Transforming ‘traditional’ urban main roads into sustainably-safe roads

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Contribution to the Second International Symposium on Highway Geometric Design, 14-16 June 2000, Mainz, Germany

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Abstract

Urban street design is a matter of local road authorities. However, the Dutch national government has provided general ‘recommendations for traffic provisions in built-up areas’. These recommendations are currently being revised. The main goal of the revision is to implement the principles of a ‘Sustainably Safe Traffic and Transport System’. These principles aim at a traffic and transport system which is inherently safe: prevention (before accidents happen) is better than curing (after accidents have occurred).
The application of these principles to residential street design will result in a type of design which is close to our ‘traditional design’ (streets with a speed limit of 30 km/h). However, the design of main streets (distributors) will be quite different from the design we are used to.
This paper will focus on the knowledge required to design inherently safe distributor roads without disturbing the many functions (for public transport, shopping, delivering of goods, parking) of this type of street too much. This paper describes the ‘ideal’ inherently safe distributor, and confronts this design with the possibilities and impossibilities caused by the urban functions and demands.

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1. Introduction

The term ‘sustainably-safe traffic’ has been a concept in the Netherlands since 1992 (Koornstra et al., 1992). The main objective of a sustainably-safe road traffic system is to reduce the present annual number of road accident victims to just a fraction of that number. During the last few years, a lot of research has been carried out into just what such a system will look like. One group working on the subject is the CROW working party ‘Categorizing Roads’, which has drawn up preliminary requirements for categorizing roads based on sustainable safety (CROW, 1997). A subsequent step will be to adapt the existing design standards and guidelines according to these requirements.
The following sections discuss adaption of the design guidelines for urban main roads, beginning with a brief explanation of the sustainably-safe traffic and transport system.

2. Sustainably-safe road traffic and transport system

The three main principles of a sustainably-safe road system are:
- functionality,
- homogeneity,
- recognizability/predictability.

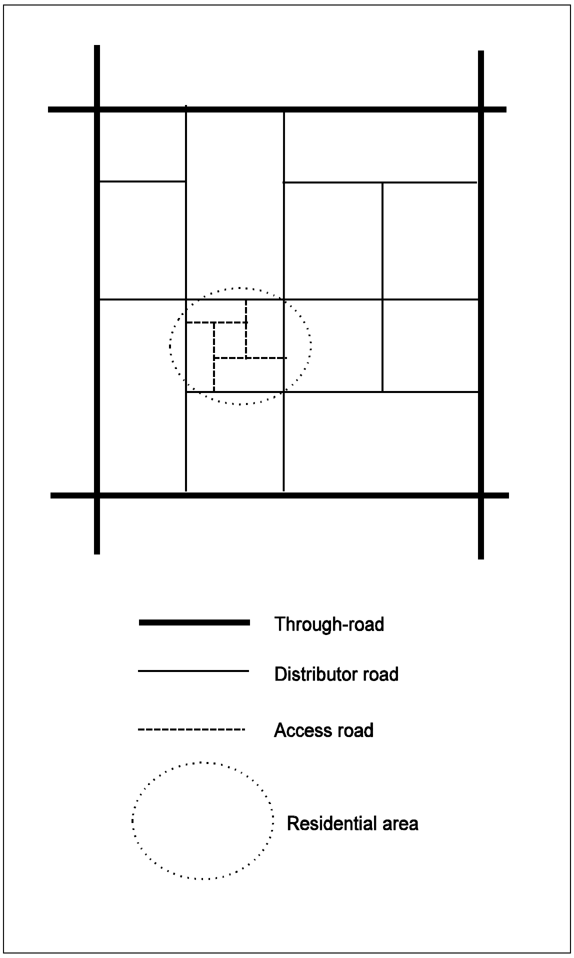

Figure 1. *Sustainably-safe categorized road network*.

The *functionality* of the road system is important in that it matches actual use with intended use. This produces a road network with three categories: through-roads, distributor roads, and access roads. Each road or street may only have one function. For example, a distributor road may not give direct access to houses, shops or offices. This is illustrated in *Figure 1*.

