

Land use planning in Safer Transportation Network Planning

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Safety principles, planning framework, and library information

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Contents of the project: The design tool - Safer Transportation Network Planning - is intended to guide network planners in designing safe transportation networks. This report is one in a series of reports which will be used in the development of the tool. The information in this report is intended to guide the structure and programming of Safer Transportation Network Planning with respect to land use planning.

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Summary

This report is one in a series of publications, used in the development of the network planning tool 'Safer Transportation Network Planning' (Safer-TNP). The publications were used to guide the development of planning structures, diagnostic tools, planning recommendations, and research information in the computer tool Safer-TNP.

Safer-TNP is a design tool that guides network planners in designing safe transportation networks (or improving safety of existing transportation networks). It provides the practitioner with diagnostic tools, and guiding information. At the moment of publication of this report, Safer-TNP is still being developed.

Besides this 'Land use planning report', the following reports have been published in this series:

- Access management in Safer Transportation Network Planning (Hummel, 2001a);
- Route management in Safer Transportation Network Planning (Hummel, 2001b);
- Intersection planning in Safer Transportation Network Planning (Hummel, 2001c).

The information in this report is used to guide the structure and the programming of different parts of the Safer-TNP tool with respect to land use planning. Described is, in a step-by-step procedure, what information is needed, and in what way the information should be processed. In the last chapter of the report, background information is provided to give users of the tool guiding information. Because of the specific purpose of this report, its structure and style deviate somewhat from regular research reports. Because the different chapters are used in different stages of the development of Safer-TNP, there is some repetition of information. Furthermore, the information is written in telegraphic style, to simplify the electronic packaging of information in Safer-TNP.

Land use planning may have an important influence on both mobility and traffic safety. This because the number of generated trips, the modal choice, the length of trips and the choice of route are to a large extent determined by the spatial organisation of land use.

In this report, effects on road safety of the following land use decisions are discussed:

- Distribution of origins and destinations
- Density of land use
- Urban growth patterns
- Safe network shapes
- Size of residential areas
- Provisions for alternative modes.

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1. Background

1.1. Definition

- In the context of safety planning, land use planning can be described as the planning of the relative location of different types of land use and of the way they are connected.
Land use planning deals with the spatial allocation of urban functions and the design of urban structures.
- The spatial organisation of land use types in an area determines:
 - the number of generated trips
 - the modal choice
 - the length of trips
 - the route choice.
- The chosen urban structure determines:
 - travel distances between the separate origins and destinations
 - general road network design
 - functional classification of road network.
- Land use planning can have a major influence on both mobility and safety.

1.2. Scope

- Important land use decisions with a possible influence on traffic safety are:
 - Spatial allocation of origins and destinations
 - Urban density
 - Patterns of urban growth
 - General shape of the network
 - Size of residential areas
 - Provisions for alternative modes.

1.3. Potential benefits

- If the safety effects of decisions in land use planning are considered at a very early stage of land use planning, developments can be directed towards a safer direction.
- Deficiencies in land use planning may create unsafe structures and shapes, and can lead to an increase in the amount of vehicle kilometres of travel. To prevent those deficiencies, traffic safety should be a major design consideration in an early stage of land use planning.

2. Planning principles

2.1. Safety principles

- The overall Transportation Network Planning approach is based on a framework of safety planning principles (i.e. as discussed in more detail in the 'Learn' Module).
 - **Minimize Exposure**
 - Promote efficient land use.
 - Provide efficient networks where the shortest routes coincide with the safest routes.
 - Promote alternative (non-motorised) modes.
 - **Minimize Risk**
 - Promote functionality, by preventing unintended use of each road.
 - *Provide homogeneity, by preventing large differences in vehicle speed, mass, and direction of movement.*
 - *Provide predictability, thus preventing uncertainty amongst road users by enhancing the predictability of the road's course, and enabling the behaviour of other road users to be anticipated.*
 - **Minimize Consequences**
 - Reduce speeds.
 - *Provide a forgiving roadside.*
 - *Protect vulnerable road users.*
- This chapter discusses the interaction between these principles and land use planning. The principles printed in italic are not considered to be relevant to land use planning and will therefore not be addressed in this chapter.

2.2. Minimize exposure

2.2.1. *Promote efficient land use*

Discussion

- Land use patterns with high-density housing or concentrated employment located in isolation from each other, produce heavier work-travel demands than when housing and employment are located in close proximity of each other.
- A combination of employment and housing reduces car travel demands.
- An increased urban density can cause a decrease in the number of generated car trips and a decrease in the number of injuries.
- Growth patterns that connect to the existing urban area generate less extra car trips than satellite growth separate from the existing urban area.

Guiding principles

- New developments should be planned in close proximity to the existing urban area.
- Employment and housing should not be separated spatially, but should be located in close proximity.
- To reduce the number of car trips and promote the use of alternative modes, densities of new developments should be high and building structures should be compact.

