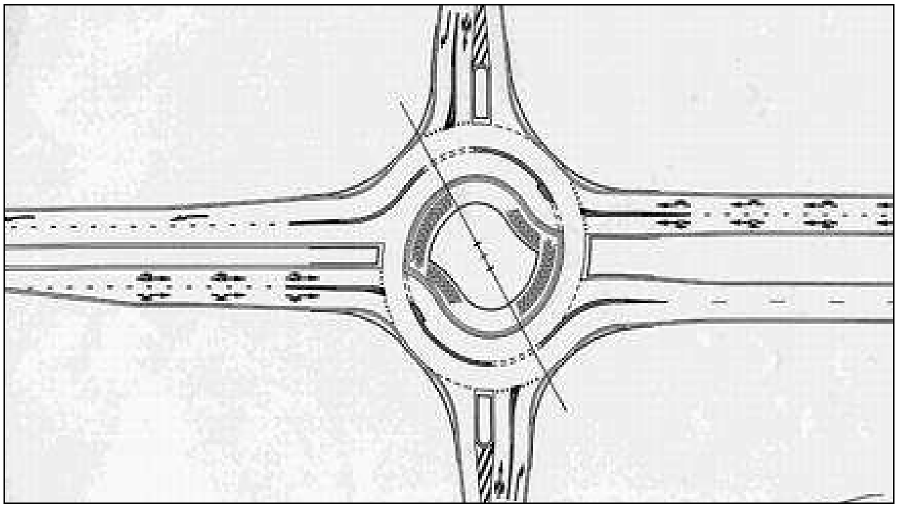


Figure 31: Multilane roundabout 'turbo'

5.3 Priority junctions

5.3.1 Lay out priority junction

The prescribed marking of priority junctions with traffic signs is usually not sufficient. The design should also be such that the perception of the priority corresponds with the priority rule at the location. The design should clearly support the priority rules and show which of the roads is the main road and which the minor road. This can be done by providing a physical difference between the two roads by, for example, applying a (long) median in the main road and a traffic island or refuge in the minor road.

Before entering the junction, the traffic without right of way must be provided with sufficient visibility of the presence and speed of traffic on the main road. The visibility should be provided at a minimum of 5.00 m back from the edge line of the main road. The visibility requirements depends on:

- the speed of traffic on the main road;
- the critical gap drivers without right of way need to execute the proposed manoeuvre (right turn, straight on or left turn).

When the critical gap is 6 sec and the 85% speed on the main road is for instance 90 km/hr, the minimum visibility requirement is 150 m.

Design
A standard priority junction (without traffic lights) in a distributor road should have at least the following design elements (figure 32):

- maximum of one lane per direction;
- separate left-turn lane;
- traffic island(s).

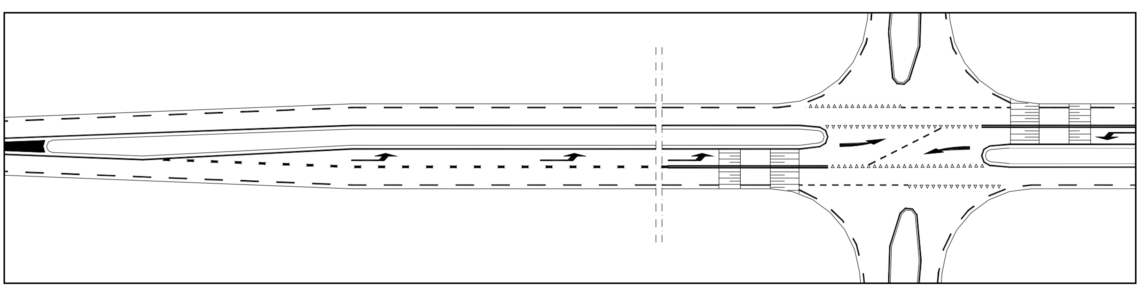


Figure 32: Standard priority junction with a narrow median (distributor road, single carriageway)

Priority junctions in accordance with figure 32 should only be applied in road type II of the distributor road. A narrow median is not a standard design element of the junction. This design element is, however, strongly recommended for various reasons (see also right photo, page 55). In figure 32 a raised plateau has been installed in the main road directly before the junction to reduce the speed (see also left photo, page 55). This makes the main road easier to cross (road safety). Initial experience is currently being gained with such plateaus in The Netherlands.


Priority junction in distributor road (rural area)


Speed limit 50 km/hr, raised plateaus to reduce speeds in distributor road (rural area)

5.3.2 Design elements

In addition to the various design parameters of the cross-section, priority junctions include the following (specific) design elements:

- on the main road:
  - the through-traffic lane;
  - the median;
  - the separate left-turn lane;
- on the minor road:
  - the (through-traffic) lane;
  - the traffic island;
  - the entrance and exit curve.

In general the most compact junction is the safest. In the Netherlands, nowadays, the aim is to make the junctions as compact as possible. The total number of lanes is in some cases reduced.



Compact junctions by reducing number of lanes (low cost measures)

5.3.2.1 Number of through lanes

In the junction area, the cross section continues largely unchanged. At the location of the junction a number of design elements are added, which allow for turning movements. Priority junctions without traffic lights should only be applied in distributor road type II. For road safety reasons it is not permitted to construct two lanes in one or both directions at the location of the junction. If to increase capacity measures are needed, then a roundabout or a priority junction with traffic lights should be opted for. In the latter case extra lanes can be built if necessary. Priority junctions in dual carriageways must always be equipped with traffic lights.

Only one through lane at junction

5.3.2.2 *Median*

Narrow median

There can be several reasons for providing a priority junction with a narrow median (width approximately 2.00 m between the pavements):

- pedestrians, cyclists and, depending on the width, also drivers of passenger vehicles can cross in two stages, reducing the waiting time. A median is of high benefit for pedestrians;.
- the visibility and recognizability of the junction is improved;
- the illegal use of the left-turn lane by overtaking is physically prevented. This is the case only if the median physically closes off the left-turn lane;
- a median offers excellent possibilities for installing traffic lights at a late stage;
- road furniture can be installed where necessary in the median;
- with a median it is easier to install traffic calming measures.

In the event of crossing pedestrians and cyclists a width of 3.00 m of the median is recommended. The length of median is determined by the length of the separated left turn lane. It is preferable to design the median so that the left-turn lane cannot be used as an overtaking lane. The median should not be constructed higher than 0.07 m from the road surface when kerbstones are used. These kerbstones should preferably be bevelled at an angle of 45°. In the Netherlands, a median at junctions without left-turn lanes has a positive effect on road safety:

- at T-junctions a median alone leads to a reduction of approximately 10% of the number of accidents in relation to T junctions without a median;
- at four-branch junctions the reduction amounts to as much as approximately 60%.

The combination of left-turn lanes and medians is less favourable. It should be mentioned here that non-elevated medians are more advantageous than elevated medians. This relates to a lower rate of single vehicle accidents.

Wide median

With wide medians (15 to 20 m), all drivers of the regular vehicles can cross in two stages. The capacity of priority junctions with a wide median is slightly higher than that of a junction without a wide median. Practical experience and accident analyses have, however, taught us that except at T-junctions the road safety at junctions with the wide median is less. The wide median may impedes the visibility and recognizability of the second carriageway that has to be crossed. There is very often a cluster of give way accidents at the second carriageway.

The design is also extremely unfavourable when a traffic control system is to be installed in the future. To limit clearance times (wasted time), as compact a junction as possible is the ideal. From safety considerations, priority junctions with a wide median are strongly advised against.

5.3.2.3 Left and right-turning lanes on main road

Separated left turn lane

With separate lanes for left-turning traffic (figure 33, table 8):

- the left turn lane prevents blockage of the through-traffic lane
- the speed differences between through and turning traffic remain limited, as some of the speed reduction takes place in the left turn lane;
- any waiting to allow oncoming traffic free passage takes place alongside the through lane, to avoid hindrance on the lane.

The necessity of left turn lanes on the main road at priority junctions is far greater than that of right turn lanes. Left turn lanes must always be constructed on the national and regional roads (distributor road type I and type II). In most cases, right-turn lanes are unnecessary on the main road.

In the Netherlands, provision of separated left-turn lanes on the main road at priority junctions, compared with junctions without left turn lanes, generally leads to an accident reduction of:

- 60% at three-branch junctions;
- 50% at four-branch junctions.

Left turn lane on distributor road

A left turn lane increases the junction area and therefore the crossing length for traffic coming from the minor road. This negative effect is extremely slight, however, in comparison to the indicated positive effects.

The length of left-turn lanes should be restricted. They primarily have the function of ‘streaming space’ and are not intended as ramps on through roads. The recommended dimension (figure 33 and table 8) is a compromise between reasonably comfortable exiting and braking and the prevention of improper use. The width of the left-turn lane is generally 0.25 m less than the adjacent through lane, with a minimum of 2.50 m between the markings.

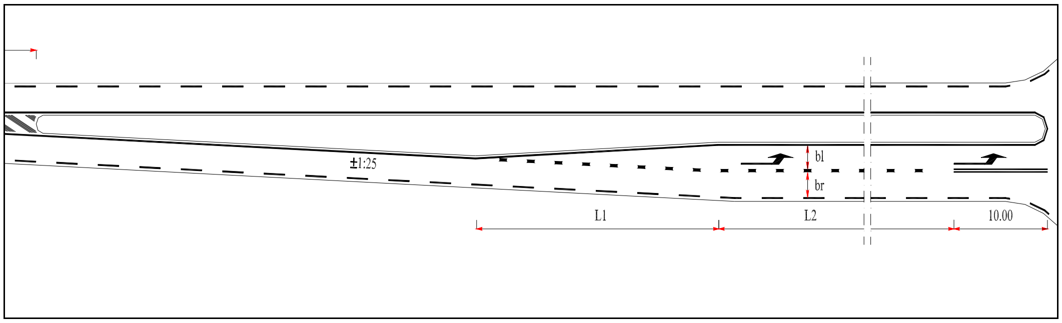


Figure 33: Design of a left-turn lane on the main road

Table 8: Dimensions for left-turn lane on main road

Design speed (km/hr)	W_1 (m)	L_1 (m)	L_2 (m)
100	2.75	40	95
80	2.60	35	65
60	2.50	35	35

The length of the left-turn lane ends or begins at the top end of the lane divider or conflict area. Whenever the recommended length cannot be realised, it is always better to construct shorter left-turn lanes than to omit them entirely. The chief objective is to allow left-turning traffic to position itself alongside the lane for the through traffic.

Right-turn lane on the main road

Right turning traffic continues moving at a reduced speed in many cases, and in practice, few rear-end accidents occur. It is often not essential to construct a right turn lane.

In the case of right-turn lanes, the right-turning traffic obscures visibility. Drivers on the minor road have their visibility of vehicles on the through traffic lane obscured for a period by right-turning traffic. This time period is within the critical time when vehicles are waiting for a gap. The consequential give way accidents are more serious than any rear-end accidents occurring in the absence of the right-turn lane. Evaluation research, after removing right-turn lanes at priority junctions on main roads in the Netherlands, has show that road safety is improved without a right-turn lane. Many right turn lanes are now removed or blocked.

Right turn lane closed off

5.3.2.4 Intersecting angle

It is essential for the axes of the two roads to be approximately at right angles. The reasons are:

- a symmetrical junction design;
- improved negotiability of the junction;
- improved visibility of through traffic from the minor road.

The intersecting angle should preferably be 90°. Angles between 80° and 120° are, however, still acceptable. If the angle of a junction is smaller than 80° or larger than 120°, then the road axis should be adjusted in such a way that the angle between the road axes is within the indicated limits (figure 34).

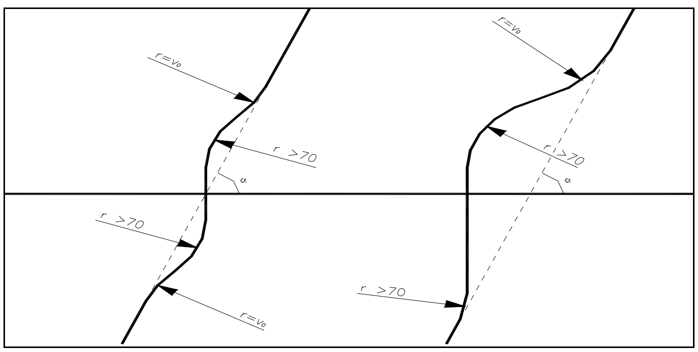
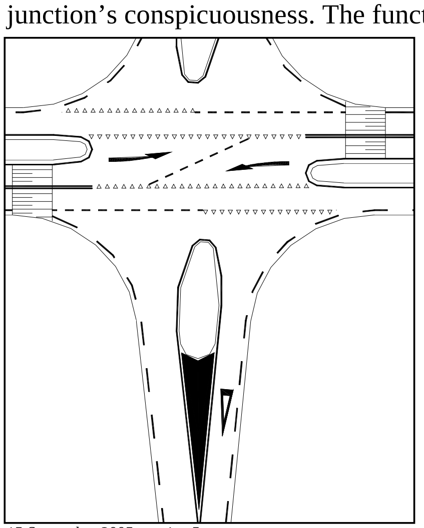


Figure 34: Intersecting angle between 80° and 120°

For through traffic the visibility of the junction, on approach, should be not less than the stopping sight distance at the relevant design speed. In extreme case, the approach speed will have to be controlled to the stopping sight distance using traffic calming measures.

5.3.2.5 Traffic island in minor road

For safe flow the traffic island fulfils a function for the traffic on both the minor road and the main road (figure 35). As a design element, a traffic island contributes to the improvement of a junction's conspicuousness. The functions of the traffic island on the minor road are as follows:



- visual restriction of the end of the minor road, so the drivers promptly adjusts their speed accordingly when approaching the junction;
- emphasis of the status of the side road and the give way rules at the junction;
- guide the traffic to avoid any vehicles waiting on the minor road obstructing the traffic turning off the main road.

The functions of the traffic island on the main road are:

- increasing the driver awareness of the junction due to the greater connecting width of the minor road and the third dimension (elevation) of the island;

- directing turning traffic onto the minor road.

Traffic islands may only be applied in minor roads of a priority junction. The dimensions must remain limited, as the traffic island should not be confused with a median on the main road. The manoeuvres of the design vehicle determine the location and design of the front of the island.

Figure 35: Traffic island minor road

The front of the island must be no closer than 3.00 m, preferably 4.00 m and no further than 5.00 m back from the edge line of the main road. The island must be elevated with height of 0.10 m above the road surface recommended. The island must not constitute a dangerous obstacle for the traffic on either the main road or the side road.

5.3.2.6 Number of lanes on minor road

Every means available should be used to support the give way situation. Constructing a number of lanes in the minor road alters the subordinate character of this road, despite the traffic island.
At priority junctions (without a traffic lights) there should be no more than one entry lane in addition to the traffic island. An extra lane for turning traffic may increase the capacity, but accident statistics have shown a reduction of road safety. The causes of higher accident risk are:

- the strong reduction in the visually restricting effect of the traffic island when approaching the junction;
- vehicles waiting in the lanes obscuring the clear view of traffic on the main road, when both approaching and entering the junction from the minor road.

If there is a significant proportion of right-turning traffic from the side road, the designer can consider constructing a separate, short right turn lane. The disadvantage is that the vehicles waiting to cross or turn left obscure right turning road user's view when entering the junction.

5.3.2.7 Curve

Together with the width of the road pavement of the intersecting roads, the dimension of the exit and entrance curves determines the total size of the junction. As we established earlier, the junction should be as compact as possible. This calls for tighter curves. The dimensions of the curves depend on the design vehicle and the desired speed with which the turning manoeuvre has to be executed.
The choice will always be a compromise, the success of which depends largely on the driving conduct of the road user. In practice, a radius of 15 metres has proved a good solution in most cases. Larger radii should be avoided, due to the negative effect on driving conduct.

5.4 Priority junctions with traffic lights

It is only acceptable to install traffic lights at a priority junction when:

- the waiting times for the subordinate traffic flows are unacceptably high;
- other solutions, such as constructing a roundabout, do not offer a satisfactory solution;
- road safety with either options is unacceptable, on the understanding that the installation of traffic lights can be expected to have a positive effect on road safety.

Application of traffic lights in single carriageways is, in principle, not recommended. The application of a single or double-lane roundabout is far preferable, due to:

- road safety: the roundabout is approximately 60% safer than a priority junction with a traffic control system;
- the total waiting time: in the event of traffic volume lower than the capacity the waiting time at a roundabout is considerably shorter;
- the capital costs (investment costs, management costs and depreciation): the costs of a roundabout are substantially lower.

The capacity of single and two lane roundabouts with two lane entrances, and any bypasses, may be insufficient for dual carriageways. If a roundabout is not feasible for some reason, then the priority junction in the regional access road, with 2 x 2 lanes will often need to be equipped with traffic lights, regardless of the traffic volume. Moreover, the system has to be operational 24 hours a day.

Great caution is urged in assessing the effect of a traffic control system on road safety. At priority junctions with traffic lights the following types of accident frequently occur:

- rear-end accidents due to varying responses to the amber and red lights;
- accidents caused by drivers ignoring red lights;
- accidents as a result of conflicts in the regulation (not conflict-free);

Speed limit 50 km/h, camera and raised plateau

The incidence of drivers ignoring red lights can be reduced by, for example:

- providing sufficient capacity (preventing vehicles from all queue cleared during ‘green’ period being ‘left over’);
- limiting the speeds (maximum speed 50 or 70 km/hr) on approach;
- enforcement by means of speed and ‘red light’ cameras;
- making the lights more visible.

Clear visibility of traffic lights is absolutely essential to road safety on roads with high speeds. Both the traffic lights and the meaning of the light signals must be visible and clearly recognisable under all weather conditions. Traffic lights on roads with a maximum speed of 80 km/hr must therefore be visible from 200 m before the stop line. Only then will the driver have sufficient opportunity to react to stationary or braking vehicles. There should therefore always be lights above the (through) lanes. The visibility distance on the minor roads (maximum speed 60 km/hr) should be 135 metres.

Traffic lights above each lane

The following rules apply in the Netherlands for determining the number of lights and their position above or next to the road:

- for more than two lanes width, there must always be at least one light positioned above the road
- on distributor road (national and regional roads) there must always be at least one light positioned above the road
- where several lights are positioned above the road, one light per lane must be positioned in the middle of each lane;
- where lanes for turning traffic are not regulated in a conflict-free manner a light above the relevant streaming lane is not sufficient. In practice, you will have to consider whether a third light can be placed to the left of the road or, for visibility reasons, above the left-turn lane;
- where right-turning traffic turns off before the highest positioned light, then a low light should be installed for this traffic;
- in a situation with two regulated junctions, one immediately after the other, the signal control at both junctions must be synchronised to minimise the risk of a driver reacting to the signals from the wrong traffic lights;
- Outside urban area no two lights for two separately regulated movements in one driving direction may be positioned next to each other on one mast.

In principle, the design of a priority junction controlled by traffic lights should correspond as closely as possible with that of a junction without traffic lights. After all, the system may be intentionally or unintentionally out of order, in which case the traffic flow must be able to operate as safely as possible.

6 SUSTAINABLE SAFE ROAD DESIGN: ALIGNMENT

6.1 Introduction

The alignment of a road is a three-dimensional line containing the geometrical elements constituting the basic design of a road or a road section. For design purpose the alignment is split into horizontal and vertical alignments. The design elements are straights, grades, curves and transition curves. Coordination between the horizontal and vertical alignment is important to achieve:

- the desired function of the road;
- the road image and the environmental quality;
- the uniformity and recognizability.

A proper alignment related to the design speed and the route speed. The design speed is used to determine other design parameters, such as sight distance and the elements of the horizontal and vertical alignment. Which speed to choose depends on the desired level of road safety and the capacity of the road. Through the combination of regulated velocity regime and a consistent design, predictable traffic conditions are created.

Drivers base their choice of route mainly on the time needed for a certain journey, the reliability of the intended route and the driving comfort of the route. The route velocity is therefore an important criterion for checking the quality of the actual capacity. The speed level is influenced by the limitations in the cross section the alignment.

6.2 Sight distance

Driving speed

Safe driving demands the capability of recognising traffic situations and the ability to predict the outcomes. The sight distance is an important parameter for road design. The definition of sight distance is: the distance the driver can observe the length of the road in front of him.

The sight distance is strongly influenced by the driving speed:

- The necessary stopping sight distance is greater with a higher driving speed.
- The perception angle (the area a driver can observe without moving the eyes) is narrower with a higher driving speed.

The stopping distance is composed of the following parts:

- The distance covered during the perception-reaction time.
- The distance covered while executing the necessary actions (breaking, steering and adjusting).
- The distance covered while recognising a certain design element, such as a curve or an object.
- The distance added for comfort or extra safety.

Perception-reaction time

The perception-reaction time differs per individual and is influenced by the characteristics of the road and its surroundings. The expectations of the driver are important as well. Research has revealed perception-reaction times from 0.7 seconds for clearly expected, highly visible events to about 3 seconds for unexpected events. The average time is 2 seconds.

Apart from characteristics of the road (curvature) and traffic (volumes and behaviour), warning signs, such as markings, beacons and signs raise the attention of drivers. In these cases a perception-reaction time of 1 second can be justified.

Type of sight distance

The type of necessary action (maintaining course, stopping, changing course) determines which sight distance to allow for in the design:

- visibility of the alignment ahead;
- visibility of stationary traffic or an obstacle downstream;
- visibility of local discontinuities.

These sight distances are measured approximately parallel to the road axis. Sight distance in road design is an integral matter. This means that apart from the alignment, other parts of the design, junctions and cross sections also play a role when determining the sight distance. Allowing additional sight distances for reasons of comfort or extra safety depends on:

- non-frequent events require a longer sight distance;
- the additional sight distance (safety margin) is larger as the consequences of a emergency reaction are more severe.

Critical sight distances

Critical sight distances may suggest a certain manoeuvre, although the distance as such is insufficient to carry out the manoeuvre safely. Critical sight distances are to be avoided. Some examples:

- extensive visibility on minor roads at the approach to junctions, may lead to vehicles crossing the give way lane at high speed;
- the sight distance is almost sufficient to overtake safely, at locations where overtaking is prohibited at the link.

Sight limiting objects

Objects which limit visibility should not be located within the necessary sight distance. These objects should be replaced, lowered or removed. A single tree or lamp post will not directly limit or hinder the sight distance.

6.2.1 Driving sight distance

Driving sight distance is defined as the visible length of the road required to perform driving in a safe and comfortable manner. The relation between driving speed and driving sight is shown in the table 9.

Table 9: Sight distance

Driving speed (km/hr)	Sight distance (sec)	Sight distance (m)
60	8	135
80	9	200
100	10	280

The necessary sight distance to enter a horizontal curve in a comfortable manner is composed of the perception-reaction distance and required recognition length of the curve (table 10). The latter is the part of the curve the driver has to perceive to recognise the curve as such. The details of the sight distance are presented below.

Table 10: Sight distances approaching a curve

Driving speed (km/hr)	Sight distance before curve		Visible part of the curve		Total sight distance	
	sec	m	sec	m	sec	m
100	2	55	3	85	5	140
80	1.75	40	3	65	4.75	105
60	1	20	2	35	3	50

Additionally while negotiating the curve, the driver needs to observe the road link ahead over a sufficient length of road. Where signs and lighting insufficiently identify the location at a junction in a curve, no objects which restrict visibility should be placed in the shoulders of the road. If this cannot be avoided, the radius of the curve should be increased.

A junction is a local discontinuity. Locating a junction in a large horizontal curve has a favourable effect on road safety. At these junctions 20 % less accidents occur as compared to a junction located in a straight. The reduction in the number of accidents with injuries is even higher, at 30%.

Driving sight distance in vertical curves is different for crest curves and for sag curves. Provision of a crest curve based on the driving sight distance criteria, subject to the gradients of the adjacent straight sections and the design speed, results in very large vertical radii and frequently to extensive earthworks for sections of cuttings. A design based on driving sight distance is therefore frequently net feasible or economic and it may be necessary to base the design on the requirements for stopping sight distance, although this results in reduced standards of road safety. A cost benefit analysis (see Chapter 11) can help to decide which type of sight distance to use.

Limited sight distance inside horizontal bend

Problems with sag curves may occur in tunnels and under structures, especially for drivers of lorries and buses (eye level 2.50 m). For sag curves the combination of eye level, grade, head room and desired sight distance are determinative for the radius of the sag curve.

Visibility in sag curves is also restricted in night time conditions, where headlight beam illumination is the critical factor.

6.2.2 Stopping sight distance

Stopping sight distance is the most fundamental of the sight distances, and must be provided at every point along the road. Stopping sight distance is the distance that a driver must be able to see ahead along the road in order to identify hazards in the road and bring his vehicle safely to a stop when necessary. The following diagram (figure 36) shows the stopping sight distance in relation to driving speed and vertical grade.

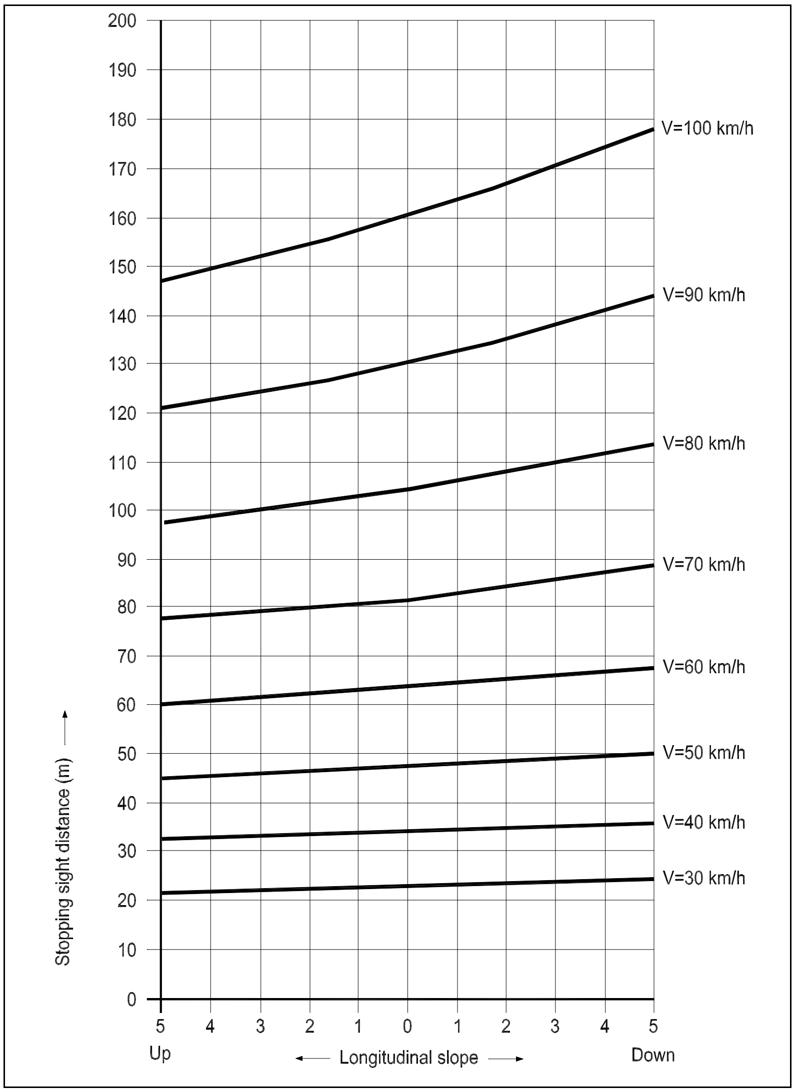


Figure 36: Stopping sight distance

The stopping sight distance can be calculated with the formula:

$$L_{stop} = prt\frac{v_0}{3,6} + \left(\frac{v_0}{3,6}\right)^2 \times \frac{1}{2g\left(f_{\lg} \pm p/100\right)}$$

L_{stop}	=	*stopping sight distance (m);*
V_o	=	*design speed (km/h);*
prt	=	*perception-reaction time (s);*
f_{1g}	=	*skid resistance factor;*
g	=	*acceleration by gravitation (9,81 m/s^2);*
p	=	*gradient (%).*

6.2.3 Overtaking sight distance

At the start of an overtaking manoeuvre the critical factor is the ability of the driver to estimate the length of the necessary gap in the approaching traffic flow. There is a critical area of overtaking sight distance in the range related to a ‘time’ gap of 16 to 25 seconds. Table 11 gives some figures on the overtaking sight distances in relation to the design speed.

Table 11: Overtaking sight distance

Design speed (km/hr)	Distance too short (m)	Critical distances (m)	Acceptable distance (m)
100	450	450 – 700	> 700
80	350	350 – 500	> 500
60	270	270 - 350	> 350

In the sustainable safety design concept, overtaking is preferably prohibited or even made impossible (see Chapter 3).

6.3 Horizontal alignment

The horizontal alignment is composed of straights, curves and transition curves. Conditions on these are determined by road safety, capacity of the road, driving comfort and vehicle properties. Spatial elements covered in this chapter are:
- the straight;
- the horizontal curve;
- the sequence of straights and curves;
- the transition curve;
- the application of super elevation;
- the road widening.

6.3.1 Horizontal straight

Long straights in an alignment are to be avoided to create a sufficiently varied image of the road.
Also, in a combination of long horizontal and vertical straights, visibility of the approaching traffic flow is reduced. As a rule of thumb, the maximum length of a straight (m) should be 20 times the design speed (km/hr). Other points are:

- short straights between two curves in the same direction are aesthetically unattractive;
- the desired length of a straight or a large radius horizontal curve is 500 m; this reduces excessive speed maximum;
- application of successive long and short straights may lead to visual discontinuities in the road alignment.

6.3.2 Horizontal curve

Application of curves enlivens the road image. Figure 37 shows the minimum horizontal curve for various design speeds. Centrifugal forces, determined by the speed of the vehicle and the radius of the curve, are partially neutralised by the super elevation. This means that the minimum radius is related to the applied super elevation of the curve. The horizontal curve can be calculated by the following formula.

$$R_h \geq \frac{\left(\frac{v_0}{3.6}\right)^2}{\left(f_z + \frac{i}{100}\right)g} = \frac{v_0^2}{127\left(f_z + \frac{i}{100}\right)}$$

R_h = *radius of horizontal curve (m);*
V_o = *design speed (km/h);*
g = *accelaration by gravitation (9,81 m/s^2);*
f_z = *skid resistance factor;*
i = *super elevation*

Successive horizontal curves in the same direction are not desirable for aesthetic reasons. Also combinations of horizontal curves in different directions have limitations, as is shown in figure 38, and subsequent curves should have radii between the two black areas. If, as an example R1 has a value of 300 m, then R2 should be between 200 m and 500 m. Combinations falling in the black area are acceptable but not ideal.

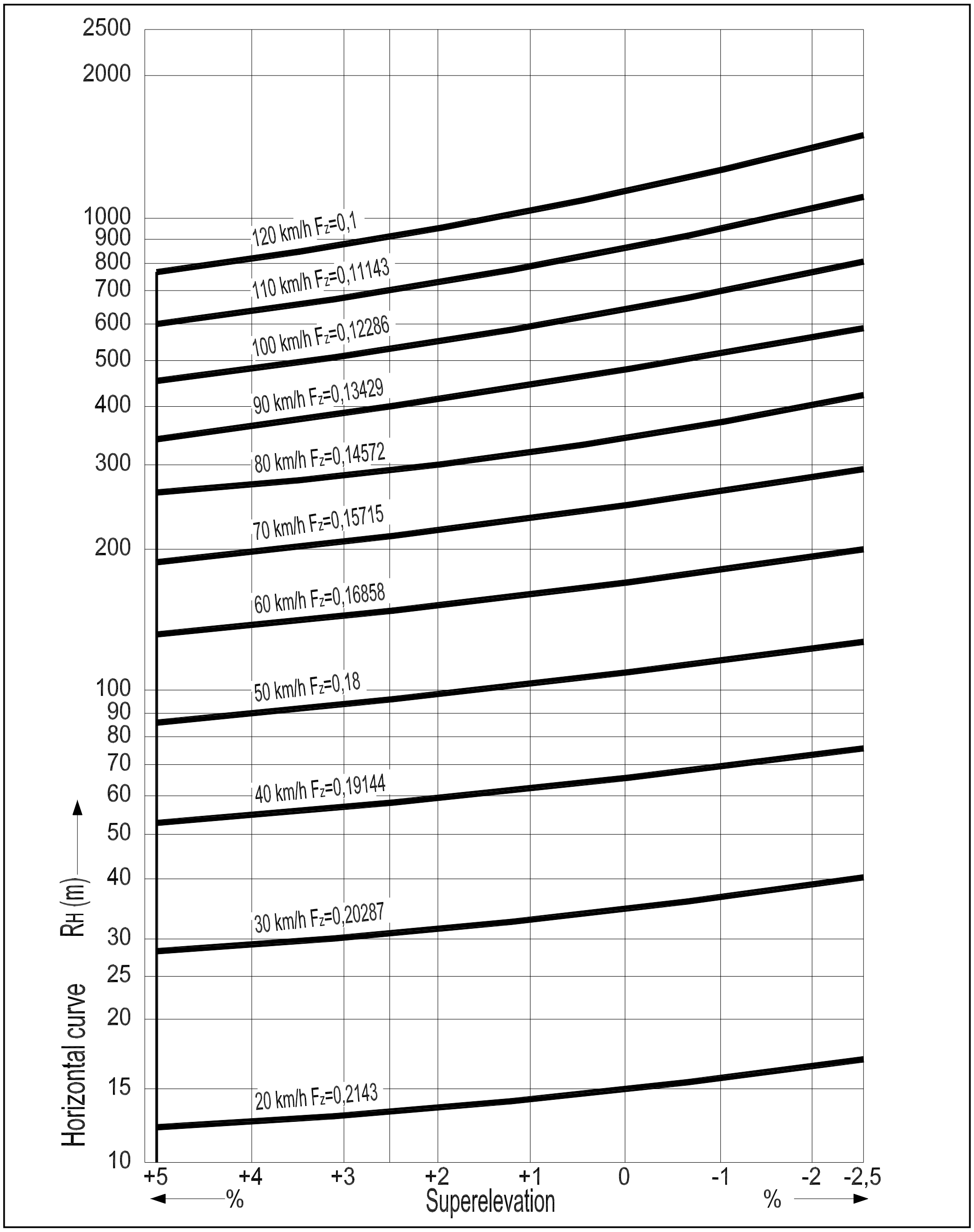


Figure 37: Minimum horizontal curve (Fz = skid resistance)

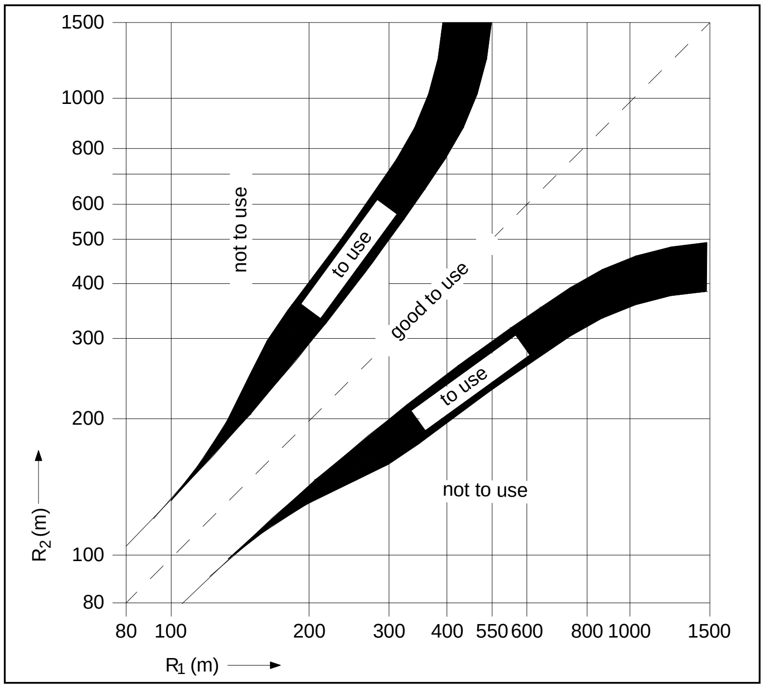


Figure 38: Successive horizontal curves

6.4 Transition curves

Horizontal curves of through roads and distributor roads are always preceded and followed by transition curves. The definition of a transition curve is: the gradual transition between a straight and a curve radius or between two curve radii. The functions of the transition curve are:

- to allow for a gradual rotation of the steering wheel, resulting in a gradual increase or decrease of the centrifugal force;
- to avoid kinks in the road image;
- to create a length within which superelevation can be gradually applied, between a straight and a curve radius or between two curve radii of opposite direction;
- to apply a gradually increasing or decreasing curve widening.

