

# **Safety effects of route choice in a road network: Simulation of changing route choice**

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Research in the framework of the European research programme In-Safety

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**SIXTH FRAMEWORK PROGRAMME**  
**PRIORITY 1.6. Sustainable Development, Global Change**  
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**Safety Effects of Route Choice in a Road Network: Simulation of Changing Route Choice**

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## Summary

In the Netherlands, the concept 'Sustainably safe traffic' is the leading vision in road safety policy and research. The main goal of a sustainably safe road transport system is to reduce the annual number of road crash casualties to a fraction of the current levels. Important requirements following from this vision are that journeys should follow safe roads as much as possible, should be as short as possible, and the quickest and the safest route should coincide. This report focuses on the development of a method which enables the planner to find out the safety effects of existing route choices, and also of changes in route choice.

Road safety can be described in various ways. It has previously been shown that micro-simulation models are a suitable aid for route choice studies. They make it possible to examine beforehand how the route choice will change as a result of new or adapted facilities alongside or on the roads, or in vehicles. Safety indicators are required when evaluating the safety effects of the route choice of (all) vehicles in a network, and when evaluating the effects of changes in these route choices. In this report these indicators are formulated and used in a test network in a micro-simulation model.

We chose two types of road safety indicators: general and vehicle-dependant. The general indicators are independent of the traffic volume on a road network. They are derived from the route characteristics that are closely related to road safety, such as the route length or the number and types of transitions between different road types. These general safety criteria are rooted in the 'route diagram' which is a method of visualizing the Sustainable Safety character of a route. The optimal route diagram shows a journey that contains all road types in the correct sequence and in the correct proportions of length. The deviation from the optimal diagram determines how unsafe the presumed route is. Thus the route diagram expresses a qualitative safety that can be translated into quantitative criteria.

The vehicle-dependant indicators allow for the real-time traffic situation on the network. They express the extent to which vehicles encounter other vehicles along a route and how these meetings end; they are 'conflict indicators'. The mass of the vehicles, their direction, speed, and lateral position largely determine the severity of conflicts. Here we are still speaking of calculated conflicts in a simulation model; in other words not of real conflicts, let alone near-misses.

The results of the calculation methods used do not all give the same safety effects for a specific route choice. Further research is necessary to find the explanation for this and to determine the methods' utility.

In principle, the route choice safety criteria are suitable for (computer) programs used in route planners.

Applying the micro-simulation model to a test network is insufficient for deciding whether such models are a suitable road safety research instrument. For a well-founded decision, a micro-simulation must be tried on

a real-life road network, and the registered safety, usually expressed in crashes, should be compared with the calculated safety.

More research is needed to model serious conflicts between road users. It is especially important that the number and nature of calculated conflicts are similar to the real ones. That is why observations in real traffic are required.



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# 1. Introduction

In the research project *Route choice in road networks*, the Dutch SWOV Institute for Road Safety Research wishes to study the possibilities of influencing motorists' choice of route in such a way that the chosen route corresponds with one of the functional requirements of the 'Sustainable Safety' policy; i.e. that the fastest route should also be the safest one. This project covers three main topics:

1. Which research methods are suitable for studying route choice?
2. How safe are the routes that are currently being chosen? This requires the development of indicators and criteria for the safety of routes. Specific sets of indicators and criteria will be developed for each (research) method (e.g. simulation models, safety assessment procedures).
3. Is it possible to influence route choice in such a way as to direct drivers towards the safe routes? If so, how? And what effect will this have on road safety?

The results of the first topic (Dijkstra & Drolenga, 2007) showed that micro-simulation models are a very useful research method. Among other things, a micro-simulation model allows a researcher to establish how frequently and in what manner vehicles encounter one another. The variations in speed and direction in these encounters give an indication of the degree of safety on the road network. A micro-simulation model also enables researchers to identify various characteristics of the routes that are followed. Some characteristics also give indications of lack of safety; for example, the number of times that a vehicle turns left or the number of intersections that the vehicle passes.

The second topic focussed on the development of indicators and criteria for assessing the safety of routes. This report gives an overview of these indicators and criteria. It also gives examples of the way these indicators and criteria can (and should) be applied.

The third topic is dealt with by using micro-simulation. The simulations show the effect of giving up-to-date information about the traffic situation (mainly congestion) to drivers by means of a route navigation system. In a follow-up study this third issue will be elaborated.