2.2.2. *Provide efficient networks*

Discussion

- To minimize exposure, trips should be short, and direct (without detours).
- To minimize the negative effects of rat runs, the shortest routes in a network should also be the safest routes.
- Large residential areas (without the presence of distributor roads) are safer than smaller residential areas with a larger amount of distributor roads. Residential areas without through-going distributor roads can be as large as 100 ha. before the accessibility of the area becomes problematic.

Guiding principles

- To minimize exposure, trips should be short, and direct (without detours).
- To minimize the negative effects of rat runs, the shortest routes in a network should also be the safest routes.
- Large residential areas without through-going distributor roads should be preferred. Those areas consisting of only residential streets can become as large as 100 ha.

2.2.3. *Promote alternative modes*

Discussion

- A combination of employment and housing in close proximity, promotes the use of alternative modes, because of the shorter distances.
- High urban densities promote the use of alternative modes, because of shorter distances and concentrated numbers of passengers.
- New developments in close proximity of the existing urban core cause more use of alternative modes than isolated satellite development.

Guiding principles

- New developments should connect directly with the existing urban core.
- Densities in urban areas should be high.
- Employment and housing should not be located isolated from each other, but mixed and in close proximity.

2.3. Minimize risk

2.3.1. *Promote functionality*

Discussion

- The number of casualty accidents decreases with an increase of the share of T-intersections and/or roundabouts (instead of cross-intersections).
- Organic networks and limited access networks are safer than grid networks (less intersections, more T-intersections, shorter straight sections).

Guiding principles

- For the network structure, an organic structure or limited access (tree) structure should be preferred.

2.4. Minimize consequences

2.4.1. *Reduce speeds*

Discussion

- On grid networks, possible driving speeds are higher than on limited access networks or organic networks, due to the longer straight road sections.

Guiding principles

- Organic network structures or limited access network structures should be preferred, rather than a grid network structure.

2.5. **Planning process**

Scale	Phase			
	Strategic policies	Shaping/ Conceptual	Definition	Feasibility
Regional	- growth patterns	- distribution of origins and destinations - density - growth patterns - network shapes - size of residential areas		
Municipal	- growth patterns	- distribution of origins and destinations - density - growth patterns - network shapes - size of residential areas		
Local area		- distribution of origins and destinations - density - network shapes - size of residential areas		
Element				

Table 1. *Phases and scales of the planning process.*

3. Planning practices

3.1. Understand the area

- In order to obtain a safe and consistent land use plan in a study area, it is essential to develop an understanding of the study area.
- At least the following items need to be surveyed to get an understanding of the study area:
 - Land use types
 - Spatial allocation of origins and destinations
 - Density
 - Network structure
 - Urban growth patterns.

3.1.1. *Land use types*

- The following land use types need to be distinguished:
 - residential
 - industrial
 - offices
 - shopping site
 - schools (special attention because of large numbers of vulnerable road users)
 - highway commercial development
 - recreational
 - farmstead/ field
 - resources (well site, gravel pit, log haul etc.).

3.1.2. *Spatial allocation of origins and destinations*

- The location of the different land use types has to be determined and plotted.
- Legislation on zoning for different land use types (e.g. industrial sites, resources) has to be surveyed.

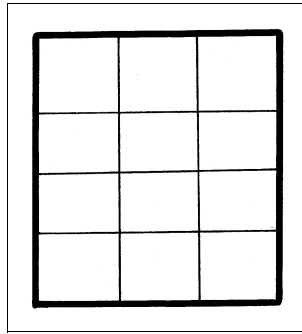
3.1.3. *Density*

- The following densities of land use need to be surveyed or estimated
 - Residential land use: number of inhabitants per hectare
 - Employment: number of employees per site or area
 - Other: number of daily visitors.

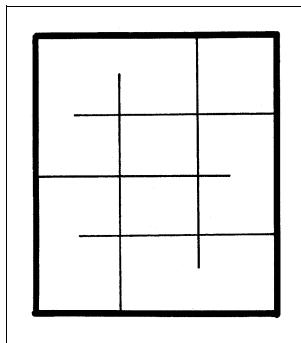
3.1.4. *Network structure*

- The type(s) of network structure(s) in the study area need to be determined. The following types of network structure can be distinguished.

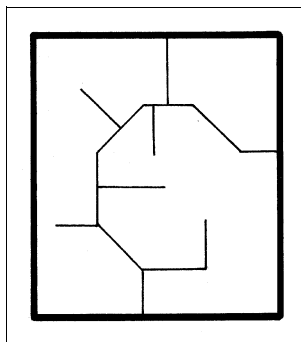
- Grid network structure



- Limited access network structure



- Organic network structure



3.1.5. *Urban growth patterns*

- The types of urban growth in the study area need to be determined. The following types of urban growth can be distinguished:
 - peripheral growth
 - corridor growth
 - satellite growth.

3.2. **Problem identification**

- To identify possible problems, desire lines between origins and destinations have to be visualised, and network structures have to be analysed.

