Intersection planning in Safer Transportation Network Planning

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Safety principles, planning framework, and library information

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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 'Intersection 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);
- Land use planning in Safer Transportation Network Planning (Hummel, 2001c);

The information in this report will be used to guide the structure and the programming of different parts of the Safer-TNP tool with respect to intersection 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.

Decisions in the design of intersections are often implicitly made in the network planning phase. It is therefore important to consider safety implications of these decisions in this early design phase. A choice for the safer three-legged intersection or the roundabout, should not be made physically impossible in the network design.
In this report the safety characteristics of intersection types, intersection spacing, and design characteristics are discussed. Recommendations and guiding information is provided.

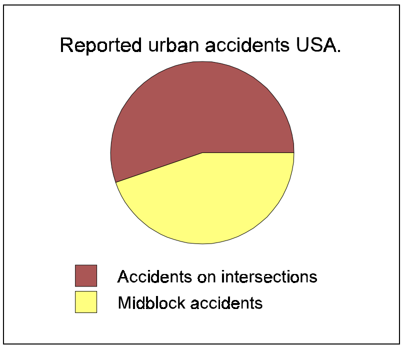
Contents

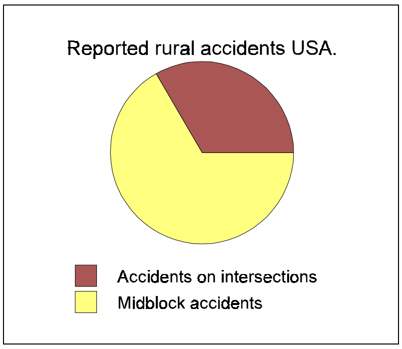
1. Background

1.1. Definition

- Intersections are important elements in a road network. The planning, distribution and lay-out of intersections determine:
  - safety of the network
  - efficiency of the network
  - travelling speeds on the network
  - costs of operation
  - capacity of the network.

- Safety of the network:
  - Intersections are the most critical elements in a road network. Road users of different types, in different masses, from different directions and moving at different speeds have to use the same space, resulting in a large number of potential conflicts.
  - Whereas intersections constitute a very small part of the entire transportation network, more than 50% of all motor vehicle accidents occur at intersections. In some European countries percentages of up to 70% of the total accident number are reported.





Figures 1.a and 1.b. *Accident rates on intersections in the USA (Kuciemba & Cirillo, 1992).*

- Because of the over-representation of intersection-accidents, intersections require special attention in the planning and designing of road networks.

- Objectives of safe intersection planning:
  A. Optimum spacing
  B. Safe configuration
  While:
  C. Facilitating capacity, ease and comfort.

1.2. Scope

- The most important decisions concerning the design of intersections are (often implicitly) made in the network planning process. Generally, once a less favourable choice has been made in this planning phase, the negative consequences cannot easily be reversed in the geometric design phase.
  Safe intersection planning is therefore an important aspect in the network planning phase.
- Decisions in the network planning phase generally affect one or more of the following elements:
  A: Optimum spacing:
    - number of intersections
    - intersection spacing.

  B: Safe configuration:
    - intersection types (for instance, once the choice for a cross intersection has been made in the planning phase, this choice cannot easily be converted to the safer T-intersection)
    - general lay-out of the intersection
    - intended use of the intersection (priority regulations, signalization).

1.3. Potential benefits

The potential benefits of incorporation of intersection planning in the network planning phase are:

- Specific attention to intersection planning in the network planning phase may seriously improve the safety of the entire road network.
- Paying attention to (often implicitly made) choices for intersection design in the planning phase, may prevent unfavourable choices resulting in lower safety levels and/or high costs of reconstruction or maintenance.

2. Planning activities

2.1. Activities

I Planning Framework

At the start of an intersection planning exercise, it is important to develop an understanding of the study area. At least the following elements need to be surveyed to obtain an understanding of the study area:

- Local policies
- Classified road network (existing road network)
- Future plans (land use plans and traffic plans)
- Desire lines and traffic volumes
- Travel times
- Emergency response centres/ routes/ targets.

II Diagnostics

Intersections in the existing network should be studied and evaluated. At least the following aspects should be studied:

- Accessibility
- Conflicting volumes
- Number of intersections in study area
- Spacing between intersections
- Intersection types used (and on which road category)
- General layout of intersections.

III Option generation and evaluation

A number of possible options for the new situation should be designed. Each option should be evaluated and -if necessary- refined. Based on the evaluation, one final option can be chosen.

Refinements or improvements of intersection safety in the network may be divided into:

a. Deal with causes of poor safety:
   - remove, relocate or add intersections
   - change intersection type or layout

b. Deal with symptoms of poor safety:
   - change road form/ speed management.

- Important factors affecting the safety of intersections are:

  Optimum spacing:
  1. number of intersections
  2. intersection spacing.

  Safe configuration:
  3. intersection type:
     - number of legs
     - basic form
  4. general layout:
     - angle of intersection
     - sight distances
     - alignment
     - approach speed

    - provisions for vulnerable road users
    - orientation of staggered T-intersections
5. intended use of the intersection:
    - priority regulations
    - signalization.

- Although general layout and choice of intended use are generally considered to be factors of geometric design, the most important impact of these factors is often established in the network planning phase:
    - The angle of intersection is determined by the network sketch (orientation of network links).
    - Sight distances are determined by the location of buildings or other visual obstructions in the proximity of intersections (limited sight angles).
    - The alignment is determined in the network sketch.
    - The approach speed is mainly determined by the alignment and length of the approaching links.
    - Priority regulations are dependent on categorisation of network links (road categories and functions of intersecting links).