The *homogeneity* of the road system is meant to avoid significant differences in speeds, driving directions, and mass (preferably by segregating incompatible traffic types, and if this is not possible or desirable, by forcing motorised traffic to drive slowly).

For a sustainably-safe road system, it is of utmost importance that road users are familiar with the behaviour demanded by different road types, and what they may expect from other road users. This acquired pattern should be supported by optimizing the *recognizability* of the road types.

3. Sustainably-safe urban road network

The proposed sustainably-safe road network for urban areas should not include through-roads. The through-function should be taken care of by roads outside or close to the urban area. Within the urban area, therefore two functions/road types remain: distributor and access roads. The task of a section (part of a road between two junctions) in a distributor road is to allow the traffic to flow. The task of a junction in a distributor road is to facilitate an exchange between different parts of the network. Both junctions and sections of an access road have the task of allowing road users to exchange, either between the network and their origin/destination or to between two access roads (see *Table 1*).

	Road elements	
Road type	Road section	Junction
Main road / distributor road	flow	exchange
Access road	exchange	exchange

Table 1. *Traffic tasks for elements of distributor roads and access roads (Source: CROW, 1997).*

3.1. Requirements

The design of the road network should meet certain requirements in order to fulfil the principles of a sustainably safe road network. There are two types of requirements: functional and operational.
The *functional* requirements can be regarded as the basic principles for dividing the roads in the network into the various categories. There are also *operational* requirements for each of the roads assigned to a specific category in this way. These requirements involve the most important characteristics of the cross-section, the alignment, the types of traffic (car, bicycle, moped, pedestrian) allowed to use the road as well as their position on the cross-section. Both the functional and operational requirements should be incorporated into the existing guidelines for urban and rural roads.

3.1.1. *Functional requirements*

The functional requirements apply to all road categories in the entire road network (both rural and urban). This set of requirements should be considered as an inextricable whole, since the road system will only be sustainably-safe if the set is applied as a whole. The set for the road network (for cars) consists of the following twelve requirements:

- largest possible areas with traffic-calming (both in rural and in urban area),
- a maximal part of the journey using relatively safe roads and routes,
- journeys must be as short as possible,
- the quickest and shortest routes must coincide,
- avoid the necessity to search for directions/destination,
- easily recognizable road categories,
- limit and make uniform the number of possible types of design,

- avoid encountering oncoming traffic,
- avoid encountering traffic crossing the road being used,
- separate types of traffic,
- reduce speed at potential points of conflict,
- avoid obstacles near the carriageway.

3.1.2. *Operational requirements*

The operational requirements have been formulated in such a way that the next step involves the design specifications. However, the operational requirements provide designers with many opportunities to vary the road design according to local conditions or their own preferences. The operational requirements must ensure that the differences between the road categories are greater than the differences within the road categories. *Table 2* illustrates these requirements for road sections, and *Table 3* illustrates the requirements for junctions.

	Requirement	Distributor road	Access road
B	Marking (longitudinal)	fully (but different from through-roads)	no
B	Physical separation of directions (number of lanes in one direction)	yes (1 or more)	no (only 1)
B	Pavement, surface irregularity	minor	major
B	Obstacle-free zone	medium	(very) small
B	Directional signing	(to be decided)	(to be decided)
B	Lighting	(to be decided)	(to be decided)
w	Speed limit (km/h)	50	30 or less
w	Type of physical separation	difficult to cross	not applicable
w	Emergency facility	hard shoulder or lay-by	no
w	Private or business accesses	no	yes
w	Crossing (mid-block / between junctions)	grade separated or install a quasi-junction	at grade
w	Parking	parking lane	carriageway
w	Public transport: stops	bus bay	carriageway
w	Cyclists on the carriageway	no	yes
w	Moped-riders on the carriageway	yes	yes
w	slow-moving motorized vehicles (e.g. agricultural vehicles)	yes	yes
w	speed-reducing facilities (e.g. humps)	occasionally	yes

B, w: see section 6.1.