3.3. Diagnostics

Possible safety problems can be caused by:

- Inefficient land use distribution
 - Can travel distances be shortened by a different location of origins and/or destinations?
 - Can travel distances be shortened by a more compact urban form?
 - Can traffic be reassigned to safer routes by the change of the location of origins and/or destinations?
- Unsafe network structure
 - Is the chosen network structure inherently safe?
- Do routes cross barriers such as high-volume roads or high-speed roads?
- Feasibility of alternative modes
 - Is the use of alternative modes promoted?
 - Short distances enable the transfer to alternative modes.
 - Location of origins and/or destinations in vicinity of transit line promotes the use of transit.
 - High urban densities improve the feasibility of transit, because of shorter distances and concentrated numbers of passengers.

3.4. Policy formulation

- Before generating different land use planning options, policies have to be formulated on the following items:
 - Allocation of urban functions
 - Urban density
 - Urban growth patterns
 - Shape of network structures
 - Size of residential areas (areas without distributor roads)
 - Promoting alternative modes and increasing feasibility of transit.

3.5. Option generation/ Option evaluation

- If in an existing or proposed network, incompatibilities are determined, the following actions can be undertaken:
 - I Solve causes:
 - change land use
 - change location of land use
 - change density of land use
 - change network structure
 - change urban growth pattern.
 - II Change symptoms:
 - route management
 - speed management
 - traffic management.
- In existing situations, the change of land use will be very difficult and in most cases impossible.
- The safety implications of the generated options should be carefully examined, and compared.

4. Library information

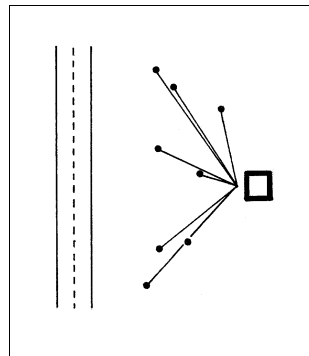
4.1. Understanding

- The relative location of different types of land use and the way they are connected are among the most important explaining variables for the number and length of trips in an area.
The spatial division of different functions in an area is the origin of trip generation.
- The spatial organisation of land use types in an area determines:
 - the number of generated trips
 - the modal choice
 - the length of trips
 - the route choice.All of the abovementioned factors determine the level of traffic safety in an area.
- Choices made in urban planning are of direct influence on the design of the road network (network structure, functional classification, length of straight road sections etc.).
- Despite the major influence of land use planning on mobility and safety, traffic safety is often not an important consideration in the spatial allocation of urban functions and the design of urban structures.
- Traffic safety is often introduced as a design consideration after major decisions on spatial allocation, network structures and shape of the network have already been taken.
- Negative safety impacts of decisions on land use planning are often very difficult to mitigate or redesign. When built, the structure will exist for a long period. Only marginal improvements can then be made.
- To prevent deficiencies in land use planning that can cause unsafe structures and shapes, traffic safety should be a major design consideration at an early stage of land use planning.

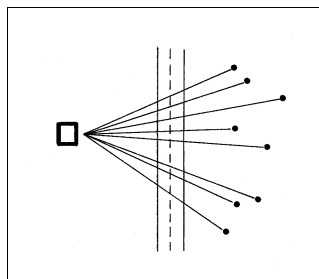
4.2. Distribution of origins and destinations

- The effects of workplace location and workplace concentration on traffic safety were found to be positive, but small (Ogden, 1970).
A carelessly chosen location can however create long and/ or hazardous routes.
- A land use pattern with high density housing or concentrated employment located in isolation from each other, produces heavier work-travel demands than when they are located in close proximity of each other (Ogden, 1970).

- A combination of employment and housing reduces car travel demands. Work travel lengths are reduced, and alternative modes are promoted, because of the shorter distance (Verroen, 1994; Hilbers, 1996).
- Analysis of simulations showed that the number of vehicle kilometres in combined/mixed situations can be approximately 1.5% lower than in situations where employment and houses are separated. The number of casualties was found to be approximately 0.5% lower (Hilbers, 1996).
- Frank & Pivo (1994) concluded that density and mix are both related to mode choice. The level of land use mix at the trip origins and destinations is related to the reduction in single occupant vehicle (SOV) travel and an increase in transit and walking.
- Ewing, Haliyur & Page (1994) concluded from a travel survey for Palm Beach County, Florida, that a mixed concentration of facilities enables households to link trips, thus decreasing the number of vehicle miles travelled.
- Facilities that attract vulnerable road users, should be located in such a way that:
 - routes to and from the facility are short and direct
 - routes to and from the facility do not cross major barriers (e.g. hazardous or high-volume roads). See figures below.



Instead of...