2.2. Planning process

Scale	Phase			
	Strategic policies	Shaping/ Conceptual	Definition	Feasibility
Regional		- Number of intersections - Intersection spacing - Number of legs - Angle of intersection - Orientation T-intersect.	- Intersection spacing (fine tuning) - Basic form - Alignment - Auxiliary lanes - Channelisation - Sight distances - Approach speed - Vulnerable road users	
Municipal		- Number of intersections - Intersection spacing - Number of legs - Angle of intersection - Orientation T-intersect. - Intended use	- Intersection spacing (fine tuning) - Basic form - Alignment - Auxiliary lanes - Channelisation - Sight distances - Approach speed - Vulnerable road users	- Intended use
Local area		- Number of intersections - Intersection spacing - Number of legs - Angle of intersection - Orientation T-intersect. - Intended use	- Intersection spacing (fine tuning) - Basic form - Alignment - Auxiliary lanes - Channelisation - Sight distances - Approach speed - Vulnerable road users	- Intended use
Element			- Intersection spacing (fine tuning) - Basic form - Alignment - Auxiliary lanes - Channelisation - Sight distances - Approach speed - Vulnerable road users	- Intended use

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

The emphasis of intersection planning will be mainly on the four cells in the centre of the matrix. These are the planning stages during which the main safety effects of safe intersection planning will be attained (highest potential leverage for safety).

3. Safety principles

3.1. Collision characteristics

- Accident analysis in Australia (Cairney & Catchpole, 1991) showed the following accident types on urban intersections (results corrected for right side driving traffic):

Accident type	Percentage
Cross traffic	16 %
Left near	17 %
Left against	16 %
Rear-end	16 %
Single vehicle	17 %
Pedestrian	13 %
Pedal cycle	5 %

Table 2. *Percentage of total injury accidents on urban intersections for seven accident types (Cairney & Catchpole, 1991).*

- Sixty percent of all drivers involved in an intersection accident failed to see the other unit in time to avoid a collision.
- Visual obstructions were a contributing factor in 35% of these cases. A majority of these visual obstructions were manoeuvring vehicles.

- 51 % of all rear-end accidents involved vehicles waiting to make a left-turn manoeuvre from main road to minor road. By comparison, only 1% rear end accidents involved right-turning vehicles being hit.

- Of all accident participants who saw the other vehicle or pedestrian, 12% misjudged its/his/her speed or distance.

3.2. Planning principles

Introduction

- 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**
    - *Provide compact urban form*
    - Provide efficient networks
    - Promote alternative modes

  - **Minimize risk**
    - Promote functionality, by preventing unintended use
    - Provide homogeneity, by preventing large differences in vehicle speed, mass and direction of movement.

    - Provide predictability (of the course of the road), thus preventing uncertainty amongst road users, 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 intersection planning. The principle printed in italic is not considered to be relevant to intersection planning and will not be addressed in this chapter.

3.3. Minimize exposure

3.3.1. *Provide compact urban form*

Discussion

- The chosen urban form influences the density of the road network.
  A densely designed network requires a dense network of intersections.
  Yet:
  - An intersection is a hazardous element in the network; the number of intersections should therefore be limited.
  - A dense intersection network may cause insufficient intersection spacing to ensure the safety of individual intersections.

Guiding principles

- A compact urban form improves safety by reducing exposure by:
  - reducing the travelled distance,
  - thereby allowing the use of safer travel modes.
- A compact urban form requires a dense network of intersections, which could influence traffic safety negatively. The intersection spacing should be carefully monitored.
- The number of intersections (especially between non-residential streets) should be limited.
- Distances between separate intersections should be large enough to allow safe intersection performance.

3.3.2. *Provide efficient networks*

Discussion

- Intersections are important determining factors in:
  - efficiency of a network
  - travelling speeds
  - capacity of a network
  - safety of a network
  - costs of operation.

- Efficiency, capacity and speeds are determined by:
  - number of intersections
  - intersection spacing
  - intersection type
  - general layout of intersection
  - priority rules/ signalization.
- The shortest routes should coincide with the safest routes (for each travel mode).

Guiding principles

- Let the shortest routes for each travel mode coincide with the safest routes.
- The ideal network structure for each travel mode should have:
  - small delays on intersections (limited number of intersections, small delays on each individual intersection)
  - safe intersection for all travel modes.

3.4. Minimize risk

3.4.1. *Provide functionality*

Discussion

- Each road class should ideally have only one function; unintended use (other functions) should be prevented (e.g. no through-traffic on residential roads, no residential traffic or private accesses on through-roads).
- Important activities in intersection planning with respect to the functionality of a network are:
  - the allocation of intersection in the network
  - intersection spacing (low density of intersections of through-roads and distributor roads)
  - intersection types.

Guiding principles

- The allocation, spacing, and chosen intersection type should support the function of the intersecting roads.

Road function	**Through**	**Distributor**	**Access**
Through	Low density. Grade separated.	Low density. Grade separated.	Not applicable.
Distributor	Low density. Grade separated.	At grade. Speed reducing design. Priority regulations.	At grade. Speed reducing design. Priority regulations.
Access	Not applicable.	At grade. Speed reducing design. Priority regulations.	At grade. Speed reducing design. No priority regulations (ROW for right).

Table 3. *Recommended allocation, spacing, and intersection type for intersecting roads, dependent of functionality*.

3.4.2. *Provide homogeneity*

Discussion

- A homogeneous transportation network precludes encounters with large differences in speed, mass and/or direction.

Guiding principles

- Where road functions require high speeds, encounters with differences in speed and/or directions should be precluded (grade-separated intersections).
- Conflicts with different directions should only be allowed at low speed intersections.
  See also *Table 3*.

3.4.3. *Provide predictability*

Discussion

- A uniform intersection type for each intersection class in a network contributes to the predictability. With a uniform and monofunctional use of intersection types, road users can predict the function of the intersecting roads and thereby the traffic characteristics to be expected.

Guiding principles

- The basic form (type) of each intersection should reflect the function of the intersecting roads. For each class of intersection (e.g. access-access, residential-access etc.) a uniform intersection type should be used as much as possible.
  See also *Table 3*.