The geometric form for the transition curve is the clothoid. This is a spiral with radius and length inversely proportional to each other. The formula is:

$$\mathbf{A^2 = R * L}$$

Where
L = distance from start of the transition,
R = radius to that point,
A = constant (based on desired speed).

For reasons of visibility (curve detection) the value of A should be as small as possible. Therefore the limits are: 1/3 R_c < A < $R_{c,}$. (R_c = radius of circular curve). Minimum values of A are related to the design speed:

- 100 km/hr 207;
- 80 km/hr 117;
- 60 km/hr 76.

6.5 Super elevation

Super elevation is defined as the traverse grade or cross fall of the pavement surface in a horizontal curve designed to counteract for the centrifugal forces at driving vehicles. In a straight the standard cross fall is typically 2.5 %, which is for drainage purposes. A single carriageway pavement surface is normally camber shaped. In curves the camber shifts gradually to a one sided sloping surface. The reason for this are two-fold:

- to partially counteract the centrifugal forces;
- to increase visibility in the curve.

The maximum desirable super elevation is 5 %. In exceptional cases it can be increased to 7 % to provide more visibility in the curve. In combination with the vertical grade, the maximum spatial slope should not exceed 7 to 9 %. When changing from camber to super elevation the rotating is first on the outside halve of the road around the centre line. Cross all and levels on the inside halve of the road remain unchanged. When the cross fall along the whole cross section of the road has reached the value of 2.5 %, and the required super elevation is more, the rotation continues but now around the left marking on the inside lane. This assists in a proper detection of the curve by the driver.

6.6 Vertical alignment

In a vertical alignment only straight grades and curves are applied. The vertical alignment is defined as the sequence of crest and sag curves, grades and horizontal straights. The sloped straight is preferably only applied when large difference between the top of the crest and the bottom of the sag curve occur.

6.6.1 Grades

Grades have influence on the capacity and the safety of the road. The desirable grade depends on other road and traffic characteristics, such as the design speed, the length of the grade, the horizontal alignment, the location of junctions, the traffic volumes and the composition (types of vehicles). Maximum desirable grades related to the design speed are presented in the table below:

- 100 km/hr : 4 to 5%;
- 80 km/hr : 5 to 6%;
- 60 km/hr : 7 to 12%.

The grade and the grade length influence the traffic behaviour and the capacity of the road link. Large differences in speed between lorries and other traffic should be avoided. Gradients should not limit capacity. It is clear that in mountainous areas this may be hard to achieve in many cases.
For safety reasons differences in speed between types of traffic should not be more than 20 km/hr; however, 30 km/hr in individual cases may be acceptable.
To determine the maximum gradient for road links when the level differences exceed 10 m, the loss in speed by ascending lorries should be considered. For reasons of safety and capacity, the decrease should not exceed 20 to 30 km/hr. When measures are necessary, the following options are conceivable:

- reduce the grade percentage without providing additional lanes (and accept the extra cost of earthworks);
- add an extra lane (overpass lane) at the left side of the continuous (ascending) lane;
- add an extra (climbing) lane at the right side of the continuous lane.

The latter option is not desirable for road safety reasons. Lorries have to change lanes twice which is often neglected. Furthermore, at the end of the lane, the slow moving traffic has to enter the lane at the left, merging with the faster moving traffic. In any of the two cases the extra lane should be continued to a point where the difference in speed in the lanes has reduced to an acceptable value after the top of the crest.

6.6.2 Vertical crest curve

Crest curve: sight distance is normative

The vertical crest curve is applied to round off the vertical intersection of two grades and ideally curve length should be such that the end of a crest curve is coincident with the start of a sag curve. The geometric element is a circular radius. To dimension crest curves the sight distance is a basic requirement. Some figures on the sight distance (see also chapter 6.2) and the related crest curve radius are presented below.

Table 12: Minimum crest curve (stopping sight distance)

Design speed (km/hr)	Stopping sight distance (m)	Curve radius (m)	Driving sight (m)	Curve radius (m)
100	161	5,570	280	12,500
80	105	2,500	200	6,500
60	64	950	135	3,000

In principle the curve radius related to the driving sight should be applied and curve radius related to stopping sight distance is not advised for reasons of road safety. Table 12 can be used to determine the crest curve radii for various sight distances and object heights. The same figure can be used to prepare a new design as well as to audit an existing design.

The desired driving comfort (related to the acceptable vertical acceleration and deceleration) is not a normal consideration for the determination of the crest curve. Variations in vertical forces remain far below the maximum values when the driving sight or even the stopping sight distance related crest curves are applied. For comfort reasons the radii are, in relation to the design speed:

- 80 km/hr: 1,000m;
- 60 km/hr: 550 m.

6.6.3 Vertical sag curve

The vertical sag curve is applied to round off the intersections of two vertical grades, but is preferably directly connected to the vertical crest curve. The geometric element is a circle radius. To dimension sag curves the road image is a key factor. Some figures on the minimum sag curve radius is presented in table 13.

Table 13: Minimum vertical sag curve

Design speed (km/hr)	R sag (m)		
	Comfort	Minimum	Ideal
100	1,500	11,150	25,000
80	1,000	5,000	13,000
60	550	1,900	6,000

The minimum values are two times the values for crest curves related to the stopping sight distance. To keep the view at the road appropriate, the tangent point between the sag and the crest curve should be at a sufficiently high level.

6.7 Composed alignment

The spatial design of a road or road link is determined by the combination of horizontal and vertical alignment and the cross section. The driver observes a constantly changing image, which is further influenced by traffic signs, lighting, structures, landscape, vegetation and buildings.

A high quality spatial design aims at emphasising a harmonic, fluent and calm road image, with additional elements (beacons, signs) provided to clarify the intended use of the road. Required road equipment and furniture should improve the guidance for drivers rather than misleading them.

A road link cannot be studied or judged as a single element. The function and image of preceding and subsequent links should always be taken into account. The following basic elements can be distinguished:

- the spatial straight;
- the horizontal curve with constant grade;
- the vertically curved, horizontal straight alignment;

- the composite curve; this is a spatial element with a radius in both the horizontal and vertical planes.

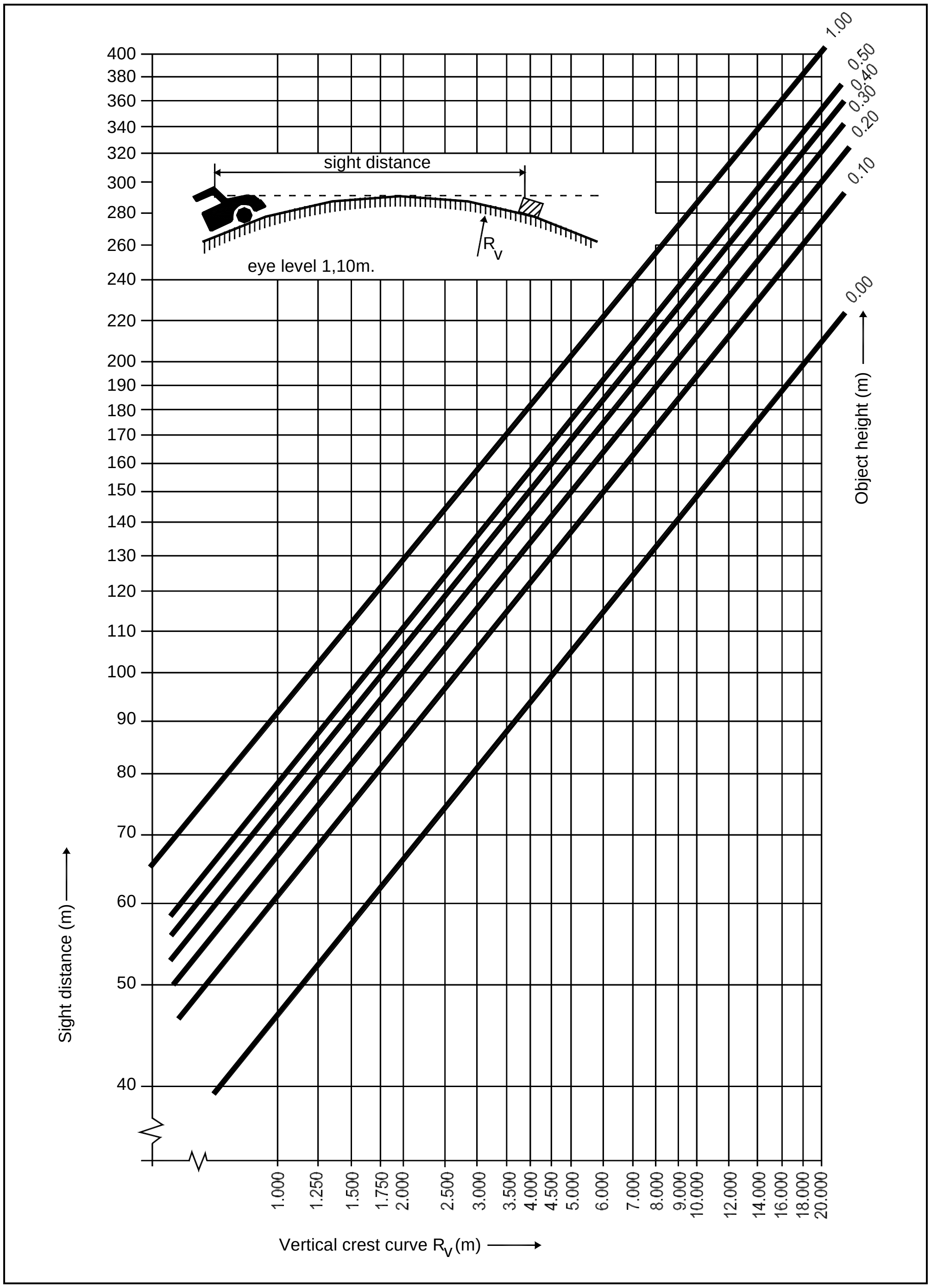


Figure 39: Minimum crest curve radii for various sight distances and object heights

6.7.1 The spatial straight

The spatial straight is a straight in the horizontal alignment with a constant longitudinal grade. It has a number of disadvantages:
- The danger of being monotonous when applied over long distances;
- Increased fatigue of the driver due to a fixed background and vision of distant object;
- Poor visibility of vehicles ahead under high traffic volume conditions. This may possibly lead to inadequate distances between subsequent vehicles;
- Connection of other elements to long straights leads to kinks in the view;
- A short straight between curves gives the impression of a counter curve.

6.7.2 The horizontal curve with constant grade

The alignment is curved horizontally and has a longitudinal slope. Positive qualities are:
- It leads to an varied road image;
- Large radius curves offer a good view of the road and the traffic;
- Large radius curves can easily be connected to other elements of the alignment.

Lower values of radii in horizontal curves have the following disadvantages:
- Junctions cannot be located in these curves;
- Application of super elevation is required and difficult to apply, which may lead to increased cost when drainage facilities have to be constructed;
- Structures in the inner curve (guard rails, barriers, noise reduction walls, obstacle protections) may cause problems;
- The capacity is influenced;
- Driver appreciation the curve radius and the curve length become difficult when the curve is visible for a small part only.

The horizontal curve is a basic element for the road design. Three classes of curves are distinguished, each with its own field of use:
- very large radii curves to be applied instead of straights;
- mid range radii in normal sections of road;
- tight curves in junctions (50 m < R < 1,000 m).

6.7.3 The vertically curved horizontal straight

The vertically curved straight consists of a horizontal straight in combination with a sag or crest curve. The straight with a sag curve is a spatial element with good forward visibility. Use of a short sag curve in a horizontal straight may give appearance of a kink, or should be avoided. The sag curve may be applied in underpasses. In other cases a compound curve is preferred.

The horizontal straight in combination with a crest curve may limit forward visibility. The required sight distance determines the value of the radius. Visual discontinuities are not a problem when applying this type of element. This type of element can be applied in straight sections. Due to the limited sight distance much care should be taken at transfigurations.

6.7.4 The composite curve

A composite curve is created when combining a horizontal curve and a vertical curve. The vertical curve can be sag or crest curve.

The sag-composite curve has very good sight qualities. Other basic elements can be easily connected. In case of a tight horizontal radius the curve can be over-estimated by drivers, which may lead to dangerous situations. It is therefore recommended to design the curve with a larger radius than technically required.

Composite of horizontal and vertical curves

The crest composite curve may restrict forward visibility of the road. The crest curve should not be combined with two horizontal curves with opposite directions. This type of element can be applied anywhere if the sight distance requirements are fulfilled. Curves of this type are estimated by drivers, to be tighter than in reality, making them therefore reasonably safe elements.

7 SUSTAINABLE SAFE ROAD DESIGN: LINEAR VILLAGES

7.1 Traffic calming

The Netherlands has a long history in the field of improvements with regard to environmental and road safety measures in (existing) residential areas. As in other countries, the massive growth in car ownership and use means that motorized traffic in the Netherlands has taken increasingly dominant position. Activities typical to residential areas were crowded out, while the urban dweller felt increasingly threatened by motorized traffic and by high speeds.

During the seventies, an entirely different principle was developed for residential areas in the Netherlands: total integration of the different transport modes. The concept has also become internationally known by the Dutch word 'woonerf' (Home Zone). Motorized traffic – excluding transit and regional traffic – is accepted but is subordinate to the other 'woonerf' users. In a 'woonerf' motorized traffic is permitted to drive at walking pace (5-8 km/hr). Separate provisions for pedestrians (such as sidewalks) are absent. All road users have the same rights.

In 1976 the 'woonerf' achieved legal status. The 'woonerf' concept has greatly influenced thinking on the improvement of road safety and environmental aspects in the Netherlands. The 'woonerf' led indeed to a substantial reduction in the number of injury accidents. In some projects, injury accidents reductions of about 70% were reported. From these first experiences we learned that two features were essential: reducing driving speeds and reducing transit traffic. From accident studies it turned out that the collision speed should remain below 30 km/hr, because then the probability of a serious injury will be minimal.

Woonerf (home zone)

Since 1983, Dutch road authorities have been able to install a legal limit of 30 km/hr on roads or in zones within built-up areas. Based on a recent survey it could be concluded that about 50% of the residential area (access roads inside the built-up area) is part of '30 km/hr zones'. To guide Dutch municipalities to design effective speed restricting and transit-traffic-preventing measures, a handbook was developed. Recently the effect on the number of injury accidents has been studied and it was determined that the number of injury accidents had dropped by more than 25%.

7.2 Problems encountered linear villages

A linear village is that part of a (transit) road which lies within a built-up area. The pressure of the fast-growing amount of transit traffic means that an even larger part of the public environment, within the built-up area is used for traffic flow. This large-scale layout, which is inconsistent with the small-scale nature of the rest of the village, turns the road into a dividing element in the residential area and means the urban harmony is lost. The layout of the road does not suit the character of the environment at all. Roads within a built-up area often look just like the road outside the built-up area, and in many cases the road is an asphalt road with a width of 7-12 metres or more, without any speed-reduction measures or specific provisions for crossing pedestrians. Although the residential areas have speed limits of 60 km/hr, 50 km/hr or 40 km/hr, these speed limits are generally ignored as a result of the character of the road. The urban section of the transit road is not only important for access to and from the built-up area, or the area around it, but in many cases also for carrying long-distance transit traffic. Within the built-up area, there is not only housing alongside the cross-town link, but often also public buildings with a ‘service’ function, and commercial properties.

In many countries the increase in car ownership and car usage leads to ambitious road plans, including the construction of motorways and constructing or widening roads outside built-up areas. Within the built-up area of cities and villages, the road is extended or widened to become a transport line. And even larger parts of the limited public area are used for motorised traffic and, after a period of time, the disadvantages of this car-led policy in relation to cross-town links start to manifest themselves:

Linear village, traffic and residential function

- demand for high operational speed for transit traffic;
- an unfavourable accident situation, with relatively large numbers of accidents concerning pedestrians, problems/conflicts for local traffic and specially for vulnerable road users;
- feelings of lack of safety amongst residents and pedestrians;
- disruption of the residential, living and shopping environment;
- barrier function of the road difficult to cross;
- parked cars make a strong claim on the public space;
- excessive levels of noise, vibration and air pollution, bad social climate.

Linear village: pedestrian crossing

Through roads in built-up areas therefore are a specific problem area – on the one hand the problems largely pertain to road safety and living conditions for neighbouring residents and on the other hand to the flow of the motorised transit traffic. The user of the public space not only runs the risk of becoming involved in a road accident, but the speed, volumes and sheer volumes of the motorised traffic induces feelings of being unsafe.

Motorised traffic, either moving or stationary, usually makes too great a claim on the available public space. The main problem is the conflict between motor vehicles and vulnerable road users (cyclist and pedestrians).

7.3 Problem analysis

The problem analysis should identify the following (see Chapter 2):
- *Origin/cause:* where (location) and when (time) do the problems manifest themselves and who (target group) experiences the greatest difficulties? Which causes could these problems be attributed to?
- *Goal/objective*: which objectives do we aim to meet with the solutions?

The residential function of parts of the linear village is mainly determined by the service functions of the adjoining buildings and the designated use of the surrounding area. The inventory and analysis should therefore relate to the interrelationship between the lack of safety and:
- the network function of the road and any discrepancies between the use of the road and the intended network function;
- the urban characteristics of the built-up area, the road environment and the road design;
- the characteristics of the road users (pedestrian, cyclist, car, bus and heavy vehicles) who make use of the road either lengthways or crossways.

Road safety

Assessment should start with an inventory and analysis of registered road accidents and traffic complaints. Although the absolute number of accidents on a cross-town link is sometimes too limited for a systematic study, an accident analysis (see Annex 1) may nevertheless improve the insight into the problems. During the analysis of the accidents, the following points require special attention:
- junctions and pedestrian crossings or any road sections with concentrations of accidents;
- accidents involving cyclists and pedestrians;
- the various types of accidents.

Network function

The primary function of through roads, being the regional network, is providing access to and from rural and residential area with a regional or greater than local importance – national or regional distributor road (see chapter 4). When such a road runs through a built-up area this often produces conflict, because the traffic function of the cross-town link is at odds with the residential function. In principle, it is difficult to combine both functions, which means that a bypass is often considered in such situations. If a cross-town link forms part of a network of access roads, a bypass is often not necessary (see chapter 3)

The road user bases his choice of route predominantly on:
- the travelling time required for the intended journey;
- the reliability of the intended journey in terms of travelling time;
- the comfort of driving on the route;
- the road environment and the road design;
- habits of the driver.

Establishing qualitative differences between roads on the basis of average speeds is an excellent method to produce the required network planning. The average speed, in the case of a cross-town link is therefore an important criterion for testing the quality of the traffic flow in so far as there is a through function. The flow on the cross-town link can be disrupted by the lack of provisions for pedestrians and cyclist in a lengthways or crossways direction, by a heavy exchange of local traffic at junctions, by car parking and by any traffic calming measures.
When a study of a traffic structure shows that there is an alternative route for transit traffic or that drivers are taking short cuts using non-through roads, supplementary studies may be necessary in the form of a study of origin, destination or journey times.

Changes to the road infrastructure, in order to ensure that motorised traffic behaves in a ‘suitably adjusted’ manner, may influence the choice of route. Undesirable route shifts should be avoided by carefully selecting the objectives and by considering supplementary measures elsewhere in the network of roads. Furthermore, the interests of public transport and the emergency services must also be taken into consideration.

Spatial quality
The spatial quality of many linear villages is poor and the cross section is often wide and uniform in favour of a good flow of motorised traffic. The residential area no longer has its own ‘identity’. The unique points are no longer recognisable in the size, the materials, the public lighting, and other street furniture. There is no longer a difference between the town or village centre and the rest of the cross-town link. By diverting traffic to a bypass or by making the traffic function subservient to the residential function there are opportunities for spatial quality to be created (structures can be established or historical elements emphasised).

The environmental quality makes a considerable contribution to living conditions. Its importance increases when there is a concentration of service functions along the road. Good urban planning allows for fewer traffic measures, signs and boards, whilst road users still display the required behaviour.

Nature and volumes of traffic
The volume of (transit) traffic means that the problems on a cross-town link could have arisen for three reasons:

- Social developments: there is a historical situation. Autonomous growth and internal and external traffic developments have created a discrepancy between function, form, and usage.
- town planning: there are adverse influences of expansions. The implementation of an expansion plan may have no or insufficient account of the increase in traffic.

To reduce excessive speeds is more important than to reduce high volumes

- Bottlenecks in the network of roads: capacity problems elsewhere mean the cross-town link is used as a short cut.

The cross-town link provides access to and from the village and the network of roads and/or to and from a village with a local or regional service function. In relation to the village it therefore usually relates transit traffic, which is typical for cross-town links. The higher the share of transit traffic or regional traffic, the greater the local problems and the more this aspect contributes to the desirability of a bypass or ring road. This requires two caveats:

- studies will have to show whether the share of transit traffic is sufficient warrant a bypass;
- a ring road is only effective when it is more attractive in terms of journey time and comfort for the target group than the redesigned cross-town link.

Cyclists and pedestrians

The movements of cyclists and pedestrians are also related to coming from or going to service buildings and residential neighbourhoods. Not all services attract equal amounts of pedestrians and cyclists. A shop usually attracts more pedestrians than a health centre, whilst a primary school generates more bicycles than a leisure centre. They are usually targeted movements, but town or village centres with shops could have 'criss-cross' movements. Therefore, at the location of concentrated or staggered crossings it is important to have good insight into the origin and destination of the pedestrians / cyclists movement.

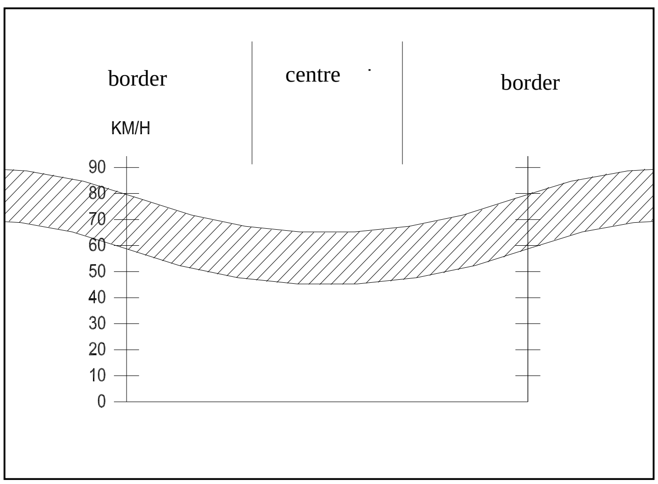


Figure 40: Typical speed patterns of cross-town links (85-percentile value)

Residents (participation), parents of pupils and other users of public environment have a great deal of knowledge on the usual pedestrian and cycle routes. These routes could run parallel to the cross-town links (longitudinal relationship) or cross the cross-town link (transverse relationships). It is important to realise planning relates to actual pedestrian and cycle routes rather than desired routes. If pedestrians or cyclists need to take a detour, this harms the intended residential quality.

Speed of motorised traffic

The speeds of motorised traffic have a greater influence on safety than the volume of traffic and the share of heavy traffic. The speed situation in a linear village largely depends on local

Speed camera

circumstances, but often shows the pattern represented in figure 40.
Radar speed measurements at representative points may be necessary in order to substantiate any complaints regarding excessive speeds. Furthermore, tackling speed behaviour is often one of the most important objectives of the altered design.

Road characteristics
A thorough study of the cross-town link by means of videos, photographs and drawings, should be used to determine to what extent the layout of the road contributes to the lack of road safety and the negative experiences of the public environment. Often the cross-town link plays a dominant role as a transport line. Points of attention include:

- the alignment and the cross section of the road, both outside and inside the built-up area;
- the design of junctions and pedestrian crossings;
- the presence and design of any car parks;
- the situation of any exits;
- the traffic signs;
- any planting, public lighting and other street furniture.

During this phase of the study, attention should be paid to the provisions for pedestrians, cyclists and public transport. With respect to pedestrians and cyclists it is particularly important to have an insight into the cycling and walking routes. In terms of public transport it is not only important to check whether the routes and locations of the bus stops could be optimised.

7.4 Goals

The problems in linear villages mainly concern the objective, subjective lack of road safety and the poor traffic conditions. From this it is possible to derive the three main objectives regarding the layout of the cross-town link. These objectives are general and could apply to any situation. The main objectives must be detailed into operational goals:

1. all normal types of use of the public environment should be given the best possible opportunities;
2. the new layout should contribute to a positive safety experience of the public environment:
   a. the number and seriousness of the road accidents should be reduced;
   b. the living conditions (noise and barrier effect) should be improved;
3. the destinations inside and outside the village must remain accessible.

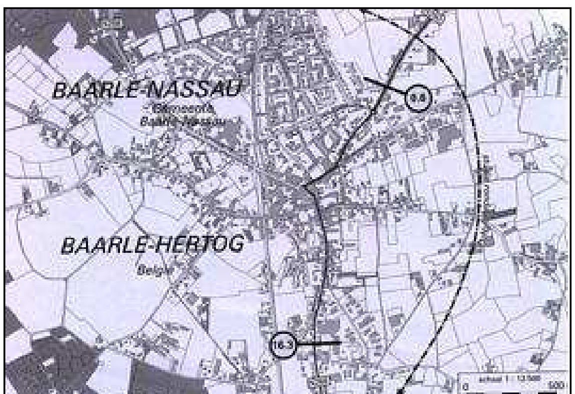
7.5 Solutions

7.5.1 Ring road

The problem of transit roads through urban centres requires an assessment of:

- the required balance between living conditions, safety and access and whether this can be achieved with a partially redesigned layout of the existing cross-town link;
- whether it is necessary or desirable to construct a bypass or ring road.

For each specific road and traffic situation the designer should check whether the regional transit traffic should be given a bypass in order to create sufficient room for local activities – the residential function. There is no clear answer, because it depends on the importance of the built-up area and lack of safety, but also on the spatial quality. Furthermore, the traffic to and from the village sometimes forms such a large part of the total traffic that a bypass offers little help.



Linear village, a ring road is considered

A redesigned layout of the cross-town link is required immediately after the construction of a bypass. In the most favourable situation, the share of the transit traffic will have been reduced to zero and the layout of the public environment should be focused on the access function. In other situations, 70-80% of traffic on the cross-town link may be local traffic, and in such a case a bypass is not useful and the layout of the link has also to be changed.

7.5.2 Tackling the urban section

Transition in function distributor road ⇔ access road

The previous paragraphs have shown four important findings:

1. The problems on the cross-town link can be traced back to a conflict of use of the public environment between the motorised (transit) traffic on the one hand and all other potential uses of the public environment on the other.
2. Only when the network function of the cross-town link has been established, is it possible to tackle the redesign on the basis of that function. Initially this may require a thorough problem analysis of the cross-town link:

   a. the road categories must be altered and earlier choices of access road must be reviewed fully or partially;
   b. the problems can only be solved properly with a partial bypass by means of existing and/or new roads.
3. tackling and redesigning of cross-town links largely consists of:
   a. locating and designing properly recognisable changes in road categories;
   b. redesigning the remaining parts of the cross-town link in line with their allocated function.

One of the most important variables that affects safety and the living environment is the speed limit – the lower, the better – whilst this variable hardly influence access and capacity.
The cross-town link is a road within the built-up area that is often strongly focused on the traffic function, whilst the environment requires a road that is focused on the residential function. Depending on regional and local circumstances, priority must be given to either the residential or the traffic function and this requires a clear view of the regional network of roads.

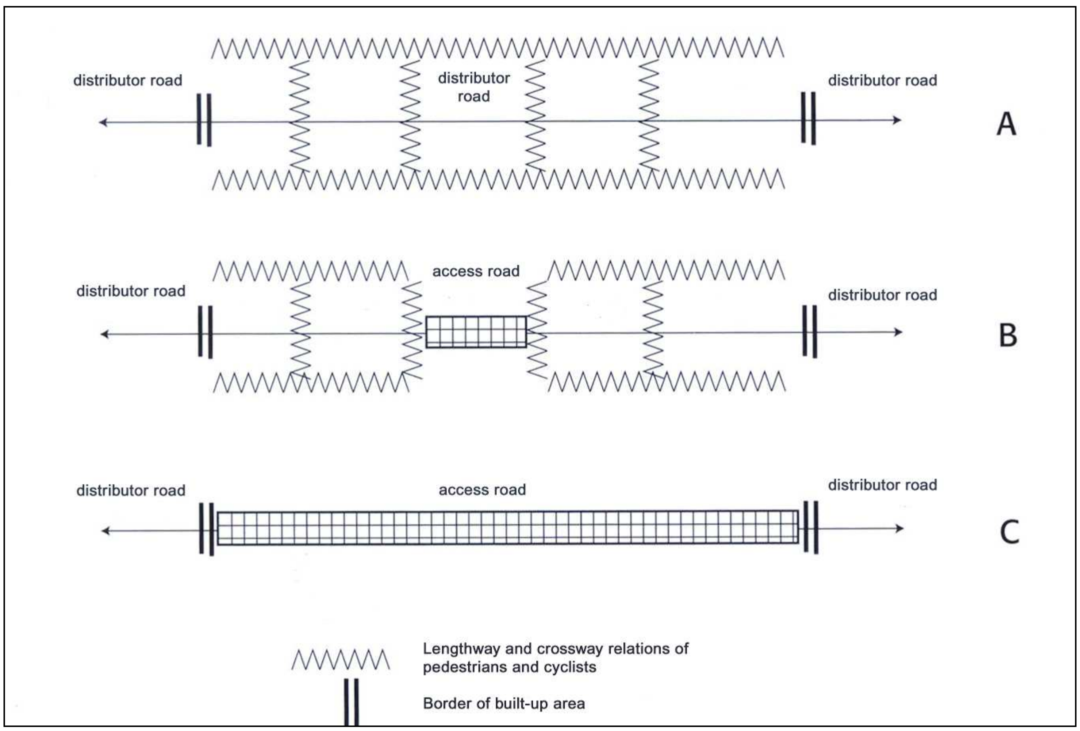


Figure 41: Determine the function of the urban section

A town-cross link can usually be split into five different areas on the basis of the environment:

- access area: border of the village or town;
- transitional area to the centre;
- village or town centre;
- a transitional area to the border;
- exit area – border of the village or town.

Both the traffic and the residential function place their specific demands upon the layout of the public environment. On the basis of the experiences there could be three situations in relation to the choice that determines the layout objectives (see figure 41):

A. The traffic function is given priority, and the residential function is accommodated where possible. Generally this will apply to cross-town links that form part of distributor road and where there are no alternatives for regional traffic.
B. For a certain part of the cross-town link – the centre or social centre - the residential function is given priority (access road), and the traffic function (distributor road) is accommodated where possible/necessary**.** In many centres there is such a strong link between the service function and the residential function that this must be given priority.
C. The residential function is given priority over the full length of the link (access road), and the traffic function is accommodated where possible/necessary. This option is considered where there is a compact centre with a strong residential function over the entire length of the road.

As shown in figure 41 three aspects appear to be particularly important:

- the transition between the road categories, including the centre boundary;
- the required speed limit in conjunction with the road category;
- provisions for pedestrians, lengthways or crossways. For the provisions for pedestrians, please refer to Chapter 8.

Local circumstances play an important role during the redesign of cross-town links. It is not possible to give standard ‘designs’, but this manual has given examples that may be used by the ‘design team’.

7.5.3 Border of built-up area

A built-up area is that part of the city or village where the buildings have a certain density and it is identified with signs. The main requirements for the centre boundary are:

- the border of the built-up area is characterised by consecutive buildings alongside the road, with such a size and density that the road user notices a considerable difference between the road environment inside and outside the built-up area;
- at the location of the border there must be a significant change in road characteristics that the difference in character of the road before and after the border is emphasised as much as possible.

No changes in road characteristics

When these requirements are tested in practice, it appears that not all borders comply. Too often, the border is in uninhabited area, so it is not surprising that the driver ignores the speed limit. In many countries this is the rule rather than the exception. The clearer it is that the road and the environment have the character of a built-up area near the border, the lesser the need for specific traffic calming measures and the greater the driver's understanding.

When it is not possible to meet the requirements for the centre boundary in relation to buildings, it may be that the situation is not considered as a built-up area, and therefore there is no cross-town link. However, this does not mean that you cannot take any measures. Within the framework of a comprehensive speed policy, traffic calming measures could be implemented.

Border of village before reconstruction

Border of village after reconstruction

The main requirements in terms of the location and layout of borders of built-up area can be determined from the perspective of the road user:

- determine whether there is a built-up area:
  - the distance from the buildings to the centreline of the road is maximum 3x the height of the adjoining buildings with a maximum of 25m;
  - the length of the built-up area is at least 400m;
  - for buildings on one side of the road the building density – building frontage related to road length - ≥ 50% and ≥ 30% for buildings on both sides;
- determine the location of the border:
  - preferably at a location where the different characteristics of the landscape join;
  - take account of short-term spatial developments;
  - try to support the border with new environmental characteristics;
  - ensure that the border, at the planned location, is visible at the actual approach speeds.

Border of built-up area and roundabout

The border forms a clear transition from outside to inside the built-up area, where both the environmental and road characteristics are important. This applies for all circumstances and in principle depends on the function of the road. The road user must adjust his behaviour to the circumstances of the residential, working or living environment. The degree of adjustment is determined by the function of the road and the residential function.

The speed behaviour and attitude of all road users is determined by the total view of road and environmental characteristics. With good coordination it is possible to obtain the optimum conditions in terms of clarity, recognition and acceptance. Such a redesign of the public environment is the only way to ensure compliance with speed limits at the border. Some effective examples include:

Border: distributor road bends outwards

- consider replacing a cross roads junction before the border by a roundabout;
- realign lanes outwards on both sides, to create an eye-shaped central island. The centre boundary sign – seen from the outside – is placed just before diverting the lanes (figure 42).
- Introduce bends that are suitable for a speed of approximately 50 km/hr for passenger cars. This measure reduces speed for both incoming and outgoing traffic. The unilateral bent road – sometimes there is no option to bend both lanes outward and there is only room for an outward bend of the lane that enters the centre. The disadvantage of this measure is that outgoing traffic is not slowed down.
- The '50 km/hr plateau' – a raised crossing area with slopes designed to be crossed at a maximum of 50 km/hr. Applying a plateau to the border requires an introductory measure, for instance a long, narrow median (figure 43).