## 2. Study set-up and implementation

In a sustainably safe traffic system, it is an important requirement for road networks that the quickest route should also be the safest route. This requirement can have the undesirable result that motor traffic would have to pass straight through residential areas (which usually have very safe roads and streets). Therefore, there is a supplementary requirement that journeys may only start and end by travelling along access roads, while the remainder (and biggest part) of the journey uses through roads or, if these are not (adequately) available, distributor roads. If such route choice is to be put into practice, the resistance (usually expressed in journey time) of a route straight through residential areas would have to be greater than that of a route via through roads and/or distributor roads. The route choice can also be influenced by instructions at the roadside or in the vehicle and, if necessary, by the design of the road and its surroundings. It is essential to a well-functioning sustainably safe road network that traffic is able to flow along through roads, otherwise the resistance of a route through residential areas will be seen as preferable to the resistance of a route via through roads.

For a sustainably safe road network it is also important that the selected road categorisation corresponds to the desired functional distribution of traffic across the road network. The mesh of the distributor road (and trunk road) network is an important factor here (Van Minnen, 1999). Very little has been decided regarding the intended mesh of these road categories. In addition to the mesh itself, the nature of the desired links between various types of residential centres (depending on the number of inhabitants or facilities) can be a major consideration for the structure of a sustainably safe road network (Dijkstra, 2003).

The intention of the 'Sustainable Safety' policy is to incorporate road safety into traffic planning and thereby influence the safety of the ultimate traffic situations in advance. In the planning and design stage of these traffic plans, it must be established whether the network will function in line with the above requirements, especially with regard to safety. It is difficult to get an overview of the consequences of a traffic plan, due to the numerous factors that play a role in these plans (many possible starting points and destinations, motives for travelling, modes of transport and alternative routes). For that reason, planners frequently use traffic models and traffic simulation models. Traffic models divide the potential movements between areas of departure and destination among the various modes of transport and then divide the resulting journeys among the routes in the various networks (specifically, for bicycles, public transport and motorized traffic). The traditional traffic models only give a distribution of the total quantity of traffic (for each mode of transport) across the road sections of the various networks.

In micro-simulation models, it is possible to make individual vehicles follow a route through a network. The route selected by each simulated vehicle depends on a number of pre-set parameters and different variables (which are functions of vehicle-mounted aids, facilities on the road, driver motives,

timing and interaction with other traffic). In this way, it is possible to determine in advance how the choice of route will change when planning new or modified facilities on or alongside the road or in vehicles.

This research project focuses on the simulation of route choice behaviour. The simulated journeys involve routes through various types of road networks (rural, urban, town centres and transitional areas). All road categories should preferably be represented in each network. To an important extent, this determines the spatial scale of the desired networks and of the areas in which they are situated. Route choice can be modelled and simulated in various ways, as is shown by the differences between the existing models. These differences are not the prime object of study in this project. When considering the route choice in a given model, the important factors are the characteristics of each route and the consequences they have for road safety.

This report mainly deals with the indicators for the safety of each (potential) route. Two angles of approach were selected for this: safety criteria and conflict measures.

The safety criteria relate to the requirements with regard to the characteristics of a route that bear a strong relationship to road safety. For example, a long route gives more exposure to risk than a short route. Almost all the criteria are derived from the desired route diagram, also known as 'Sustainable Safety Steps' (Van der Kooi & Dijkstra, 2000). The desired route diagram shows a route progression that contains all road categories in the correct sequence and in the correct length ratios. The deviation of a route from the desired diagram determines the degree of assumed risk.

The conflict measures give a quantitative insight into the extent to which vehicles encounter other vehicles along a route and how these encounters progress. The nature of the vehicles (weight) and their direction, speed and position (in cross-section) to an important extent determine the severity of the conflicts. A simulation model always involves calculated conflicts and not real conflicts, let alone (near) accidents. Different types of conflict measures were developed and tested, each giving a specific view on the conflicts between vehicles.

### 3. Indicators of road safety in micro-simulation models

#### 3.1. Introduction

This chapter introduces a number of road safety indicators for routes that can be calculated in micro-simulation models. Within this framework, a route is seen as a chain of road sections and junctions by which a certain destination may be reached from a given point of departure. There are two reasons for obtaining an indication of the safety of routes. Firstly, it gives the possibility to optimise the total road safety performance, at OD (Origin to Destination) level and thence at network level, by distributing the vehicles among the various routes in such a way as to minimise traffic hazards. In addition, it creates the possibility to factor in the safety of the routes chosen by individual vehicles; in micro-simulation models this normally depends only on journey time and distance.