3.5. **Minimize consequences**

3.5.1. *Reduce speeds*

Discussion

- High speeds at intersections can only be allowed at grade-separated intersections. If potential conflicts between traffic from different directions are possible, passing speeds should be low.

Guiding principles

- If potential conflicts between traffic from different directions are possible, speeds should be lowered. Possible measures to reduce speeds at intersections can include:
  - Low speed intersection design (e.g. roundabout or T-intersection instead of cross intersection, four-way stop intersection instead of priority intersection)
  - Traffic calming measures at, or on the approach to the intersection.

3.5.2. *Protect vulnerable road users*

Discussion

- Potential conflicts between vulnerable road users should be avoided where possible. Where road functions require high speeds, intersections with vulnerable road users should be grade separated.
- At intersections with possible conflicts with vulnerable road users, speeds of motorised traffic should be low (not higher than 30 km/h.).

Guiding principles

- Potential conflicts with vulnerable road users require low speeds of motorised traffic.
- The possible presence of vulnerable road users at intersections should be made clear to motorised traffic.
- Attention of motorised traffic should be directed at the approach directions of vulnerable road users.
- Priority regulations should be made clear for both motorised traffic and vulnerable road users.

4. Planning framework

- In order to obtain a safe and consistent complex of intersections in the network, it is essential to develop an understanding of the study area. Only then, the intersection planning can be properly adjusted to the existing situation.
- At least the following items need to be surveyed to get an understanding of the study area:
  - Local policies
  - Classified road network
  - Future plans
  - Desire lines/ volumes
  - Travel times
  - Emergency response centres/ routes/ targets.

4.1. Local policies

- Are there any local policies that can influence or limit the choice of:
  - intersection spacing (e.g. access requirements)
  - intersection type.
- Is it possible or necessary to develop a policy on intersection planning (for instance the policy to promote the use of safe intersection types and standardized intersection spacing).

4.2. Classified road network

- Ideally, each road in a network should serve only one designated traffic function (flow, distribution or residential). The design of roads should be in accordance with the function. To improve the predictability, each road category should have a uniform design.
  The classification in different road categories in the existing network should be surveyed, to fit the network of the new development logically into the existing network.
- Similarly, the allocation, spacing and configuration of intersections should support the function of the intersection and of the intersecting roads. Ideally, each combination of intersecting roads should have one designated intersection type and accompanying intersection spacing, to improve the predictability.
- Basic standards for a road and intersection categorisation plan should be formulated for the new network. Such a classification plan for intersections could for instance have the following form:

Road function	**Through**	**Distribution**	**Access**
Through	Grade separated Very low density	Grade separated Low density	Not applicable
Distribution	Grade separated Low density	Roundabout Low density	T-intersection Intermediate density
Access	Not applicable	T-intersection Intermediate density	Cross-intersection with speed reducing measures High density

Table 4. *Example of a classification plan for intersections*.

4.3. Future plans

- Survey future plans (both land use and road development plans), or possible developments foreseen in the future.
- Check if the future plans:
  - can set limitations or preconditions for the studied network
  - can be simplified by certain provisions in the studied network (flexible planning).

4.4. Desire lines/ volumes

- Draw desire lines, based on origin-destination relations for study area (including origins/ destinations in new development).
- Desire lines through the new development should form the basis for the road network plan.
- Volumes (estimations) on desire lines give indications for traffic functions and the road category (classification plan).
- If desire lines and the planned network do not match, rat runs and improper use (use in conflict with road functions) are created.

4.5. Travel times

- Map routes in the existing network with excessive travel times.
- Check if the new development can cause a deterioration or improvement of these excessive travel times.
- Check if travel times can be improved by the use of other intersection types with smaller delays, or by the limitation of the number of intersections on the routes.
- Excessive travel times can cause rat runs and improper use (i.e. use in conflict with road functions).

4.6. Emergency response

- Map emergency response centres and main emergency response routes.
- Draw desire lines for emergency response routes in the new development.
- Check travel times on emergency response routes and desire lines.
- Check if travel times can be improved by the use of other intersection types or by the limitation of the number of intersections on the emergency response routes.

5. Library information

5.1. Understanding

- In general the design of an intersection has to be:
  - Perceptible:
    - timely visible
    - noticeable
    - recognisable
    - locatable
  - Surveyable:
    - intersection
    - connecting roads
    - traffic
  - Understandable:
    - quick
    - correct
    - unambiguous
  - Passable:
    - gradual transition of design elements
  - Balanced:
    - sum of design elements forms an integrated entity
  - Complete:
    - traffic should be able to proceed in all occurring directions
  - Safe.

- To establish/ secure the abovementioned preconditions in the network planning phase, the following points of interest require special attention:
  Optimum spacing:
  - Number of intersections
  - Intersection spacing

  Safe configuration:
  - Intersection type:
    - number of legs
    - basic form.
  - General layout:
    - angle of intersection
    - sight distances
    - alignment
    - approach speed
    - provisions for vulnerable road users.
  - Intended use:
    - priority regulations
    - signalization.

Although general layout and choice of intended use are generally considered to be factors of geometric design, the most important influence of these factors is often established in the network planning phase. Decisions made in network planning often limit the possible solutions in the geometric design phase and should therefore carefully be considered:

- The angle of intersection is determined by the network sketch (orientation of network links).
- Sight distances are determined by the location of buildings or other visual obstructions in proximity of intersections (limited sight angles).
- The alignment is determined in the network sketch.
- The approach speed is mainly determined by the alignment and length of the approaching links.
- Priority regulations are dependant on categorisation of network links (road categories and functions of intersecting links).