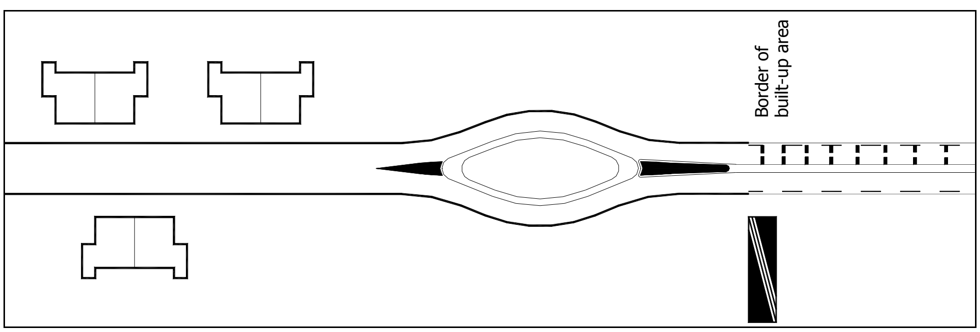


Figure 42: Border of built-up area in conjunction with diversion of both lanes

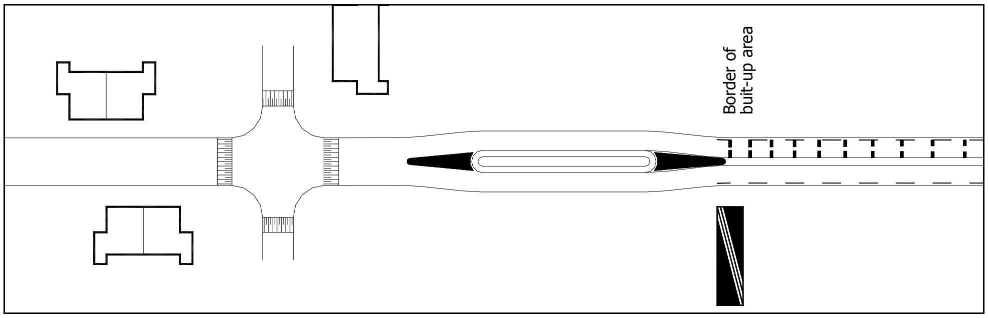


Figure 43: Border of built up area in conjunction with a long narrow island and a raised plateau

7.5.4 Measures in transitional area and centre

Raised plateau (junction) transitional area

The measures in the transitional area are intended to maintain the speed levels. Whether this requires local physical traffic calming measures depends on the circumstances. Preferably, you should strive towards a roadside character that enforces speeds of 50 km/hr or lower. It is important that traffic calming measures are installed at junctions and pedestrian crossings. This could involve measures such as a refuge, a local narrowing of the road or a raised plateau.

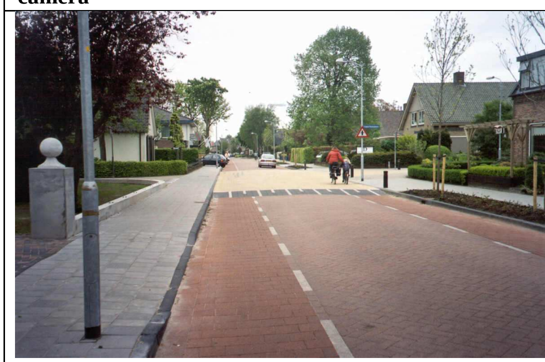
If there is a clear centre, where the residential function must have priority, this must be well signed. A lower speed level of for instance 30 km/hr should be enforced. Some possible measures are shown in the photographs below. For a distributor road, dual carriageway and locations with (very) high volumes, controlled intersections can be used to create a system of coordinated signalised intersections.

Access road: visual median in the centre of the village

Access road: refuge, raised plateau, pedestrian crossing

Distributor road: 'median', parking bays, speed camera

Access road: square in the centre



Access road: bike lanes, raised plateau

Access road: long, raised plateau in centre of the village

8 SUSTAINABLE SAFE ROAD DESIGN: PEDESTRIAN CROSSING

8.1 The problem

While transportation used to be restricted mostly to travel on foot, growing availability of cars (and bikes), greater time pressures and larger distances have increased the car's share in the modal split. Many countries are increasingly adjusting their public environment to provide for motorised traffic.

In daily traffic, many pedestrians using a pedestrian crossing will thank drivers who stop. It is behaviour that is typical of crossing pedestrians. Pedestrians act subordinately to the other road users in view of the massive differences in mass, speed and vulnerability. They therefore deserve extra protection. The basic principle of 'sustainable safety' (see chapter 4) leaves no doubt: avoid confrontations involving great differences in speed and direction and great differences in mass and vulnerability.

Pedestrians are vulnerable participants in traffic. The nature and scope of the risks these participants run in traffic are considerable and growing. While pedestrians cause hardly any danger to themselves, they run major risks when interacting with other road users. The situation will deteriorate, particularly for children, senior citizens and people with a disability due to the growth of motorised traffic. Solutions to deal with pedestrian crossing movements are becoming increasingly urgent.

A pedestrian-friendly policy aims not only at making travel on foot possible, but also at stimulating safety and attractiveness of pedestrian facilities. Pedestrians face the biggest problems when crossing roads. Pedestrians' interests need to be constantly weighed up against those of cyclists, drivers and public transport passengers, but should also take into account the pedestrians' vulnerable position.

8.2 Causes / origins

Pedestrians are unprotected and vulnerable participants in traffic. In a collision with a vehicle, pedestrians are always the weakest party, running the biggest chance of being injured or killed. In a collision between a pedestrian and a car the chances of the pedestrian surviving the collision are:

- 95% involving a vehicle speed of 30 km/hr;
- 55% involving a vehicle speed of 50 km/hr;
- 15% involving a vehicle speed of 65 km/hr.

The vehicle speed is not only a key factor in the cause of accidents, but is also of considerable influence on the outcome of the accident. While this is a generalisation, it holds particularly true for pedestrians crossing the road. Account must be taken of the fact that, as a rule, the maximum speed limit is exceeded by all motorised traffic. In designing the road infrastructure, circumstances should be created which avoid collisions of pedestrians with vehicles travelling at a speed of over 30 km/hr.

8.2.1 Defensive behaviour

Pedestrians are generally agile and nimble due to their low mass and speed. If a conflict threatens, the danger can be relatively easily averted (defensive and anticipating traffic behaviour). Despite pedestrians' defensive traffic behaviour, the share of victims amongst pedestrians is relatively high. Pedestrians' defensive behaviour may also have the opposite effect, with drivers more or less assuming that pedestrians will simply wait or step out of the way. The degree of defensive behaviour may vary considerably between individual pedestrians. Children, elderly and people with a disability, for example, behave much more defensively than youngsters. In addition, many pedestrians have a mobility handicap:

- children have too little experience and find it difficult to assess (complex) traffic situations. Moreover, they tend to 'forget' traffic while playing in adjacent areas, and many stray into the traffic lane;
- elderly often walk slowly, respond slower and have increasing trouble assessing complex situations;
- people suffering a functional disability (motor and/or sensory) experience additional problems, yet they have the same movement needs and/or patterns as other pedestrians.

Exit of school

Wheelchair users, or people who have difficulty walking, who are visually handicapped, deaf or hard of hearing experience additional problems. People carrying heavy luggage, senior citizens with or without Zimmer frame, people with shopping trolleys, buggies or prams all experience specific problems. The issue of pedestrian facilities therefore often requires a tailor-made solution and not all public areas can be made accessible or useable for people with a mobility restriction.

8.2.2 Walking routes

In considering whether to travel on foot or not, the walking distance plays a role. Walking is an excellent way of covering short distances. Pedestrians usually opt for the shortest route and are virtually impossible to deter from their choice of route. They will avoid using the shortest route only if they expect serious hindrances or unsafe situations or if the longer route lies in a particularly attractive environment. By ensuring that the shortest routes has safe and attractive conditions, pedestrians (or pedestrian flows) may be concentrated. People who do not know the area will use landmarks in choosing their routes.

The importance of a crossing facility should be considered not only from a quantitative point of view (number of pedestrians, waiting times), but also from a qualitative point of view. Of all movements on foot, crossing carriageways generally present the biggest problem, involving the most accidents. Wide, high-speed and/or high-intensity roads in particular present significant barriers for pedestrians. Whether or not these crossings of the road should be scattered or concentrated depends on the function of the road in question, the local traffic and road circumstances.

8.3 Objectives

Key objectives for pedestrians' routes and crossing facilities for pedestrians are:

- *Road safety*. The more the pedestrian is separated in distance or time from the other traffic, the safer the conditions. The speed of the motorised traffic is the main cause of feelings of insecurity in pedestrians. Concentrated crossings are recommended only in situations of high-intensity traffic.
- *Social safety*. Everybody must be able to move freely in the public space. Social safety may be enhanced by the overall quality of the surroundings (design, furniture, public lighting).
- *Direct and short connections.* Pedestrians usually opt for the shortest route and are virtually impossible to deter from their choice of route. They will only avoid the shortest route if they expect serious nuisance or unsafe situations or the longer route lies in a particularly attractive environment.
- *Sufficient freedom of movement.* The infrastructure of pedestrian routes in particular should have ample dimensions, both in length and width, based on the peak hour use.
- *Clear and understandable situations*. Uniform crossing points near junctions or on stretches of road with an important traffic function in particular should be recognisable, clear and simple for both pedestrians and crossing traffic.
- *Environmental quality.* A high quality environment is desirable from the point of attractiveness and social safety. A walking route that runs through a park is much more attractive than a route that runs along a busy road. However, the attractive route may present a social safety problem after dark.
- *Smooth and non-slippery surface*. A smooth and non-slippery walking surface is essential for all pedestrians, particularly for people with a mobility restriction. Natural stone may be extremely slippery in wet conditions for example.
- *Protection from the elements*. Pedestrians tend to seek shelter from the elements where possible and will use roofs, awnings, facades and fences for this purpose.

8.3.1 Road category and pedestrian facilities

There are three road categories (see Chapter 3) for which the following pedestrian facilities are recommended, both along and across the road.

The following comments apply to table 14:

- A split-level crossing should be used wherever pedestrian routes cross through roads. Incidentally, there should be no roads with a flow function inside built-up areas. Through roads should be entirely isolated and not form part of the built-up area (or should be perceived as such).
- In general, no physically separated pedestrian facilities are required outside built-up areas along distributor roads. Simple, separate facilities are desired for the few pedestrians that need these.

Table 14: Recommended pedestrian facilities and crossing solutions per road category

Road category	Inside built-up area		Outside built-up area	
	Along the road	Across the road	Along the road	Across the road
Through road [1])	forbidden	split-level crossing	Forbidden	split-level crossing
Distributor road [1])	separated	at-grade crossing at junctions and road links	Separated	at-grade crossing or split-level crossing at junctions [2])
Residential access road [1])	separated	at-grade crossing at road links and junctions	on carriage way	at-grade crossing at road links and junctions

[1]) please see comments!

[2]) split-level interchange for dual carriageways and/or major junctions

- Within built-up areas footpaths or pavements along access roads are required on either or both sides, unless the spatial structure excludes pedestrians.
- In principle, distributor road crossings in built-up areas should be located at or near junctions. However, wherever an important pedestrian route crosses a distributor road on a particular road section, this crossing point may also be denoted as a junction. This means that well-established pedestrian crossings on distributor road links are possible within built-up areas.
- Pavements or footpaths are required along residential access roads in built-up areas for reasons of objective and subjective safety. Crossing pedestrians (routes), such as school routes, require particular attention.
- No specific pedestrian facilities are required either along or across access roads outside built-up areas, except for specific situations (recreational areas).

8.3.2 Pedestrian crossing movements

If a pedestrian wants to cross a carriageway, he needs to assess the road and traffic circumstances:

- the time required to make the crossing which depends on his walking speed and road width;
- a usable gap in the traffic flow that is at least equal to the estimated crossing time;
- the risk that he is willing to take in crossing depending on the average waiting time.

The pedestrian crossing time is determined by the width of the carriage way and the walking speed of the ‘average’ pedestrian. The average walking speed of a pedestrian in good health is 1.5 m/sec or 5 km/hr. No other group of participants in traffic, however, is more diverse than the group of pedestrians. About 10% of all elderly persons walk at speeds of less than 0.6 m/sec, while about 10% of all youngsters walk faster than 2.2 m/sec.
As situations become more complex, allowances must be made for additional time for observation, judgement and decision. This time increases as vehicles drive faster than 50 km/hr. Adult pedestrians often judge traffic situations while walking, but children in particular will stop at the edge of the pavement before starting their crossing.

Waiting time

The average waiting time is determined by the vehicle intensity and the gap required, which is related to the crossing length and the walking speed. For a good insight into the waiting times (the average and range), these should be recorded at the actual location. If the waiting time for a suitable gap is too long, pedestrians get impatient and will take extra risks. The average waiting time (W) qualification for crossing pedestrians is set out below:

- $0 < W \leq 5$ sec : very good;
- $5 < W \leq 10$ sec : good;
- $10 < W \leq 15$ sec : moderate;
- $15 < W \leq 30$ sec : poor;
- $W > 30$ sec : very poor.

In the event of an average waiting time of about 15 seconds or more, pedestrian crossing movement is compromised. The maximum waiting time accepted by pedestrians is about 30 seconds. At bus stops, schools, hospitals, offices and factories pedestrians are often in a rush (functional movements). Groups of pedestrians that tend to form at such crossings often force a gap in traffic by their sheer mass.

Pedestrian crossing points should generally meet a number of requirements in the field of safety and comfort. Safety issues particularly require that:

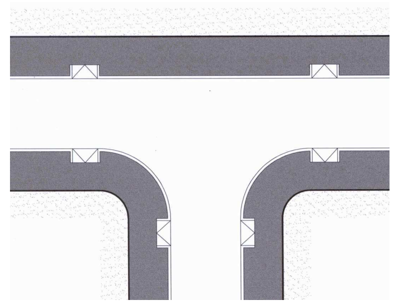
- the crossing facility lies on the pedestrian's 'natural' walking route;
- the speed of the motorised traffic approaching and passing the crossing site does not exceed 50 km/hr (V85 -- 85-percentile speed motorised traffic), preferably approximately 30 km/hr;
- the mutual line of sight between the pedestrian wishing to cross and the driver is clear and protected;
- the average waiting time for pedestrians does not exceed 15 seconds with a maximum of 30 seconds;
- the distance to the nearest crossing facility on distributor roads is limited (75 to 125 m);
- the combination of pavements, footpaths, pedestrian areas and crossing facilities should be of a uniform nature and appearance, enabling pedestrians to move safely and directly.

8.4 Solutions

Footpath on both sides

Along streets in built-up areas with houses and buildings on both sides, clearly recognisable and physically separated pedestrian facilities are required on both sides of the road. Where roads are lined with buildings on just one side of the road, one pedestrian facility will suffice on that side. Road sections without buildings within built-up areas may have a pedestrian facility running alongside to make a direct connection between a point of origin and destination.

A gradual transition ramp should be provided between the pavement and the carriageway at the crossing site or at the place where pedestrians usually cross on (every corner of) a junction or roundabout . This transition should be wide enough to accommodate wheelchair users (≥ 1.20 m) and have a gentle gradient (≤ 1 : 10). This gradient is also suitable for use by pedestrians travelling with a zimmer frame, a shopping trolley or a pram.



Transition ramps wheelchair users

Design of crossing facilities
A crossing facility is an infrastructure or traffic measure that makes it safer and more pleasant for pedestrians to cross the road. Measures to improve pedestrian crossing movements, both separately and in combination, may be grouped as follows:

- infrastructure measures that simplify crossing:
  - guaranteeing mutual line of vision;
  - reducing the carriage way width on one or both sides by narrowing the lanes or reducing the number of lanes;
  - the interruption of parking lanes by means of expanded protrusions;
  - the construction of a refuge;
  - speed limit control by the police and /or the application of speed-reducing facilities such as raised crossings;
  - improving recognition of the crossing site by means of pavement elements, flashing traffic lights, traffic signs, markings and planting;
- traffic measures (separation in time):
  - pedestrian crossing site;
  - crossing guard;
  - traffic lights;
- split level crossings (separation in space) by means of a bridge or an underpass.

8.4.1 Sight distance

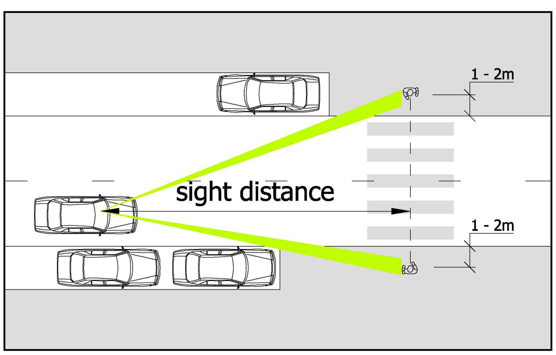


Figure 44: Sight distance

It is important that pedestrians who wish to cross the road have a good sight of all oncoming traffic. This sight must be available about 2.00 m before the carriageway to be crossed (figure 44). Equally important is that drivers can see the pedestrians, so that they can act if pedestrians make an error of judgment. In other words, mutual lines of sight should be possible under all circumstances.

The sight distance required is determined by the crossing time required, which in turn depends on the pedestrian's walking speed, the width of the carriageway to be crossed in one movement and the speed of the oncoming traffic. This relationship has been set out indicatively in table 15. It is extremely difficult to estimate the speed of vehicles approaching more or less head-on. It is especially difficult for children and/or in the case of speeds more than 50 km/hr. The situations below the dotted line in table 15 should be prevented.

Table 15: Sight distances required depending on pedestrian's walking speed, crossing length and vehicle speed

Speed	Walking speed 1.0 m/sec				Walking speed 1.5 m/sec			
	Crossing length (m)				Crossing length (m)			
	4	8	12	16	4	8	12	16
40 km/hr (11.1 m/sec)	45	90	135	175	30	60	90	120
60 km/hr (16.7 m/sec)	65	135	200	265	45	90	135	180
80 km/hr (22.2 m/sec)	90	175	265	355	60	120	175	240
100 km/hr (27.8 m/sec)	110	225	335	445	75	150	225	295
120 km/hr (33.3 m/sec)	135	265	400	533	90	180	265	355

8.4.2 Reducing the crossing length

Pedestrian crossing movements on roads with two lanes and two-way traffic are seriously compromised when the carriageway is wider than 7.00 m. In roads that are wider than the minimum width, narrowing the carriage way should initially be considered. Pedestrian crossing movements may be improved by:

- narrowing the carriageway and /or lanes while maintaining the number of lanes;
- narrowing the carriageway by reducing the number of lanes.

Pedestrians experience great difficulties when crossing dual carriageways with 2x2-lanes. These situations are very complex or threatening, particularly for children and elderly persons. The crossing site should in principle be provided with a traffic control system or, if possible, a split level crossing. In extreme cases unsatisfactory crossing sites may be obstructed physically.
Parked cars restrict not only the clear view between the pedestrian and the driver, but also increase the crossing length due to the parking bays. The width of a parking bay, or of the cars parked on the carriageway, should be included in the overall crossing length (figure 45).
By expanding parking bays by some 2.00 m, the sight is guaranteed while pedestrians have ample waiting room. The protrusion should preferably lie 0.30 m to 0.70 m maximum in front of the parked cars (Figure 46). Protrusions may be used only, if they do not present any added risks to cyclists.

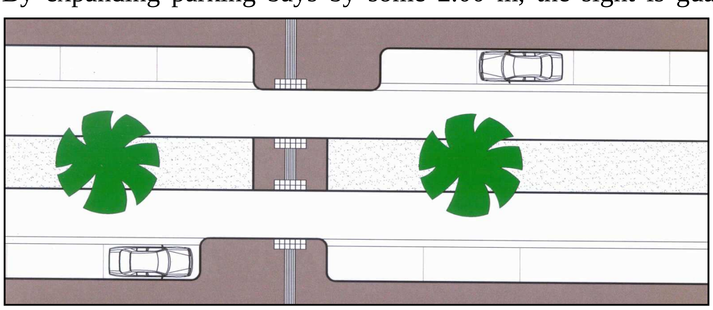


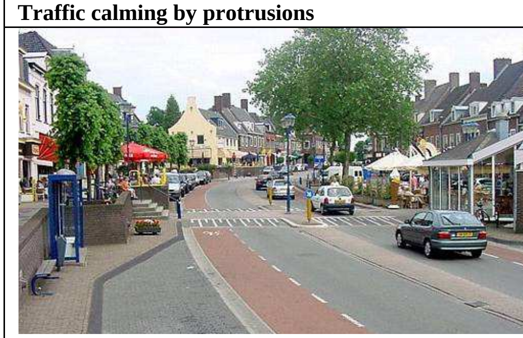
Figure 45: Reducing crossing lengths by protrusions

8.4.3 Traffic calming

The speed of the motorised traffic is perhaps the parameter that is easiest to influence in securing a safe crossing. This involves not only the vehicle speed on approach to the crossing point, but also the speed passing the site. In many situations of dissipated crossing, speed restrictions are in fact the only measure available to solve the problem. For this reason, dissipated crossings are permitted on access roads only. Distributor roads have concentrated crossing only.

Traffic calming by protrusions

Traffic calming by raised plateau near bus stop



Traffic calming by raised plateau (shops)

Traffic calming by convex 'median' and narrow lanes

Speed-reducing measures must be introduced for these crossing sites (V85 < 50 km/hr). On distributor roads (within built-up area) raised junction provides a suitable speed-reducing facility.

Refuge in schoolroute

8.4.4 Refuge

A refuge allows pedestrians to cross the road in two stages, enabling them to look in only one direction at a time. The volume and the crossing length per crossing are more or less halved, acceptable gaps occur more frequently (reducing waiting times). Refuges are much appreciated by pedestrians as a way to improve the crossing movements at distributors inside built-up areas.

The refuge should have a width of at least 2 m, preferably 3 m. Vertical signing and street furniture can be created on the refuge. These elements should not be so wide that they would obstruct the sight between the pedestrian and the driver.

Staggered pedestrian crossing

When constructing a refuge, the two crossings should preferably not be positioned in a direct line, but be staggered by a few metres (bayonet), forcing pedestrians on the refuge to walk in the opposite direction to the flow of traffic that they are about to cross. Staggered crossing will not work properly unless pedestrian barriers erected on refuge.

Crossing restrict to a minimum (Bulgarian)

Dissipated crossing (shops)

Dissipated crossing

Unlike distributor roads, dissipated crossing on access roads is permitted. This can be problematic on relatively busy residential access roads. Combined with traffic calming, a long refuge or a central reservation of at least 2.00 m wide offers an excellent crossing facility.

8.5 Give way crossings

There are three ways of reinforcing pedestrian crossing facilities, namely:

- the pedestrian crossing (marking);
- instructions from a traffic controller (crossing warden);
- the traffic lights

8.5.1 Pedestrian crossing

Pedestrian crossings sites (road markings and signs) are permitted:

- On roads in built-up areas where a maximum speed of 30, 40 or 50 km/hr applies. Maximum speeds of 50 km/hr generally require traffic calming measures so that 85% of the traffic will actually drive slower than 50 km/hr.
- On roads outside built-up areas, providing the approaching speed of at least 85% of the motorised vehicles is below 50 km/hr.
- While regular use of the crossing site is preferred for reasons of efficiency and acceptance, it is impossible to give a minimum number of crossing pedestrians for a particular time unit.
- Pedestrian crossings are not permitted on distributor roads with a maximum speed of 50 km/hr and dual carriageways (2x2 lanes) in built-up areas.
- Pedestrian crossing marking is not recommended in combination with a traffic control system.
- In situations where traffic flow equals or exceeds 1,000 vehicles/hour (peak hour), the use of a pedestrian crossing site combined with an adequate central island is recommended.

A high quality, at-grade solution for a crossing site without traffic lights on a distributor road link within built-up areas (V_{max} = 50 km/hr) comprises the following design elements:

- pedestrians crossing site or marking (width 4 m or more);
- a refuge of at least 2 m wide;
- crossing length of 4.50 m per lane;
- a traffic calming measure in the form of a raised plateau with a passing speed of 30 to 50 km/hr;
- the traffic sign ‘pedestrian crossing site’ above the carriageway;
- high quality street lighting;
- additional facilities for people with a mobility restriction.

8.5.2 Crossing guards

Crossing guards with manually operated barrier

Crossing guards or crossing wardens are particularly effective during brief intervals when (large) groups of pedestrians cross the road (school route). While the use of crossing warden is a safety measure, it should be regarded as a temporary measure in acute problem situations. After all, responsibility for safe participation in traffic does not lie with the volunteer, regardless of the fact that he or she trained as a crossing guards. Infrastructure measures are always preferred when solving crossing issues. Crossing wardens may be used on school routes inside built-up areas at crossing sites on distributor roads where a maximum speed of 50 km/hr applies. The crossing sites should be preferably near junctions with traffic lights or near a clearly recognisable crossing site (pedestrian crossing marking, refuge and speed-reduction facilities). Crossing wardens may use manually operated barriers. Since cyclists and mopeds are less inclined to stop, this facility is particularly useful on cycle routes.

8.5.3 Traffic lights

Linear village Poland: refuge, pedestrian crossing, traffic lights

Pedestrians (and cyclists) are usually a secondary consideration within the traffic light schemes in (complex) junctions. They might have to wait a long time for the lights change to green, and may even be caught out when the lights turn back to red when they are still crossing the road. Pedestrians often find traffic lights irrational and will cross as soon as the opportunity presents itself, irrespective of the traffic light. To be certain they will be able to cross at some point, they will press the button to demand a green phase. Ignoring the red light is not only unsafe and an offence, but quite often also means that a requested green phase will go unused. This is an issue particularly at solitary crossings with a relative low intensity of motorised traffic.

Junction with traffic lights

Traffic lights may be required or desired:

- for reasons of traffic processing and/or motorised traffic road safety;
- to (vastly) improve pedestrian and cyclist crossing movements;
- if there is not enough room to accommodate a central island.

Traffic light controlled crossings on distributor roads inside built-up areas are possible both on road links and on junctions as part of a general scheme. For a crossing site on a road link the following preconditions apply:

- the traffic control system on the crossing site must be supported by a central island and preferably also a raised crossing;
- volume crossing motorised traffic > 1,000 pve/peak hour;
- frequent pedestrians (and cyclists);
- 85-percentile speed motorised traffic < 70 km/hr;
- distance to junction > 50 m.

Traffic lights near a bus stop

At junctions and road links the installation is operated at the pedestrian's request. The green phase, however, must be as long as the crossing time at normal walking speeds. Safety and comfort depend particularly on:

- the time to the next green phase (waiting time);
- the time for vehicle queus to clear the crossing site from the start of the red phase;
- a scheme with or without one or more conflicts between different flows.

8.6 Split level crossings

As regards road safety, a pedestrian route that crosses a road (or railway) by means of a flyover is always preferred. However, it will be used by pedestrians only if the split level crossing is as attractive as the level crossing. The choice for split level crossing for pedestrians (and cyclists) is made based on an integral consideration in which the following aspects play a role:

- increasing road safety for crossing traffic by addressing the volumes and speed of the motorised traffic on the road to be crossed;
- removing barriers at level solutions with major crossing lengths (split level crossings are strongly recommended on dual carriageways);
- a reduction of psychological barriers;
- the volumes and nature of the crossing pedestrians and cyclists and in particular of specific groups such as school pupils.

Footbridge (without elevator)

Underpass or bridge

Well-designed split level crossing for cyclists and pedestrians

Split level crossings may be designed as:

- a pedestrian underpass where the infrastructure to be crossed is situated on street level;
- a pedestrian bridge where the infrastructure to be crossed is on street level;
- the infrastructure to be crossed is directed over the pedestrian route, at street level by means of a flyover;
- the infrastructure to be crossed is directed below the pedestrian route by means of a underpass;

- an intermediate solution where one of the two infrastructures is semi-sunk and the other one raised, so that the differences in height are halved in both directions.

The choice for a pedestrian underpass or bridge is based on a number of factors:

- The difference in height to be bridged and the manner in which this difference can be bridged. The difference in height also depends on the infrastructure to be crossed (water, railroad or road infrastructure). For example, in the case of a bridge across a road, the vehicular headroom should be 4.20 m to 4.60 m. A headroom of 2.30 m to 2.50 m suffices for a pedestrian tunnel.
- As the height to be bridged increases, more pedestrians will avoid the facility for physical reasons.
- Architecturally underpasses impact less on the environment than a bridge. However, a carefully designed bridge may also contribute positively to the overall image and act as a landmark.
- In the field of social safety a long, narrow underpass may have (major) consequences and even work claustrophobically.
- Accidents in underpasses may have far-reaching consequences for their users.
- Cost considerations also play an important role.

To promote the effective use of a pedestrian tunnel or bridge, it needs to be accessible quickly, safely and directly. The underpass or bridge should be a continuation of an existing or potential pedestrian route. Design continuity is desired to promote recognition of the walking route. Clear signposting may also contribute to its optimum use.
From the point of view of social safety underpasses should not be isolated from residential areas. By integrating underpasses into residential areas they are experienced less as anonymous pieces of no-man's land without social control. The tunnel design also influences feelings of (un)safety.

Narrow and/or dark underpasses or tunnels should be avoided to prevent feelings of claustrophobia or social unsafety. The main criteria are:

- the minimum headroom for pedestrians is 2.30 m. If cyclists use the underpass, the minimum headroom is 2.50 m;
- the width equals at least 1.5 times the height;
- the underpass should offer a clear view of the other side; straight underpasses are preferred over curved underpasses;
- the use of sound-absorbing materials is recommended for long underpasses, as well as (natural) ventilation;
- steep slopes and stairs at underpass entrances should be avoided.

Bad social safety, claustrophobia

Good (public) lighting is essential. The more that daylight can enter, the more people will experience the underpass as safe. For long underpasses light domes, gaps or openings in the roof will be constructed where possible. The use of bright colours also generates an effect of space and openness. Also a gradual transition from daylight to artificial light is required.

9 CASE STUDIES IN DIFFERENT COUNTRIES

9.1 Case study: Poland

A summary of a case that Poland demonstrates, the type of practical short and long-term solutions and measures can improve road safety. Among several other cases this junction was analysed with local experts. Different solutions were developed and compared with the previous plans to solve the problem of the junction.

The photo and figure 46 show the present situation. Between 1994 and 1998 15 accidents occurred around the junction, of which 12 were on the junction itself, with a total of 30 injuries and 4 fatalities. Most accidents were priority accidents, where speeding played a major role. Although many pedestrians and cyclists cross the road n°73, none of them were involved in the accidents.

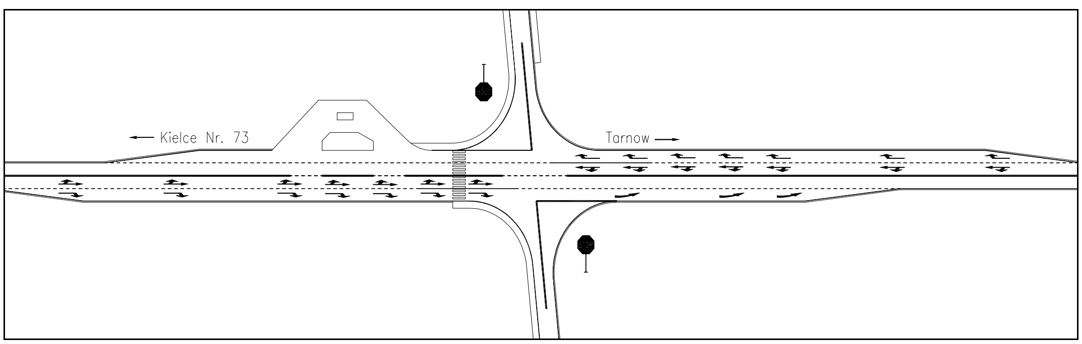


Figure 46: Present situation

The local Road Directorate proposed the following measures to improve the junction (figure 47):

- introduce additional left turn lanes on n°73;
- use a median strip to separate the two directions on road n°73, therefore the petrol station would only be accessible from one direction;
- construct an extra side-walk along road n°73;
- place chain fences along the side walk, pedestrians can only cross road n°73 on the crossing;
- place reflectors to emphasize road markings.

Discussions about the solution above resulted in the following conclusions:

- if extra lanes are introduced the crossing area would be much larger thus more dangerous;
- the extra lanes for the left turn traffic are in theory well designed, but are not really necessary with regard to the type of accidents recorded;

- the priority situation will worsen for traffic coming from the road n°765 thus more accidents;
- the crossing length for pedestrians increases and the barrier effect will also be stronger.

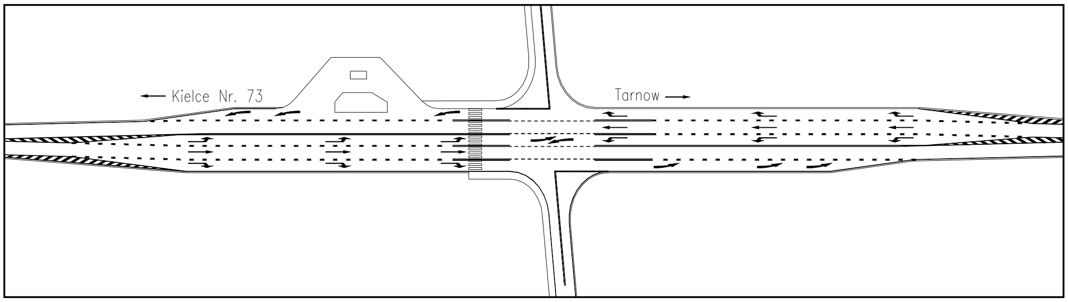


Figure 47: Solution of the local Road Authority

The following solutions were developed during the training and are results of discussion between the local and Dutch experts. The minimum solution (figure 48) contains the following measures.

- different division of the two lanes of road n°73, such as the left turn becomes a separate lane by changes in the road marking;
- the crossing width remains the same, this improves road safety.

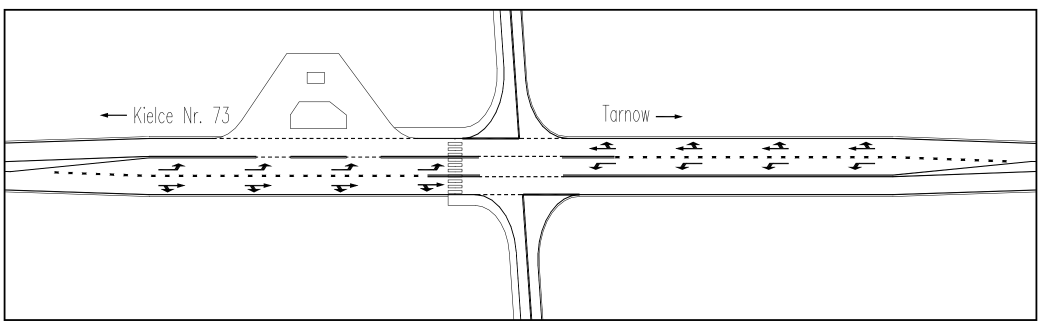


Figure 48: Minimum solution (training)

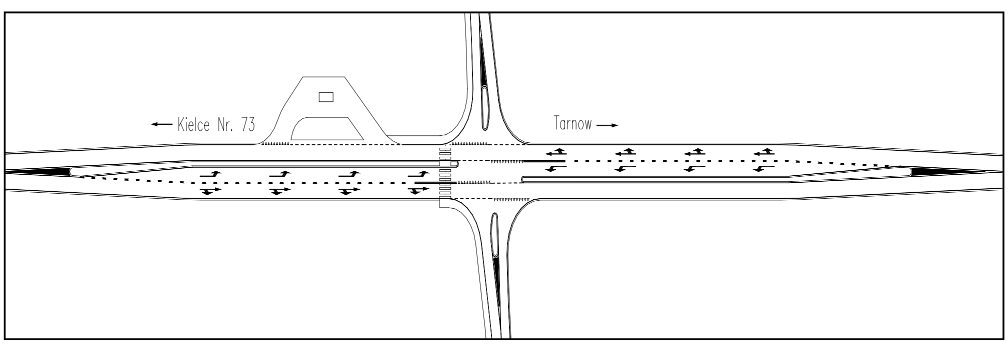


Figure 49: Improved solution

Figure 49 shows a further improvement of the present situation:

- if the two directions are separated, illegal overtaking over can be prevented;
- pedestrians can cross road n°73 in two section: safer situation;
- additional road markings on the crossing of roads n°73 and n°765 emphasizes the priority situation.