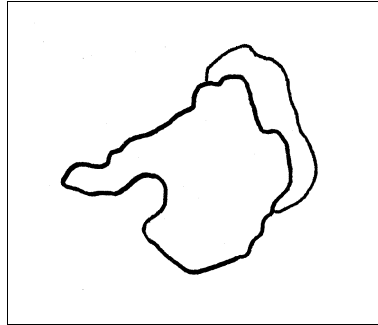


4.3. Density

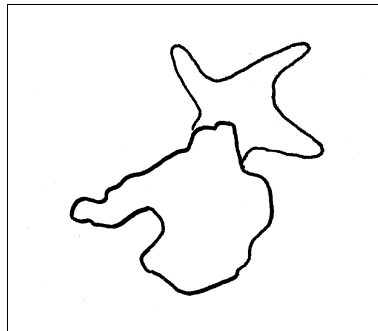
- In a compact urban design with high-density land use, distances between origins and destinations are small.
- Reduced trip lengths improves road safety:
 - Shorter trip length results in reduced exposure to risk.
 - Shorter trip length promotes the use of alternative (safer) transportation modes.
- High densities cause compact traffic patterns, causing:
 - more walking and cycling trips
 - improved basis for public transportation, because more urban functions are located in the vicinity/ influence of stops.
- New developments in the vicinity of existing urban structures proved to cause less extra mobility and accidents than more spread-out development (Hilbers, 1996).
- Analysis of traffic model results in Melbourne showed that increased densities have a positive effect on the generated mobility, but that effects are very small.
Large changes in density are needed to cause significant changes in work-travel characteristics (Ogden, 1970).
- A German study on the relation between safety and building structures in existing German and Dutch cities, found a strong relation between density (number of square metres per inhabitant) and the number of accidents (Apel, Kolleck & Lehmbrock, 1988).
A more recent German study (Becker et al., 1992) also found that an increased density causes a decrease in the number of injuries.
- Compact patterns of regional densities for residence and employment decrease the number of vehicle miles travelled (Lupa et al., 1995).
- Steiner (1994) concluded that residents of high-density areas use transit or walk more frequently than residents of lower-density areas, and travel shorter distances overall. Steiner also found that the rate of automobile ownership was higher in low-density areas. It has to be noted that the results were not corrected for possible differences in income.
- Frank & Pivo (1994) concluded that density and mix are both related to mode choice. Car use and the use of single occupant vehicles (SOV) is higher in areas with lower densities.
- Ewing, Haliyur & Page (1994) concluded from a travel survey for Palm Beach County, Florida, that households in a sprawling suburb generate almost two-thirds more vehicle hours or travel per person than comparable households in a traditional city.

4.4. Growth patterns

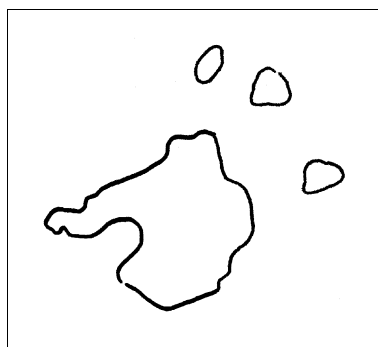
- In the analysis of the growth of urban settlements, the following basic growth patterns can be distinguished.
 - a. Peripheral growth: more or less uniform growth around the fringes of an urban area.



- b. Corridor growth: channelisation of growth in corridors radiating from the urban core.



- c. Satellite growth: development of satellite towns, completely separated from each other and from the urban core.



- The following additional characteristics were distinguished in a Dutch study on the safety effects of urban growth (Hilbers, 1996):
 - a. A mix of functions versus spatial separation: Mixture is interpreted as the bringing together of the urban functions employment, urban facilities and the residential function; separation is the physical separation of those functions.
 - b. Satellite growth versus connecting with existing urban area: Connecting with the urban area can be either peripheral or corridor growth.
 - c. Orientation on one existing town versus orientation on more than one existing town.
 - d. Location in the vicinity of an existing freeway.
 - e. Urban growth combined with substantial realisation of additional infrastructure for public transportation and car.

- Developments with a mixture of employment, urban facilities and housing reduce car travel demands. Work travel lengths are reduced and alternative modes are promoted, because of the shorter work-travel distances (Hilbers, 1996; Ogden, 1970)

Transport mode	Passenger kilometres	Deaths	Casualties
Cars inside urban areas	+ 0.1%	0.0%	+ 0,1%
Cars 80 km/h roads	+ 0.1%	+ 0.3%	+ 0.2%
Cars freeway	+ 0.7%	+ 0.4%	+ 0.3%
Public transportation	+ 0.3%	0.0%	0.0%
Walking and cycling	0.0%	- 0.1%	0.0%
Total	+ 1.2%	+ 0.6%	+ 0.5%

Table 2. *Effects of separation of functions on mobility and safety, in comparison with mixture of functions (Hilbers, 1996).*

- Connecting with existing urban areas leads to less mobility and less casualties than satellite growth (see Table 3).
Ogden (1970) found similar effects, but differences were very small, and mainly located in fringe areas.