5.2. Number of intersections

- Intersections are the most critical elements of transportation network. Simultaneous use of intersection space by road users with:
  - different directions
  - different travel modes
  - different speeds
  - different masses.
- Accident figures in the USA (Kuciemba & Cirillo, 1992):
  - 55% of reported urban accidents take place at intersections.
  - 32% of reported rural accidents take place at intersections.
  - Although intersections form a small part of the transportation network, over half over the motor vehicle accidents take place at intersections.
- Accident figures USA and Canada (Long, Gam & Morrison, 1993; Li, 1993):
  - Accident rates increase directly proportional with the average number of intersections per kilometre.
- The number of intersections and access points should be limited.
  - Especially on through-roads and distributor roads the number of intersections should be limited.
  - Where possible access points should be combined to reduce the number of intersections.

5.3. Intersection spacing

- Intersection spacing influences:
  - the total number of intersections (potential conflicts).
  - the individual safety performance of intersections. Intersections and access points should not be located within functional intersection areas of other intersections.
- Functional intersection area (TRB, 1996) is determined by:
  - stopping sight distance
  - intersection sight distance
  - length of turn lanes.

Stopping sight distance (AASHTO, 2001)

- Stopping sight distance is the distance traversed by a vehicle from the instant an object in its path is detected to a complete standstill in front of the object (see *Table 6*).
- Stopping sight distance has to be provided at all intersections.

Intersection sight distance (AASHTO, 2001)

- This is the distance that stopped or slowed vehicles on the minor road have to be able to see in order to detect oncoming, conflicting traffic on the major road and to cross the intersection area safely.
- Intersection sight distance (ISD) is the length of the leg of the sight triangle along the major road (m). See *Table 6*.

  ISD = $0.278\ V_{major}\ t_g$

  V_{major} = design speed of major road (km/h).

  t_g = time gap for minor road vehicle to enter the major road (see *Table 5*).

Design vehicle	**Time gap for minor road vehicle (sec)**
Passenger car	7.5
Single-unit truck	9.5
Combination truck	11.5

Table 5. *Time gaps for minor road vehicles to enter the major road (t_g) in seconds.*

Note that the time gaps are given for a stopped vehicle to turn right or left onto a two-lane highway without median and with grades of 3 percent or less. The values of *Table 5* require adjustment as follows, for:

- Multilane highways: For left turns onto two-way highways with more than two lanes, add 0.5 seconds for passenger cars, or 0.7 seconds for trucks, for each additional lane to be crossed by the turning vehicle.
- Minor road approach grades: If the approach grade is an upgrade that exceeds 3 percent; add 0.2 seconds for each percent grade for left turns.

Design speed (km/h)	**Stopping sight distance (m)**	**Intersection sight distance for passenger cars**	
		Calculated (m)	**Design (m)**
20	20	41.7	45
30	35	62.6	65
40	50	83.4	85
50	65	104.3	105
60	85	125.1	130
70	105	146.0	150
80	130	166.8	170
90	160	187.7	190
100	185	208.5	210
110	220	229.4	230
120	250	250.2	255
130	285	271.1	275

Table 6. *Stopping sight distance and intersection sight distance in metres (AASHTO, 2001).*

Note: Intersection sight distances in *Table 6* are for a stopped passenger car to turn left onto a two-lane highway without median and with grades of 3 percent or less.

Length of turn lanes (AASHTO, 2001)

- Intersections with turn lanes require longer stopping sight distances, because moving laterally to the turn lanes, while decelerating is a more demanding task. The turn lane should thus be longer than the stopping sight distance.

Speed (km/h)	Length of turn lane (m)
50	70
60	100
70	130
80	165
90	205

Table 7. *Length of turn lanes in metres; turning traffic leaving the through-lane with a speed difference of 15 km/h.*

Spacing of signalized intersections

- The spacing of traffic signals is an important determining factor in the performance and safety of a road network.
- Traffic signals can cause:
  - constrained capacity
  - delays
  - reduced arterial travel speeds
  - increase in accidents.
- Traffic signal spacing is one of the most important and basic access management techniques.
- Studies in the United States found that the number of accidents (as well as the number of injuries) increased with an increasing number of signalized intersections per mile.
- At present there are no safety-guidelines for determining the spacing of unsignalized intersections, other than making spacings as large as possible. Guidelines for traffic signal spacing as used in practice are approaching the spacing from a capacity point of view (reducing delays, travel times).

5.4. Intersection type

- In general the intersection type is determined by:
  - number of legs
  - basic intersection form.
- The following intersection types can be distinguished:
  - Cross intersection
  - T-intersection
  - Staggered T-intersections
  - Roundabouts
  - Multi-leg intersections.

- Traffic safety of intersection types is determined by:
  - number of conflict points (points where traffic from conflicting directions meet)
  - severity of the conflicts (mainly determined by speed).

Cross-intersection:
- 24 points of major conflict (see *Figure 2*)
- 4 of 12 directions are through-going (no speed reduction by deflection angle).

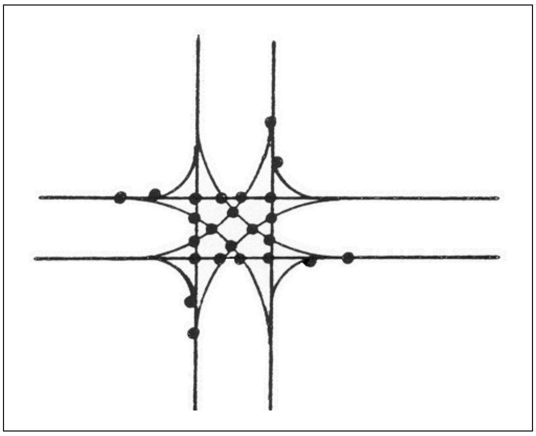


Figure 2.

T-intersection:
- 6 points of major conflict (see *Figure 3*)
- 2 of 6 directions are through-going (no speed reduction by deflection angle).