The previous two solutions still have one major disadvantage: the speed of motor vehicles along road 73 will still be too high (even though the section is within an urban area). This is partly due to the slope of road 73. The only possible way to reduce speeding is frequent police control.

Introducing a roundabout can also solve this problem, and according to the discussion this would be the optimal solution (figure 50). The speed for all directions is low, thus improving road safety significantly.

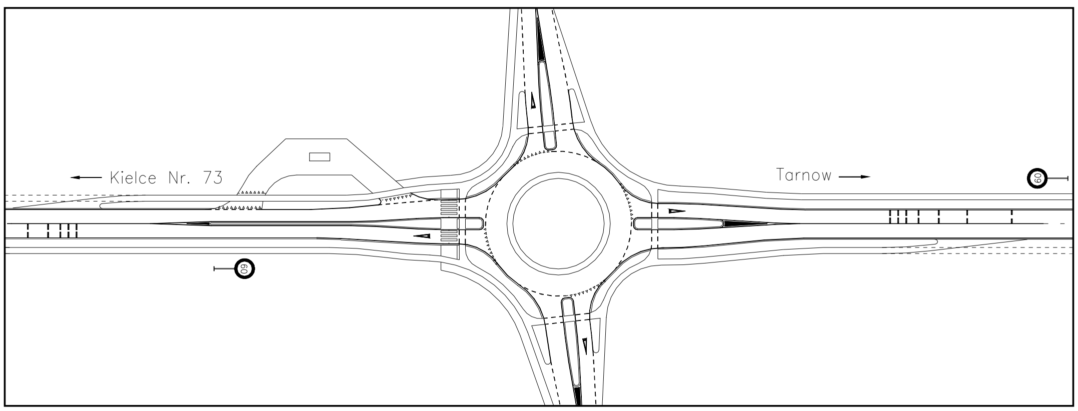


Figure 50: Optimal solution, roundabout

9.2 Case study: Latvia

9.2.1 Existing situation

Crossing of the state main road A12 Jekabpils– Rēzekne – Russian border with intensive secondary road P36 Rēzekne – Gulbene at grade.

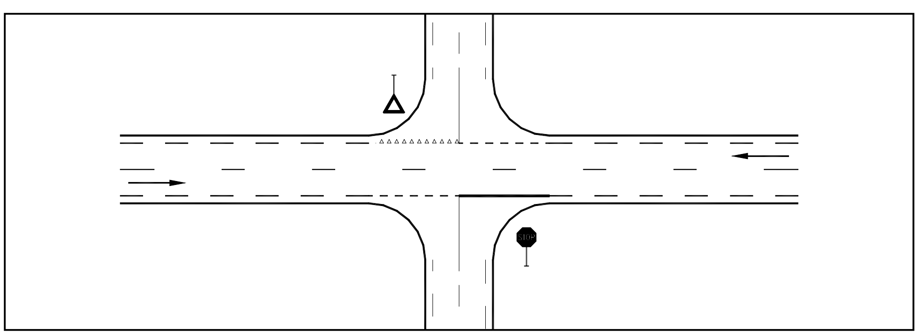


Figure 51: Sketch of the current junction.

The crossing is located on the top of vertical curve and this hinders the visibility. This terrain does not provide drivers with advanced recognition at the location and form of the junction. The junction has no public lighting and this adds more danger in the hours of darkness.
As the inspections show, many vehicles park directly near the junction in order to let passengers in or out. Pedestrians use the shoulders to go home or to other destinations.

Road A12, approaching the junction

Road A12: near the junction

Secondary road P36 (yield)

Secondary road P36 (stop)

9.2.2 Traffic and accident data

The present layout and traffic regulation are the main reasons for traffic accidents and therefore the crossing is entered into the list of black spots. The total number of registered accidents is 7. There were no recorded injuries of fatalities.

Total traffic volumes are (AADT):
- section Jekabpils – junction with P36: 2200 (35% trucks);
- section junction P36 – junction with A12: 2300 (40% trucks).

9.2.3 Suggestions for solutions

The main road has the normal cross section of 2 lanes of 3.5 m width and hard shoulders at both sides of 2 m. This implies that a vehicle that uses the paved shoulder can be overtaken easily,

but that oncoming traffic has to shift to the right too. Problems arise when vehicles are parked on the hard shoulder.
The traffic volumes are (very) low, so it is not necessary to reconstruct the junction in the form of a roundabout or to install traffic lights. A junction must be visible from an adequate distance, conspicuous and clearly recognisable and locatable as such. In this case opportunities to improve the visibility are (figure 52):

- main road: a left turn lane or/and a median (by use of paved shoulders);
- minor road: traffic island.

To keep the cost of reconstruction to a minimum and for reasons of low volumes and the vertical curve, the proposal is to construct the median in the main road and not the left turn lane. In the future a left turn lane may also be necessary for reason of growing volumes.
Public lightning and a traffic sign, located on the median and traffic islands, make the junction perceptible from a longer distance. The proposed sign is the round blue sign with a white arrow pointing to the right bottom, coated by retro reflective material. Under the sign a yellow retro-reflective strip is mounted.

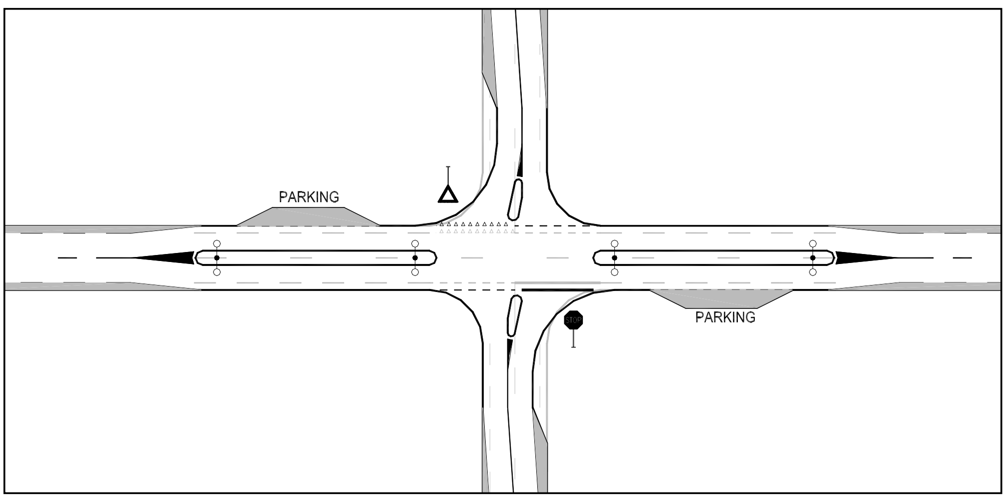


Figure 52: Sketch of proposed reconstruction

Parking bays should be located just behind the junction. This reduces the disturbances of traffic flows and avoids interruption of the sight lines from the minor road of the vehicles on the main road.

9.3 Case study: Estonia

9.3.1 Current situation

The road link is located near by the city of Tartu. The road is single carriageway and with two lanes per direction. There are local settlements alongside the road on both sides. The junction Tõrvandi-Ülenurme is located at km 190.6. A school is located at one side, which results in a number of pedestrians crossing the main road.

The traffic volume on the main road is 10,000 to 12,000 vehicles daily (AADT, 2003). Local turning traffic is heavy, especially at peak periods. Public transport bus stops are located at the main road and the minor road.

	
Main road: cross section	**Junction, main road**

The municipality and the local school have complaint about the safety situation. The road link is considered as a black spot (21 casualty accidents, 1999-2003).

9.3.2 Reconstruction proposal

Figure 53 shows the proposal for reconstruction of the junction by the Road administration. The Positive to very positive factors in this design are the reduction of through lanes, the provision of separated left turn lane and the refuges in the main road.

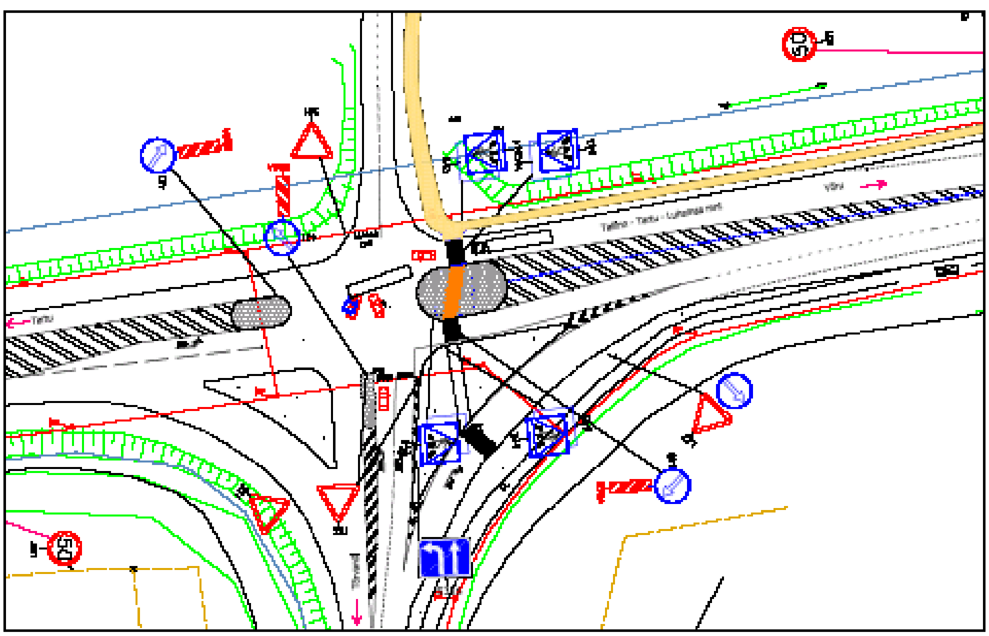


Figure 53: Proposal for reconstruction by the Road Administration.

More or less negative aspects are:

- The large radii between the main road and the minor road . The speed of turning traffic is high. This is not safe for pedestrian crossing movements.
- Traffic calming is very favourable for pedestrian crossing movements, but in this case a limit of 50 km/hr has to be supported by traffic calming measures.
- Two lanes (left turn lane and through lane) on the minor road.

The design discussed in the training is given in figure 54. The design is as compact as possible. Significant aspects are:

- It is better to locate the pedestrian crossing (zebra marking) on the main road at the left side of the junction (school route);
- Bus stops should be located just behind the junction. This reduces the disturbances of traffic flows and avoids restriction of the sight line from the minor road.
- It would be an advantage if footpaths could be construct for the school route.

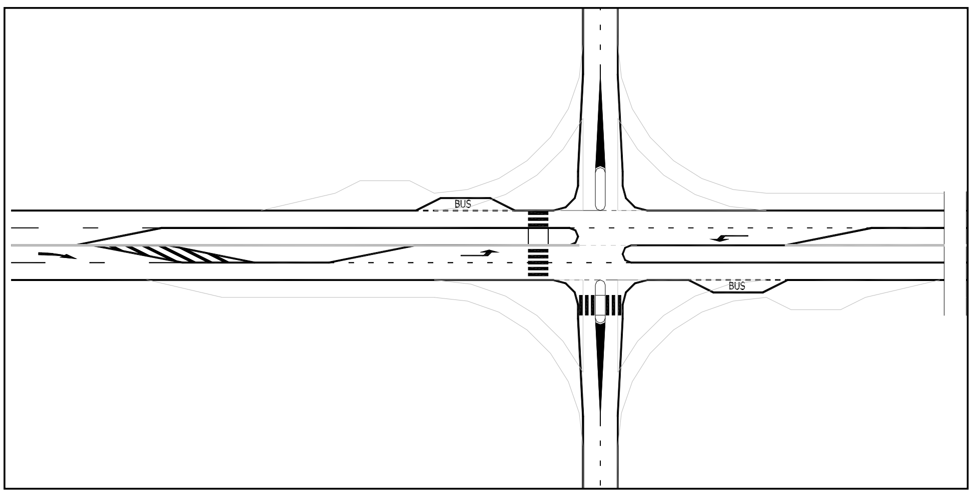


Figure 54: Discussed design in the training

The traffic volumes on the main road are rather high, but the volume on the minor road is not known. For reason of capacity (and safety) a roundabout or a junction equipped with traffic lights will be necessary in the near future.

9.4 Case study: Lithuania

9.4.1 Current situation

The case of Lithuanian is a linear village, with national through road A6 passing through the village of Karmélava. Along both sides of the road are residences (living houses) and some shops. There is a small airport near the village (see figure 55).

The road A6 has dual carriageways (2x2 lanes) with a very narrow median (see figure 56) and a guardrail. This guardrail is provided with a handrail to avoid uncontrolled crossing movements by pedestrians. There is a narrow footpath alongside part of the A6 (1 m). Residents and visitors regularly park cars on the gravel shoulders.

Figure 55: Map of Karmélava

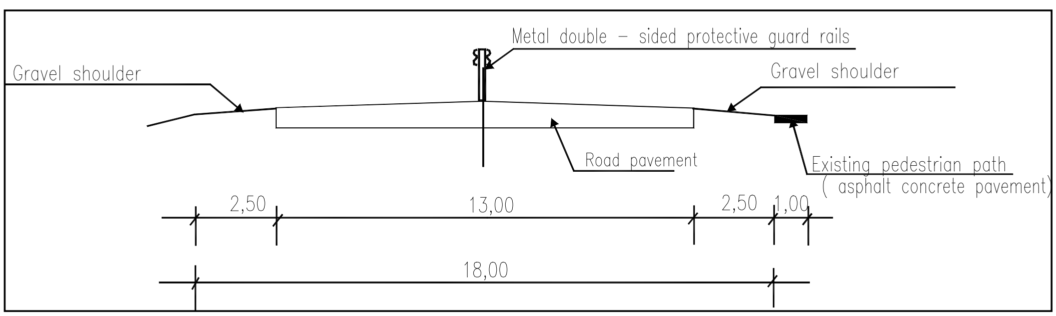


Figure 56: Cross section A6

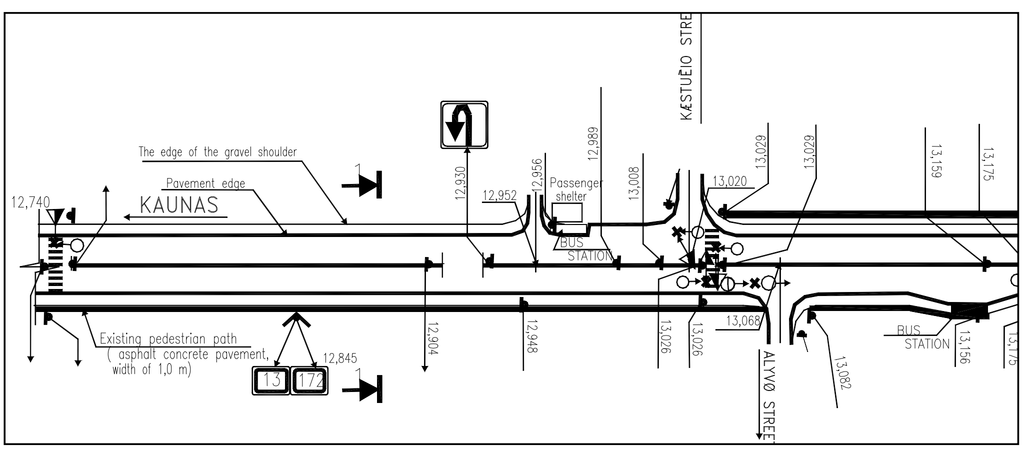


Figure 57a: Sketch of the current situation (continue next figure)

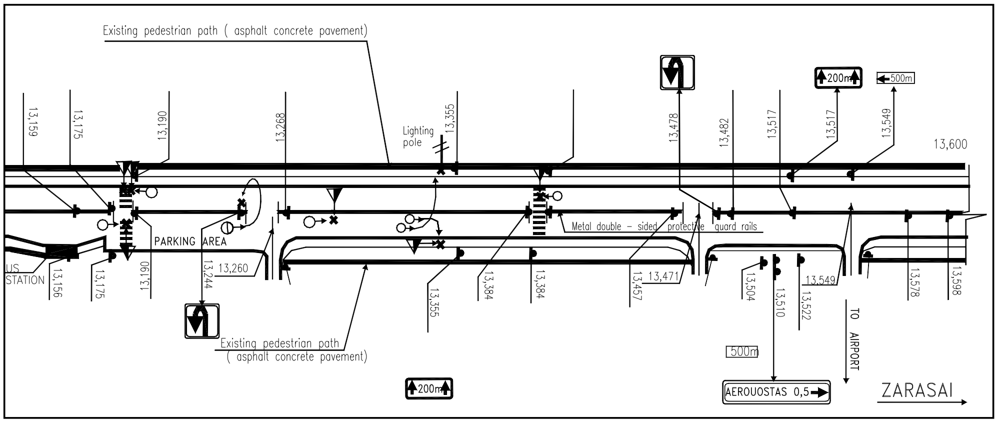
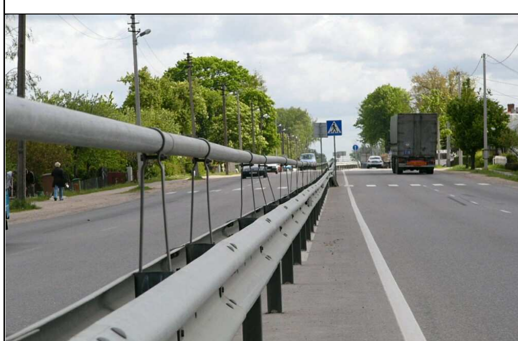


Figure 57b: Sketch of the current layout

Border of Kamélava (black spot)

U-turn (only passenger cars)



Handrail to avoid pedestrian crossing movements

Pedestrian (zebra) crossing

The known traffic data is:

- 7 accidents involving pedestrians with 3 fatalities (2000 – 2003);
- traffic volumes:
  - Kaunas – Kamélava : 12,600 veh/day;
  - Kamélava - Zarasai : 7,500 veh/day;
- speed limit: 50 km/hr.

9.4.2 Proposed solutions

The main safety problem for the linear village A6/Karmélava is the conflict between the traffic or flow function and the residential function:

- conflicts between through traffic and local traffic;
- conflicts between motor vehicles and vulnerable road users (primarily pedestrians).

The cross section must be adapted to the (expected) traffic volume and the intended speed limit. The traffic volume should dictate the number of lanes and the width of the lanes should be decided by the design speed.
The (expected) traffic volume is less than 25,000 veh/day, so a single carriageway, two-way road, is more than sufficient. The conflict between the transit traffic and the local traffic and the conflicts between motor vehicles and vulnerable road users have to be solved. This can be solved in two ways:

- A6 has inside the built-up area an access function (speed limit 30 km/hr);
- A6 has inside the built-up area a distributor function (speed limit 50 km/hr).

Adopting the line of the distributor function, service roads (access roads) on both sides are necessary. In this way the conflict between through traffic and local traffic is solved. The sketch in figure 58 is based on the above way of thinking. Remarks are:

- one way traffic proposed on the service roads;
- side roads are connected to the service roads and in this manner the number of junctions with the distributor road is reduced;
- all at grade crossings of the distributor road and the access roads, and the pedestrian crossings, are equipped with traffic lights. The traffic lights are coordinated (green wave) at a maximum speed of approximately 50 km/hr.

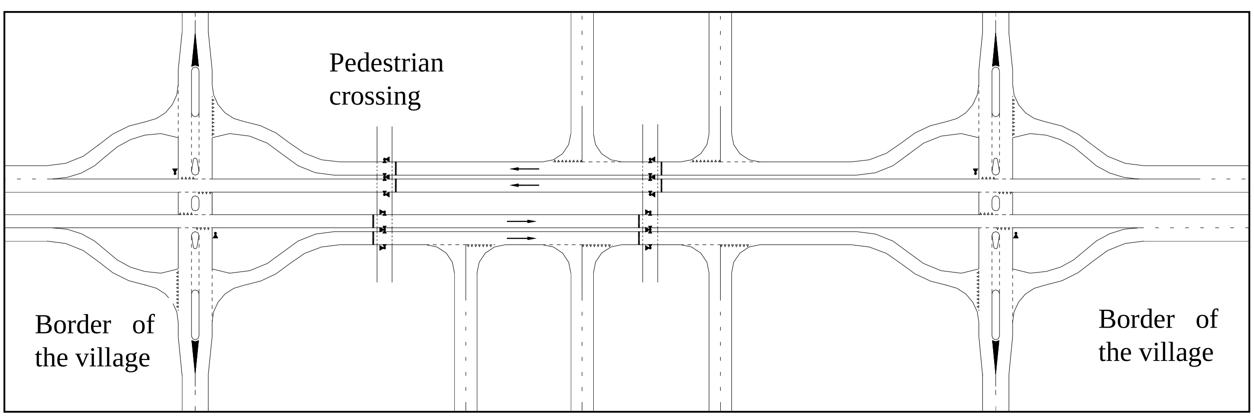


Figure 58: Sketch of suggested solution

The sketch was made before the training and the side inspection. The inspections indicated that the total space between the properties was limited, and wide median in the distributor road was not possible. During the training the proposed width of the single carriageway was fixed at a total 6.50 m:

- lane width: 3.00 m;
- crossable direction separation, indicated by two continuous lines (0.50 m);
- kerbstones on both sides (separation of service road).

The width of the service road is approximately 5 m including parking bays at the right side of the road, and of course a footpath between the service road and the properties is necessary.

9.5 Case study: Bulgarian

9.5.1 Current situation

Road III, 8641 between Smollan and Pamporovo is a winding mountain road. The horizontal bends are sharp and often in combination with steep slopes. In these bends the speed limit is usually 40 km/h and overtaking is prohibited. One of the sharp bends is near km 7,340.

	
Sharp bend, speed limit 40 km/h, overtaking forbidden	**Sharp bend and steep slope**

The road is normal width of 7,00 m. Near km 7,340 the horizontal bend (radius 25 m) is about 15.45 m in width (see figure 59).

Traffic data

The total traffic volume is about 1.710 vehicles per day:

- passenger cars : 1400;
- bus : 85;
- heavy duty vehicles : 225.

The number of accidents near the bend is unknown. On a 7-kilometer stretch of road, 16 accidents were recorded (2 injured persons). The side inspection yield the following results:

- probable run off road accidents mostly in the direction of Pamporovo;
- against the background of the panorama the sharpness of the bend is not recognizable;
- insufficient information and guidance within the bend.

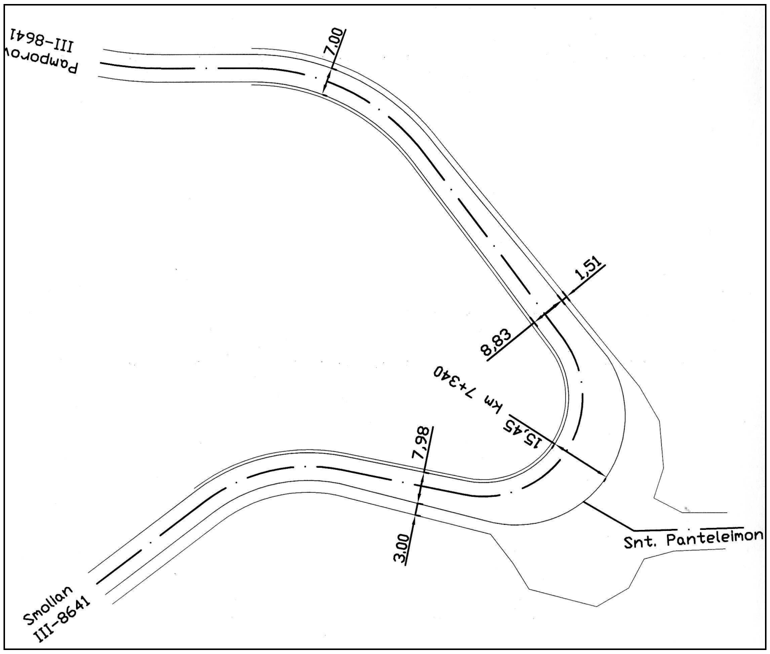
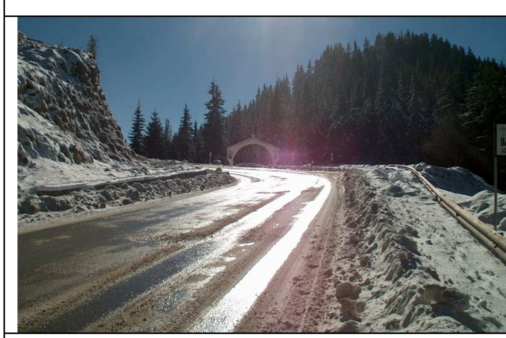
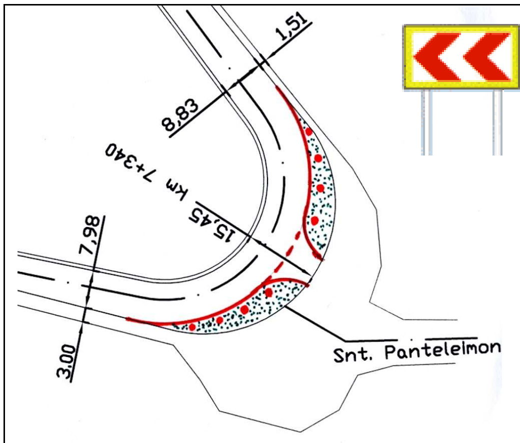


Figure 59: Sketch of the current design sharp bend is near km 7,340

	
Sharp bend, direction Pamporovo (summertime)	**Sharp bend, direction Smollan (summertime)**
	
Sharp bend, direction Pamporovo (wintertime)	**Sharp bend, direction Smollan (wintertime)**

9.5.2 Proposed solution

The proposed solution is an upgrade of the curvature and guidance for the drivers. Of course widening of the cross section in the bend is necessary, but a total width of about 8,50 m is enough. The guidance of the drivers can be done by kerbstones (height about 100 mm) and vertical objects (figure 60). Examples of vertical objects are given.



Improved design

Example of vertical objects (retroreflective)

Figure 60: proposed design of the curve

9.6 Case of Romania

9.6.1 Current situation

The road DN 1 is the main road linking Bucuresti via Brasov-Cluj and Oradea with the Hungarian Border. The road is a European road (E60) in the European road network, main traffic on road is long distance and regional traffic.
Coming from Bucuresti the road has 4 lanes without a median in a general flat alignment. A few kilometres after Campina the mountains start, in general the road has a smaller cross section, with only two lanes and sometimes an additional lane for climbing traffic on longitudinal slopes. In contrast to towns and villages further North, Campina has a ringroad west on the urban area thus the road doesn't cross through the town. The speed limit on the ring road is 100 km/h, unlike the other towns it passes through where the limit is lower.

Campina has three connections to this road:

- Campina South at km 89;
- At km 92,2 entrance to a customs office. The connection is of minor importance; no left turns admitted to and from the side road. In addition, the connection is illegally used by heavy duty vehicles travelling to the custom office;
- Campina North at km 95.

	
Road DN1 (from footbridge)	**Footbridge, zebra and restaurants**

The junction at km 92,2 is meant especially for traffic to and from the custom office for registration of administrative documents. The junction is often used by heavy trucks, despite not being constructed for this type of traffic. Just south of the junction there are restaurants on both sides of the road (with car parks) and about 100 m to the North there is another restaurant/motel facility on the east side of the road.
At km 92.5 there is a pedestrian crossing. Until recently this was a zebra crossing, but a few months ago a new footbridge was constructed. There is only one pedestrian crossing between km 89 and 95. There is no street lighting along the DN 1, except at the pedestrian crossing where there is some basic lighting.

Traffic data
Average traffic volumes are estimated around 15 000 vehicles a day.
The available data of road accidents for the inspected section are very limited. Over a section of two kilometres there are 20 accidents registered in a period of five years:

- only four of these accidents took place in daylight, so the majority occurs in darkness;
- a concentration of accidents is registered at km 92,2 at the afore mentioned pedestrian crossing. At this location 2 fatalities with pedestrians were registered and there were 7 seriously wounded persons in the same period. This location accounts for 7 accidents out of the total of 20.
- the rest of the casualties is spread evenly throughout the section, including 5 fatalities with pedestrians.

9.6.2 Proposed solution

The percentage of accidents with pedestrians is considerable. Apparently this is due to the stream of pedestrians from Campina to its suburban region. A substantial amount of pedestrians take the risk and use the grade crossing; instead of the footbridge. The bridge takes more time and energy than the at grade and the zebra crossing is still present. Furthermore, the supports of the footbridge are “protected” by a large concrete block. This means an unacceptable obstacle close to the carriageway.

No left turns are admitted to and from the side road, but in practice the junction is illegally used by heavy vehicles in both directions. The problem is two-fold: firstly the signposting to the customs should be improved, secondly the design of the junction should be improved to reduce the number of conflict points. The entrance to the side road is too narrow for many of the trucks:

- the right turn from main road is very difficult;
- no lane to the left on the main road;
- the left turn from side road is very difficult, visibility to the left is limited.

While there is no separation between the space of the restaurants and the carriageway a lot of the visitors / customers of the restaurants do not use the parking lots in a proper way. Between the carriageway and the premises of the restaurants at both sides of the DN 1 is no separation. Many vehicles are parked all over the place and just next to the traffic lanes of the DN 1.

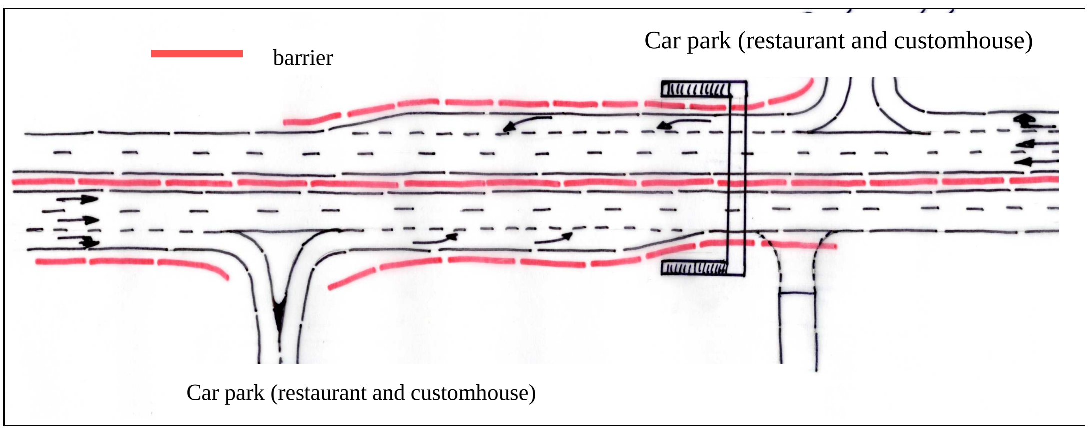


Figure 61: Sketch of the proposed design

Firstly, the pedestrian crossing including the relevant traffic signs should be removed completely (figure 61). Secondly, in order to prevent illegal crossing of the carriageway a physical separation (concrete or steel barrier) on both sides of the DN 1 should be installed. This facility will also serve other goals:

- the barrier will prevent illegal left turns to and from the side road to the customs;
- the barrier will also prevent frontal collisions at the DN 1;
- the barrier will also prevent pedestrians crossing the DN 1 at other places.

Thirdly, in order to ensure the footbridge is accessible for all relevant road users, including people with disabilities some additions to this structure are recommended. Along the stairs of the bridge a guiding construction has to be made for bicycles, enabling cyclists to take their bicycles by the hand without any difficulty.

Finally the concrete obstacle of the supports of the footbridge should be changed with improved protection. This might be considered in combination with a separation of the space along the road at the restaurants.

In the current situation, the side road to the customs is an unacceptable junction. An initial idea was to close the junction completely, which would mean that the road users have to leave or to enter the DN 1 at the other remaining intersections. Closer investigation of this solution showed that this would be impractical because there is a substantial difference in level between the customs station and the rest of Campina with an unsuitable road network for heavy traffic. Instead possibilities have to be studied to move the intersection to a point closer to the restaurants. There seem to be some open spaces at this location.

9.7 Case of Turkey

9.7.1 Current situation

One of the cases of Turkey is a junction at the road Bergama Kavsagi, Altinova – Bergama Ayr – Zeytindag Ayr (km 70), with the main road (priority) is Cannakale – Izmir (see figure 62).

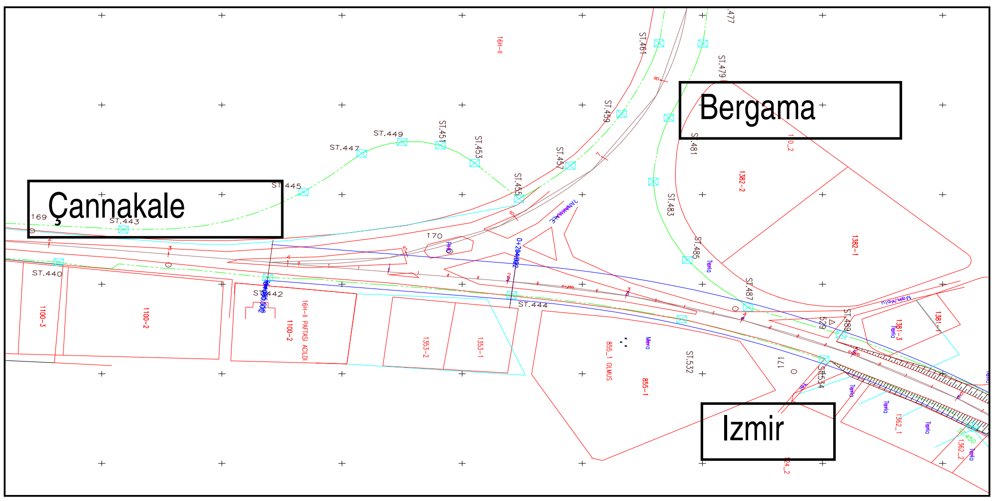


Figure 62: Current situation

Table 16 shows the traffic volumes on the main road. The total number of vehicles is about 7.000 vehicles/day. The number of heavy goods vehicles is relative high. The accidents are given in figure 63 (one year).

Table 16: Traffic volumes (veh/day) main road

Year	Car	Bus	Heavy duty vehicles	Total
1998	3.780	480	2.540	6.935
1999	4.080	460	2.250	6.945
2002	3.560	430	2.370	6.510
2003	4.845	480	2.660	7.095

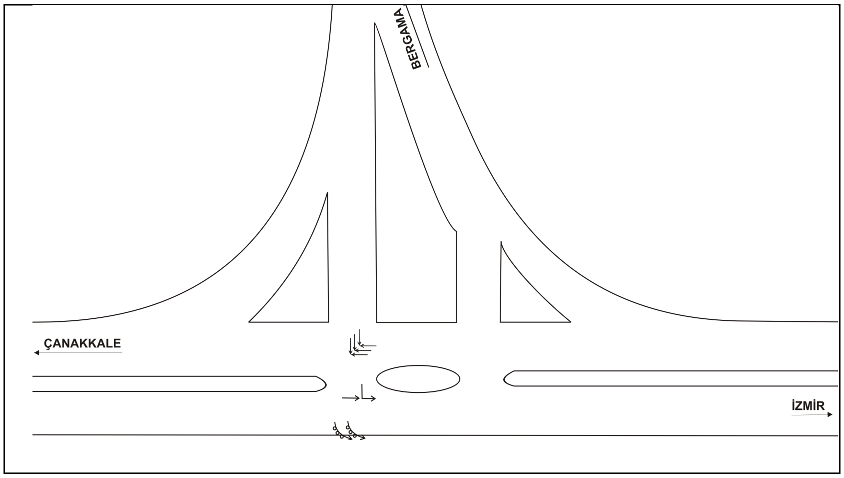


Figure 63: Collision diagram (6 accidents in one year)

9.7.2 Proposed solutions

Figures 64 to 68 show the proposals for reconstruction of the junction by the Road Administration. The first three designs are priority junctions with different numbers of lanes. In all solutions the design is significantly exceeds requirements. In normal situations the capacity of a single carriageway, with two way traffic is 20 to 25.000 veh/day. The need of a dual carriageway (two lanes each direction) can only be justified if the traffic volume increases considerable in future. A two lane bypass (figure 66) is also considered as overdone.