Transport mode	Passenger kilometres	Deaths	Casualties
Cars inside urban areas	+ 0.1%	0.0%	+ 0,1%
Cars 80 km/h roads	- 0.1%	- 0.1%	- 0.1%
Cars freeway	0.0%	0.0%	0.0%
Public transportation	- 0.3%	0.0%	0.0%
Walking and cycling	0.0%	- 0.1%	- 0.1%
Total	- 0.3%	- 0.2%	- 0.1%

Table 3. *Effects of satellite growth on mobility and safety, in comparison with connecting with existing urban areas (Hilbers, 1996).*

- Differences in mobility between peripheral growth and corridor growth were found to be negligibly small, although in general trips associated with the fringes of the peripheral growth alternatives were slightly shorter than those from the fringes of the corridor growth alternative (Ogden, 1970).
- The development of a network of cities (orientation on more than one town) causes slightly more mobility and more casualties than a scenario with orientation on one town/ centre (*Table 4*).
The increase in casualties is slightly larger than the increase in mobility, because a substantial part of the growth in mobility is located outside the built up area (more hazardous roads).

Transport mode	Passenger kilometres	Deaths	Casualties
Cars inside urban areas	0.00%	+ 0.01%	+ 0.01%
Cars 80 km/h roads	+ 0.04%	+ 0.11%	+ 0.08%
Cars freeway	+ 0.02%	+ 0.02%	+ 0.02%
Public transportation	+ 0.04%	0.00%	0.00%
Walking and cycling	0.00%	+ 0.04%	0.00%
Total	+ 0.10%	+ 0.18%	+0.11%

Table 4. *Effects of network cities on mobility and safety, in comparison with orientation on one town/ centre (Hilbers, 1996).*

- Location of a new development in the vicinity of a freeway generates an increase in mobility, but causes a decrease in the number of casualties (*Table 5*). The additional vehicle kilometres are mainly travelled on the freeway (safe road type) and are diverted from the underlying network (less safe roads).

Transport mode	Passenger kilometres	Deaths	Casualties
Cars inside urban areas	+ 0.5%	+ 0.6%	+ 0.3%
Cars 80 km/h roads	- 1.9%	- 3.5%	- 4.0%
Cars freeway	+ 4.1%	+ 2.5%	+ 3.0%
Public transportation	- 0.3%	0.0%	0.0%
Walking and cycling	- 0.2%	- 1.5%	- 1.2%
Total	+ 2.2%	- 1.9%	- 3.7%

Table 5. *Effects on mobility and safety, of a location in the vicinity of a freeway, in comparison with a location further from the freeway (Hilbers, 1996).*

- Realisation of extra infrastructure for cars and public transportation causes an increase in mobility and a slight increase in deaths (*Table 6*).

Transport mode	Passenger kilometres	Deaths	Casualties
Cars inside urban areas	+ 0.6%	+ 0.3%	+ 0.5%
Cars 80 km/h roads	- 0.9%	- 1.4%	- 1.0%
Cars freeway	+ 5.6%	+ 2.8%	+ 1.9%
Public transportation	+ 1.1%	0.0%	0.0%
Walking and cycling	- 0.3%	- 1.2%	- 1.4%
Total	+ 7.1%	+ 0.5%	0.0%

Table 6. *Effects of extra infrastructure for cars and transit on mobility and safety (Hilbers, 1996).*

4.5. Safe network shapes

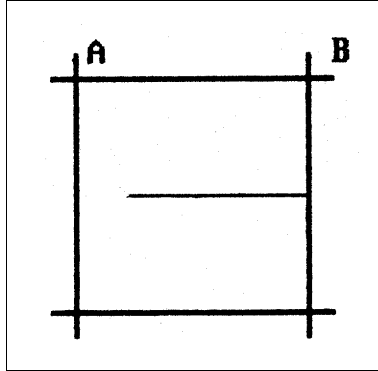
- The number of casualty accidents decreases with an increase of the share of T-intersections (instead of cross intersections; Dijkstra, 1988).
- Cerwenka & Henniger-Hager (1984) studied the number of accidents per 1000 inhabitants and per hectare for five types of residential areas:
 - single family dwellings
 - closed building blocks
 - groups of row houses
 - compact high rise building structures
 - mixed building structures (mix of previous types).

The study showed that both the number of accidents per 1000 inhabitants and the number of accidents per hectare were largest for closed building blocks, and smallest for mixed building structures. A pluriform building structure improves traffic safety.
- Network structures should provide good accessibility as well as high safety standards.
- Number of casualties = travelled distance x risk
Reduction of the number of casualties will occur after:
 - reduction of risk per road type
 - reduction of travelled distance
 - shift of traffic to safer road types.
- Trips should be short, and direct (without detours).