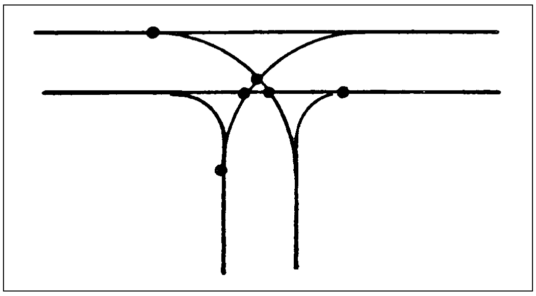


Figure 3.

Roundabout:
- 4 points of major conflict (see *Figure 4*)
- all directions are confronted with an entry deflection angle, forcing speed reduction.

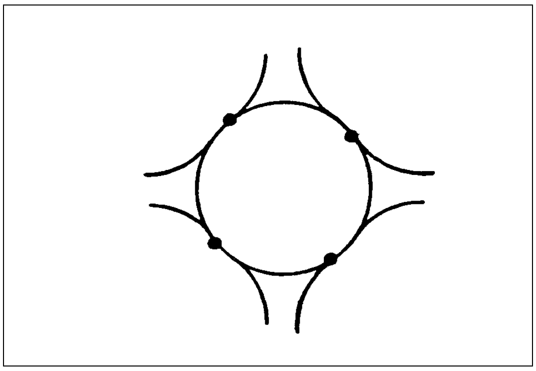


Figure 4.

Staggered T-intersection:

- 12 points of major conflict (see *Figure 5*)
- 4 of 12 directions are through-going
  (no speed reduction by deflection angle)

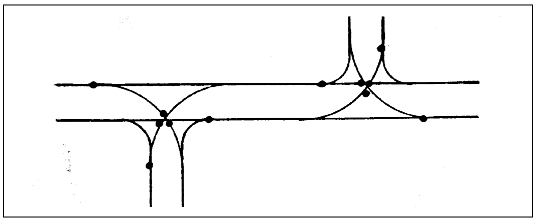


Figure 5.

- Relative safety of compared intersection types (comparison of points of conflict and passing speeds):
  1. Roundabout:
     - 4 points of conflict
     - low passing speeds
  2. T-intersection:
     - 6 points of conflict
     - no speed reduction on 2 directions
  3. Staggered T-intersection:
     - 12 points of conflict
     - no speed reduction on 4 directions
  4. Cross-intersection:
     - 24 points of conflict
     - no speed reduction on 4 directions.

- Comparison of accident rates for intersections types:

United States (Kuciemba & Cirillo, 1992)

Rural intersections

Intersection type	Average accident rate
Roundabout	-
T-intersection	0.80
Staggered T-inters.	0.58
Cross-intersection	1.35

Urban intersections

	Avg. accident rate for classes of Avg. Daily Traffic			
Intersection type	<5,000	5,000-10,000	10,000-20,000	>20,000
Roundabout	-	-	-	-
T-intersection	1.3	1.6	2.7	4.2
Staggered T-inters.	-	-	-	-
Cross-intersection	1.3	1.9	3.0	8.0

(accidents per million entering vehicles)

Australia (Barton, 1989, cited by Ogden, 1996)

Intersection type	Average casualty accident rate
Roundabout	0.16
T-intersection, rural	0.33
T-intersection, urban	0.15
Staggered T-inters., rural	0.29
Cross-intersection, rural	0.52
Cross-intersection, urban	0.24

(casualty accidents per million entering vehicles)

Norway (Elvik, Mysen & Vaa, 1997)

Intersection type	% traffic from secondary road	Avg. casualty acc. rate
Roundabout	all	0.05
T-intersection, rural	0-14.9 %	0.06
	15-29.9 %	0.12
	>30 %	0.26
T-intersection, urban	0-14.9 %	0.08
	15-29.9 %	0.11
	>30 %	0.11
Staggered T-inters.	-	-
Cross intersection, rural	0-14.9 %	0.07
	15-29.9 %	0.27
	>30 %	0.58
Cross-intersection, urban	0-14.9 %	0.07
	15-29.9 %	0.10
	>30 %	0.31

(casualty accidents per million entering vehicles)

United Kingdom (Layfield et al., 1996)

Intersection type	Accidents per 100 million vehicles
Cross-intersection	33.0
Staggered T-inters.	23.2

(accidents per 100 million entering vehicles)

The Netherlands (Dijkstra, 1990)

Intersection type	Average casualty accident rate
T-intersection, unsignalized	0.11
Cross-intersection, unsignalized	0.21
T-intersection, signalized	0.08
Cross-intersection, signalized	0.20

(casualty accidents per million entering vehicles)

- Accident rates in the United States as well as various European countries prove that roundabouts and staggered T-intersections are safer intersection types than cross-intersections. The replacement of cross-intersections by roundabouts or staggered T-intersections is considered to be an effective traffic safety measure both in the United States (e.g. Jacquemart, 1998) and in Europe (e.g. Van Minnen, 1990).

- Multi-legged intersections should not be used:
  - Accident rates for multi-legged intersections are twice as high as for normal cross-intersections. This is caused by:
    - complex traffic situation
    - unfavourable sight angles.

- The speed-reducing effect of roundabouts is caused by:
  1. Deflection for entering traffic
     - no tangential entries permitted
     - no straight movements through intersection
     - entering traffic points towards central island.
  2. Limited diameter of roundabout
     - mini-roundabout: outside diameter approx. 15 m
     - compact roundabout: outside diameter between 30 - 35 m
     - multilane roundabout: outside diameter up to 150 m.

  (Jacquemart, 1998)

5.5. **General layout**

5.5.1. *Angle of intersection*

- The angle of intersection should be as close as possible to 90 degrees.
- Angles other than 90 degrees cause the following safety problems:
  1. The area of conflict increases (see *Figure 6*).
  2. The visibility is limited.
  3. Larger turning roadways are required (especially for trucks).
  4. The exposure time through the intersection increases.