Table 2. *Operational requirements for road sections within urban areas (Source: CROW, 1997)*.

Road category intersecting with	Distributor road	Access road
Through-road	interchange	not applicable
Distributor road	at grade, speed reduction, priority regulation	at grade, speed reduction, priority regulation
Access road	at grade, speed reduction, priority regulation	at grade, speed reduction, no specific priority regulation

Table 3. *Operational requirements for different types of urban junctions (Source: CROW, 1997)*.

3.2. **Predictability**

The mechanism which ensures the right level of predictability consists of two steps: Firstly, road users must be able to recognize the road category by a small number of design elements. Secondly, based on education and experience, road users should know which possible traffic situations belong to 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:

- marking,
- separation of directions,
- pavement, irregularity of the surface,
- obstacle-free zone (emergency lane on motorways).

This set is the outcome of research which focussed on rural roads (Kaptein & Theeuwes, 1996). However, this set has also been used for urban roads, and the relevance of the obstacle-free zone is particularly doubtful here because it will not be very prominent on such roads.

A follow-up to this research will also focus on urban roads.

4. Designing traditional urban main roads

The design of urban main roads in the Netherlands is not strictly governed by national design guidelines. Local governments are fully responsible for the design and lay-out of their roads. They can, however, consult the national set of (non-mandatory) recommendations (CROW, 1996). These recommendations cover the theoretical and practical aspects of urban road design. Because of the wide variety of urban areas (size, structure, land use), it was decided that these recommendations should not prescribe or even advise a standardized system of road classification or categorization.

The majority of these recommendations have been set up as a catalogue of traffic measures and provisions. Flow charts help the user to arrive at the right measure. But many users neglect these flow charts and select a measure from the catalogue which obviously meets their needs. This way of using the recommendations is not likely to contribute to a high level of consistency and uniformity in the urban road infrastructure.

5. Sustainably-safe urban distributor/main roads

Before starting to adapt the existing design guidelines for urban roads, a CROW working party has made an overview of the implications caused by applying the operational requirements to the design of urban roads. These implications are already known for residential areas/access roads. According to previous decisions regarding a sustainably-safe road network, residential areas should be transformed into zones with a speed limit of 30 km/h. This type of measure has been used many times since 1984 (when this measure was approved). However, many implications for urban main/distribution roads are unknown or are at least not very clear:

1. Some of the requirements (*Table 2*) are meant to underline the difference *between* road categories, while other requirements should guarantee the safety *within* a road category. However, the requirements in *Table 2* have not (yet) been classified according to these different aims.
2. Although the list of requirements is already quite long, some important requirements are still missing, e.g. requirements with regard to the network (distances between junctions, structure), with regard to discontinuities of the cross-section, and with regard to sight distances.
3. Which types of design element or combinations of elements belong to a certain requirement?
4. What should be the dimensioning of the design elements?
5. What is the effect (in relation to conflict reduction and/or accident reduction) of a certain design element?
6. And finally, do all requirements have the same 'weight' (is implementation of one requirement as important for road safety as implementation of another)?

Another important matter is the extent to which the sustainably-safe design will cope with the other aspects of an urban main road:

- accessibility (for all modes),
- car flow (on section level and on network level),
- environmental quality/liveability (for residents).

When these aspects are compared with the safety requirements, this results in a number of dilemmas. These dilemmas will be dealt with in Chapter 7 after discussing the above-mentioned implications caused by introducing the functional/operational requirements.

6. Implications of the functional/operational requirements

6.1. Different requirements for different aims

The set of requirements found to be important for *predictability* (marking, separation of directions, pavement, obstacle-free zone) is also relevant when clarifying the difference between road categories. But lighting and direction signing can be used for this aim too (see requirements with ‘B’ in *Table 2*). Váhl (1985) suggested a lighting system with lower lighting poles in residential streets and higher poles along main roads. In addition direction signs can vary in height and shape according to the road categories.
The other requirements (‘w’ in *Table 2*) are aimed at guaranteeing safety *within* a road category.