- Effects of dead-end streets on travelled distance (values are relative distances; Van Minnen, 1993):

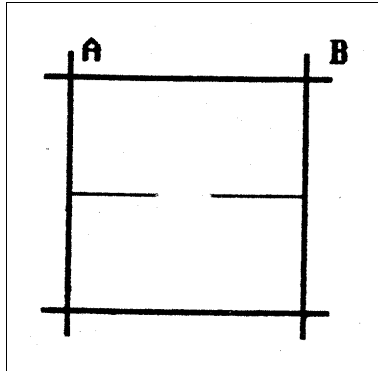
Dead-end residential street

Travelled distance on residential street	10
Travelled distance on arterial	20
Total travelled distance	30



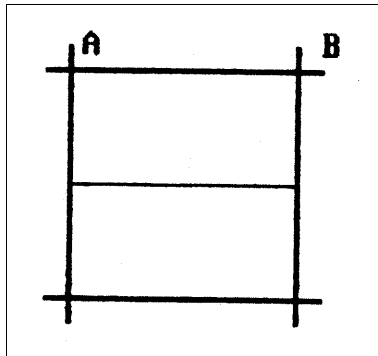
Cut residential street

Travelled distance on residential street	5
Travelled distance on arterial	20
Total travelled distance	25



Closed circuit

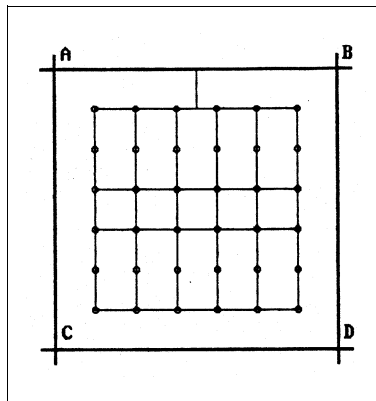
Travelled distance on residential street	10
Travelled distance on arterial	10
Total travelled distance	20



- Dead-end streets limit through-traffic and therefore limit travelled distances on residential streets, but cause detours and therefore longer total travelled distances.
- Smallest travelled distances are reached with through-going (closed-circuit) streets.
- Effects of the number of connections on arterials (Van Minnen, 1993):

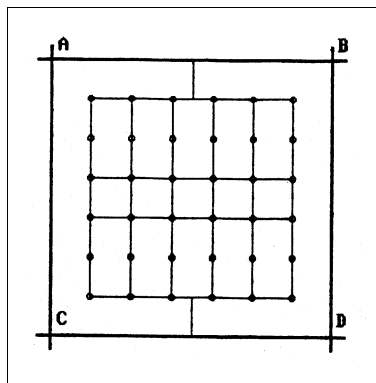
One connection

Travelled distance on residential streets	180
Travelled distance on arterial	252
Total travelled distance	432



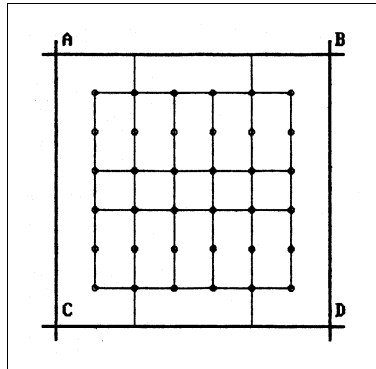
Two connections

Travelled distance on residential streets	150
Travelled distance on arterial	168
Total travelled distance	318



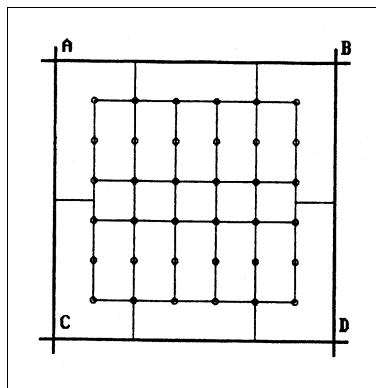
Four connections

Travelled distance on residential streets	126
Travelled distance on arterial	150
Total travelled distance	276



Six connections

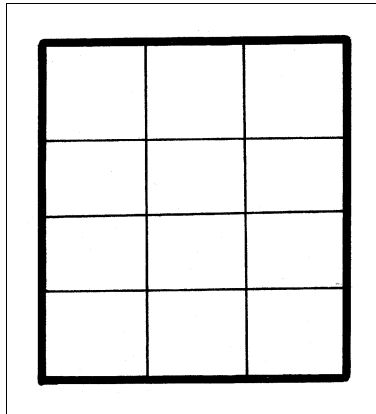
Travelled distance on residential streets	102
Travelled distance on arterial	169
Total travelled distance	271



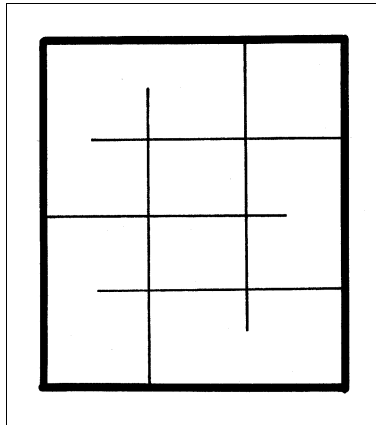
- A closed network structure with a large number of access points generates the smallest travelled distances.