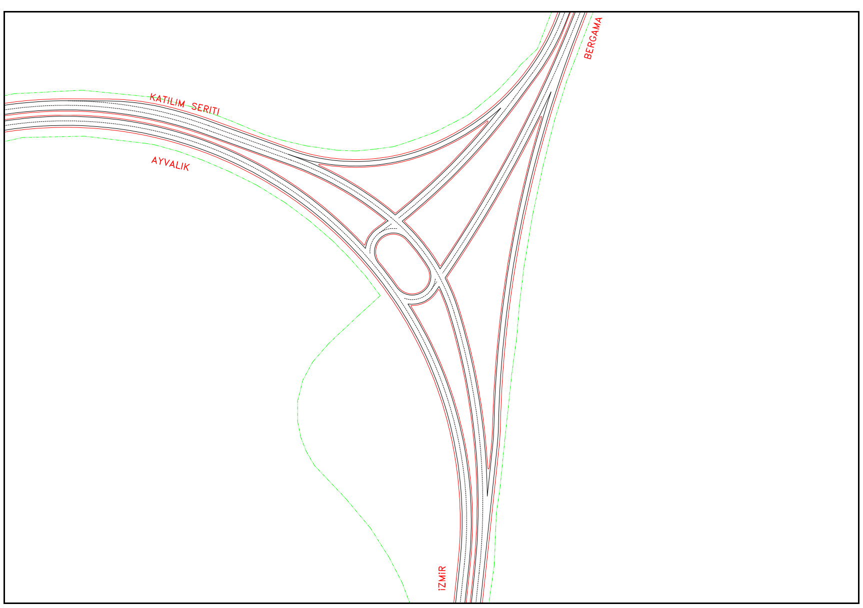


Figure 64: Proposed solution, two lanes weaving section, one lane on bypass (alternative 1)

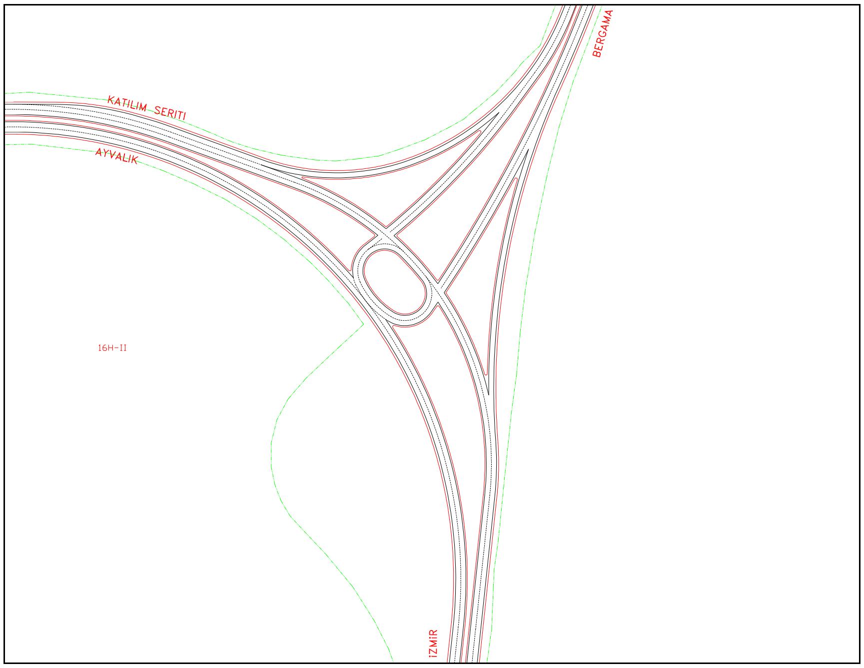


Figure 65: Proposed solution, three lanes weaving section, one lane on bypass (alternative 2)

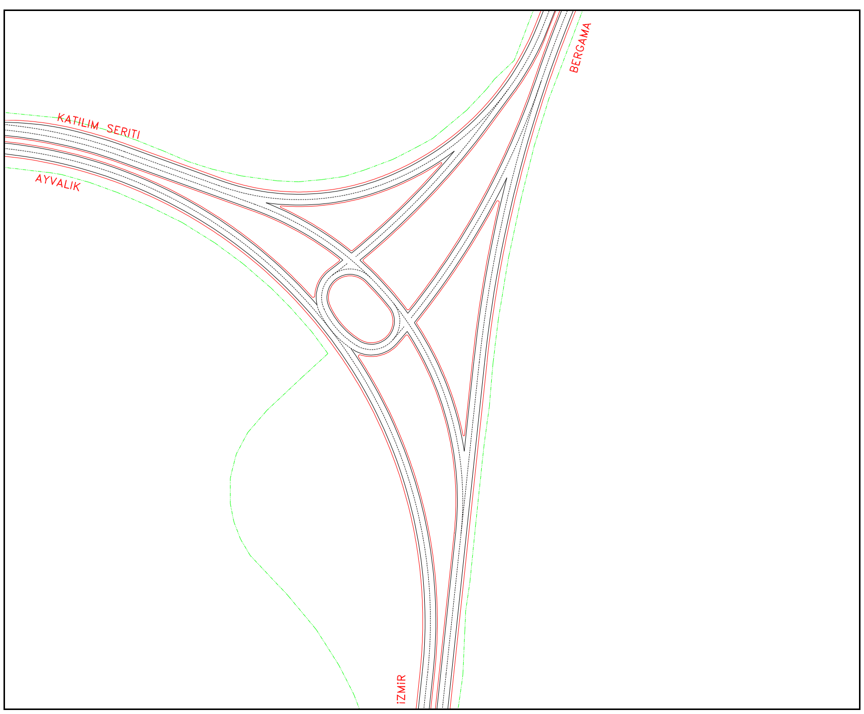


Figure 66: Proposed solution, three lanes weaving section, two lanes on bypass (alternative 3)

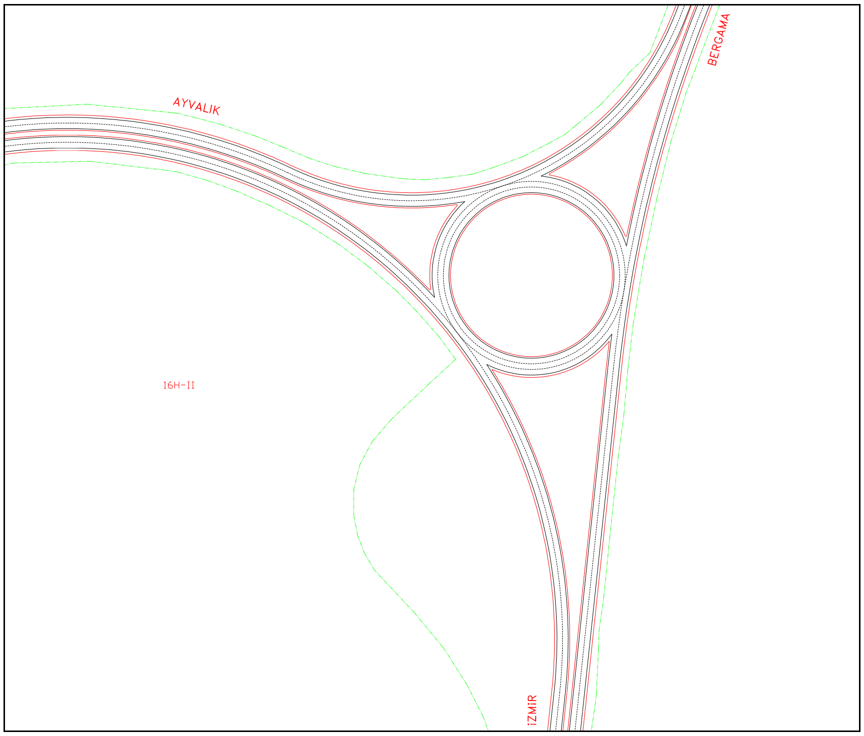


Figure 67: Proposed solution, three lanes on roundabout, connections tangential linked up, three lanes weaving section (alternative 4)

Figure 67 shows a large roundabout. The exchange of traffic in this design is based on weaving sections within the roundabout. Three remarks:

- the differences in speeds are high due to large radius curves at the entry lanes;
- the length of the weaving area is short;
- the give way situation is unclear.

In the city of Amersfoort (The Netherlands) there is a roundabout quite similar to this design. In this municipality this is the black spot with the highest number of accidents. Recently the one connection of the roundabout was changed to a modern roundabout. The other connections will be changed in the near future.

The alternative shown in figure 68 is the preferred solution of the five alternatives. It is essential that the axes of the approach roads are more or less radial linked up to the roundabout. For reason of capacity there is no need for a two lane roundabout or for a dual carriageway. If there is a need for a two lane roundabout in the future, is better to phase the design. A roundabout with one lane on the entrance, exit and on the roundabout, is the safest solution.

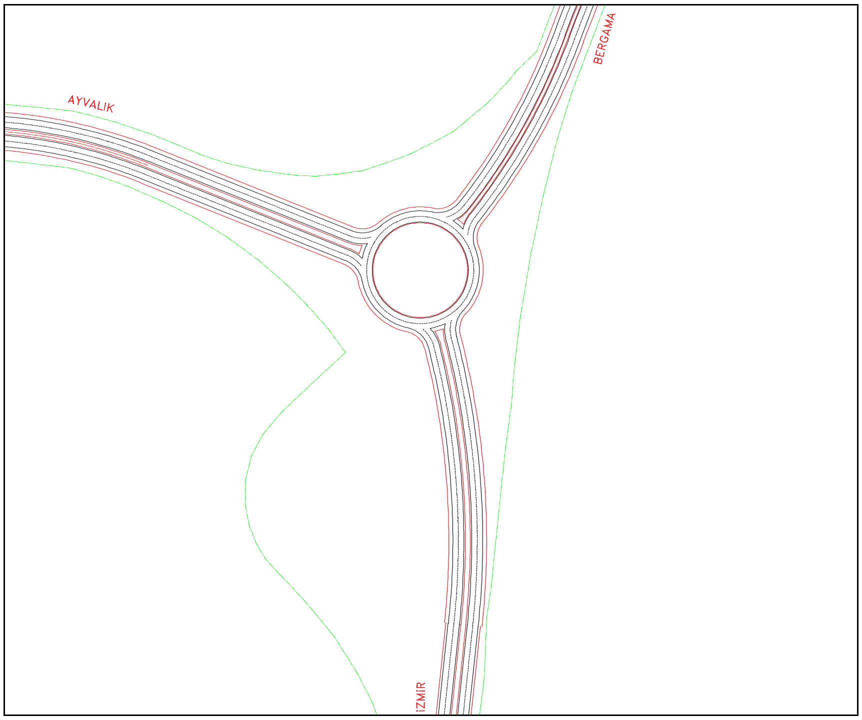


Figure 68: Proposed solution, modern roundabout, two lanes on roundabout, two lanes on entrances and exits

10 ANALYSIS OF BLACK SPOTS

10.1 Introduction

The occurrence of accidents is founded on a complex array of factors related to human behaviour and vehicle, road and environmental characteristics. The Dutch MATAC method (Manual Analysis of Traffic Accident Concentrations) is a valuable tool here. The MATAC method is a technique for analysing concentrations of road accidents at individual locations and/or short sections. The objective of the analysis is to draw indications from the similarities in accident characteristics at the location relevant to required improvements. Designers should note that use of MATAC analysis requires a certain degree of knowledge and skill. It requires knowledge of general accident characteristics, traffic science and traffic behaviour.

The road traffic system consists of 3 components: man, vehicle and road (environment). Deficiencies in one or a combination of these components increase the chances of accidents. A study in England into the main causes of accidents resulted in the following findings:

- human factors : involved in 95 % of accidents.
- road factors : involved in 18 % of accidents.
- vehicle factors : involved in 6 % of accidents.

As only 18% of the accidents are either partly or totally attributed to the 'road' component, one might be led to believe that there are few possibilities for preventing road accidents using infrastructural measures. One should, however, remember, that:

- In principle all accidents can be attributed to human factors. In legal terms, the way it is put is that the road user has not exercised the necessary care and attention within the given circumstances.
- A good, uniform design assists the task of driving, which reduces the chance of accidents (see chapters 3 to 9).
- Traffic behaviour can also be positively influenced by information, law enforcement and education (see chapter 12).

A reduction in the number of fatalities is difficult to achieve, but it is possible. Figure 69 shows the increase of mobility, cars and of the decrease of fatalities in The Netherlands during the period 1961 – 2002.

In general, infrastructural measures are highly preferable. The desired traffic behaviour is therefore not achieved legally and more or less non-committal, but actually enforced. This does not, however, mean that non-infrastructural measures should not be considered. In certain situations these can also achieve interesting results.

Testing of the road safety aspect, following an accident, is often inadequate. The testing should cover not only the road design, within the given road environment, but also the expected traffic behaviour. The following two practical examples illustrate the situation where the benefits of measures related to road safety have been underestimated.

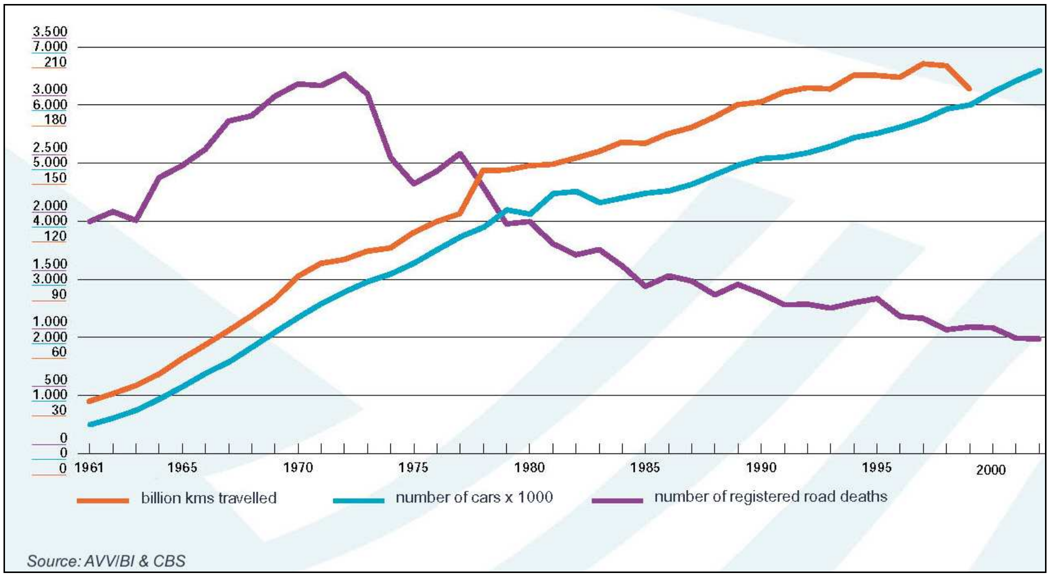


Figure 69: Number of cars, vehicle kilometres and the number of fatalities

Example 1

To provide relief through the centre of a village, the decision is made to build a bypass. Due to the (residential) buildings alongside the planned route, the road is incorporated into the built-up area (speed limit of 50 km/hr). The design provides for a 7.00 m-wide main road with quite long straight stretches without junctions, large radius curves and separate cycle paths. It is not difficult to predict that the majority of drivers will ignore the speed limit of 50 km/hr with all the associated consequences. The design complies fully with the design guidelines, but there is a definite flaw with regard to the traffic management aspect.

Example 2

A number of companies which generate freight and agricultural traffic are situated alongside a country road (3.50 m wide). The traffic volume per day, however, is low. There is an avenue of trees on both sides at a distance of 1.50 m from the edge of the road surface. The road maintenance authority has to reprofile the shoulders every year to ensure drainage (and therefore also safety). Accidents, however, are rare. After widening the road to 5,50 m the shoulder problem is solved entirely. The road safety, based on number of accidents, however, is drastically reduced. Causes are: far higher speeds, cutting corners as traffic volumes are low and the trees standing closer to the road.

Give way accident

The MATAC method is extremely valuable. After a serious accident, the opinions of politicians, road users and local residents, as regards which measures should be taken, are often rapidly formed. In response to this, decision makers are tempted to enforce immediate solutions. There is the risk of:

- measures being taken that do not actually solve the problems;
- a far higher investment being made than necessary to solve the actual problems.

Measures should be based on a thorough, objective analysis of the problems. This is what MATAC promotes. The way that all stakeholders are involved in the process of solving traffic problems, thorugh an integrated approach is explained in Chapter 2.

10.2 Minimum number of accidents

The MATAC method can only be applied if a particular minimum number of (injury) accidents have occurred at a location. It is therefore a reactive approach to road safety: assessing situations that have previously resulted in accidents.

The location can be either a junction or a road link. A road link is, in principle, a section of the road between two junctions several hundreds of metres or kilometres long. As an indication, a section of roughly 100 to 200 m length of homogeneous road can be considered as a unit.

What is a 'black spot'?
The utilisation of the MATAC-manual related to identifying black spots, focused initially on the number of accidents: the worst black spots were those with at least 12 accidents during a period of 5 years. Later, this rule of thumb was adjusted to 6 or more injury accidents occurring in a 3 year period. If the concentration of accidents occurs not at one location (junction) but along a particular length of road, then this is referred to as a dangerous road link. To apply the MATAC method successfully, the following should be recorded at the location in the preceding 3 to 5 years:

- at least 10 accidents in total or,
- at least 5 accidents of a similar character.

The numbers quoted should be treated as a practical minimum in order to apply the analysis technique. Reliability of the analysis results is dependant upon the avoiding of data. With a small number of accidents incidental factors may be determinative for the analysis results.
A concentration of accidents has to be observed to identify a location suitable for application of the MATAC method. If, for example, 40 accidents have occurred on a road link of 3 km long, it is preferable to apply the alternative method(s) and routes and not the MATAC. If the 40

accidents have occurred over a length of a few hundred metres, then this is considered as an accident concentration and the MATAC method can be applied.

10.3 Methods of black spots selection

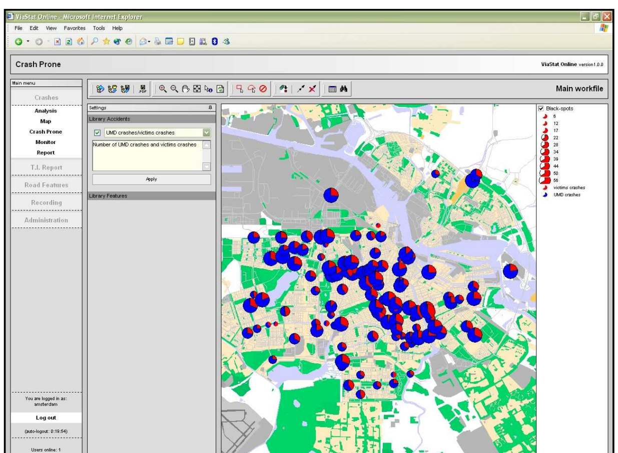
Method 1

Based on the available accident statistics a list is drafted indicating accident concentrations with the highest frequency of accidents involving injury. The list is divided into junctions and road links, the latter specifying the number of accidents involving injury per kilometre.

Method 2

Another option is the inventory map. This is a map of the area managed by the road owner or road authority. It is actively updated on an annual basis, with a record of all current accidents. Each new accident is located on the map with a coloured pin. The colour of the pinhead varies according to the seriousness of the accident and/or the seriousness of the injuries of those involved.

The map data for previous years is incorporated into a presentation map, showing the number of accidents during the period. A rapid visual interpretation of the map provides the starting point for a road safety policy, including the selection of accident black spots.



Inventory map: highlighting locations of accidents

© Via Traffic Care The Netherlands Screen shots from accident analysis software ViaStat-Online

Based on the presentation map, a list of black spots is drawn up. Not all the selected situations will qualify for an accident analysis. Reasons for cutting down the list to a working list are for instance:

- an established traffic plan, in which the location in question will shortly be given a different traffic function, possibly combined with reconstruction;
- the location has only recently (less than 3 years ago) been reconstructed to a large extent in relation to the MATAC method. The location is however relevant evaluation as part of the POGSE approach (chapter 2).

The working list may also include those locations where accidents have already been analysed, in accordance with the MATAC method, in the past. Possible reasons for being on the list are:

- the measures have not, for some reason, been implemented. The locations in question can be removed from the list;

- the MATAC analysis did not yield conclusive results. A further analysis with accident data from more recent years (at least 2 years) may lead to a result;
- evaluation of the measures shows insufficient or no effect. The location is kept on the list if a period of at least 3 years has elapsed since reconstruction.

Locations at the top of the list have the highest priority for analysis. Lower ranking locations may be given a higher priority if, for example, these are already included in a roads and sewers maintenance programme. Alternatively, in situations where the black spot inventory has not yet been completed, these programmes should be examined for the existence of black spot locations. Suspicious locations, although not yet occurring on the list, should be analysed and safety measures be included in the maintenance plans.

10.4 Essence of the method

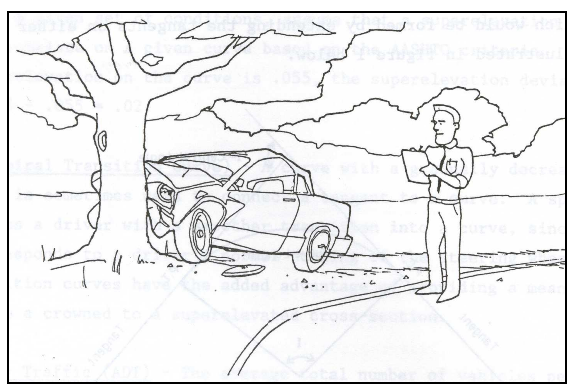
A road accident is a phenomenon generally characterised by a chain of related and non-related events. More than one possible cause can be indicated. For those involved, a chain of events precedes the accident. This chain begins at the point when the decision is made to travel. The party involved chooses a time of departure, a mode of transport and a particular route, and then exhibits a particular traffic behaviour depending on mood, time available and suchlike. In a chain of events that ultimately results in an accident, several moments can usually be identified at which a different decision (another time of departure, another route, lower speed, no alcohol) would not have led to the accident in question. In other words, there are ‘failure chances’ at various moments in the chain.

The MATAC analysis focuses chiefly on the failure chances in the situation directly preceding the accident (coincidence and collision).

Every accident has its own chain of preceding events and is therefore unique. There are also similarities between accidents in those chains. The following four examples of accidents on a meandering stretch of road illustrate that fact.

Accident 1

John (36 years old) oversleeps and misses the train. He decides to take the car to work and ends up in a traffic jam. He is going to be late, so leaves the motorway to take a local road. Despite the fact that he is not familiar with the route, John drives too fast. He misjudges a fairly sharp bend. The road surface is still wet. John skids and hits a tree on the outside of the bend. John is taken to hospital with serious injuries.



Accident 2

Pete (20 years old) has been by car to a party and has drunk a lot. Afterwards he gives his friends a lift home. To impress them he drives rather fast. He thinks he is quite capable of doing so, as he knows the route very well. There is a high-spirited atmosphere in the car, which distracts Pete. Due to his reduced responses and his high speed, he sees the sharp bend too late and fails to turn in time. The car hits the tree head on, with fatal consequences for Pete and one of his passengers.

Accident 3
Keith is a bit older (54 years old). His sight is deteriorating. He has problems in the dark and rain, in particular. He is aware of this and therefore drives with caution. Until, one rainy night, he misses the bend in the road and crashes into the tree. The relatively low speed means that Keith comes out of it with nothing more than a shock.

Accident 4
Catherine (42 years old) is a sales representative for household items. She has visited several customers and already driven 350 km that day. After her last customer, she wants to get home as fast as possible to be on time to fetch the children from nursery. She is tired, but pleased with a number of substantial orders. She looks back at the negotiations with a smile on her face. Due to this lack of concentration she fails to see the bend in time and, despite braking hard, she cannot avoid hitting a tree. The car sustains only damage to the bodywork.

The four examples highlight a number of issues:

- each of the accidents is the result of a unique chain of events;
- various factors played a role in causing each accident; there was not one clear cause;
- there are also similarities between the accidents: all four happened at the same location where the tree on the outside of the bend was hit;
- in three of the four accidents the driver was driving too fast and two of the four cases ended with serious consequences;
- in two of the four cases the road surface was wet and it was dark;
- in three of the four accidents the driver was paying insufficient attention to the driving.

In the event of a clustering of accidents at a particular location most probably one or more of the links in each unique chain are identical. This is shown as a diagram in table 17.

The essence of the MATAC method is to find starting points for improving the design or use of the infrastructure based on similarities between accidents.

Data available
To fathom the causes of an accident, insight into the entire chain of events immediately before the accident (weather and traffic conditions, physical and mental state of those involved) is a requisite. Presently, many of these details are not even recorded and are therefore unknown. For an accident involving injury, the police record a number of facts on the analysis form. The form also includes a brief description of the manoeuvres on which the accident was based, with a view to possible reconstruction during the analysis.

The description is based solely on the conclusions of the duty police officer shortly after the accident. This therefore provides an incomplete picture of what happened. Any (witnesses') statements included in the report can provide more insight into the manoeuvres carried out, although the causes of the errors made usually remain undiscovered.

Often only limited data is available when investigating the causes of accidents. Road authorities having limited, or incomplete, accident data are seriously hampered throughout the process as described in the following chapter. For this reason setting up and maintaining a proper data collection and registration system (accident databank) is essential

Table 17: Accident schedule

Number of accidents	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Day									
Date									
Time		**x**	**x**	**x**	**x**		**x**		**x**
Victims/seriousness			**x**		**x**	**x**	**x**		
Type of collision			**x**		**x**		**x**		
Light conditions	**x**		**x**		**x**		**x**	**x**	
Weather conditions			**x**	**x**	**x**		**x**		**x**
Road surface		**x**	**x**		**x**		**x**	**x**	
Road user 1, nature	**x**		**x**		**x**			**x**	**x**
Road user 1, age		**x**				**x**	**x**	**x**	
Road user 1, movement			**x**	**x**			**x**		
Road user 2, nature		**x**			**x**			**x**	**x**
Road user 2, age	**x**	**x**					**x**		**x**
Road user 2, movement			**x**		**x**				

10.5 The MATAC process

As indicated earlier, the objective of the analysis process is to be able to reconstruct the chain of events directly preceding the accidents as accurately as possible. Many factors play a role in causing accidents, which means reconstruction is no easy task. The chance of success is greatest if the analysis process is carried out systematically, step by step.

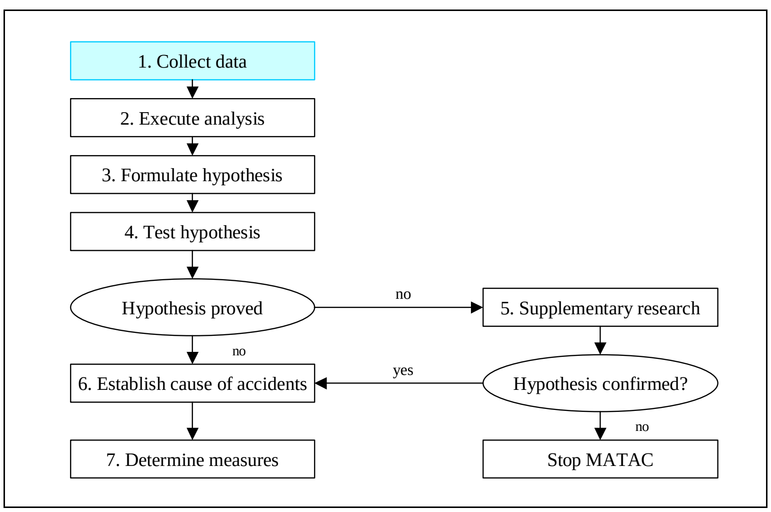


Figure 70: MATAC Step-by-step

The MATAC method is divided into 7 steps. Each step will be dealt with individually, with the results of each step illustrated with a practical example. Figure 70 MATAC indicates, step by step, an outline of the analysis process

10.5.1 MATAC 1: collecting and processing the data

To carry out an MATAC analysis properly, at least the following data is necessary:

- accident data;
- traffic data;
- situation data;
- other data.

Accident data

The basic data on all accidents at the study location, recorded in the 3 to 5 years preceding the study, must be known. Here, you can use the original registration forms (generally available from the local police) and/or the accident statistics. Advantages of using the registration form are:

- The addresses of the parties involved are known, which discloses (to a certain degree) whether they were familiar with the location.
- The location of the accident is indicated more accurately.
- The circumstances of the accident are included, usually containing interesting information.

Traffic data

To establish the right measures at a black spot insight is needed into the existing and future function of the relevant roads in the study zone. If one of the roads is being used improperly, (for example as a short cut), then a choice needs to be made between the following strategies:

- Gearing the proposed measures to the proposed function of the road and preventing 'short cut' traffic.
- Gearing the proposed measures to the actual use, accepting the short cut traffic and redesigning the layout of the infrastructure as safely as possible.

Additionally, the following data is important:

- the use of the location by specific groups of road users or modes of transport;
- the traffic volumes at the location, preferably by vehicle type, direction and time;
- any changes in the traffic structure during the study period, inducing volumes increase or decrease in the study period;
- if the traffic structure (road network) probably contributes to an increased chance of accidents in a certain area, a further analysis of the traffic structure in accordance with the 'black zones and routes approach' method is advised.

Situation data

A plan of the location, preferably on a scale of 1:500 is needed. At least the location of the various traffic facilities should be shown.

If known, it may be useful to include records of complaints from residents or survey data from the police (surveillance, speed checks) in the analysis. At a later stage in the study a need for supplementary data may arise, for example on traffic behaviour (see MATAC, step 5).
The data collected should be systematically sorted. Two worksheets have been developed for this: the manoeuvre diagram in figure 71 and the accident schedule in figure 72 [All forms in this chapter can be found as template in the annex for you to use].

Manoeuvre diagram

The manoeuvre diagram is a schematic representation of the accidents, superimposed on a location plan. The nature of the accident is shown using the manoeuvre picture or illustration. The accident is graphically identified using arrows, which represent the primary collision parties. The arrows also show the manoeuvre carried out (traffic direction) and points of impact. The meanings of the symbols are shown on the MATAC worksheet.
Grouping the accidents into accident type is generally the best starting point for the analysis. It is therefore advisable when filling in the manoeuvre worksheet to place the accidents of the same type (same manoeuvre picture), which happened at the same spot in the location, next to each other on the plan. This generates an initial sorting of the accidents.
The following data is also shown in the manoeuvre worksheet:

- the period to which the accidents relate.
- the order in which the accidents occurred (by numbering them chronologically).
- the seriousness of the accident, using a symbol next to each accident number.
- the traffic management measures and traffic control at the location (e.g. traffic signals, priority control).
- the traffic volume.

Figure 71 includes a Dutch example of a manoeuvre diagram at a black spot (40 accidents in 3.5 years). This concerns a road link with a horizontal bend, just outside the built-up area. There is street lighting on the outside of the bend with red and white checked barriers.

Accident schedule

The accident schedule contains the most important known data for each accident. The logical course of action is to arrange the accidents in chronological order. With a view to further analysis, however, it is also advisable to group the accidents in the accident schedule in accordance with the clusters in the manoeuvre diagram.

The ‘collision type’ can best be graphically illustrated in the same way as when filling in the manoeuvre diagram. The accident schedule for the Dutch example is shown in Figure 72.
A few practical guidelines for filling in the accident schedule:

- When using the analysis forms, go through the description of the accident thoroughly and indicate all the particulars in the accident schedule.
- Register the traffic participant who caused the accident in the schedule as "first party involved".
- With a graphic representation of the manoeuvre picture in the accident schedule this picture should preferably be oriented the same way as in the manoeuvre diagram. In the accident schedule for the Burgemeester Mollaan example the accidents are grouped according to accident type and location on the bend.

- Showing the mode of transport and the first and second parties involved in the same way as the traffic directions in the manoeuvre picture, discloses in most cases the first party involved in the manoeuvre picture.

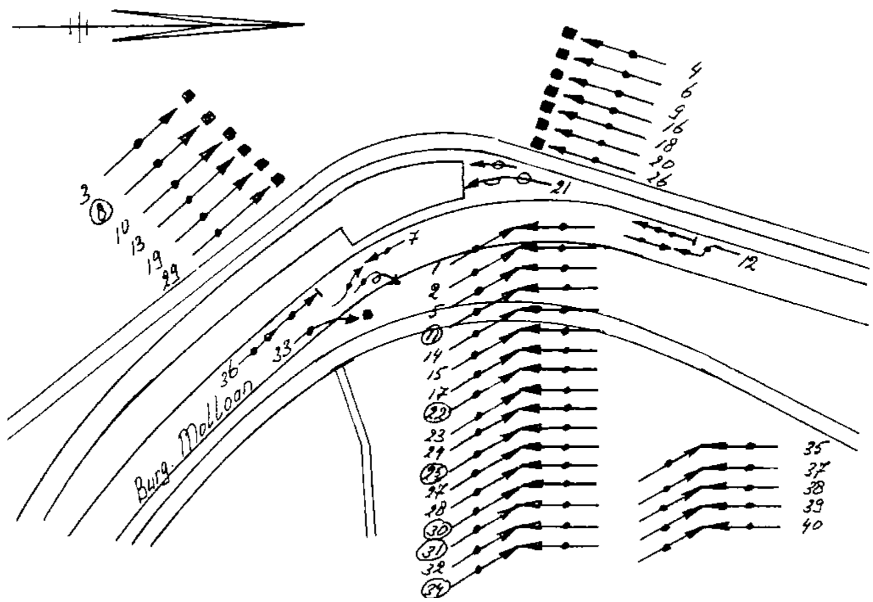
At a location with an exceptionally high number of accidents, for example 50 to 75 in 3 years, and a significant number of accidents of the same type, it is not always necessary to process all the accidents. It is time consuming and the overview is often lost as a consequence. In this case, the number of accidents in the last two years, for example, would suffice. In this type of selection commence with the data from the most recent year, and then work backwards until sufficient data is available, provided that all accidents in any specific year are to be processed. Processing the data by computer will facilitate working with large numbers of accident data.

Including only those characteristics deviating from the 'normal' picture in the accident scheme will provide a more orderly schedule. For example: the state of the road surface is only noted if it is 'wet' or 'snowy', the light only if the accident occurred in the 'dark' and so forth. Only 'deviating' characteristics are noted in the example.