6.2. Additional requirements

The original list of requirements (*Table 2*) is missing several requirements which are relevant for road safety:
- The length of a road section/junction density: the flow task of a road section of a main road can only be fulfilled properly if the junction density and the length of the sections are in the right proportions. The flow task is also important for safety because the proper functioning of the main roads is a prerequisite for traffic calming in residential areas. Specifications for length and density are still being studied.
- The structure of the road network in residential areas: the network structure influences road safety; see Chapter 6.
- Discontinuities in the cross-section: these should be kept to a minimum. If a discontinuity is inevitable, road users should be given enough clues so that they can react adequately.
- Sight distances: a common design variable and an important ‘tool’ for predictability. However, this is inherently characterized by the trade-off between sufficient sight distance for drivers who have to stop or slow-down for crossing traffic and redundant sight distance which can easily result in speeding (exceeding the design speed/speed limit).
- Specific sign or marking for a road category: despite the requirements for the distinction between road categories, an unmistakable element could be added which reminds road users of the road category they are driving on.

6.3. Connecting design elements to requirements

Each requirement should be translated into at least one design element, including dimensioning. Most of the requirements have been formulated so that it is obvious which design element belongs to it, e.g. parking on distributor roads on a separate parking lane. However, the requirement ‘physical separation of directions’ is more ambiguous because it can be designed in many ways, ranging from a profiled marking line to a concrete barrier (AOSI, 1997). Some requirements, such as ‘cyclists on the carriageway’, have no direct connection with a design element but are formulated as a condition.

6.4. Dimensions of elements

Until now, the dimensioning of design elements has not occupied a prominent position in the sustainably-safe road system. However, the implementation of some parts of this system is imminent, and road designers are beginning to request more explicit guidelines on this subject. The sustainably-safe road system does not necessarily assign a characteristic dimension to each design element. However, a badly chosen dimension can spoil the work carried out on the higher design levels. Knowledge about this dimensioning can only be derived from new and existing ex-post research into the effects of elements which have been applied in practice. This type of research has many disadvantages - for example, sample size, statistical techniques, quality of data, confounding factors, regression-to-the-mean (see Opiela & Mcgee, 1995, for a more extensive list), - but there seems to be no other way of getting 'hard' data on this subject.

6.5. Effects of (combinations of) design elements on safety

Many studies have been carried out into the effects of different types and/or combinations of design elements. The results of some of these studies are relevant to urban main roads, and will be dealt with in this section.

6.5.1. *Private or business accesses*

According to the requirement no accesses are allowed on sections of urban main roads. This prevents conflicts arising from crossing manoeuvres. An exception has been made for merging and diverging manoeuvres by introducing semi-access points at which traffic is only allowed to go to the right (both on the main road and on the access road).
The safety aspects of this requirement are not purely theoretical, but only a few studies show a clear relationship between the access density (number of accesses per unit length) and the number of accidents. A frequently cited study by Fee et al. (1970) shows a quantitative relationship between the number of business accesses per mile (on three different types of urban main roads) and the number of accidents per million vehicle miles (accident rate). A more recent study by Li (1993) also shows a quantitative relationship between the number of business accesses per kilometre (on two-lane 'suburban highways') and the number of accidents per million vehicle kilometres.
Both studies have their origins in North-America; no European studies of this kind could be traced. Reducing the business access density seems to be - at least in the American situation - a way of increasing safety. Both studies also show that intersections density has a far greater effect on the accident rate.

6.5.2. *Pedestrian crossings on road sections*

In the nineteen-eighties the Dutch national government encouraged local road authorities to install different types of pedestrian crossings on urban main roads (e.g. by narrowing the carriageway, adding a median island).
A number of these crossings were recently evaluated by Bos & Dijkstra (1998). The overall effect on the total number of accidents was found to be minus 6 per cent (after correction for local trends). However, the number of

pedestrian accidents increased by 23 per cent. The number of pedestrians killed or injured in these accidents actually increased by 34 per cent! Fortunately this negative result was not shown for each type of crossing. Some types showed a positive result on the number of pedestrian accidents and casualties.
This result underlines the requirement to install a quasi-junction on road sections rather than separate mid-block crossings.

