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.

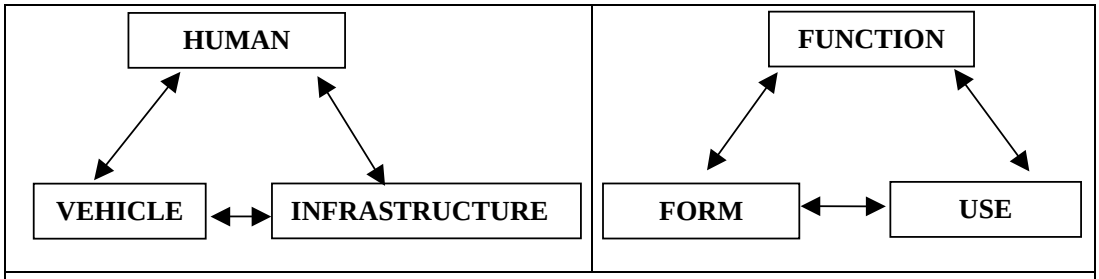

Figure 3: Systematic approach to Sustainable Safety

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).

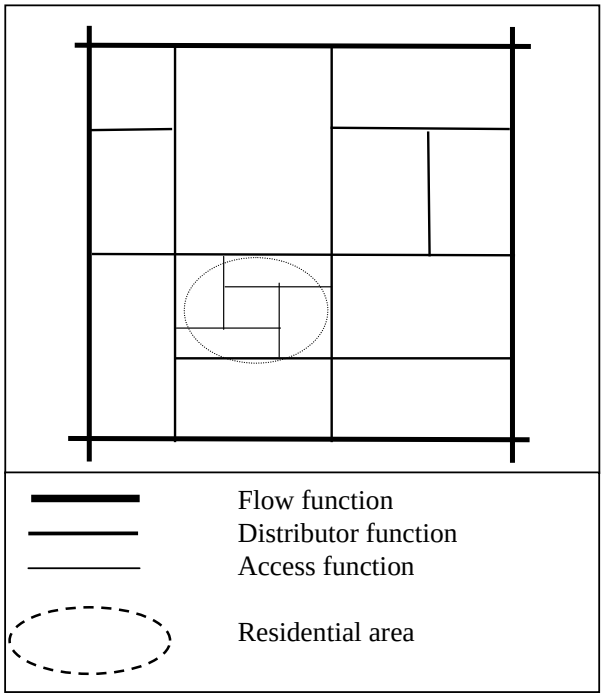

Figure 7: Categorisation in a road network according to Sustainable Safety

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.

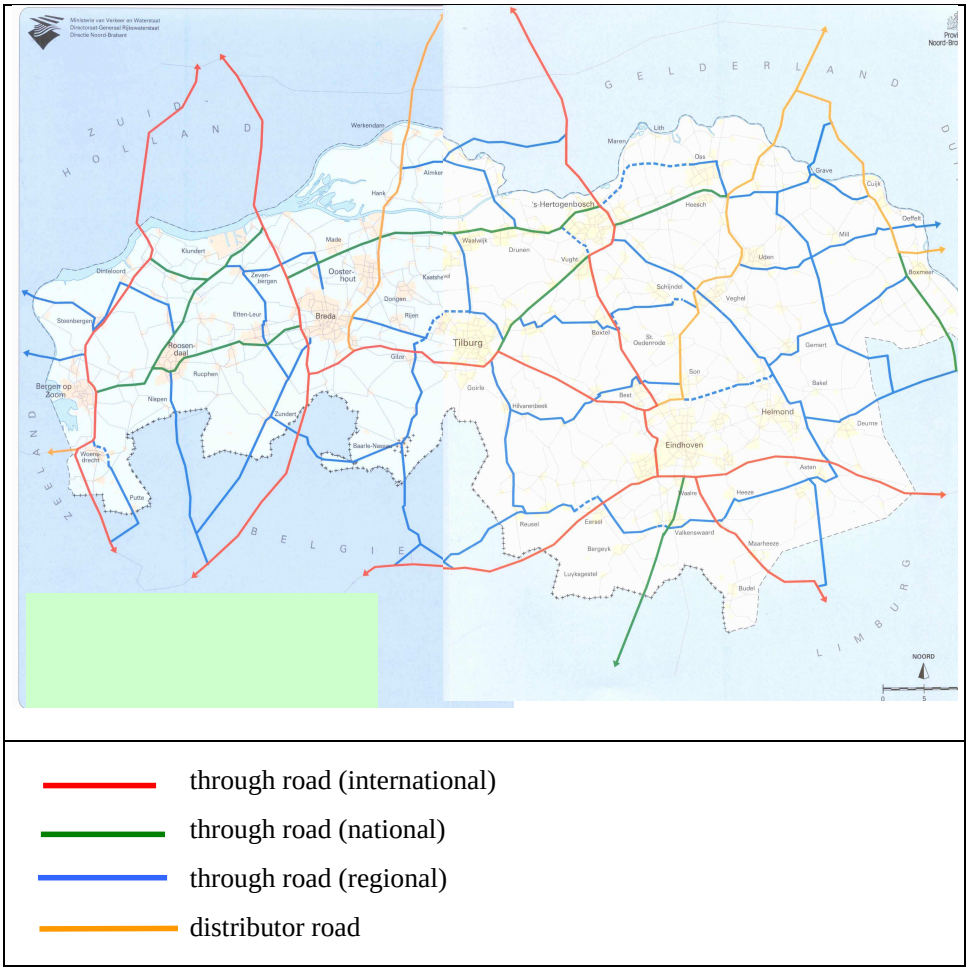

Figure 8: Example of road categorizing plan of a Dutch province Noord Brabant

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