- There are three basic road structures:

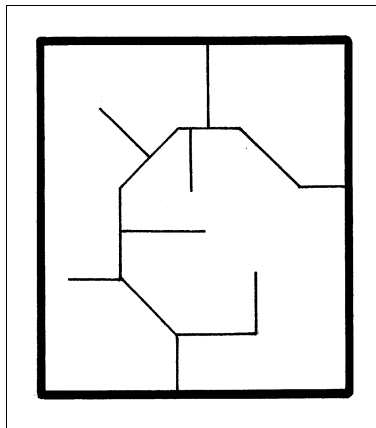
Grid network:



Limited access network



Organic network



- The suitability of the three different network structures can be judged by the following indicators:

Road safety

- travel distances
- volumes on residential streets (exclusion of through-traffic)
- driving speeds (limited number of straight road sections)
- share of T-intersections.

Accessibility

- travel distances
- detours
- distribution of volumes on road network.

Costs

- length of traffic network's roads
- requirement of speed reducing measures.

- Grid network:

Road safety

- smallest travel distances
- through-traffic through residential streets
- long straight road sections enable high driving speeds
- many cross intersections.

Accessibility

- smallest travel distances
- direct connections
- even distribution of volumes on network.

Costs

- Length of traffic network's roads is slightly bigger than for limited access and organic structure.
- Speed reducing measures are needed, because of long straight road sections.

- Limited access network:

Road safety

- Travelled distances are longer than on grid network, but shorter than on organic network.
- Because of dead ends, there is no through-traffic on residential streets; volumes on residential streets are limited.
- Because of shorter straight road sections, speeds are lower than on grid network.
- Limited access networks have less intersections and a larger share of T-intersections than grid networks.

Accessibility

- Travelled distances are longer than on a grid network, but shorter than on an organic network.
- Detours are generated.

- Because there are no closed circuits, detours are needed, and there is no even distribution of volumes on the network.

Costs

- The total length of the traffic network's roads is slightly smaller than on a grid network.
- Because of shorter straight road sections, fewer speed reducing measures are needed than on grid network

- Organic network:

Road safety

- Travelled distances are longer than on grid network and limited access network. Journey times can be up to 30% longer than on a grid network.
- There is no through-traffic on residential streets. Volumes on residential streets are limited.
- Because of short straight road sections, organic networks have lower driving speeds than grid and limited access networks.
- Organic networks have less intersections than grid networks and limited access networks.
- Organic networks have a larger share of T-intersections than grid networks and limited access networks.

Accessibility

- Travelled distances are longer than on grid network and limited access network. Journey times can be up to 30% longer than on a grid network.
- Because there are no closed circuits, detours are needed.
- Traffic is not evenly distributed over the road network.

Costs

- The total length of the traffic network's roads is smaller than on grid networks, and comparable with the length on limited access networks.
- Because of the speed reducing character of the network, organic networks need less additional speed reducing measures than grid networks and limited access networks

- In summary:

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

Table 7. Score of three network structures on three indicators. The score '- ' indicates that an aspect has scored badly: high costs, many accidents, poor accessibility.

- Modelling results show that the neotraditional network (grid) generates approximately 10.5 percent fewer kilometres of travel during the a.m. peak than does the conventional network (limited access and organic; McNally & Ryan, 1993).
- The mean trip length in the neotraditional network (grid) is approximately 15.5 percent shorter than the trip length in the conventional network (limited access and organic; McNally & Ryan, 1993).

4.6. Size of residential areas

- Large residential areas, without through-going distributor roads, have the following advantages:
 - reduced length of distributor roads in total network (residential street is safer than a distributor)
 - reduced number of intersections with distributor roads
 - reduced need for crossing distributors within area.
- The upper limit of the size of residential areas (without distributors) is set by the following criteria:

Road safety:

- Limit the travelled distance within the area.
- Limit the traffic volumes within the area.
- Prevent through-going motorised traffic through the area.
- Limit speeds of motorised traffic.

Liveability:

- Limit traffic volumes in the area (simplified crossing by pedestrians and cyclists, environmental improvements).
- Limit traffic volumes on surrounding distributor roads.
- Limit speeds of motorised traffic (simplified crossing by pedestrians and cyclists, environmental improvements).

Accessibility:

- Accessibility for emergency response vehicles.
- Accessibility of urban facilities by pedestrians and cyclists.
- Accessibility for public transportation
- Accessibility for cars.

- Review of the abovementioned criteria gave the following limiting conditions for the size of residential areas (Van Minnen, 1999):
 - Total travelled distances (on residential streets and distributor roads):
Total travelled distances are hardly influenced by the size of the residential area. No limiting values can be set.
 - Travelled distance on residential streets:
An increasing size results in an increase of travelled distance on residential streets. No limiting values can be set.
 - Volumes on residential streets:
If a residential area with only one connection to a distributor is larger than 20 - 30 hectares, volumes on residential streets exceed 3000 - 5000 vehicles per day. In a situation with a large number of connections, the size of the residential area can be up to 200

hectares, without exceeding an average daily traffic of 3000-5000 vehicles (*Table 8*).