Manoeuvre diagram

Road Authority: ***Municipality Waalre***

Location: ***Burgemeester Mollaan***



Road user	Manoeuvre	Period: 1986 – Aug. 1989
Pedestrian	Straight on	Priority: / Time:
Bicycle	Halt	
Motor bike	Parking	
Moped / scooter	Turning	
Motor vehicle		Volumes:
Heavy vehicle	Overtaking	
Agricultural vehicle	U-turn	
Delivery bicycle and other vehicles	Out of control; skid	
Tram / train	Change lane	
Animal		
Lose object	Reversing back	Ca. 10,000 veh/day
Fixed object	Location unknown	

6 Accident with material damage only.

(7) Accident with injuries

(8) Accident with fatality

No. of accidents: 40

With fatalities: 0

With injuries: 8

With m.d.o.: 32

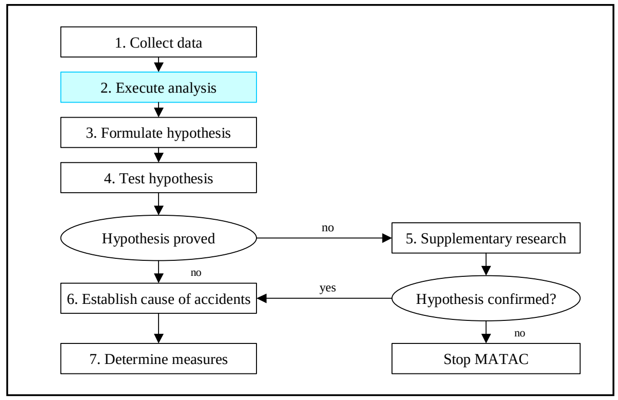
Figure 71: Manoeuvre diagram Burgemeester Mollaan (example)

Number of accidents	1	2	5	11	14	15	17	22	23
Day	Tu	Sun	Sun	Tues	Wed	Tues	?	Wed	Sun
Date	4-2-1986	23-3-1986	1-6-1986	21-10-1986	26-11-1986	2-12-1986	?/?/86	17-6-1987	23-8-1986
Time	12:10	19:00	20:10	14:05	16:05	14:20	?	14:10	16:00
Number of involved objects		3					3		
Number of victims				1				1	
Picture of manoeuvre									
Main cause of collission	28	39	39	39	28	28	28	39	28
Road user 1, age	18	33	29	33	37	43	33	40	57
Road user 1, transport									
Road user 2, age									
Road user 2, transport									
Light conditions									
Weather conditions	Snow		Rain	Rain					Rain
Road surface	Wet		Wet	Wet	Wet	Wet	Wet	Wet	Wet
Alcohol use							Yes		
Remarks									

Number of accidents	39	40	3	8	10	13	19	29	4
Day	Sun	Mon	Wed	?	Mon	Fri	Thurs	Tues	?
Date	23-4-1989	5-6-1989	23-4-1986	?-?-86	18-8-1986	14-11-1987	30-4-1987	14-3-1988	?-?-86
Time	17:15	15:50	17:15	?	13:15	8:45	20:25	14:30	?
Number of involved objects	3						3		
Number of victims		1		1					
Picture of manoeuvre									
Main cause of collission	39	39	35	35	77	39	77	39	39
Road user 1, age	42	26	45	40	20	52	19	47	?
Road user 1, transportd									?
Road user 2, age	55	62							
Road user 2, transport									
Light conditions				Dark					?
Weather conditions	Rain							Rain	?
Road surface	Wet				?	Wet	Wet	Wet	?
Alcohol use				Yes					
Remarks									

Figure 72: Accident schedule (selection) Burgemeester Mollaan

10.5.2 MATAC 2: executing the analysis



The analysis is the core of the MATAC study. As previously mentioned, the objective is to trace the common factors that have contributed to the chances of failure in the coincidence and collision situation.

Dominant accident types

It is advisable to begin the analysis with the manoeuvre diagram, as an initial grouping of accidents has already been carried out by type and location (and traffic direction). Experience has shown that type and location generally provide the most important information. From the manoeuvre diagram, the dominant accident types can be deduced. Statistical criteria for the dominance of a particular type or characteristic do not exist, although there is a relation with the total number of accidents. The analyst will be inclined to devote more attention to accidents involving injury, for example, than to accidents involving solely material damage. As a guideline, an accident type is considered dominant when occurring as a cluster of 5 accidents or more.

Accidents of a type not belonging to a dominant group are, in principle, excluded from the analysis. The numbers are too low to lead to conclusions based on common characteristics. Some notes:

- Accidents of different nature may have the same cause. If a junction is not identified sufficiently clearly, this can lead to both give-way accidents (reacting too late to traffic with priority crossing) and rear-end accidents (reacting too late to the car in front, stationary and wanting to give way). Disregarding what at first sight are non-dominant accident types should be thoroughly considered.
- At a location with relatively few accidents, for example 10 accidents in 3 to 5 years, a dominant accident type is hard to distinguish. A dominant characteristic (direction of approach, time, light and so forth) will facilitate the analysis better than the accident type.
- With low numbers of accidents it is not advised to use percentages when formulating conclusions. For example: “3 out of 4 accidents occur in the dark” illustrates the actual situation better than “75% occur in the dark”.

Before further analyzing the dominant group, the distribution of the clusters of accidents over the location should be subjected to a further study. If, for example, the give-way accidents are only concentrated in one or two quadrants of the junction, there could be an underlying, exceptional cause. There could be a relationship with the volume of the various traffic flows or with the fact that the problem of priority only arises at that specific place. It is therefore important to compare the flow diagram with the accident picture. Never assume beforehand that the design is less safe from one direction than from the other.

Going back to the example, the manoeuvre diagram shows the following:

- In 13 accidents the vehicles collided with a fixed object in the shoulder; in 7 cases the vehicle was traveling in a southerly direction and 6 cases in a northerly direction.
- There were 22 head-on or side collisions accidents. Although this group cannot be considered as a one-sided accident type as a whole, all accidents may be caused by the same factors as the one-sided accidents.
- Accidents nos. 7, 12, 21, 33 and 3 are other accident types and have therefore not been taken into consideration.
- There is a dominant accident type (driving accidents) divided over three clusters
  - side collisions;
  - collisions with fixed object, driving from the north;
  - collisions with fixed object, driving from the south.

Dominant characteristics

The further analysis is initially carried out per dominant accident type. Within these groups of accidents similarities in other characteristics (dominant characteristics) are sought. For this reason, the accidents in the accident schedule are therefore grouped by type. There are two other worksheets available for the accident analysis in addition to the manoeuvre diagram and the accident schedule:

- The time analysis table (figure 74) can be used to look for time similarities (month of the year, day of the week, hour of the day). The hour of the day is shown in a double ring, so the light can be noted (outer ring: daylight; inner ring: dark).
- The analysis overview (figure 75). This overview can be filled in per dominant accident type and shows the findings with regard to any similarities in other characteristics.

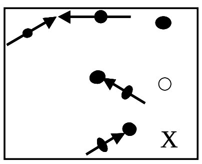
With a dominant accident type consisting of a large number of accidents a further analysis level could be required. If, for example, 12 of a cluster of 20 single accidents turn out to have occurred in the dark, a separate analysis of these 12 accidents is needed to disclose other similarities (driver's age, alcohol and so forth.). A separate accident schedule, time analysis table and analysis overview is filled in for this subgroup.

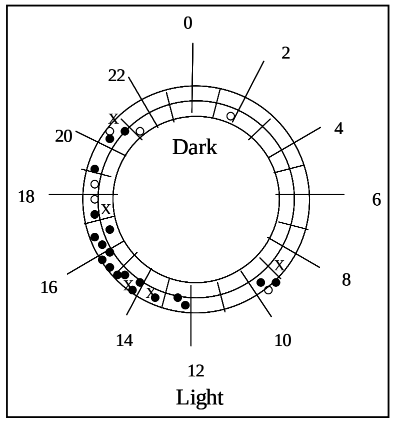
In addition to the determination of dominant accident types and/or characteristics, the remaining part of the analysis can best be carried out using a 'question and answer' technique. Two main questions are raised:

- Does the similarity have any significance?
- What conclusion can be drawn from this?

Road Authority:	***Municipality Waalre***
Location:	***Burg. Mollaan***
Accident type:	***Driving accidents***

Hour:





Day:

Year	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**	**Total**
1986	●?○?X?X	●●●○○	●X		X	○	●●	7+4+4
1987	○		●	X		●○	●	3+1+2
1988	●	●X			●○	●●		5+1+1
1989	●				●●●●		●●	7
Total	3+2+2	4+1+2	2+1+0	0+1+0	5+1+1	3+0+2	5+0+0	35

Figure 73: Time analysis table Burgemeester Mollaan (MATAC 2)

If, for example, it turns out that 70% of the accidents occurred on a wet road surface, specific questions are:

- Is that number larger than can be expected based on the dry-wet road surface-time relation?
- Does this provide a point of departure for formulating hypotheses regarding possible accident causes?

The common characteristics of the accidents in the Burgemeester Mollaan raise the following questions (also see analysis overview, Figure 74):

- Why are 28 of the 35 accidents caused by traffic in a northerly direction? Is this in relation to the intensities or are there differences in the road (environment) from the two directions of approach? Considered over a period of twenty-four hours the volumes in both directions are the same, but in the morning and evening rush hours there are considerable differences. In the accident picture this latter factor (see time analysis table, Figure 74) is not recognizable. We can therefore conclude that the design evidently does play a major role.
- Why are only passenger vehicles involved in the accidents? Is there a ban on trucks or does this group of road users not have any special problems? There is no ban on trucks. Evidently an (experienced) truck driver can better oversee the situation or drives more slowly.

- Why is the age of the first party involved under 30 years in 37% of the cases? It is a known fact that young drivers are involved in accidents relatively more often than other age groups (in general they accept a higher level of risk).
- Why do 91% occur in daylight? Evidently the situation is clearer in the dark with street lighting than in daylight. Is there some misleading factor in daylight?
- Why do 71% of the accidents occur on a wet road surface? The road holding is poorer with a wet surface than a dry surface. Are the (approach) speeds too high in relation to the radius of the bend or do drivers misjudge the angular displacement (angle detection)?

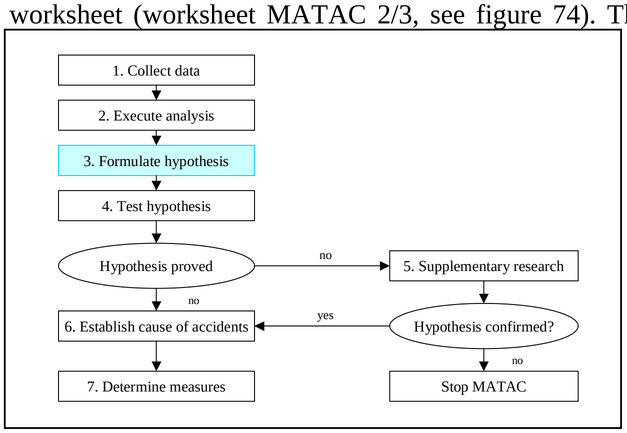
Reference data is required to interpret the information. At location level this data is virtually unavailable. After all, the composition of the traffic flows over a road link or junction, and the distribution of the traffic over the day differ from location to location. For a few of the characteristics, such as the proportion of the accidents on a wet road surface, national figures can be used.

Road Authority	***Municipality Waalre***	**Location**	***Burg. Mollaan***
Type of accident	***Driving accidents***		
Nº	**Characteristic**	**Observation**	**Conclusion / comments**
1	*Hour*	*Especially between 14:00-16:00*	*Less traffic*
2	*Day*	*Friday, Saturday, Sunday*	*Tourists?*
3	*Victims*	*6x head-on accidents*	*Unfavorable action*
4	*Type of manoeuvre*	- *28 x caused in Northern direction* - *7x caused in Southern direction* - *63% collision with on-coming traffic*	- *Differences in curve detection or approaching speed* - *Not taking turn well, speed too fast*
5	*Age*	*37% aged 30 or younger*	*High level of risk*
6	*Type of vehicle*	*Only passenger car*	*Driving experience* *Overview of situation*
7	*Day light*	*91% during daylight*	*Deception, no occurrence at night*
8	*Road surface*	*71% wet road surface*	*Frictional resistance, high speed, drainage*
Hypothesis 1:	*The curve, for traffic coming from northern direction is not clearly visible*		*Nr:4, 6, 8*
Hypothesis 2:	*The approach speed varies too much with the possible speed in the curve*		*Nr: 4,5,6*
Hypothesis 3:	*In daylight visual guidance is insufficient*		*Nr: 7*

Figure 74: Analysis overview Burgemeester Mollaan (MATAC 2/3)

10.5.3 MATAC 3: formulating hypotheses

Hypotheses regarding the possible accident causes should be formulated based on the analysis results. This is done for each dominant accident type or characteristic separately. It is important for the various conclusions from the accident analysis to be compared. They can be either contradictory or even complementary to each other. Additionally, various types of accidents sometimes have the same cause (for example priority accidents and rear-end accidents). The hypotheses should be formulated for each individual dominant type of characteristic, based on the total picture of the accident analysis. These can be set out on the 'analysis overview' worksheet (worksheet MATAC 2/3, see figure 74). The formulation of the hypotheses is the most difficult step in the MATAC analysis.



It is absolutely essential that the 'sequential theme' of the analysis (dominant accident type - conclusion analysis – hypotheses – establishing causes - measures) be maintained from beginning to end of the study. Therefore the use of the diagrams, incorporating that theme, is strongly advised.

10.5.4 MATAC 4: testing hypotheses

A location study is carried out to 'test' the formulated hypotheses. There cannot really be any statistical testing. The assumptions regarding the possible causes (hypotheses) are examined as closely as possible to determine their accuracy. The investigation can also reveal causes not foreseeable when formulating the hypotheses.

The road and traffic situation at the location is examined using the results of the accident analysis as a point of departure. This is done individually for each dominant accident type, based on the formulated hypotheses (see also appendix 1). All findings, both positive and negative, deemed relevant to the hypotheses should be recorded in the study. Some important instructions for the location study:

- The researcher should put himself in the accident situation as best as possible. The location should be approached a number of times with the 'dominant' mode of transport from the relevant direction. Attention should also be devoted to the route leading to the location (expectations generated earlier on in the route, speed behaviour, road layout, attention level, irritation caused by unnecessary delays at preceding junctions and so forth).
- The study should be carried out as much as possible under circumstances identical to those prevailing at the time of the accidents (time, light, weather conditions and so forth). It is also advisable to study the situation at other times. Any differences in the findings could point to a possible cause.
- It is sensible to make a list of points of attention per hypothesis for the location study beforehand, based on the accident analysis.

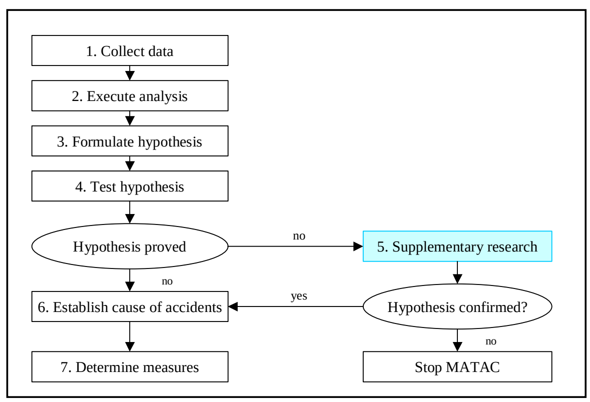
- The traffic behaviour at the junction or road link should be observed closely, using the formulated hypotheses as a guideline (approach behaviour, observation behaviour, functioning of priority regulations, crossing behaviour, complexity of the manoeuvre and so forth).
- Testing the design against the applicable guidelines is not the most important issue in the location study. The guidelines are based on general principles not necessarily entirely applicable to the study location. The main objective is to establish the accident causes by finding confirmation of the hypotheses (the sequential theme).
- Possible causes, not recognised from the accident analysis may come to light during the location study. Produce a good photo or video report to enable assessment of the situation afterwards. The recordings should preferably be made from the position of the party involved (location and eye level).
- Take the time for a location study. A chat with a resident on the corner can also generate supplementary information.

If the location study still provides insufficient insight into the causes of the accidents, then supplementary research is required (MATAC 5.)

10.5.5 MATAC 5: supplementary research

In general, the supplementary research would be specialist research, such as:

- A further inventory of accident data, for example by studying the police reports (in cooperation with the police) or interviewing the parties involved.
- Interviewing road users who regularly pass the location.
- Conducting a study into traffic behaviour focused on the dominant accident type.



Available methods for studying traffic behaviour are:

- Conflict observations: a method for systematically investigating the cause of near misses in traffic. In the Netherlands, the DOCTOR method is used (Dutch Objective Conflict Technique for Operation and Research). It should be mentioned that there is not always a clear relationship between accidents and conflicts. Training is necessary to be able to conduct conflict observations.
- Using models for traffic behaviour: systematic analysis of driving (observe-recognise-process, information-decision-action), to find leads pointing to possible causes of the relevant accident type.

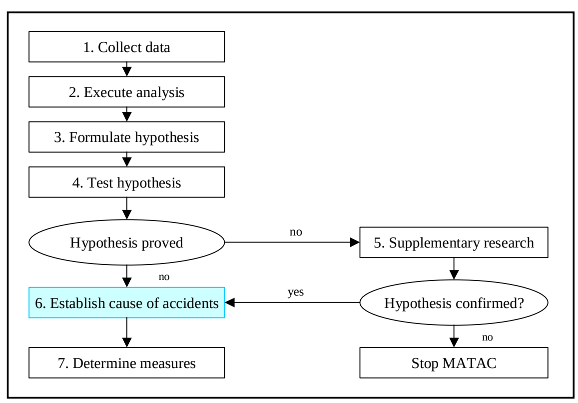
If the supplementary research also fails to lead to proof of the hypotheses, the MATAC study has to be concluded without success. It should be mentioned here that supplementary research is only of any use if there are good reasons based on the research already carried out.

Road Authority	*Municipality Waalre*		**Location:**	*Burgemeester Mollaan*
Type of accidents:	*Driving accidents*			
Hypothesis	**Check hypothesis (research on location)**	**Hypothesis correct?**	**Cause of accident?**	**Measure**
1.	- *Second curve comes as surprise* - *Curve signs for traffic in northern direction misleading*	*Yes*	*Yes*	- *Replace gradual turn with one new turn* - *Change to T-junction*
2.	- *The quotient approaching speed / passing speed is equal to 0.5 (dangerous situation)*	*Yes*		
3.	- *Good street lighting; guidance during darkness much better* - *Second curve not visible during daylight*	*Yes*		

Figure 75: Analysis summary Burgemeester Mollaan (MATAC 4/7)

10.5.6 MATAC 6: establishing accident causes

If the location study provides sufficient evidence for the formulated hypotheses, then the probable accident causes can be established for each dominant accident type. It is important to compare the various findings from the location study. They can be contradictory or even complementary. Various types of accident can also sometimes have the same cause. Based on the total picture, the hypotheses should be confirmed or rejected for each dominant type of characteristic. A worksheet (MATAC 4/7) has been developed on which the conclusions of the location study can be noted per hypothesis with regard to the possible causes and the measures. This guarantees retention of the ‘sequential theme’.



10.5.7 MATAC 7: defining measures

MATAC is an analytical method to determine the causes of accidents at a certain location. As such it is part of the second step (origin/cause) in the POGSE approach (see chapter 2). Traffic experts mainly carry out the MATAC method.

With the causes of each dominant accident type being established (MATAC 6) based on the location study (MATAC 4) and any supplementary research (MATAC 5) the results are discussed amongst the stakeholders. Next, the goals and solutions are to be defined. The process was already explained in Chapter 2.3. In this paragraph some guidelines on the specification of goals and solutions are presented (MATAC 7).

The measures should eliminate the established or assumed causes. The different measures for preventing the various dominant types should form a cohesive whole solution. If the research brings deficiencies in the design to light, the design is to be adjusted. This is achieved by a combination of constructive (physical) and visually supportive measures. Physical measures have a direct influence on the freedom of driving with regard to choice of route or manoeuvre behaviour. Visual measures (markings, barriers, planting and so forth) generally have a supportive function and therefore an indirect (psychological) effect.

If the cause lies in the use of the infrastructure and little can be done through infrastructural measures or only at extraordinarily high costs per life saved, then measures such as traffic education, information and law enforcement (specific traffic supervision) are more appropriate. Information and supervision can also be extremely useful as a supplement to infrastructural measures.

MATAC does not provide a summary of possible measures per accident type. The possible causes are generally too diverse and the local situations differ too much. Fixed solutions for specific causes would limit the flexibility and creativity of the designers. As indicated earlier, testing the design against the applicable guidelines is not the most important issue. After all, the guidelines are based on general principles that need not necessarily apply (entirely) to the study location. The main objective is to establish the accident causes by confirming the hypotheses (the sequential theme).

Evaluation of cases in The Netherlands has shown that good results can generally be achieved with:

- ‘hard’ measures that influence the alertness and speed of the traffic participants;
- measures compensating for a clear deficiency in the ‘presentation’ of a location, such as construction of left-turn lanes (particularly outside the built-up area) or improving the visual guidance in bends;
- measures expected to influence the mentality of drivers appear to generate relatively little effect.

Causes and possible solutions, as a result of the testing, are summarized in a sheet as shown in figure 75 above. The preferred solution (change to a T-junction) is identified and designed as shown in figure 76 (also implemented).

Measures should be problem solving, while estimating side effects as accurately as possible. Combating one type of accident might, after all, lead to the generation of another accident type. A speed-limiting measure such as a raised plateau in a junction can, for example, have a beneficial effect on the number of give-way accidents. When applied to a main road, however, with high traffic volumes and speeds of over 50 km/hr, where such a measure is not generally expected, this remedy can be worse than the problem.

Attention should be devoted to potential side effects when applying structural measures, in particular measures influencing the traffic circulation. Displacing the traffic flow can also displace the problems. In such cases, thorough and systematic investigation of the roads and the junctions affected by the measures and their suitability for the intervention is required. The investigation should start with determination of the study area. This is not limited to the road link or junction itself. Benefits and side effects can cover a number of roads or a road network.

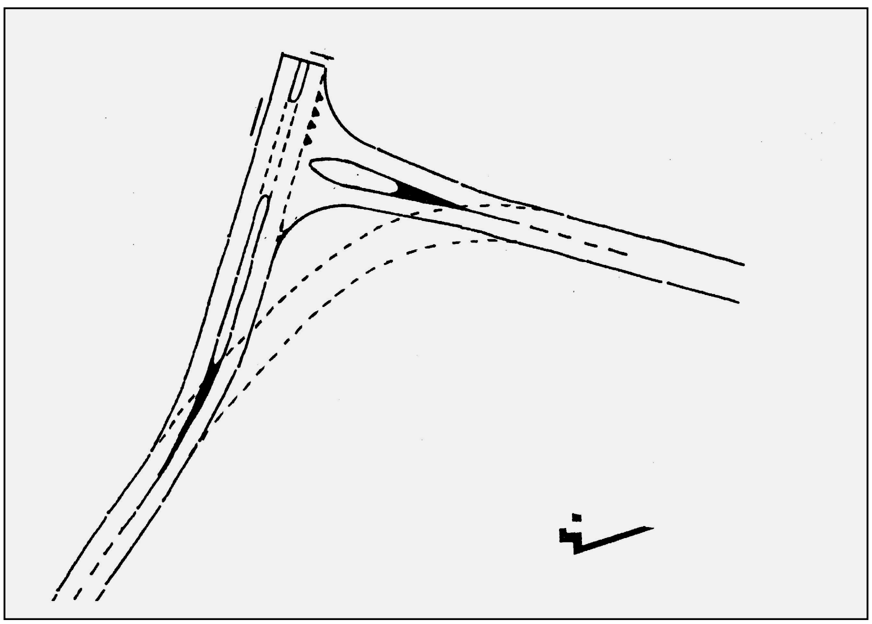


Figure 76: Solution Burgemeester Mollaan

10.6 Summary

The MATAC method is a technique for analyzing concentrations of road accidents at individual junctions and road links. The objective of the analysis is to identify ways for improving the design of a certain location from the similarities in the accident characteristics at that location.

It is absolutely essential that the ‘sequential theme’ in the analysis: ***all accidents → dominant accident type or accident characteristic → conclusion analysis → hypotheses → establishing causes → measure***, is maintained from beginning to end of the study. It is therefore strongly advisable to use the worksheets and diagrams.

It requires a certain degree of knowledge and skill to execute a MATAC analysis. When processing the data, the less experienced traffic expert may have to make an interim step in order to be able to process the accident data in the required manner.

Linking conclusions to the established dominant accident types and characteristics is difficult and requires knowledge of general accident characteristics, traffic science and traffic behavior. If this part of the analysis is carried out accurately and leads to concrete results, formulating hypotheses regarding possible accident causes is a relatively simple task.

Evaluation research in the Netherlands has shown, for example, that the number of accidents at concentration points has fallen by an average of 32% after measures were taken, following the MATAC method. The reduction in the number of accidents involving injury is as much as 45%. This demonstrates that tackling road accident concentrations is an excellent means of promoting road safety.

11 COST BENEFIT AND COST EFFECTIVENESS ANALYSIS

11.1 Introduction

This chapter examines cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) as tools for assessing road safety measures. CBA examine of whether the benefits of an investment in road safety exceed the costs. In addition to safety effects, other social effects, e.g. effects on mobility and environment, are taken into account in a CBA. In this way, a CBA makes it possible to make statements about the social return of an investment. An overview of social costs and benefits can serve as basis for prioritising separate measures or measure packages (combinations of measures). In addition, CBA is used to weigh up investments in various policy areas. Such choices are necessary when making policy plans, fixing the national budgets, and prioritising or phasing investment options. A CBA is useful in this context because it involves summarizing a great deal of information in a rational framework. The focus of this chapter is on the use of CBA for decision making while implementing a road safety measure, or package of measures, and to prioritise measures. It mainly examines the safety effects; other effects, like mobility and environmental effects, are beyond the scope of this chapter.

Cost-effectiveness analysis (CEA) is closely related to CBA and can be seen as a simplified variant thereof. This type of analysis only examines the road safety effects (e.g. casualty saving) and costs. Measures can be ranked, based on the costs necessary to save one casualty. Unlike a CBA, the results of CEA do not provide information about the social return of the various alternatives, because it does not weigh the benefits against the costs. With CEA measures can only be ranked, based on the costs necessary to save one casualty.

Firstly this chapter examines the main elements of a CBA:

- Defining an alternative; that means alternative road safety measures or packages of measures. Also other alternatives, like continuing the current policy, should be addressed as will be explained in paragraph 11.2.
- Estimating costs of road safety measures, like investments and operational costs. These are the costs in a CBA or CEA (paragraph 11.3)
- Estimating the effects of measures (paragraph 11.4)
- Attaching monetary values to effects: in a CBA the effects are expressed in terms of value. The effects, expressed in a monetary unit, are called the *benefits* in a CBA (paragraph 11.5). This element does not apply to CEA.
- Social return calculations; in this step of a CBA calculations are made to compare the benefits to the costs, as will be explained in paragraph 11.6.
- Cost- Effectiveness-Analysis (paragraph 11.7)

All elements are illustrated by an example. The example and the numbers used are fictitious and are only meant as an illustration of CBA. The chapter is based on a guideline for cost-benefit analysis of road safety measures developed by SWOV (SWOV, 2005). Also see ECMT (2001) and Hakkert & Wesemann (2005) for an introduction into CBA and CEA for road safety measures.

11.2 Defining alternatives

In a CBA the situation with a measure (the project alternative) is compared with the situation that would develop without the measure (the 'do nothing' alternative). Therefore, a first step in a CBA is defining one or more project alternatives and the null alternative. Project alternatives consist of road safety measures or packages of measures. The null alternative can be the autonomous development or the continuation of current policy. Estimations of autonomous developments can be based on scenario studies, describing trends in mobility and demography for example. By defining a null and project alternatives, the effects of a measure are distinguished from the autonomous effects, as illustrated by figure 77.

Project and null alternatives are compared over a long period, e.g. 10, 20 or 30 years, depending on the duration over which the measures are effective. A fixed time period for the CBA should be chosen; the alternatives describe developments in this period of time.

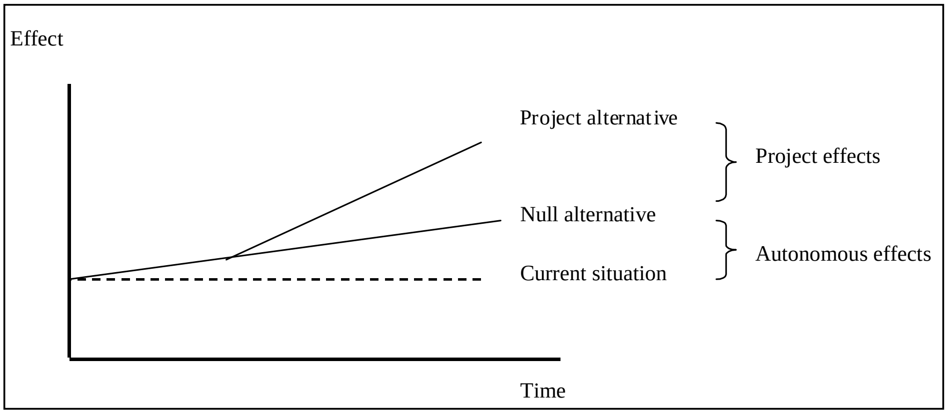


Figure 77: Project alternative and null alternative

Example: traffic lights or roundabout?

In a municipality there are five four-arm junctions with give way, at which 56 accidents occurred in a three years period:

- 1 fatal accident
- 5 accidents with severe injury
- 10 accidents with slight injury
- 40 accidents with material damage only

The number of fatal accidents is assumed to decrease by 1 percent per year. Two measures can be taken to prevent accidents: installing traffic lights at each junction or replacing them by roundabouts. The null alternative in this case is that no extra road safety measures will be taken. The number of accidents decreases by 1 percent each year. This is the autonomous effect. There are two project alternatives:

1. Installing traffic lights; suppose that after 15 years the traffic lights have to be renewed, so the effectiveness duration is 15 years.
2. Constructing four-arm roundabouts; the effectiveness duration of the roundabouts is 30 years.

In the CBA these project alternatives are compared with the null alternative. A time period of 30 years is chosen, based on the effectiveness duration of the roundabout. This implies that renewal of the traffic lights (after 15 years) should taken into account.

11.3 Estimating costs of road safety measures

In general, two types of costs of road safety measures can be distinguished:

- Implementation costs: the costs for implementing a measure, such as those for changing the infrastructure or vehicles, and enforcement costs. These costs are also referred to as the investment costs.
- Operational costs: costs occurring while the measure is operative. There are three types of operational costs:
  - Replacement costs; (partly) replacements have to take place for measures with an effectiveness duration shorter than the time horizon of the CBA.
  - Maintenance costs; these costs are particularly relevant for infrastructure measures.
  - Enforcement costs; generally these are only the costs of employment (wages) needed for enforcement.

Note that only the extra costs due to a measure as defined in a project alternative compared to the null alternative are considered. This means, for example, that regular enforcement costs or maintenance costs of the existing infrastructure are not taken into account. If a project alternative consists of measure packages, cost savings resulting from combining measures must be considered.

Example (continued)

The costs of the project alternatives consist of:

1. Installing traffic lights: implementation costs, costs of replacement after 15 years and the (extra) maintenance costs.
2. Constructing roundabouts: only implementation costs. There are no replacements costs and maintenance costs are assumed to be the same as the costs of maintaining the junctions with right-of-way, so there are no extra maintenance costs compared with the null alternative.

Table 18 gives the yearly costs of each alternative and the year(s) in the time period in which they occur.

Table 18: Costs of installing traffic lights and constructing roundabouts (euro's)

	Traffic lights		Roundabouts	
	Costs	Year	Costs	Year
Implementation	1,000,000	1	2,000,000	1
Replacement	1,000,000	15	0	--
Maintenance	10,000	1-30	0	--

11.4 Estimating the effects of measures

The next step is to estimate the effects of road safety measures. The effects of measures are always determined in comparison to the null alternative. In a CBA the effects are called the benefits, which can have a positive or negative value. In case of a negative value, for example an increase in the number of accidents or negative mobility effects caused by a road safety measure, they are expressed as 'negative benefits'. It is not recommended to call them 'costs', because this might lead to confusion when calculating cost-benefit ratios (see paragraph 10.6).

In a CBA all relevant effects are quantified where possible. The road safety effect is the reduction in road traffic accidents resulting from implementing a measure or measure package as defined in a project alternative, in comparison to the null alternative. This means that information is needed about:

- The number of accidents in the current situation for the location(s) at which a measure is proposed.
- The increase or decrease in the number of accidents at the location(s) in the null alternative, i.e. in the autonomous development of the number of accidents.
- The percentage reduction of accidents as a result of the measure. Reduction percentages can be obtained from ‘in depth’ research and meta-analyses. In meta-analysis a large number of studies have been reviewed. Appendix 8 presents estimated reduction percentages for a number of measures, based on a meta-analysis and published by Elvik (1996). The upper and lower bounds of the percentages can be used for sensitivity analyses (see paragraph 11.6).

Note that the period in which a measure is effective may differ from the period of implementation. For example, infrastructure measures have effects after implementation and the effects of police enforcement mainly occur during implementation.

Example (continued)

We assume that installing traffic lights will reduce accidents by 20 percent and that the reduction percentage of roundabouts is 40 percent. We further assume this reduction percentage applies to all types of accidents.

To estimate the effects firstly the number of accidents in the null alternative has to be calculated for each year in the time period considered. We assume that in the year before implementation of a measure the number of accidents is 19 (56 accidents/3 years). In the first year the number of accidents has decreased by a factor 1.01 (1 percent), the second year by a factor 1.01^2 and in the 10^{th} year, for example, by a factor 1.01^{10}. So in the 10^{th} year the estimated number of accidents is $19/1.01^{10} = 17$ (rounded). The ratio fatal accidents/accidents with severe injury/slight injury/material damage only is assumed to be constant.

In the first project alternative, installing traffic lights, accidents are reduced by 20 percent. The effect of the measure in the first year is preventing 0.20*19 = 4 accidents; the effect in the 10^{th} year is a reduction of 0.20*17 = 3 accidents. Constructing roundabouts is assumed to prevent 40 percent of the accidents. So in the first year the effect is a reduction of 0.40*19 = 7 accidents and in the 10^{th} year, for example, 0.40*17 = 7 accidents (all effects are rounded).

Since safety benefits depend on the type of accident, a distinction should be made between fatal accidents, accidents causing severe injuries (admission in hospital), accidents causing slight injuries (no admission) and accident with only material damage. If there is no information available about reduction percentages of a measure for each type of accident, the same percentage may be applied for all types of accidents.

The most important other effects concern mobility and the environmental. Mobility effects consist of changes in travel time and travel costs. Environment effects consist of changes in emissions and noise nuisance.

11.5 Monetarizing effects

In a CBA all effects are expressed in terms of money where possible. This is called monetarizing. By monetarizing, effects are made comparable to each other and to the cost, because they are expressed in the same unit. The monetary valuation of safety effects consist of the social costs saved by preventing accidents. These are the *benefits* of road safety measures. The following types of social accident costs (savings) can be distinguished:

- *Medical costs.* These result from the treatment of casualties, and are e.g. costs of hospital, rehabilitation, medicines, and adaptations for the handicapped.
- *Production loss.* These result from the temporary or permanent disability of the injured, and the complete loss of production by fatalities.
- *Material costs.* These result from damage to goods such as vehicles, freights, roads, and fixed roadside objects.
- *Settlement costs.* These result from the settlement of crashes and the resulting expenses incurred by organizations such as the fire brigade, police, law courts, and insurers.
- *Quality of life loss* of casualties and their families and friends. This is called 'human costs' or 'human losses'. These are the immaterial costs through suffering, pain, sorrow, and loss of the joy of living.

This is the classification as recommended by the COST 313 study, an extensive international comparative study about the way in which 14 European countries determine road safety costs (Alfaro et al., 1994). In many countries costs of all accidents occurring in one year are estimated, consisting of these cost categories. For example, see the studies of Elvik (2000) and Trawén et al. (2002) for international overviews of road safety costs. Estimates of the cost of all road traffic accidents in a country are used to calculate the costs per type of accident. Then the benefits of road safety measures can be calculated by multiplying the decrease in accidents by the (saved) costs per accident.