6.5.3. *Cyclists not on the carriageway?*

According to this requirement, cyclists should not be allowed to use the carriageway of urban main roads. This requirement aims at segregating cyclists and motor vehicles, and can be elaborated in two ways: by means of either a cycle path or a cycle lane (although a cycle lane is formally part of the carriageway). Both types of bicycle facilities have their advantages and disadvantages: a cycle path is safe on road sections, but not very safe at (minor) junctions, while the reverse is true for a cycle lane: safe at the (minor) junctions, less safe on sections (Welleman & Dijkstra, 1988). Cycle lanes are not safe at road sections mainly because the lanes are often too narrow (1.00 m instead of 1.50 m), car drivers can block the lane suddenly by opening car doors, and cars and trucks may park illegally on the lane. Nonetheless, cycle lanes are often implemented because the cross-section is too limited for cycle paths and because lanes are much cheaper. Cycle lanes can indeed be a reasonable option indeed if the width is 1.50 metres, and parking adjacent to the lane is not allowed.

6.5.4. *Facilities for reducing speed on main roads*

The speed limit on urban distributor roads will be 50 km/h. This limit also formally applies to junctions and at crossings. The question, however, is does this comply with the requirement ‘reduce speed at potential points of conflict’? The new guidelines for sustainably-safe rural roads (Infopunt Duurzaam Veilig, 1999) suggest halving the limit at junctions (also for main roads), which would mean 50 / 2 = 25 km/h. If this were applied at urban main junctions, speed-reducing facilities would become inevitable. This would certainly have an effect on the network flow. More research is needed to establish the pros and cons of this new type of speed limit, including speed-reducing facilities.

6.5.5. *Structure of the road network within residential areas*

The areas in between the main roads (*Figure 1*) affect the safety of these roads due to the number and the locations of access roads.
The structure of the road network within these (residential) areas not only determines the level of safety within the area - it also partly contributes to the safety on the surrounding main roads. Three structure types are relevant here: grid (Alexander, 1966), organic (Reichow, 1959) and limited access (Marks, 1957); see *Figure 2*.

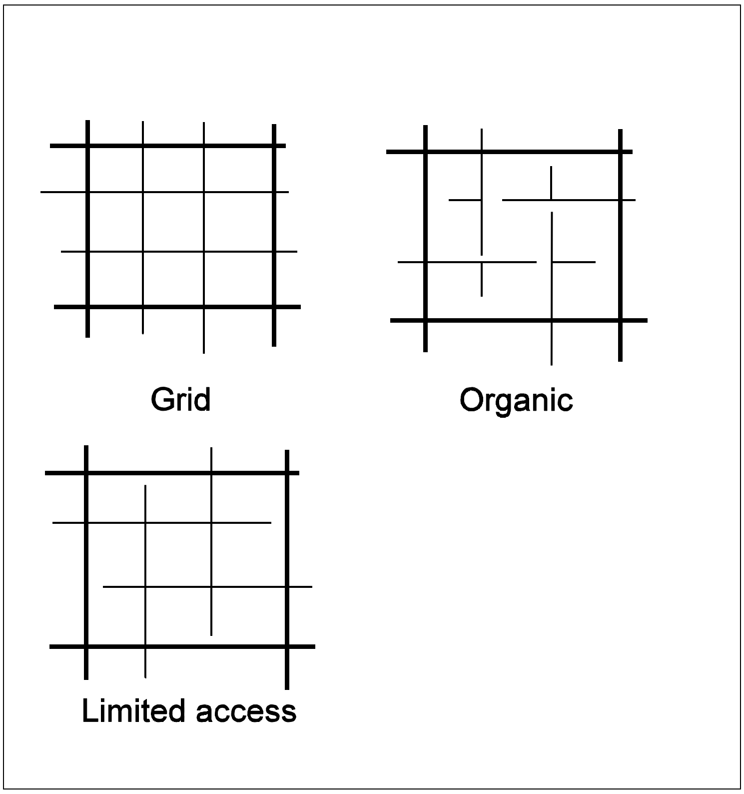

Figure 2. *Schematic representation of three types of road structures (Source: Dijkstra, 1997)*.