Size of area (ha.)	Density (houses per ha.)	Number of houses	Volume (ADT)	Maximum volume for given number of exits								
				1	2	4	6	8	10	12	16	20
10	30	300	1500	1500	900	450	300	225	180	150	113	90
10	45	450	2250	2250	1350	675	450	338	270	225	169	135
10	60	600	3000	3000	1800	900	600	450	360	300	225	180
20	30	600	3000	3000	1800	900	600	450	360	300	225	180
20	45	900	4500	4500	2700	1350	900	675	540	450	338	270
30	30	900	4500	4500	2700	1350	900	675	540	450	338	270
20	60	1200	6000	6000	3600	1800	1200	900	720	600	450	360
40	30	1200	6000	6000	3600	1800	1200	900	720	600	450	360
30	45	1350	6750	6750	4050	2025	1350	1013	810	675	506	405
30	60	1800	9000	9000	5400	2700	1800	1350	1080	900	675	540
40	45	1800	9000	9000	5400	2700	1800	1350	1080	900	675	540
60	30	1800	9000	9000	5400	2700	1800	1350	1080	900	675	540
40	60	2400	12000	12000	7200	3600	2400	1800	1440	1200	900	720
80	30	2400	12000	12000	7200	3600	2400	1800	1440	1200	900	720
60	45	2700	13500	13500	8100	4050	2700	2025	1620	1350	1013	810
100	30	3000	15000	15000	9000	4500	3000	2250	1800	1500	1125	900
60	60	3600	18000	18000	10800	5400	3600	2700	2160	1800	1350	1080
80	45	3600	18000	18000	10800	5400	3600	2700	2160	1800	1350	1080
120	30	3600	18000	18000	10800	5400	3600	2700	2160	1800	1350	1080
100	45	4500	22500	22500	13500	6750	4500	3375	2700	2250	1688	1350
150	30	4500	22500	22500	13500	6750	4500	3375	2700	2250	1688	1350
80	60	4800	24000	24000	14400	7200	4800	3600	2880	2400	1800	1440
120	45	5400	27000	27000	16200	8100	5400	4050	3240	2700	2025	1620
100	60	6000	30000	30000	18000	9000	6000	4500	3600	3000	2250	1800
200	30	6000	30000	30000	18000	9000	6000	4500	3600	3000	2250	1800
150	45	6750	33750	33750	20250	10125	6750	5063	4050	3375	2531	2025
120	60	7200	36000	36000	21600	10800	7200	5400	4320	3600	2700	2160
150	60	9000	45000	45000	27000	13500	9000	6750	5400	4500	3375	2700
200	45	9000	45000	45000	27000	13500	9000	6750	5400	4500	3375	2700
200	60	12000	60000	60000	36000	18000	12000	9000	7200	6000	4500	3600

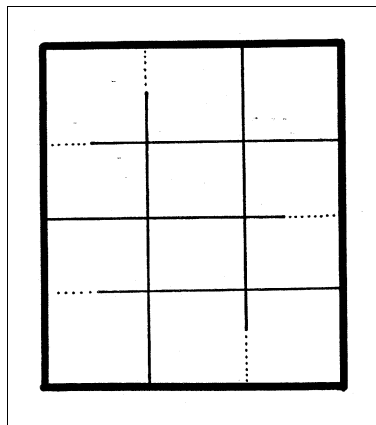
Table 8. Maximum volumes on the exits of a residential area, dependent on size of area, densities, and number of connections. The results are based on theoretical calculations (Van Minnen, 1999).

- Volumes on distributors:
An increase in size results in an increase of volumes on distributor roads. In typical residential areas problems can arise if the size of the residential area is larger than 100 hectares.

- Speed on residential streets:
Up to a size of 200 hectares, the size of the residential area has no influence on the speed on residential streets.
 - Speed on distributor roads:
The size of the residential area has no influence on the speed on distributor roads.
 - Accessibility for pedestrians and cyclists, inside residential area:
Larger residential areas increase the accessibility for pedestrians and cyclists.
 - Accessibility for pedestrians and cyclists, external relations:
The size of the residential area has no influence on the external accessibility of pedestrians and cyclists.
 - Accessibility for cars:
An increasing size of the residential area decreases the accessibility for cars slightly. No limiting values can be set.
 - Accessibility for emergency response vehicles:
An increase in the size of the residential area can increase the emergency response time. For a fire truck, the additional response time with increasing size ranges from 11 seconds (growth to area size of 25 hectares) to 31 seconds (area size of 200 hectares).
 - Accessibility for public transportation:
The extra travel time for areas larger than 60 - 70 hectares, exceeds one minute.
- Conclusion:
The size of residential areas (only residential streets) should be as large as possible.
However:
If the size exceeds 100 ha. traffic volumes on distributor roads become too large; If the size exceeds 200 ha. traffic volumes on residential streets become too large.
Accessibility for emergency response vehicles and public transportation should be monitored carefully.

4.7. Provisions for alternative modes

- To promote the use of alternative modes (walking, cycling, transit), short and direct routes are very important.
- A grid network provides short and direct routes, and is therefore the most appropriate network structure for alternative modes.
- Other network structures could be adapted by creating shortcuts for exclusive use by the alternative modes (cycle track, bus lane). In this way also limited access or organic networks can provide short and direct routes to promote alternative modes



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