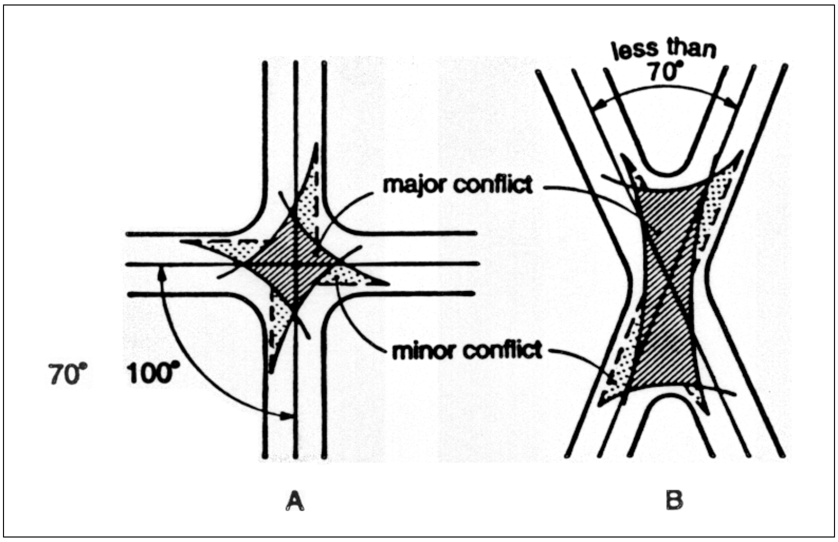


Figure 6. *Areas of conflict at intersections with different angles*.

- Examples of reconstruction of skew intersections are given in *Figure 7*.

Unfavourable Improvement

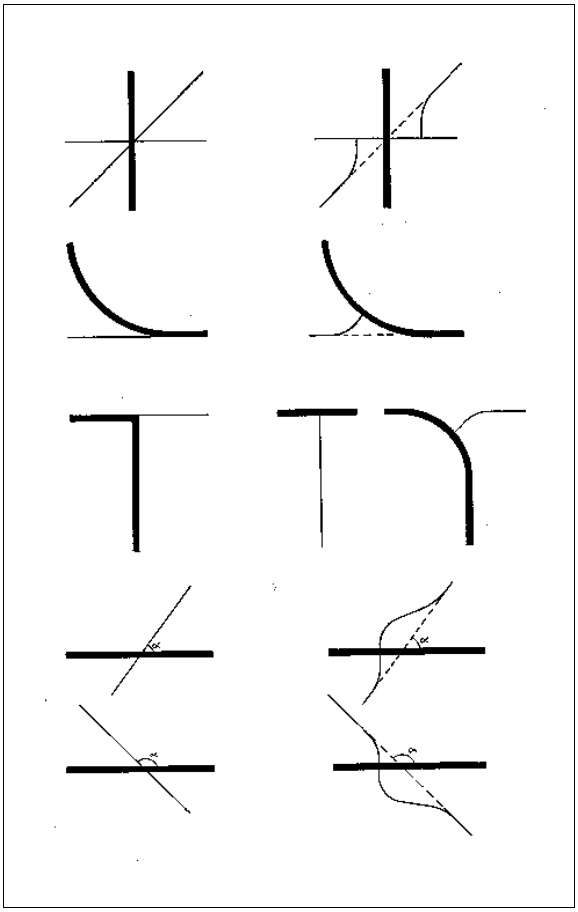


Figure 7. *Unfavourable skew intersections (left) and examples of improving reconstructions (right).*

5.5.2. *Sight distances*

Values for stopping sight distance, intersection sight distance, and length of turn lanes, are given in section 5.3 ‘Intersection spacing’.

5.5.3. *Alignment*

- Avoid gradients steeper than 2% in intersection areas (AASHTO, 2001).
- In mountainous terrain, intersections should preferably be located in sags (AASHTO, 2001).
- Intersections on sharp curves should be avoided (AASHTO, 2001). Superelevation and curve widening cause:
  - complex traffic situation
  - reduced sight distances.

5.5.4. *Approach speed*

- Speed at intersections should be lower than the design speed on midblock sections.
- Motorists should lower their speed while approaching an intersection.
  - Most important requirements: Intersection must be perceptible and surveyable.

- Measures to improve timely perception of intersection (Slop et al., 1996):
  - Advance direction signs
  - Danger warning signs and traffic signs
  - Road markings
  - Landscaping:
    - reference points for better estimation of approach speed
    - effective background for road signs
    - improving general visibility of intersection.

- Examples of landscaping to improve intersection visibility are given in *Figure 8*.

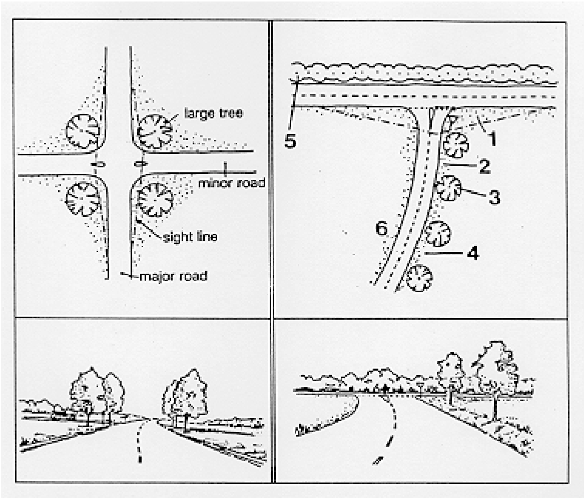


Figure 8. *Possible landscaping measures to improve intersection visibility*.

- Design elements to reduce speed on approaching legs (La Cour Lund, Jorgensen & Nielsen, 1998):
  - narrowing
  - staggering
  - central traffic islands in approach legs
  - ramps and raised carriageways
  - humps
  - changed road surface
  - traffic actuated signalization
  - speed reducing curves in approach of intersection
  - limited length of straight road sections.