Dijkstra (1997) concluded that the ‘limited access’ structure produces the best results in four aspects: safety, accessibility, liveability and costs; see *Table 4*. The relative scores in *Table 4* were deducted from studies which used quantified indicators.
For main roads the consequence of ‘limited access’ is a lower junction density. This will have a positive effect on the accident rate (Fee et al, 1970; Li, 1993).

	Grid	Limited access	Organic
Road safety	-	+	++
Accessibility	++	+	-
Liveability	++	+	-
Costs	-	++	+

Table 4. *Relative scores of three structure types awarded to four aspects. The ‘-‘score indicates that an aspect has scored badly, i.e. high costs, many accidents, a lower liveability factor, poor accessibility (Source: Dijkstra, 1997).*

6.5.6. *Discontinuities in the cross-section*

A discontinuity (of any kind) can interfere with the predictability of traffic situations (see Chapter 2). In general, discontinuities in the cross section:
- force road users to change their position (right/left) and/or speed,
- result in more, different, or more complex manoeuvres by road users near the discontinuity.

Road users should be aware of the approach of a discontinuity, the nature of this discontinuity, and the behaviour requested at that point. Key words in this area are ‘self-explaining roads’ (Godthelp, 1990) and ‘positive guidance’ (Alexander & Lunenfeldt, 1990). These two approaches have not yet been studied in detail for (European) urban main roads.

6.5.7. *Sight distances*

Stopping sight distance in junction design is a function of design speed, and assumptions about reaction time and deceleration capability. The present road system allows drivers to go faster than the design speed, thus resulting in a stopping distance which is too long. In a sustainably-safe system, design speed and actual speed should be the same. The set of facilities and measures currently available does not yet guarantee that actual speeds will be restricted at all relevant points.
Not only the actual speed is relevant but also the actual sight distances. In many cases actual sight distances are limited (vegetation, illegal parking, billboards).
The predictability of a junction is a combination of expectation (what could happen), and observation (what can be seen).
Observation can be improved by making the road environment less complex, e.g. by removing obstacles that are preventing a good sight, and by separating different types of conflicts (in time or space).
To a large extent, expectation is a matter of education and training. The road environment can support or minimize this training by providing layouts which are as uniform as possible. Furthermore, the road environment should trigger the right expectations. Firstly, an approaching junction must be emphasized. Secondly, the possible types of encounters must be clear from the marking, signs and other clues before entering the junction. Finally, the layout of the junction must be logical and adapted to the skills of road users, preferably less vital road users.

6.5.8. *Types of main junctions*

Speed reduction near and at junctions plays an important role in satisfying ‘homogeneity’. Speed reduction can be attained by physical measures (including the application of roundabouts), and partly by signalization (e.g. by signal coordination at successive junctions). See *Table 5* for the type of junction recommended for each possible connection of the different road categories.

Road category intersecting with	Distributor road	Access road
Through-road	grade separated junction	not applicable
Distributor road	roundabout, signalized junction	roundabout, three-arm signalized or priority junction
Access road	roundabout, three-arm signalized or priority junction	three-arm junction

Table 5. *Recommended types of urban junctions (Source: Dijkstra, 1999)*.

In general four-arm junctions are not recommended for priority junctions: the number of accidents with injury at four-arm junctions is relatively high; see *Figure 3*. Roundabouts are safer than both three- and four-arm junctions with respect to the number of accidents with injury (VTI, 1998; Van Minnen, 1990; Stuwe, 1991). With regard to the type of junction, VTI (1998) found the 'best choice' for different combinations of entering flows on the major road and the minor road

An important, but not very surprising, finding in many accident evaluations is that the flow level is the most dominant predictor of the number of accidents (with injury) at junctions.