A simplified approach, which is often used, is known as the 1-million-euro-test. In this approach the total costs of road traffic accidents is divided by the number of fatal accidents, resulting in costs per fatality. For example: the total costs for all crashes in Europe amounted to 162 billion in 1995 and the number of fatalities was 45,000 that year. In this case the costs per fatality is 3.6 million euro. Note that this cost figure of 3.6 million euro per fatality also includes costs for non-fatal accidents and material damage. Ideally, country specific data should be used. If these are not available, the European estimate of 3.6 million, as published by ETSC, can be used. Adjusted for inflation this is 4.4 million in 2005.

When using the 1-million-euro-test only the number of fatalities prevented by measures has to be known. The use of this approach is limited however, because it assumes that a measure prevents fatalities, injuries and material damage at constant ratio. In practice some measures mainly prevent fatal accidents, while others will have relatively more effects on injuries or accidents with only material damage.

Example (continued)

We assume that no estimates of the costs per type of accident are available, so we have to use the one-milion-euro-test. To calculate the benefits of a project alternative in each year, expressed in terms of money, we multiply the number of accidents prevented by the total costs per fatality. In this example we use 4.4 million euro per fatality.

In the first year, the benefits of installing traffic lights are 0.07 (prevented fatal accidents) * 4.4 = 290.000 euro and in the 10^{th} year 260.000 euro. They are lower in the 10^{th} because of the autonomous decrease in the number of accidents. The benefits of constructing roundabouts are higher: 570.000 euro in the first year and 520.000 euro in the 10^{th} year for example.

11.6 Return calculations

If the costs and the monetary value of all effects for a particular period have been determined, the social return is then calculated. Firstly, the costs and benefits are discounted to the first year of the time period of the CBA, using a discount rate. Discounting involves weighing the effects during a period of years, by which those effects that occur later weigh less than those that occur earlier. In this way the cost or benefit occurring later in time is valued lower. When discounting is used, measures with different effectiveness durations can still be compared with each other.

Practically this means that a cost or benefit occurring in the t^{th} year of the time period considered are divided by a factor $(1+r)^t$, where r is the discount rate. An official discount rate for government projects is preferred. The European Commission advises to use a discount rate of 5 percent. By summing the discounted cost/benefits, what is known as the present value of costs/benefits is calculated.

The present value of the discounted costs of an alternative can be calculated by the formula:

$$PVC = \frac{C_1}{(1+r)^1} + \frac{C_2}{(1+r)^2} + \frac{C_3}{(1+r)^3} + \ldots + \frac{C_T}{(1+r)^T} = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t}$$

where:
PVC = present value of the cost
C_t = cost of the alternative in year t

In the same way the present value of the benefits can be calculated.
Usual criteria for the social return of road safety measures are the comparison of the present value of benefits and costs, known as the Net Present Value (NPV), and the ratio of the present value of benefits and costs, Benefits Cost Ratio (BCR).

Implementation of an alternative is seen to be desirable if the net present value is positive or the ratio of benefits and costs is greater than 1. Based on these criteria, measures or measure packages can be compared. The higher the balance or ratio of present value of benefits and costs, the more desirable an alternative, i.e. a measure or measure package, is. These criteria can also serve to compare the social return of investments in road safety with investments in other policy areas.

Finally, it is often useful, and also usual, to examine uncertainties in a CBA's results. This can be done by testing the extent to which results are sensitive to uncertainties in, for example, effect and cost estimates, and in valuation of effects. In a sensitivity analysis the (change in) social return is calculated by using, for example, the lower and upper bound of the reduction percentages used for calculating road safety effects or by using a lower and higher discount rate.

Example (continued)

Using a discount rate of 5%, the present value of the costs and the benefits of each project alternative can be calculated as well as the NPV and BCR. Table 17 gives an overview of the present value of the costs and benefits of the two alternatives. It turns out that the NPV of both alternatives is positive and that the BCR is greater than 1. This means that the benefits of both alternatives exceed their costs, so they both yield a positive social return. However, in this example roundabouts are preferred, because the BCR of roundabouts is higher (3.3 vs. 1.3) as well as the NPV (5.5 vs. 1.0 milion euro).
As a reminder that normally monetary values of other effects (especially the assumed positive mobility and environmental effects) are also normally taken into account in a CBA, these effects are shown as ‘pm’ in table 19.

Table 19: Costs and benefits of installing traffic lights and constructing roundabouts (million euro)

	Traffic lights	Roundabouts
Costs:		
Implementation	1.0	2.4
Replacement	0.5	-
Maintenance	1.5	-
Total costs	2.9	2.4
Benefits:		
Safety	3.9	7.9
Mobility	pm	pm
Environment	pm	pm
Net present value (NPV)	1.0	5.5
Benefit-cost ratio (BCR)	1.3	3.3

11.7 Cost-effectiveness analysis

Whereas cost-benefit-analysis compares cost of road safety measures (paragraph 10.3 above) with cost of accidents (or cost savings of effects, paragraph 10.5 above), cost-effectiveness-analysis is limited to the cost of measures in comparison with the estimated reduction of accidents.

The way costs of measures are calculated is explained in paragraph 10.3 above for cost-benefit-analysis and is identical for cost-effectiveness-analysis. Capital cost per year consists of interest and depreciation of the investment. For policy analysis an interest rate of 5 or 10 % (resp. social or business economic) is generally maintained. This figure can be adjusted for countries where inflation is structural. By means of a table of annuities the total annual amount to be paid for interest and depreciation (to cover the complete capital cost of the works at the end of their estimated lifespan) can be calculated. The figures can also be found by using a formula; the arithmetic method is presented in Appendix 9.

Surplus annual maintenance and operational cost, as a result of the road safety measures, have to be estimated. The surplus is the difference between the present maintenance cost (of the existing facilities) and the future maintenance cost (of the road safety measures after their construction or installation). The cost is calculated on an annual basis. Items generating other annual costs and general costs are as such explained in Appendix 8.

One may assume that without measures in the next three years the number of accidents at the location will remain the same. Since little is known beforehand about the effect of the measures it is further assumed that all accidents of the type concerned will be prevented by the proposed measures. The same applies for, so called, side benefits: accidents that occur due to the measure taken (in fact these are negative benefits). The positive effect of the measures is the number of accidents that have been prevented.

It should be noted that for cost effectiveness analysis, the total number of fatalities and injuries at a specific location are considered and not the numbers of accidents resulting in fatalities and injuries.

The types of accidents (fatal, injury, material damage only (mdo)) have different gravity. To calculate the benefits of road safety, this gravity has to be quantified. Various calculations methods and thus resulting figures or factors exist. Differences may be up to 2 or 3 times one factor against the other. Factors like lost quality of life, pain, grief and sorrow of surviving relatives are difficult to quantify. From studies it is known that the social cost of accidents with very serious injuries and fatal accidents are many hundreds times higher than those of accidents with only material damage. In this manual the following factors are proposed:

- fatal accidents: 10
- accidents with injury and hospital admission: 5
- other accidents with injury 3
- accidents with material damage only 1

In countries where only limited accident data is available, all accidents with injuries can have the same factor (5).
For the listing of priorities a table is used, containing the following elements (see appendix 10)

a. The location of the accident; this information comes from the accident databank. It is used for reference and to enable grouping of the accidents.
b. The type of measure. Many road authorities use standard lists of measures. In the table the code is entered referring to the specific measure from that list.
c. The cost of the investment. These can be standard costs from the list of measures or the calculated cost based on a design or the quotation of a supplier.
d. The estimated lifespan of the measure. This is the period from the implementation of the measure untill its complete renewal or removal.
e. The capital cost is calculated using the method explained in appendix 9. The usual interest rate is 10 %. Using tables with the calculated factors will simplify the calculation. The capital cost is expressed as cost per year.
f. The other cost are the expenditures, directly and indirectly, related to the measure:
    - maintenance cost;
    - operational cost;
    - data collection;
    - safety inspection;
    - traffic control and enforcement.

    For simple calculations only maintenance and operational cost should be considered as the other cost are more difficult to estimate. The other cost is expressed as cost per year.
g. The total cost is the sum of the capital cost and the other cost.
h. The number of accidents is taken from the accident databank. A distinction is made between fatal accidents, accidents with injury and accidents with material damage only (mdo) over a period of three years.
i. The percentage reduction in accidents can be derived from Appendix 11. Although the figures are meant for accidents with injuries, the same percentage is taken for the other types; this is to simplify matters.
j. To calculate the score (effect of a measure), first the accident numbers of each type are multiplied by the respective factors, the outcomes added up and the sum divided by three (years). This figure is multiplied by the reduction percentage. The cost-benefit ratio is found by dividing the resulting figure by the total cost per year of the measure (see the form in Appendix 11).
k. The ranking of measures now can be performed. The measure with the highest cost-benefit ratio gets rank number 1.

In Appendix 11 two examples are presented. One uses a form and is based mainly on the method explained above. The second uses a simplified method.

12 EDUCATION AND ENFORCEMENT

12.1 Integral approach

The three main components related to traffic are the road users, the road and the transport modes. All three need to adhere to certain procedures, rules and standards to achieve the highest possible level of road safety. This is what binds these elements together. The road users, whether it is pedestrians, cyclists or drivers have to comply with traffic rules. The transport modes, vehicles but also bicycles, motorbikes, local traffic (carts) and lorries need to meet certain standards of design (technical specifications) and maintenance.
The sustainable safety strategy is characterised by a proactive and preventive attitude rather than a reactive (and curative) one aiming at addressing problems when they occur. Moreover, sustainable safety is based on an integrated systems approach where all elements of the road safety and transport system are geared to one another. At the highest level it is the interaction between human, vehicle, infrastructure and legislation.

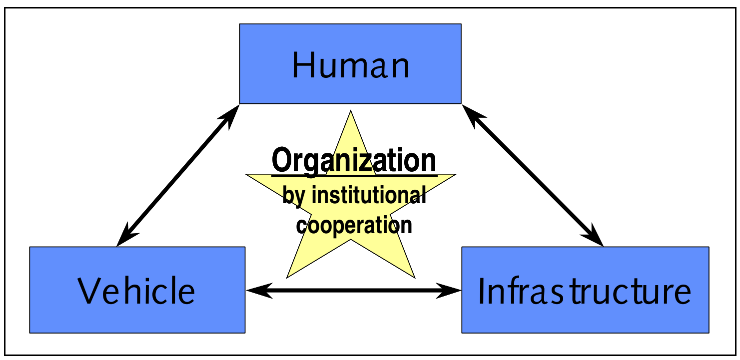


Figure 78: Interaction between human, vehicle and infrastructure.

Sustainable safety assessments has identified that more than 80 percent of road accidents are attributable (to a greater and lesser extent) to human error. Motivation, attention, emotion, observation, prediction, knowledge and skills are all aspects that influence human behaviour and that prevent humans from being the ideal traffic participant. In a sustainable safe traffic system the human takes the central role. Humans are (largely) unpredictable and influencing their behaviour is a challenge, especially to do so in the long-term.

The elements related to influencing the behaviour of the road user can be split into what is referred to as the three Es:

- Engineering: Vehicles equipped with technology to assist the driver or simplify the driving task and provided with features that protect vulnerable and other road users; and An inherently safe road environment with an infrastructure adapted to the limitations of the road user and preferably self-explanatory (constructed and marked to make obvious what sort of behaviour is expected);
- Education: road users that are well informed, adequately educated and show evidence of the expected behaviour.
- Enforcement: developing and enforcing laws, rules and regulations.

In the previous chapters road design, as part of the engineering process, was discussed. In this chapter the role of education, the spread of information and enforcement will be briefly covered.

12.2 Education

Education is one of the three E's able to influence the road user. The aim, target group, message and tools determine the different methods available to educate the population in road behaviour.

When can human behaviour be influenced? Three opportunities have been identified. They consist of: before, during and after traffic participation, namely:

- before participation in traffic, through education, information, law;
- During participation in traffic, through information and traffic signs;
- After participation, through enforcement.

Moreover, according to age, the following stages can also be identified:

- education starts at home: parents give their children an upbringing as road user (e.g.: stay on the side-walk, stop when the red-light is on);
- road safety as part of school curriculum. Basic traffic rules are introduced; children learn rules related to bicycle use, with the last lesson including a bicycle driving test at the end of curriculum;
- Driving school: future road-users learn through theory and practical courses the rules and appropriate behaviour on the road. The training course leads to the driving test.
- Road-user information aims to raise awareness amongst a large group of road users on new or different themes (no speeding, no-drink driving campaign etc).

Poster for Anti-Drink-driving campaign in Ankara

Human behaviour is influenced by knowledge, understanding, attitude and aptitude. A distinction in behaviour can be made on 3 levels:

- the strategic level; choices to avoid unsafe situations by means of adjusting behaviour according to the principles of the system;
- the tactical level; choices to avoid unsafe situations by means of adjusting behaviour to specifications of the system;
- the operational level; choices to avoid unsafe situations by means of adjusting to direct operational system.

Four different ways exist to educate road users:

- Instruct: giving an explanation of how to do something. For instance a driving instructor demonstrates how to put on a seat belt;
- Train: learning through doing. The seat belt is put on automatically;
- Role model: learning through imitating others. For instance a child observes that the mother indicates with her arm that she want to go left or right and the child does the same.
- Punish/reward: different degrees of punishment exist. For instance a child is scolded for not indicating his intention to make a left-turn; to a prison sentence for a driver who causes a fatal accident.

12.3 Enforcement

Fake police car painted on the wall, Poland

Enforcement, another one of the 3 Es will always play a role in sustainable road safety. Humans will always want to challenge or ignore rules, thus the behaviour of road users will always need to be observed, monitored and when necessary punished.
The aim of enforcement is to discourage inappropriate behaviour on the road, by making road users aware of the possibility of being caught and punished for their wrong behaviour.

Three stages can be identified in moving from the law on paper to behaviour on the road.

1. development of the law;
2. publication of the law;
3. enforcement of the law.

A road user needs logical and glamorous rules and regulations to be motivated to adhere to them. Rules and regulations should contain 3 elements:

- rules must be appropriate to the situation;
- clear and precise indication of the forbidden action;
- the rule needs to be reasonable as practical to implement.

Seatbelt wearing, Bucharest

12.4 Public awareness campaigns

A public awareness campaign is a means to raise awareness on a specific topic in road behaviour. The duration of the campaign is limited, but due to the possible intensity can be very effective. Both information distribution and enforcement is used along side each other. For example a drink-driving campaign will contain both

1. enforcement; the police will check on alcohol levels of drivers. At the start of the campaign it can be without giving fines, but distributing information and warning drivers.
2. information; disseminating information using leaflets, TV adverts, radio spots etc to create better knowledge among the target audience.

Often within such an awareness raising campaign the main object is not so much to give fines, but more to inform the public on desired behaviour.

A few points to remember when developing an information campaign is:

- regional / cultural differences;
- target group;
- differences in behaviour (it is most effective when undesired behaviour is tackled where it occurs the most);
- style the campaign.

The types of activity that can be developed in a country or region to influence road users' behaviour are:

- TV-programme on "road abusers" showing breaches of road rules and the action the police take;
- TV-advertisement campaign showing consequences of not abiding by the rules;
- video followed by discussion; video shows an accident caused by excessive speed, discussion on speeding;
- newspaper advertisement;
- billboards along the road, for instance "keep distance of 2 seconds".

Who should be involved in road safety awareness raising campaigns:

- Police: responsible for enforcement and for distributing information;
- The social organisations active in the field of road safety, their members/volunteers may be willing to actively participate in improving road safety. The organisations may have a network to produce or distribute information.
- Decision makers; often political will is needed to implement any new action and to pass laws.
- Road safety committees combining police, government, judicature and social organisations. This committee can serve to identify the road safety issues in the region.
- Municipality, the unsafe location may be situated in their area, the campaign can be of direct benefit to the situation in their municipality.
- Education; schools can play a vital role in implementing an information campaign.
- Driving schools; driving instructors provide an example to all their students who are future drivers.
- Inhabitants; what do they feel needs or be improved in their city, how could they contribute to the campaign (e.g. distributing information, organising neighbourhood meetings etc).

13 COLOPHON

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APPENDIX 1 MATAC: checklist black spot analysis

General aspects: points of attention in the analysis of accident data.

A. Factors related to the relevancy of the accident:
   1. Exceptional circumstances during the accident:
      - Extreme weather conditions (heavy rain, thick fog)
      - State of the road surface (mud on road)
      - Reconstruction, diversion in progress
      - Pavement (renewed/improved in the meantime?)
   2. Exceptional characteristics of the traffic participant:
      - Physical and mental state of the road user (alcohol, medicine, tiredness, illness)
      - No driving licence
      - inexperienced driver
   3. Manoeuvres
      - Collision with a non-static object
      - Collision with an animal
   4. Defects in the vehicle

B. Factors that can increase insight into the accident picture:
   1. Seriousness of the accident
      - Speed driven before the accident
   2. Time of the accident:
      - Seasonal influences (holidays, summer, winter)
      - Special day (bank holiday, sports event, other event)
      - Time of day (end of school, theatre or suchlike turning out, bar closing time, late night shopping)
   3. Exceptional circumstances during the accident:
      - Road user unfamiliar with location
      - Low sun
      - Creepers, shrubs, leaves in the way (season)
      - State of markings and signs at the time of the accident
      - Traffic measures at the time of the accident (traffic lights out of order, temporary measures)
   4. Manoeuvres:
      - Exact location of accident
      - Accident caused by not reacting in time to the junction
      - Accident after driving up onto junction area from stationary position
      - Accident resulting from loss of control of the vehicle

Accidents at junctions

Priority accidents on uncontrolled junctions
Priority or give-way accidents are defined as accidents that occur between vehicles driving on different roads where one or both vehicles turn left or right or crosses the other. Also possibly involved are road users on parallel roads or cycle tracks, for example.

The junction and/or the give way obligation are not recognised (in time) so the vehicle does not give way.

a. Is the junction marked?
   - Is the marking in accordance with the guidelines for barriers and road marking or are these violated?
   - Is the view at the marking obscured by an uneven road surface or other circumstances?
   - Is the marking clearly visible under all light and weather conditions?
   - Does the marking give the driver the mistaken impression that he has priority?

b. Are there any signs at the junction?
   - Do the warning signs draw the driver's attention to the junction?
   - Are the necessary signposts in place in the event of a priority junction or priority road?
   - Have bollards been installed at any traffic islands?
   - Are the signposts installed in conformity with the Road Traffic and Traffic Signals Regulations and has the installation order been adhered to?
   - Are the signs clearly visible under all light and weather conditions?
   - Is the 'give way' sign clearly distinguishable from other traffic signs and/or advertising boards from a greater distance?
   - Does the sign stand out sufficiently against the background and is it clearly perceptible in strong sunlight?
   - Is the view of the sign obstructed by plants, lampposts, trees (remember the seasons!), signposts, travelling or stationary vehicles and so forth?

c. Is there an advance warning sign?
   - Is the distance from the board to the junction in accordance with the installation order?
   - Is the sign fitted with a sign below indicating the distance?
   - Is that distance correct?
   - Answer the questions under point b

d. Is there a signpost at the junction?
   - Is the type and position in accordance with the guidelines?
   - Is the information clearly legible as you approach it?
   - Is the view of the signpost obscured by plants, lampposts, trees, vehicles and so forth?

e. Is there an advance signpost?
   - Is the information consistent with the signpost?
   - Answer the questions under point d.

f. Is the junction sufficiently conspicuous?
If not, can its conspicuousness be improved by:
- Modifying the connecting curves?
- Installing a traffic island with vertical elements such as signing, traffic bollards or signposts that emphasise the road visually?
- Locating and dimensioning the existing traffic island so the visual termination of the road is improved?
- Painting the traffic island white?
- Installing vertical elements such as plants alongside the road to be crossed, which do not impede the view?
- Lowering the verges so the carriageway and/or cycle track to be crossed becomes visible sooner?
- Filling up holes or levelling ridges or super elevations obscuring the view of the road to be crossed
- Introducing a parking prohibition directly before and after the junction?
- Installing or improving the street lighting at the junction or the illumination of the traffic signs if the accidents occur in the dark?
- Installing a flashing light at the position of the scene of the accidents?

g. Is the junction too channelled, giving drivers the impression that they have priority on the road or junction?
- Is the priority rule in keeping with the character of the two intersecting roads?
- Are the number and size of the approach lanes too large for the traffic volume?
- Is there a clear transition from one approach lane to the other lanes?
- If there is a median in the side road, can this be shortened or converted into a traffic island?

h. Does the accident analysis show that drivers unfamiliar with the local situation brake too fast or hard?
- Is the junction noticeable in time?

Answer the questions under point f.
- Is the approach speed too high?
- Does the road surface have adequate skidding resistance?

i. Do the following elements cause uninterrupted perspective lines over the junction, giving drivers the impression that they are driving on a through road or cycle track not crossed by a road with a similar or higher function?
- The facade lines of buildings?
- Avenues of trees, electricity and telephone poles or lampposts alongside the road?
- An extended route?
- Slight changes in the transverse section?
- Parked cars?
- The road surfacing, which does not deviate in colour or texture from that of the road to be crossed?
- Repairs to wheel ruts and suchlike running over the road to be crossed?
- Markings?
- Highly channelled traffic guides in the road to be crossed?

j. Can these lines be interrupted by:
- installing a traffic island with vertical elements?
- adding a background, such as barriers or trees, alongside the road to be crossed to prevent the driver having a too good a view beyond the junction?
- If the road has a one-sided parking ban, introducing it to the other side of the road beyond the junction?

k. Is the junction poorly visible or visible too late as a result of a horizontal curve?
- Are warning signs installed to alert the driver to the presence of the junction?
- Is the sight obscured by earth walls, hedges, fences, trees or lampposts?
- Is the horizontal curve dimensioned at a small radius so the driver has to devote his full attention to taking the curve?

l. Is the junction poorly visible or visible too late as a result of a vertical curve?
- If this is partly the result of a horizontal curve, then answer the questions under point k.
- Is it possible to increase the curve radius?

m. Can road safety be improved through structural measures?
- Is the use of the junction in contradiction with the function?
- Is the junction in a through route?
- Can the short cut traffic be excluded by taking traffic measures, such as a left or right turn ban, one-way traffic, or possibly access only to particular types of traffic?
- Can the signposting be revised to stop through traffic using the route?
- Can structural measures be taken elsewhere in the road network?

The junction is recognised, but the situation is misjudged

a. Are there any markings at the junction?
- Is the marking in accordance with the guidelines or are these violated?
- Are the junction area and the crossings for slow traffic clearly marked?
- Is the marking such that drivers hesitate when driving onto the junction area?
- Has the marking of the junction area recently been changed?
- Are there still remnants of old markings that might make the driver hesitate?
- Is it necessary to install street lighting or improve the existing lighting to make the marking more conspicuous in the dark?

b. Is there any signing at the junction?
- If a crossing is used in two directions, is that signed/identified?
- Do the signs installed/to be installed conform to regulations and has the installation order been adhered to?
- Are the signs clearly visible under all light and weather conditions?
- Is it necessary to illuminate a sign from inside or out?
- Do other traffic signs, trees, signposts, lampposts, vehicles, etc. obscure the view of any of the signs?

- Are traffic signs so numerous that drivers are unable to absorb all of the information?

c. Is the comprehensibility of the junction reduced by poor design of the traffic islands?
- Are they situated too far from the road to be crossed so drivers halt too far before the junction area?
- Do the traffic islands make the junction too highly channelled so that possible conflicts are not recognised?

d. If there are any moped/cycle facilities, do they reduce the comprehensibility of the junction either for the car driver or the moped driver /cyclist?
- Would the safety of the moped/cycle traffic be reduced if the crossings were removed?
- Are the intensities of the moped/cycle traffic and the car traffic so high that specific facilities are necessary, such as special cycle tracks?
- Is the crossing in a moped/cycle route?
- Is the proportion of a particularly category of road users, such as senior citizens or children, relatively so high that it would be responsible to install special facilities for them?
- Is it possible to divert the slow traffic route along other roads and junctions so the situation as a whole becomes safer?
- Are the intensities and/or speeds of the motorised traffic so high that it is necessary to install traffic lights or build the junction as a fly-over?
- Is the crossing length too much?
- Is the junction in the ‘ideal’ driving line so the facilities are used to the maximum?
- Is there sufficient room for the moped driver /cyclist to halt before the junction area?
- If the crossing crosses a traffic island, is it wide enough for waiting moped drivers /cyclists if they cross the road in two stages?
- Could the crossing be deflected far enough to be outside the influence of the junction where moped driver /cyclists have to give way to other traffic?

e. Do the accidents occur between motor vehicles and mopeds/cycles on a single-track cycle track driven in both directions?
- Is there a sufficient qeuing area for turning car drivers between the carriageway and the junction?
- Could the junction be deflected far enough to be outside the influence of the junction where moped driver /cyclists have to give way to other traffic?
- Could the one-way cycle track be replaced by a two-way track?
- Can the return flow of the moped/cycle traffic be directed via another route?
- Is it necessary to control the junction with traffic lights?

f. Is the comprehensibility of the junction reduced by:
- crossing pedestrians? Can they be accommodated elsewhere?
- stopping buses; can the bus stop be moved?
- parked or loading and unloading vehicles; is it possible to prohibit parking or stopping?

g. Can the comprehensibility of the junction be improved by introducing a priority rule on one of the two roads?

h. Are the zones of vision at the junction free from view-obstructing obstacles?
  - Is the zone of vision the same size as or bigger as the necessary stopping visibility?
  - Have measures been taken to prevent view obstruction by preventing parking and/or stopping near to the junction?
  - Can view-obscuring obstacles such as long grass, plants, trees, masts and kiosks within the angle of vision be lowered, moved or removed?

i. Is the approach visibility or crossing visibility sufficient?
  - Is the approach dimensioned according to the approach speeds of the traffic on the road to be crossed?
  - Has the junction area been kept as compact as possible so the driver has a good view of the crossing flow and the crossing distance is as limited as possible?
  - Is the view to the left or right obscured by traffic signs, signposts, bollards, trees, parked vehicles and so forth?
  - If these elements cannot be removed, would it then be advisable to install traffic lights?
  - Is the view of the through traffic on the road to be crossed obscured for a relatively long time by traffic travelling on a long exit lane?

j. Is the approach visibility limited by horizontal curves in the road to be crossed? If so, then can:
  - That visibility be increased by removing, moving or lowering earth walls, bushes, fences, trees etc.?
  - The horizontal alignment in the road to be crossed be reviewed so drivers can react correctly to approaching vehicles in the curve?

k. Is the approach visibility limited by vertical curves in the road to be crossed?
  - Is the view obscured by a combination of horizontal and vertical curves?
  - Answer the questions under point j above.
  - Is it possible to increase the radius of the vertical curves?

l. If the road to be crossed is a dual carriageway, are the second lane and the traffic travelling on it clearly visible for the crossing traffic?
  - Would it be advisable to make the median section hollow?
  - Is it a good idea to lower the median crash barriers?
  - Would it be a good idea to elevate the side roads so the car driver is looking down on the junction, as it were?
  - Is it advisable to build the left-turn lanes of the road to be crossed filtering into the median?
  - Is the driver’s attention distracted by too broad a view of the junction area?

m. Is the view between the car traffic and the moped/cycle traffic mutually sufficient?
  - Is the situation of the crossings such that the car traffic crosses it at an angle of virtually 90°?
  - If there are separate cycle tracks is the visual contact between the moped driver /cyclist and the car driver guaranteed?

n. Is the angle between the road and the road to be crossed such that the driver has to turn his head a long way? If so, then can:

- this angle be adjusted to roughly 90°?
- the driver be guided to an easier position by means of traffic islands?
- the horizontal alignment be reviewed?

o. Is the speed of the traffic to be crossed so high that the drivers cannot respond adequately? Can the speed of the traffic to be crossed be reduced by:
- optically narrowing the width of the road surface by means of vertical elements?
- reviewing the transverse section and/or horizontal alignment of the design of the road or cycle track to be crossed?

p. Are there any overtaking vehicles on the road to be crossed involved in the accidents? If so, then can:
- a guiding section of road markings be installed with a left-turn lane?
- a traffic island or median be installed so the through traffic remains in one lane and the traffic turning left is possibly provided with a separate lane?
- Overtaking be prohibited by means of signs or marking?

q. Are the waiting times on the road to be crossed too long due to high traffic volumes?
- Would it be a good idea to introduce a priority rule?
- Would it be sensible to install a median so the road can be crossed in two stages?
- Is the intensity from the turning direction relatively high?
- Is the design of the junction such that the greatest traffic flows can be easily accommodated?
- Is it necessary to control the junction with traffic lights?

r. If there is a median in the road to be crossed, is it wide enough?
- Have there been accidents between through traffic and streaming vehicles in the median where the streaming vehicle has been hit from behind?
- Can the median be enlarged?

s. Is there any conflict between traffic from the side road and traffic turning left on the road to be crossed?
- Can the marking and/or design be adapted?
- Can the vehicles drive next to each other without obscuring each other's vision?
- Is it a good idea to introduce a no left-hand turn measure on the road to be crossed?

t. Are there any collisions between traffic coming from the median and traffic coming from the right on the road to be crossed?
- Are drivers coming from the side road and waiting in the median forced to accept too small a space because:
  - The median is too small to accommodate the vehicle?
  - They are forced to drive on by traffic approaching from behind?
- Do the vehicles stand next to each other in such a way that they obscure each other's view?
- Is the visibility restricted by stationary vehicles in the left-turn lane?
- Is the dual carriageway very long and therefore obscure?

u. If insufficient or no measures can be taken at the junction to arrive at a better assessment of the situation can road safety be improved by means of structural measures?
   - Is the use of the junction inconsistent with the function?
   - Is the junction in a through road?
   - Can short-cut traffic be prevented by means of traffic measures, such as no left or right turn, one-way traffic, if necessary for specific traffic types only?
   - Can the signposting be revised so that through traffic no longer uses this route?
   - Can structural measures be taken elsewhere in the road network?

Accidents with turning traffic on uncontrolled junctions

This means accidents that occur between vehicles travelling on the same road where one or both vehicles turn left or right. This also involves vehicles travelling on parallel roads and cycle tracks, for example.

Accidents with traffic approaching from the rear

a. Is the junction not recognisable in time, particularly for drivers unfamiliar with the area?

b. Is the junction recognisable in time but the design is incorrectly interpreted?

c. Do the accidents involve two or more motor vehicles?
   - Does the design of the exit lanes conform to the guidelines?
   - If no separate exit lane can be built for turning traffic then can the lane be widened so the vehicles can pass each other at low speed, i.e. a passing lane?
   - Can traffic measures provided elsewhere in the road network:
     - to reduce the intensity of the turning traffic?
     - turning left to be prohibited?

d. Do the accidents involve moped/cycle traffic on the carriageway?
   - Are the radii of the connecting curves too large so the traffic turns off at too high a speed?
   - Can turning traffic be better channelled by installing a traffic island?
   - Is the difference in speed between the car traffic and moped/cycle traffic too great?
   - Can the speed difference be reduced by adapting the design, horizontal alignment and cross section?
   - Are separate moped/cycle facilities necessary in the form of compulsory or non-compulsory cycle lanes or streamed cycle tracks?
   - Can moped/cycle traffic be prohibited and diverted to another route?
   - Is it advisable to introduce a no left or right turn measure for the car traffic or moped/cycle traffic?

e. Do the accidents involving moped/cycle traffic occur on the cycle tracks?
   - Is the presence of the cycle track alongside the road conspicuous?

- Is the turning vehicle's view of moped/cycle traffic approaching from the rear obscured by plants, signs, parked vehicles, etc.?
- Is it advisable to situate the cycle track nearer to the road to improve visibility?
- Is the streaming area between the main road and the cycle track sufficient for turning cars?
- If not, is it possible to add an exit lane for right-turning traffic or can the cycle track be further deflected to reverse the right of way regulation?
- Do the accidents involve vehicles that have run off the road?

Accidents with oncoming traffic

a. Is the junction not recognisable (in time), particularly for drivers unfamiliar with the area?
   - Answer the questions in checklist "Right-of-way accidents where the junction is not recognised (in time)"

b. Is the junction recognisable (in time), but the design is incorrectly interpreted?
   - Answer the questions in checklist relating to the comprehensibility of the junction

c. Do the accidents involve two or more motor vehicles?
   - Is it clear to the driver turning left that there is oncoming traffic?
   - Is the left turn so smooth that the driver imagines he has the right of way?
   - Does the driver turning left have a good view of the oncoming traffic?
   - Do vehicles turning left from both directions cross each other and therefore obscure each other's view of the oncoming traffic?
   - Can the median be widened or can it be modified in such a way that the vehicles turn behind one another?
   - Is the road situated in a horizontal curve or is the driving speed high, making it difficult to estimate the speed of the oncoming traffic?
   - Could taking traffic measures elsewhere in the road network:
     - reduce the intensity of the turning traffic?
     - enable a no left turn measure?
   - Do the accidents involving moped/cycle traffic occur on the carriageway?

d. Do the accidents involve moped/cycle traffic filtering on separate cycle tracks?
   - Do the accidents involve vehicles that have run off the road?

Accidents on controlled junctions

This checklist concerns all road users (drivers and pedestrians).

a. Did the accidents occur when the traffic lights were not working due to the night programme or a breakdown?
   - Would it be sensible to have the lights working at night?

b. Is the positioning of the traffic lights optimal?
   - Does the situation conform to the order and the current traffic picture?
   - Is the distance between the lights and the stop line correct?

c. Does the equipment conform to the requirements?

d. Do people drive through red lights at times other than the beginning of the red light phase?
- Are the lights situated optimally?
- Are they situated close enough to the road so they are included in the driver's field of vision?
- Do the lights stand out sufficiently against the background at the time when the accidents occurred?
- Can the lights be clearly distinguished from traffic signs and/or advertising boards from a greater distance?
- Are the lights aligned in the right direction?
- Is the view of the lights obscured by plants, trees, lampposts, parked vehicles or vertical or horizontal curves?
- Would it be advisable to place the lights above the road using poles or gantries?
- Is there a warning sign?
  - Is the distance between the sign and the junction in accordance with the installation order?
  - Is the sign fitted with a board below indicating the distance?
- Is it advisable to install a flashing yellow light above the warning sign?
- Is it advisable to do so on both sides of the road?
- Are the lights clearly noticeable in strong sunlight at the time the accidents occurred?
- Are the waiting times too long?
- Is the regulation plausible? In other words, are there vehicles coming from conflicting directions, so it is clear to all road users why the lights are at red?
- Is the regulation vehicle actuated?
- Is it still sensible to maintain the traffic lights (due to changed traffic situations for example)?
- If the accidents occurred during the night and the traffic lights were working then should they perhaps be turned off?

e. Do the accidents occur while the lights are changing?
- Do the accidents occur just after the end of the green phase?
  - Does the green phase correspond with the traffic volume?
  - Is the streaming area long enough?
  - Is it advisable to update the phasing or to skip a phase?
  - If nearby junctions are also controlled by traffic lights then are they interconnected? If so, is that connection correctly adjusted?
  - Is the capacity of the junction too low?
  - Can the capacity be increased by reconstruction or can the intensity be reduced through structural measures?
  - Are the detectors working properly?
  - Do the detectors detect all vehicle types?
  - Has the detection system been well chosen?
  - Does the road surface have adequate skidding resistance?
- Do the accidents occur at the beginning of the red phase?