5.5.5. *Provisions for vulnerable road users*

- Locate crossing facilities for vulnerable road users at logical locations in routes:
  - Detours could lead to shortcuts, which causes crossing manoeuvres in unexpected locations.

- Locate crossing facilities for vulnerable road users at intersections:
  - higher attention and expectancy of crossing manoeuvres
  - logical allocation in cycle and pedestrian routes (mostly adjacent to roads).

  (Slop et al., 1996)

- Design principles of bicycle and pedestrian crossings:
  - enhance mutual visibility
  - minimize conflict lengths
  - reduce vehicle speed.

- Types of bicycle crossings at intersections:
  1. Mixed traffic:
     - no cycle tracks or cycle lanes
     - applied in intersections with low volumes and low speeds.
  2. Cycle lanes:
     - continue cycle lane markings through intersection
     - markings remind motorists of possible presence of cycles; interaction between motorists and cyclists improves.
  3. Cycle tracks:
     - cycle tracks preferably deflected (see *Figure 9*).

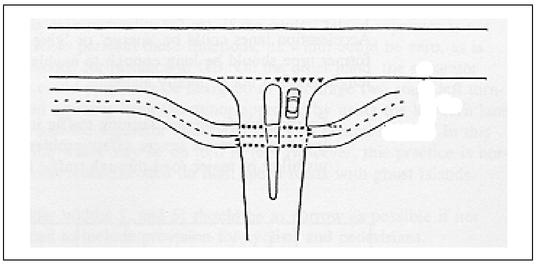


Figure 9.

Separate cycle tracks decrease attentiveness of motorists to the presence of cyclists (especially when approaching from the rear). Deflection improves the visibility of cyclists (motorists have turned before actually intersecting the cycle track).

There are two possible options for deflected cycle tracks (Slop et al., 1996):
1. Offset > 6 m (one passenger car length): yield or stop for cyclists.
2. Limited offset (4 - 5 m): turning cars yield for cyclists.

- An offset > 6 m is safer than the limited offset, but less comfortable for cyclists.

- Visibility of cyclists on roundabouts can cause problems (blind spot). Solutions:
  - Providing cycle lanes on the roundabout (see *Figure 10*):
    - This increases the visibility of cyclists.
    - Disadvantage of this solution is that turning trucks on the roundabout are unable to detect bicyclists on the roundabout, causing hazardous situations. For this reason this solution should not be preferred.

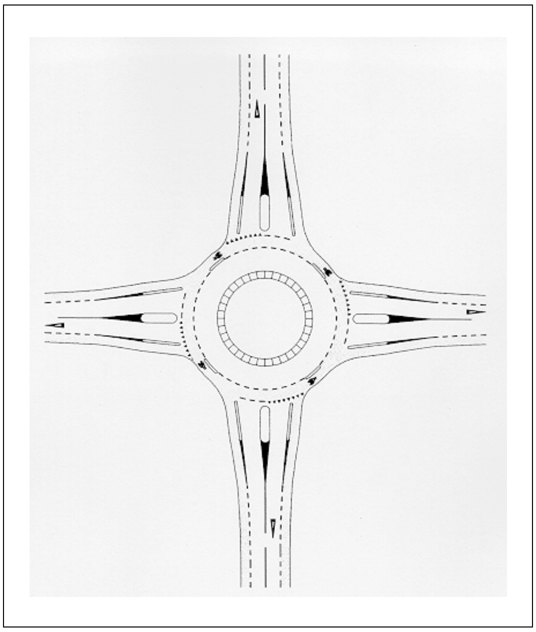


Figure 10.

  - Provide separate cycle tracks on the roundabout (cyclists yield; see *Figure 11*).
    - This is the safest solution.
    - Disadvantage of this solution are longer delays for cyclists.

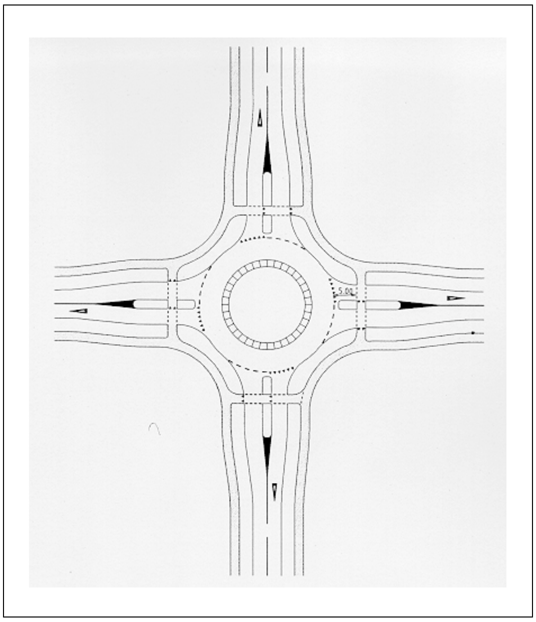


Figure 11.

5.5.6. *Orientation of staggered T-intersections*

Staggered T-intersections can have two orientations: a left-right stagger (see *Figure 12*) and a right-left stagger (see *Figure 13*; Hedman, 1990).

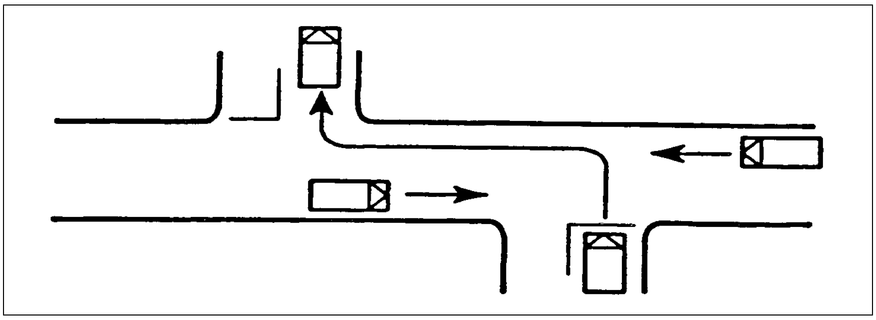


Figure 12. *A left-right staggered T-intersection (Hedman, 1990).*

Left-right stagger:

Advantage: Drivers from secondary road cross nearest lane at a right angle, and have unimpeded exit from the far lane.