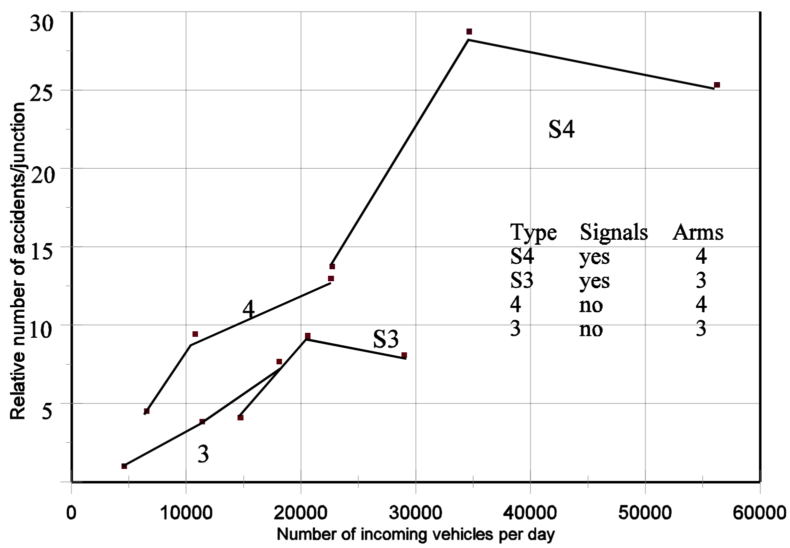

Figure 3. *Relative number of accidents at four types of urban junctions. The accident number is relative tot junction type 3 with incoming number of vehicles of 4,597 (Source: CROW, 1995).*

6.6. Weighing the requirements

Almost two dozen operational requirements (*Tables 2 and 3*) would suggest a certain level; of overkill or redundancy as input for preparing design guidelines. Some requirements have an obvious impact on safety (see the previous section), and should be given a prominent position in the guidelines: type of junction, speed reducing facilities, facilities for cyclists, mid-block crossings, private/business access, junction density, requirements regarding predictability. From a safety point of view these requirements are more important than the other requirements.

7. Dilemmas

A sustainably-safe road system is quite rigid, and some of the requirements will have an impact on accessibility (all modes), car flow, and environmental quality. Some of these impacts are treated below:

- Should the mobility of pedestrians and cyclists be restricted to increase the safety levels which apply to them - for example, by preventing mid-block crossing?

If the answer is no, safety can only be guaranteed by slowing down car traffic at any possible point where pedestrians and/or cyclists could cross.

- Should car flow on distributor roads be adapted to other types of road users on these roads - for example, by means of a general speed limit of 30 km/h?

This will have a negative effect on the functioning of the car network. However, the size of this effect has not yet been studied.

- Should car traffic be concentrated on a small number of main roads, thus creating environmental problems on these roads?

Residential areas will benefit if car traffic is concentrated on main roads. This should be considered as an important goal. Main roads will suffer from this policy, but local government can think of many compensating measures.

- Should the accessibility of shops and other business activities be restricted (less parking, no heavy vehicles) in order to create more safety (and a better car flow)?

Alternatives for parking and (un)loading, e.g. parking facilities in adjacent streets, off-street, or in garages , are not always possible. If main roads are more than just a traffic artery, parking must almost inevitably be accepted, despite the negative consequences for safety.

8. Conclusions and questions to be answered

8.1. Conclusions

The Dutch government has launched an ambitious programme to achieve a sustainably-safe traffic and transport system.
This system is based, among other things, on an extensive list of operational requirements for road design.
This list has many redundant requirements, is not always relevant for urban roads, and cannot always be (directly) translated into design guidelines.
There is insufficient knowledge available about the (safety) effects of the combination of (relevant) operational requirements.
A sustainably-safe system is very rigid, and has a major impact on other aspects of urban roads.

8.2. Questions to be answered

- Transforming urban main roads into sustainably-safe distributor roads requires greater knowledge about the (safety) effects of combinations of (relevant) requirements.
- Which combination of requirements would be optimal for a sustainably-safe system?
- If an optimal combination (package-in-one) existed, which strategies can be used to get practitioners and road users to accept this package?
- What level of unsafeness will remain after a full-scale introduction of the system?

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