- Has the duration of the amber phase been adjusted to the approach speed (50 or 70 km/hr)?
- Are the clearance times properly dimensioned?
- Is the speed of approach higher than 50 or 70 km/hr?
- Is it advisable to lengthen the duration of the green phase by means of speed detection to such an extent that a vehicle driving too fast has passed the junction before the red phase?

f. Do the accidents involve people turning left where the regulation is not conflict-free?
- Is there sufficient room at the junction so someone turning left can position his vehicle in such a way that the through traffic is not obstructed?
- Is a left hand streaming area necessary?
- Is the junction so large that those turning left do not recognise the conflict with ongoing or left-turning traffic coming from the other direction?
- Does traffic turning left try to move off before the ongoing car, moped/cycle and pedestrian traffic?
- Is the view of those turning left restricted by vehicles waiting in the opposite left-turn lane or a curved stretch of road?
- Is it advisable to regulate the left-turn traffic in a conflict-free manner?
- Do those turning left misjudge the approach speed of the car and moped/cycle traffic?
- Is it necessary to divert left-turning moped driver /cyclists onto separate cycle tracks?
- Is it necessary to regulate pedestrians and moped driver /cyclists in a separate phase?
- Are there left-turning road users involved in the accidents that are waiting for a convenient gap and expect the oncoming car and moped/cycle traffic to stop at a red light?
- Could one of these directions be stopped earlier?

g. Do the accidents involve people turning right where the regulation is not conflict-free?
- Is there sufficient room at the junction so someone turning right can position his vehicle in such a way that the through traffic is not obstructed?
- Is a right hand streaming area necessary?
- Is the junction area so large that those turning right do not recognise the conflict with pedestrians and moped/cycle traffic?
- Does car traffic turning right try to move sideways before the ongoing pedestrian and moped/cycle traffic?
- Does the traffic turning right have an adequate view of the moped/cycle traffic?
- Can the manoeuvre to turn right be simplified by improving the design of the junction (connection curves, cycle tracks and so forth)?
- Is it advisable to give pedestrians and moped/cycle traffic a head’s start?
- Could one of these directions be stopped earlier?
- Can the regulation be made conflict-free?

h. Do the regulation facilities used cover the requirements of the current traffic picture?

- Can the facilities of the regulation system be extended?
- Should the regulation system be replaced?
- Should the entire traffic control system be replaced?
- Should the junction be constructed to facilitate optimal use of the regulation system facilities?

Accidents on road sections

General questions concerning the layout of the road

a. Marking
  - Is the marking in accordance with the guidelines or have they been consciously deviated from?
  - Is the marking clearly visible under all light and weather conditions?

b. Signing
  - Is the signing in accordance with Road Traffic and Traffic Signals Regulations and has the installation order been adhered to?
  - Are the signs clearly visible under all light and weather conditions?
  - Is the sign clearly distinguishable from other traffic signs and/or advertising boards from a greater distance?
  - Does the sign stand out sufficiently against the background and is it clearly perceptible in strong sunlight?
  - Is the visibility of the sign obscured by plants, lampposts, trees (remember the seasons!), signposts or parked vehicles?

c. Cross section
  - Are the lanes wide enough in view of the road type?
  - Does the number of lanes correspond with the traffic volumes?
  - Is it necessary to install an edge strip or widen the present one?
  - Is the road surface flat enough and does it have adequate skidding resistance?
  - Is the shoulder wide enough and does it have sufficient capacity?
  - If there is a median then is it wide enough?

d. Horizontal alignment
  - Is the current driving speed in accordance with the originally designed speed?
  - Are the straight stretches too long?
  - Are the curves radii correct?
  - Is it necessary to construct transition curves?
  - If the curve is a composite curve is this then inconvenient for the road traffic?
  - Has any super elevation been applied?
  - Has the road been widened on the curve?

e. Vertical alignment
  - Are the vertical curves well dimensioned with regard to visibility and speed?
  - Is the gradient percentage geared to this?

- Is the combination of a horizontal and a vertical curve well chosen for driving?

Accidents on straight stretches of road

Accidents on straight stretches of road involving two or more vehicles

a. Are the accidents the result of changing lane or overtaking?
NB: Accidents resulting from changing lane are those where vehicles travelling in the same direction were not in the same lane just before the accident. Accidents resulting from overtaking are those where vehicles travelling in the same direction were in the same lane just before the accident.
   - Is the overtaking sight distance adequate?
   - Can those vehicles travelling too slowly in relation to the rest of the traffic be diverted to a parallel road or prohibited?
   - Do the accidents occur at or after a point in the road where a no overtaking regulation is cancelled, where there is a larger transverse section available, after the end of an obscure horizontal and/or vertical curve, a reduction in traffic intensity or the end of a speed restriction?
   - Can the traffic measures be extended to a point where it is safer to overtake?
   - Is the intensity of the oncoming traffic during the day such that there are insufficient gaps in the traffic for safely overtaking?
   - Is it advisable to prohibit overtaking?

b. Do the accidents result from speed differences (rear-end collisions)?
   - Can the vehicles travelling too slowly in relation to the rest of the traffic be excluded?
   - Do the accidents resulting from vehicles turning off occur at minor side roads or entries? Could a parallel road be built?
   - Are the accidents the result of pedestrians or moped driver /cyclists crossing unexpectedly?
   - Can crossing be concentrated at a few clearly distinguishable points?
   - Does the road have adequate skidding resistance?

c. Do the accidents involve vehicles travelling in opposite directions?

d. Do the accidents involve moped drivers /cyclists?
   - In view of the volumes of and the speed differences between car and moped/cycle traffic, is it acceptable to have mopeds/bicycles on the carriageway?
   - Can the transverse section be so revised that separate facilities (compulsory and non-compulsory cycle lanes and cycle tracks) can be provided?
   - Is the use of the compulsory and non-compulsory cycle lane in line with the function of the road?
   - Is the width of the lane sufficient?
   - Could improvement of the evenness and/or adjustment of the colour and texture of the pavement discourage moped/cycle traffic from using the lane?
   - Is the lane blocked by parked vehicles so that moped drivers /cyclists are prevented from using the lane?

- Is it advisable to replace the non-compulsory cycle lane with a compulsory lane?
- Is it advisable to build lay-bys or introduce no parking?
- Is the non-compulsory cycle lane recognisable for car drivers under all light and weather conditions?
- If accidents are caused by motor vehicles crossing the cycle lane to lay-bys or entrances, can the presence of the lane be emphasised by:
  - increasing the frequency of the bicycle symbol
  - making the pavement of the lane different in colour and texture?
  - Giving the entrances a compact design
- Is the moped/cycle traffic conducted along adjacent or separate cycle tracks?
- Is the presence of the cycle track recognised by the car driver?
- Do the accidents involve vehicles that have gone off course?
- Do the accidents occur next to exits?
  - Can the cycle track be made more conspicuous through the colour and texture of the pavement
  - Can the median between the cycle track and the carriageway be enlarged so that traffic crosses in two stages?
  - Is it advisable to remove the cycle track?
  - Can the cycle track be replaced by a parallel road?
- Do the accidents involve cyclists crossing to the buildings alongside the road?
  - Is the number of crossing moped driver /cyclists so large that a separate facility other than a compulsory or non-compulsory cycle lane is not advisable and that the car traffic volume should be reduced?
  - Could separate cycle tracks be built where crossing is only permitted at certain points?
  - Is it necessary to make the crossing safer with markings, signs or traffic lights?
  - Can parallel roads be built?

Accidents on straight stretches or road involving only one (moving) vehicle

a. Do the accidents involve vehicles leaving the road?
- Is the driver's attention level too low as a result of a long stretch of straight road?
- Could there be any sudden side wind?
- Could there by any optical deception caused by trees or lampposts, either in daylight or in the dark?
- Can the traffic be guided better by adding marking posts, fences and suchlike?
- Is there a poor road surface (ruts, aquaplaning, cracks)?
- Could the speed be influenced by
  - optically narrowing the carriageway by adding vertical elements?
  - revising the transverse section?

  - revising the horizontal alignment?

b. Do the accidents involve fixed obstacles?
- Can the obstacle be removed or moved?
- Can the obstacle be made passively safe by means of ‘break construction’?
- Is the obstacle or the danger zone guarded with a safety barrier construction?
- Is the type and position of this construction in accordance with the guidelines?
- Is the obstacle a traffic island or traffic guide?
- Is the traffic island or traffic guide within the driver’s expectation pattern?
- Can the conspicuousness of the traffic island or traffic guide be improved by vertical elements?
- Is the street lighting adequate?
- Is it advisable to remove the traffic island or traffic guide?
- Is it a good idea to add an edge strip at the location of the traffic guide?

c. Do the accidents involve a parked vehicle?
- Is there sufficient room for passing traffic?
- Is it advisable to introduce parallel parking instead of perpendicular parking?
- Is the parking properly controlled?
- Is the transverse section well laid out?
- Is it advisable to build lay-bys?
- Is the street lighting adequate?
- Is it advisable to introduce parking restrictions on both sides of the road?

d. Do the accidents involve moped drivers or cyclists?
- Is the height of the curbstones appropriate?
- Do people park in the non-compulsory cycle lane?
- Is it advisable to prohibit parking by replacing the non-compulsory cycle lane with a compulsory cycle lane and making it a no parking zone?
- Can the compulsory or non-compulsory cycle lane be replaced with a separate cycle track to prevent conflict with car passengers getting in and out of their vehicles?
- Can moped/cycle traffic be prohibited at this point and led along parallel routes that are safer?

Accidents in horizontal curves

Accidents that occur in horizontal curves are generally not the direct result of the horizontal curve itself, but of the interaction between the curve and a straight stretch. Therefore first answer the questions in the checklist of accidents on straight stretches of road (above) and then proceed to the specific questions on this checklist. These questions apply to both accidents in horizontal curves involving two or more vehicles and those involving one (moving) vehicle.

a. Do the angular displacement and the dimensions of the curve correspond with the expectations of the driver and is the curve recognisable (in time)?
- Are there any warning or advance warning signs?
- Is there any optical deception?

- Can the conspicuousness be improved by means of marking, marker posts, shields, fences or other vertical elements?
- Have the vertical elements been installed on the outside of the curve?
- Is the street lighting adequate?
- Is the overtaking sight distance adequate?
- Can visibility be improved by moving, removing or lowering trees, plants, fences, posts, earth walls, etc.?
- Is it advisable to prohibit overtaking or indicate a recommended speed limit?
- Can the horizontal alignment be improved?

b. Is it advisable to protect the separate cycle track in the curve with a safety barrier construction?

Accidents in vertical curves

Accidents that occur in vertical curves are generally not the direct result of the vertical curve itself, but of the interaction between straight stretches, horizontal curves and vertical curves. Therefore first answer the questions in checklists above for accidents on road section and then proceed to the specific questions in this checklist. These questions apply to both accidents in vertical curves involving two or more vehicles and accidents involving one (moving) vehicle.

- Is there sufficient visibility?
- Does the horizontal curve start after the highest point in the vertical curve?
- Can the course be made clear by using trees, lampposts and so forth?
- Can the horizontal alignment be placed before the highest point so the driver has a better impression of the course of the road?
- Is the alignment of the road not visible from a short distance but it is from a longer distance?
- Can the linking of the vertical curves (crest curves and sag curves) be replaced by one large curve?

Accidents involving pedestrians

Accidents at uncontrolled junctions

a. Is the best place to cross indicated with markings?

b. Does the junction have pedestrian crossings?
   - Is the marking in accordance with the guidelines?
   - Is the presence of the pedestrian crossings justified?

c. Is the crossing recognisable to crossing traffic?
   - Is the car driver’s view of the pedestrian adequate, and vice versa?
   - Have extra measures been taken to prohibit parking and/or stopping near to the crossing?
   - Is it necessary to install extra lighting?
   - Is the crossing in the ideal pedestrian desire line so the facility is used as much as possible?

d. Is there a traffic island or refuge?

- Is it wide enough, particularly for people in invalid carriages, with pushchairs, etc.?
- Can the crossing length be restricted by other measures, such as narrowing the carriageway?

e. Is there enough room for the pedestrians to wait at the crossing?

f. Is the speed of the traffic to be crossed too high? If so, can it be reduced by:
- Installing speed ramps, dips in the direction of the flow and narrowing the road?
- Visual narrowing of the carriageway by installing vertical elements?

g. If the crossing were removed, would that jeopardise the safety of pedestrians?
- Do the volumes of the vehicle and pedestrian traffic necessitate specific facilities?
- Is the proportion of a particular category of road user, such as children or senior citizens, relatively so high that it would be advisable to provide special facilities?
- Is the crossing on a pedestrian route?
- Is the intensity of pedestrians high for only a short period so that traffic measures, such as a police officer or crossing warden, would suffice?
- Does the facility fit in with the design as a whole?

h. Are the waiting times for pedestrians too long?
- Can crossing take place in two stages by installing a traffic island?
- Can the crossing length be restricted by narrowing the road?
- Should the crossing be made safe with traffic lights?
- Can the crossing be made as a fly-over?
- Is the crossing part of a pedestrian route?
- Can this route be changed to make it safer?

i. Do the accidents occur between motor vehicles or mopeds, turning left or right, and pedestrians?
- Can the driver’s view of the pedestrians be improved?
- Can the speed of the moped and car traffic be reduced with smaller connection curves?
- Is it necessary to control the crossing with traffic lights?
- Is it advisable to prohibit turning off in one or more directions?
- Is it advisable to make the traffic one-way?

Accidents on stretches of road

Accidents on stretches of road where pedestrians are walking parallel to the road axis

a. Are the intensities so limited, and is the difference in speed from that of the car and moped traffic so slight, that pedestrians use the carriageway?

b. Are there any separate pedestrian facilities?
- Is there a footpath on one side?
- Is it a good idea to add a footpath on the other side?
- Is the path wide enough for pedestrians not to have to use the carriageway at particular busy times?
- Is the footpath used for displaying goods, parking and so forth?

- Is the path of sufficiently high quality?
- Is the path well lit?
- Are the entrances and exits for pedestrians clearly recognisable?

c. Are pedestrians inconvenienced by passing car or moped/cycle traffic? If so, then can:
- the speed be reduced?
- the footpath be situated further from the carriageway or cycle track?
- a physical separation be provided?
- the intensity of the car traffic be reduced?

Accidents on stretches of road involving crossing pedestrians

a. Is there a concentration of crossing pedestrians at one point?
- Is the crossing indicated by signs?
- Is it advisable to force pedestrians to use this crossing place by using safety barriers?
- Has the pedestrian route changed over the course of time, due to a supermarket, for example, so the existing crossing should be moved?
- Do the accidents involve pedestrians coming from a bus stop?
- Is it necessary to control that particular crossing with traffic lights?

b. Is the entire stretch of road frequently crossed by pedestrians at various places?
- Can the speed of the car and moped traffic be reduced by narrowing the road, dips in the carriageway and speed ramps?
- Can the stretch of road be rebuilt into a home zone?

c. Do the accidents involve pedestrians emerging from between parked vehicles?
- Can the parking facilities be interrupted at regular intervals?
- Is it advisable to change the parking facilities, for example perpendicular parking on one side instead of parallel parking on both sides?

APPENDIX 2 MATAC: Worksheet accident schedule

Number of accident							
Day							
Date							
Time							
Number of involved objects							
Number of victims							
Picture of manoeuvre							
Main cause of collision							
Road user 1, age							
Road user 1, transport							
Road user 2, age							
Road user 2, transport							
Light condition							
Weather condition							
State of road surface							
Alcohol use							
Remarks							

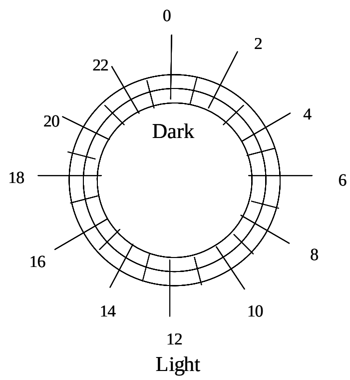
APPENDIX 3 MATAC: Worksheet manoeuvrediagram

MATAC Manoeuvre diagram		
Road Authority		
Location		
Road user	Movement	Time-period
Pedestrian Bicycle Motor bike Moped / scooter Motor vehicle Heavy vehicle Agricultural vehicle Delivery bicycle and other vehicles Tram / train Animal (D) Lose object Fixed object	Straight on Halt Parking (P) Turning Overtaking U-turn Out of control; skid Change lane Reversing back ? Location unknown	Priority ▽ Time: Intensity:
6 Accident with Material damage only (7) Accident with injuries (8) Accident with fatality	No. of accidents: ______ with fatalities: _______ with injuries: ________ with m.d.o.: _________	

APPENDIX 4 MATAC: Worksheet Time analysis table

Road Authority:	
Location:	
Accident type:	

Hour:



Day:								
Year	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Total
Total								

Month													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Total													

APPENDIX 5 MATAC: Worksheet analysis overview

Road Authority		Location	
Type of accident			
Nº	Characteristic	Observation	Conclusion
Hypothesis 1:			i.r.t.
Hypothesis 2:			i.r.t.
Hypothesis 3:			i.r.t.

APPENDIX 6 MATAC Worksheet Analysis summary

Road Authority		Location:		
Type of accidents:				
Hypothesis	Check hypothesis (research on location)	Is hypothesis correct	Cause of accident	Measure

APPENDIX 7 Examples of cost items for road safety measures

Measure	Explanation	Cost and benefits
Road, traffic and accident data collection	general activities, aimed at the creation and management of a traffic and accident data base	annual revolving cost; facilitating other measures, so no direct benefits
Road safety inspection	systematic road inspection by safety experts of the measures taken and are part of the evaluation (the "E" in the POGSE approach)	cost calculated on an annual basis; facilitating other measures, so no direct benefits
Black spot treatment	systematic black spot identification and analysis and drafting of a working list of black spots (see chapter 3)	cost and benefits derived from the definition of the specific measure
Organise POGSE approach with stakeholders	road owners will take the lead in bringing stakeholders together and go through the steps (see chapter 2)	cost calculated on the basis of time spending by safety experts; facilitating other measures, so no direct benefits
Road safety impact assessment	to investigate the benefits on road safety of proposed infrastructural projects; this includes the road safety audit as performed by road authorities	cost calculated on the basis of time spending by safety experts; benefits cannot be determined in a general sense
Traffic calming on minor roads	to reduce speed and to discourage the use of through traffic	cost derived from the definition and design of the specific measure; benefits estimated on basis of experience
Building roundabouts instead of junctions;	to avoid large differences in speed and direction	cost derived from the definition and design of the specific measure; benefits estimated on basis of experience
Safety barriers at hazardous locations	to protect drivers from fixed objects along the road side	cost derived from the definition and design of the specific measure; benefits estimated on basis of experience
Speed inhibitors on approaches to junctions	to reduce speed of approaching vehicles by narrowing driver's sight and diminishing comfort	cost derived from the definition and design of the specific measure; benefits estimated on basis of experience

Lane separation	to prevent or discourage overtaking on two-lane two-way roads	cost derived from the definition and design of the specific measure; benefits estimated on basis of experience
Uniform signing and marking of sharp bends	to achieve a uniform system for all of Europe	investments estimated per country once system is defined; benefits estimated from present accident data
Automatic enforcement of speed violations	to intensify control and use available police manpower more effectively	cost of required equipment calculated; benefits estimated on basis of experience
Closing down roads for slow moving traffic	to avoid mixing of different types of traffic	costs derived from the definition and design of the specific measure; benefits estimated on basis of experience
Maintenance of road safety features	to keep functioning of constructed and installed road safety measures (may for some measures be combined with road safety inspections)	costs calculated on a yearly basis; facilitating other measures, so no direct benefits

APPENDIX 8 Arithmetic method to calculate annual investment cost

This method assumes that the funds for the investment are commercially borrowed (e.g. from a bank). Refunding of the loan takes a pre-fixed number of years (term or duration of the loan) and is in equal amounts per year. The annual amount consists of one part for refunding and for another part of interest over the remaining sum of the loan. As the remaining sum of the loan decreases the interest amount will also become less. However, the method assumes a fixed total amount per year. This is what the calculation is about.

The notations in the formulas are:

Z: parameter for the present value of a loan when after one year the total amount is one currency unit (e.g. 1 €) for refunding of the loan plus interest
R: interest rate
t: length of the term or the duration of the loan in years
A: annual amount
L: amount of the loan (i.e. capital cost of the investment)

The present value is calculated as follows:

$$Z = \frac{1}{1 + R}$$

The value Z is used to determine the annual amount. This is found with the formula:

$$A = \frac{L * (1 - Z)}{Z * (1 - Z^t)}$$

For example:
At a junction traffic lights are installed at a cost of € 80,000.--. The interest rate is 10 % and the estimated lifespan is 10 years. What is the annual capital cost for the investment?

Z = 1 / (1 +0.1) = 0.9090909

A = 80,000 * (1 – 0.9090909) / 0.9090909 * (1- 0.9090909^{10}) = € 13,019.63

So the annual capital cost for the cost benefit analysis is € 13,019.63

APPENDIX 9 Reduction of number of accidents for various types of measures

Safety measure	Context of application	Percent change in number of injury accidents		
		Lower 95 %	Best estimate	Upper 95 %
Construct roundabouts	Three arm suburban junctions Four arm suburban junctions	-45 -50	-30 -40	-5 -30
Black spot treatment	Single black spot String of black spots	-40 -20	-30 -10	-20 0
Separate truck lanes	Reserved lane on multilane roads	-30	-20	-10
Install new road lighting	Previously unlit roads: – fatal accidents – injury accidents	 -75 -33	 -65 -30	 -50 -25
Upgrade road lighting	Roads with substandard lighting	-25	-15	-5
Install shoulder rumble strips	Motorways and motor roads	-45	-25	-5
Upgrade pedestrian crossing	Simple marked pedestrian crossings	-50	-35	-20
Create 30 km/hr zones	Access roads presently higher limit	-30	-25	-20
Limit speed on junctions	Reducing from 80 to 70 km/hr Reducing from 80 to 60 km/hr	-10 -15	-6 -10	-2 -5
Promote daytime running lights	Intrinsic effect for each vehicle Increase in use rate of 30 % Increase in use rate of 60 %	-25 -8 -15	-15 -5 -9	-5 -2 -3
Promote rear seat belts	Intrinsic effect for each user Increase in wearing rate of 30 % Increase in wearing rate of 60 %	-40 -12 -25	-25 -8 -15	-10 -3 -6
Train child pedestrian	Children 6 – 9 years Children 6 – 12 years	-20 -30	-10 -20	-5 -10
High mounted brake lights	Intrinsic effect for each vehicle Increase in use rate of 30 % Increase in use rate of 60 %	-25 -8 -15	-15 -5 -9	-5 -2 -3
Driver side airbags	Intrinsic effect for each user: - belted - unbelted 30 % of cars equipped (70 % belted) 60 % of cars equipped (70 % belted)	 -25 -35 -10 -20	 -15 -25 -6 -12	 -5 -15 -2 -4
Provisional licenses	Effect for each driver (two years)	-15	-10	-5
License withdrawal for driving under influence	Effect during withdrawal period	-50	-40	-30
Ordinary police enforcement	Maximum potential benefits Moderate increases in activity	-40 -20	-25 -10	-10 0
Automatic enforcement	Specific road and type of violation	-40	-25	-10

APPENDIX 10 Examples of cost-benefit analysis

Example 1

On a junction with right-of-way at location X during a three-year period, 15 accidents have been registered. These accidents can be categorised as follows:

- five right-of-way accidents; the junction was not recognised as such in time;
- four right-of-way accidents where the situation was not judged properly at the moment of entering the crossing itself;
- three accidents with pedestrians run over when crossing the right-of-way road;
- three accidents of non-dominant types.

Imagine, after analysis of the accidents cluster the following possible measures arise:

1. Construction of a roundabout, preventing 40 % of the accidents in three years, costing the amount of € 80,000.--. The lifespan (value of statistical life) is 10 years.
2. Construction of medians in the main road; this simplifies crossing the right-of-way road for pedestrians as well as other road users. With this measure 30 % of the accidents in three years can be prevented; the cost are € 10,000.--. The lifespan (value of statistical life) is 25 years.
3. Construction of a median with bollards in the side road, in order to increase the visibility of the crossing. It is estimated that 20 % of the accidents in three years can be prevented with this measure; the cost are € 4,000.--. The lifespan (value of statistical life) is 25 years.

Refer to the table at the end of this appendix. Solution 3 has the best cost-benefit ratio for location X and therefore has the first priority. In case measures need to be taken on more than one location, for all locations the most appropriate measures are determined. Next is determined at which location the first measures are taken. For illustration purposes the data of two other locations, Y and Z are included in the table. Obviously, measure 2 at location Y has the highest priority, before measure 3 at location X.

Example 2

The second example is a simplified method. In a region are five black spots. All concern give way accidents with severe side collisions. The cause is sight blocking by traffic using the right exit lane. The objective of the measure is to reduce chances of sight blocking. The cost must remain within the available budget, which is € 20,000.—for three years. Possible solutions are:
Solution A: Remove the right exit lane at one black spot only. The cost are € 20,000.—and the estimated effect is a reduction of 3 injuries and one fatal accidents per year.
Solution B: traffic signs and markings for all five black spots. The cost and benefits (reductions) are:

5 X € 2,000.-- = € 10,000.—for year 1 and 5 injuries
5 X € 1,000.-- = € 5,000.—for year 2 and 4 injuries
5 X € 1,000.-- = € 5,000.—for year 3 and 3 injuries

The calculation is as follows.

Solution A:	Three fatal accidents less:	3 X 10 =	30
	Nine accidents with injuries less:	9 X 5 =	45
	Total:		75

The effect of an investment of € 20,000.—spent per € 1,000.—is: 75/20 = 3.75

Solution B: Twelve accidents with injuries less: 12 X 5 = 60
The effect of an investment of € 20,000.—spent per € 1,000.—is 60/20 = 3.00

So solution A gives the best cost benefit effect.

Priority listing of measures to improve safety at locations X (three alternatives), Y (two alternatives), Z

Location (Name) a.	Measure (No.) b.	Investment (€) c.	Lifespan (yrs) d.	Capital cost (€/yr) e.	Maintenance (€/yr) f.	Total cost (€/yr) g=e+f	Accidents h. fatal	inj	mdo	total	Reduction % i.	Effect j.*	Priority (rank) k.
X	1	80.000,00	10	13,019.60	1,000.--	14.019,60	3	5	8	16	40	0,00060	5
	2	10.000,00	25	1,101.68	100.--	1.201,68	3	5	8	16	30	0,00524	3
	3	4.000,00	25	440.68	100.--	540,68	3	5	8	16	20	0,00777	2
Y	1	12.000,00	25	1,322.02	150.--	1.472,02	0	0	3	3	50	0,00034	6
	2	6.000,00	25	661.01	75.--	736,01	1	4	6	11	60	0,00978	1
Z	1	15.000,00	25	1,652.52	200.--	1.852,52	0	4	6	10	40	0,00187	4

*: example of the calculation of effects
((3/3*10+5/3*5+8/3*1)*40/100)/14,019.60 = 0.00060

APPENDIX 11 GLOSSARY

Term	Description
30 km/hr zone	Traffic Calming area
Acceleration length	Length needed by a vehicle to increase its speed comfortably
access function	Allow vehicles to depart and arrive from an individual dwelling, shop or company while ensuring the safety of the street as a meeting place
Alignment	Spatial line containing the geometrical elements constituting the basic design of a road or a road section
Bank	Nearly flat, not paved part of an embankment, not being a crest; difference is made in banks between carriageways in the different directions (better called medians), side banks, banks between main carriageways and other carriageways (better called separators), upper and lower bank (in earthworks)
Block markings	Road markings, consisting of blocks with a width of over 0.25 m, applied in a longitudinal pattern
Branch connection	Convergence point where two carriageways with the same design speed converge to one carriageway and where from both carriageways one or more lanes continue beyond the convergence point
Capacity	Calculated maximum number of vehicles passing through a certain point or location at a traffic lane or carriageway under certain conditions or digested by a homogeneous road section
Carriageway	Coherent part of a traffic route intended for driving traffic and bound by two consecutive boundaries in the shape of an edge line, pavement transition or a paved/unpaved transition
Centre line	Axis of the road, not necessarily the centre of a carriageway, to which the particulars of the alignment are allocated
Clearance zone	Part of the road, adjacent to the carriageway, where a shoulder is lacking, to provide space to stranded vehicles
Connection	Part of the road network located between two interchanges of roads of the same or a higher function
Connection curve	Curved connection line between the edges of pavement of two roadways with different directions at an intersection or in the connection of two carriageways
Connection road	Carriageway, not being a main carriageway, interchange or parallel carriageway, constituting the connection between two other carriageways at an intersection or interchange

Convergence point	Point or area where two carriageways intended for traffic in the same direction join with a flat angle and transition to one carriageway
cross section	The vertical profile of the axis of the road
Cross fall	Positive elevation of the pavement perpendicular to the center line, required to ensure drainage of water to the edge of the pavement
Crossing	Meeting point of roads where traffic is not allowed to exchange directions. At-level and split-level crossings are distinguished
Curve	Gradually arched line in an alignment or gradually arched part of a road section
Curve widening	Extension of the width of the road in a curve to accommodate for the dragging of long vehicles
Deceleration length	Length needed by a vehicle to decrease its speed comfortably
Decision point	Point or location where the driver has to decide whether or not he can change his direction, based on information received (from traffic control devices, i.e. signs, signals, markings)
Design speed	Speed adopted in the design phase to determine the minimal requirements to enable individual vehicles to drive safely and comfortably
Distributor function	For the distribution and collection of traffic to and from different districts and residential areas
Divergence point	Point or area where a carriageway transitions with a flat angle to two carriageways intended for traffic with the same original direction
Division markings	Longitudinal marking, separating lanes for traffic in the same direction and defined as a single continuous line, as a single dashed line, as a combination of a continuous and a dashed line or as a block marking
Driving sight distance	Distance the driver has to be able to view to drive in a safe and comfortable manner.
Dwelling	residential area
Earth slope	Grading surface of a cut or fill
Edge line	Longitudinal marking, dividing the carriageway into a part intended for driving traffic and non-driving traffic and defined as a continuous line
Edge markings	Single continuous line marking on the pavement, separating a through lane for traffic from pavement areas not meant for traffic

Entrance	Point or location where access of traffic to the through lane is possible with an area of influence where the traffic flow on the highway is disturbed
Entrance ramp	Connection road leading from one road to another road of a higher category
Entrance terminal	Lane of limited length at the location of a convergence point, adjacent to a through lane of a carriageway, starting in the driving direction at the extremity of the ramp nose and intended to allow traffic from a ramp to increase speed before entering the through lane
Escape space	Space next to the shoulder and bound to the pavement, intended for stranded vehicles, to keep the shoulder free as much as possible
Evading sight distance	Distance the driver has to be able to observe obstacles, to recognize these and to evade these
Exit	Point or location where outlet of traffic from the through lane is possible with an area of influence where the traffic flow on the highway is
Exit ramp	Connection road leading from one road to another road of a lower category
Exit terminal	Lane of limited length at the location of a divergence point, adjacent to a through lane of a carriageway, ending in the driving direction at the extremity of the ramp nose and intended to allow traffic from a ramp to decrease speed before entering the exit ramp
Flow function	Vehicles move rapidly and uniterrupted
Fly-over	Structure being part of a carriageway leading a traffic flow over more than two other, conflicting traffic flows
Grade length	Horizontal distance between the intersection points of the tangents of the upper and lower curves
Gradient	The quotient of the level difference, being the vertical distance between the intersection points of the tangents of the upper and lower curves and the grade length, expressed as a percentage
Guard rail	Ribbon shaped construction for guiding errant vehicles, composed of metal beams, cross supports and posts
Gutter	Paved open discharge for drainage water
Hazard zone	Area along the carriageway with obstacles
Interchange	Meeting of roads in form of cross, the traffic is not allowed to change roads, At-level and split-level intersections are distinguished
Interchange	Location where exclusively highways buckle and accommodations to change direction are provided

Interchange carriageway	Carriageway at an interchange or connection, parallel to a main carriageway, starting and ending at that carriageway and facilitating entrance, exit and weaving motions
Intersection	Meeting point of roads where traffic is allowed to exchange directions. At-level and split-level intersections are distinguished
Junction	Split level connection of a highway with an arterial street or other road not being a highway.
Junction distance	The distance between two consecutive junctions on a road.
Lane	Bound part of the carriageway sufficiently wide for one chain of traffic meant to use that part of the carriageway
Loop	Approximately circular shaped connection road in a split level interchange or junction
Lower bank	Bank, not being a side bank, adjacent to the bottom of an earth slope
Main carriageway	Carriageway intended for through traffic
Major fork	Divergence point where one carriageway splits into two more or less equal carriageways with approximately the same design speed
Median	Bank between two carriageways with opposite driving directions
Obstacle-free zone	The distance from the inner side of the edge markings wherein almost all vehicles remain when entering a flat, supportive bank and where no obstacles are placed
Overtaking sight distance	Distance the driver has to be able to view to overtake another road user travelling in the same direction
Parallax	Misleading view on a road section because the driver receives information not meant for him, but for traffic on the adjacent carriageway or lane
Parallel carriageway	Interchange carriageway covering two or more interchanges or connections
Perception/reaction time	Time required to observe an event, digest the observation and subsequently determine the necessary reaction
POGSE	Approach to systematically analyse problem. Problem-Origin-Goal-Solution-Evaluation
Radius	Value of the circularly curved element in an alignment
Ramp nose	Surface marking at the location of a convergence or divergence point, shaped as an elongated triangle
Recovery area	Paved area of limited width, located along the carriageway and intended to enable drivers to correct their course
Reverse flow carriageway	Lane alternately intended for traffic in either direction, dependent on the traffic density

Road category	Classification of road according to road function within total road network which are recognizable for the road user
road function	In a road network each road has one principle function and can have secondary functions. The three functions are: flow, distributor or access function
Road character	The information the road user is given at any moment of time according to the design of the road (including sign posting, marking, etc) and its surroundings
Road type	Design of the road within a road category
Roundabout	Roundabout, with traffic travelling in one direction. Traffic on the roundabout has priority over the traffic wanting to join the roundabout
Rural area	An area is called rural when surrounding landuse is mainly agricultural
Section	Part of the road length with homogeneous road and traffic characteristics, not influenced by convergence and divergence points or weaving sections
Section speed	the average speed of a passenger vehicle on a specific section, which with good road and traffic conditions can be attained with clear visibility and good weather conditions
Separator	Bank between parallel carriageways not being both main carriageways
Shoulder	Paved lane along the carriageway of a highway where driving or stopping is only allowed in case of emergency
Side bank	Bank adjacent to the carriageway
Side ditch	Ditch along the side bank of a carriageway
Side strip	Paved strip between the shoulder or the recovery area and the wall or parapet of a structure
Sight distance	Distance the driver has to be able to view the area ahead or the distance at which a driver can spot an obstacle
Space profile	Profile indicating the space in the cross section, required by the traffic while in motion
Spacing	Extra width of the single lane exit or entrance terminal on the spot of the extremity of the ramp nose
Phasing	step-by-step construction or reconstruction of road
Stopping sight distance	Distance the driver has to be able to view to observe obstacles, to recognize these and to bring the vehicle to a halt
Straight	Straight line in an alignment

Super elevation	Elevation of the pavement in a curve perpendicular to the center line to take care of centrifugal forces on vehicles and to improve sight of the curve
Alignment	horizontal and vertical structure of elements and the position and path of the road in the environment
Transition curve	Transition between a straight and a curve or between two curves
Transition of super elevation	Change of the value of the superelevation between two points before and beyond which this value is constant
Turbulence	Deviant behaviour of traffic over a certain length of the carriageway, characterized by braking, dodging or (anticipating) changing of lanes to an extent more than normal and in any case remarked as a disturbance of the traffic flow
Underpass	Passage of a road under a viaduct, aqauduct or tunnel
Upper bank	Bank, not being a side bank, adjacent to the crest of an earth slope
Urban area	An area is called urban when surroundings consists mainly of buildings
Vertical alignment	The chain of crest and sag curves, grades and horizontal straights
View	Interpretation by the driver of the actual path of the road, who acts accordingly and not directly consistent with the actual alignment
Weaving lane	Lane in a weaving section
Weaving length	Length required for weaving in a weaving section
Weaving section	Carriageway of limited length between convergence and divergence point intended for weaving