Disadvantage: Left turn movement from secondary road is dangerous manoeuvre in urban areas.

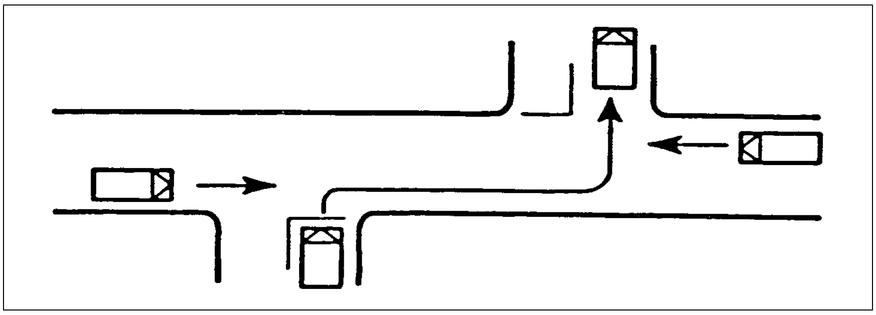


Figure 13. *A right-left staggered T-intersection (Hedman, 1990).*

Right-left stagger:

Advantage: Drivers from secondary road faces only one conflicting traffic stream per T-intersection.

Disadvantage: Left turn movement from main road is dangerous with high speeds on main road (rural areas).

- The choice of orientation has to be made based on the prevailing traffic conditions (e.g. in conditions with high speeds and high volumes on the main road a left-right stagger should generally be preferred).

5.6. **Intended use**

5.6.1. *Priority regulations*

- Priority regulations improve safety of intersections.
  - Yield- and stop-controlled intersections are safer than right hand rule intersections.
  - Stop-controlled intersections are safer than yield controlled intersections.

  (Elvik, Mysen & Vaa, 1997; Van Minnen & Catshoek, 1997).

5.6.2. *Signalization*

- Generally, traffic signals do not improve traffic safety.

- Traffic signals only improve safety if:
  - there is a significant number of accidents currently occurring (more than three casualty accidents per year)
  - these accidents are of a type that can be reduced through signalization
  - the traffic volumes warrant the installation of traffic signals.

  (Ogden, 1996).

5.7. **Capacity**

- The capacity is not a safety consideration, but an important factor in the choice of intersection type (see *Figure 14* and *Table 8*).

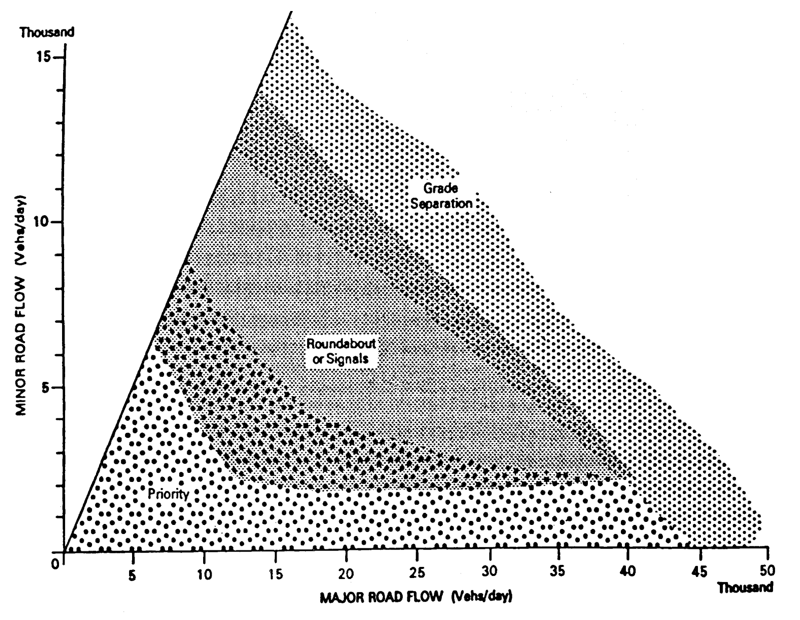


Figure 14. *Types of junction appropriate to different traffic flows (The Institution of Highways and Transportation, 1987).*

Intersection type		Capacity in vehicles/ day
Uncontrolled (priority to the right)		1,000 - 1,500
2-way stop/ 2 way yield		5,000 - 12,000
4-way stop		12,000 - 18,000
Roundabout	single lane	20,000 - 28,000
	multilane	35,000 - ? (1)
Signalized		20,000 - 80,000 (2)

1) Varies from country to country.
2) Depends on the number of lanes for the different movements.

Table 8. *Maximum capacity of different intersection types (May, 1997; TRB, 1985).*

The values in *Table 8* are indications. The exact capacity of intersections is highly dependant on the geometric design and the distribution of volumes on the intersecting roads.
The influence of the number of lanes on intersecting roads is small for yield- and stop-controlled intersections, because the capacity is mainly determined by gaps in the traffic stream on the major road.

If the capacity of intersections is used to determine whether traffic streams can be assigned to certain routes, the maximum capacities from *Table 8* should not be used. In this case the maximum capacity should be multiplied by 0.85 (usually the volume at which the intersection is not yet jammed).

To calculate the capacity in vehicles per hour, the values of *Table 8*, in vehicles/day, can be divided by the peak hour factor (approximately 10).
If the exact peak hour factor in a certain area is known, this value can be used. If the exact value is not known a default value of 10 can be used.

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