Road safety indicators can be calculated at a number of levels. *Figure 3.1* distinguishes five different levels:

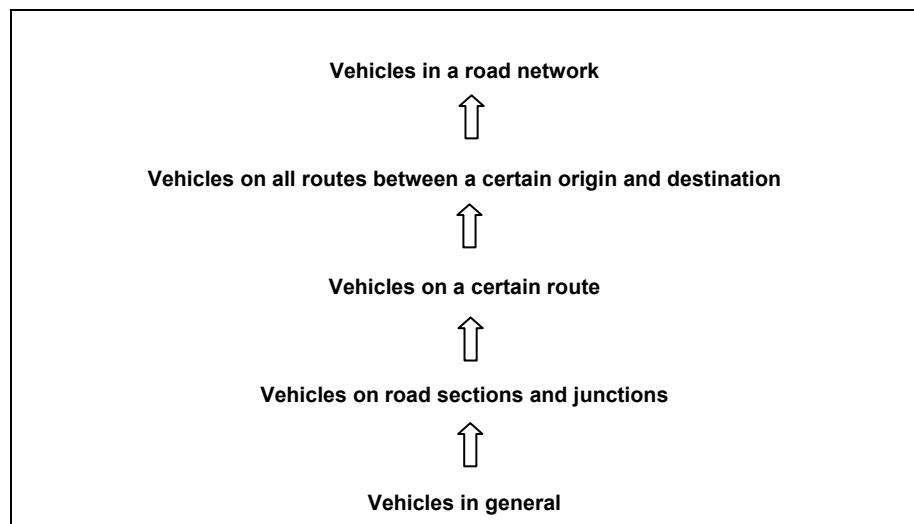


Figure 3.1. *Different levels for road safety indicators.*

From the road safety determined at vehicle level, one can progress to the road section/junction level by totalling the safety of all vehicles that pass a given road section or intersection in a certain period of time. By totalling the risks inherent in the road sections and junctions that form part of a certain route, it is possible to work out the safety of that route. If this is done for all routes associated with a given OD relationship, it is possible to get an indication of the safety at OD level. By considering all the possible OD relationships, the network level can be determined.

The road safety indicators are divided into general indicators (*Section 3.2*) and vehicle-specific indicators (*Section 3.3*).

Under the heading of general road safety indicators, the 'traditional' key figures and the route diagram (Sustainable Safety Steps) are discussed.

Key figures are at road section/junction level. The desired route level is arrived at by totalling the road sections and junctions that are on a route. The route diagram is already at route level from the start. The vehicle-specific road safety indicators are calculated at vehicle level and are therefore dependent on the current traffic situation on the network.

### 3.2. General road safety indicators

#### 3.2.1. Key safety indicators

Key safety indicators quantify the safety of certain types of roads and junctions. A key safety indicator is determined by relating the absolute level of unsafety (e.g. the number of accidents) on a certain type of road or junction to the degree of exposure.

Janssen (1988, 1994) gives a general expression for calculating a key safety figure:

$$\text{Key safety indicator} = \frac{\text{Safety level}}{\text{Degree of Exposure}}$$

The safety level is frequently quantified by using accident records. The number of vehicles or the number of vehicle/kilometres is often used to calculate the degree of exposure.

An example of a key safety indicator is the number of accidents involving injury per million vehicle kilometres driven. This key safety indicator is also referred to as the risk of a road or junction type. The risk (indicator) based on vehicle kilometres takes into account not only the number of accidents but also the road length and the number of motor vehicles that pass along it (Janssen, 2005).

By combining the length of the road section with the intensity, we can calculate the level of exposure, expressed in millions of vehicle kilometres driven in a year. The level of exposure is then calculated as follows:

$$VP_i = L_i * I_i * 365$$

in which  $VP_i$  is the level of exposure of road section  $i$  in millions of vehicle kilometres driven in one year,  $L_i$  is the length of the road section  $i$  in km and  $I_i$  is the daily volume for road section  $i$ .

Then, by multiplying the level of exposure  $VP_i$  by the associated key figure  $K_i$ , the expected number of injury accidents  $LO_i$  on road section  $i$  can be estimated.

$$LO_i = K_i * VP_i$$

The key figure for road section  $i$  depends on the type of road. The key figures used here for access roads (speed limit 30 kph), distributor roads (50 kph) and through roads within urban areas (70 kph) are shown in *Table 3.1*.

Road with speed limit in kph	Key figures in number of accidents with injury per billion motor vehicle kilometres
30	122
50	272
70	12

Table 3.1. *Key figures for three road types (edited version of Janssen, 2005).*

By totalling the calculated, expected injury accidents on the road sections that form part of a route, the total expected injury accidents on the route in question can be derived.

### 3.2.2. Requirements of the Sustainable Safety policy: route diagram

Using the lengths and categories of road sections that form part of a given route, a route diagram (Sustainable Safety Steps) can be constructed for each route. The progress of the route through the road categories in the network is compared to the distance. The idea behind the route diagram is as follows: From a point of departure, cover the least possible distance via the lower road categories, via the right upward transition points (only one category per transition point), towards the highest road category in a road network, stay in that for as long as possible and then follow the correct downward transitions (one category per transition point) via the least possible distance along the lower road categories until the destination is reached. An example of a route diagram is shown in *Figure 3.2*.

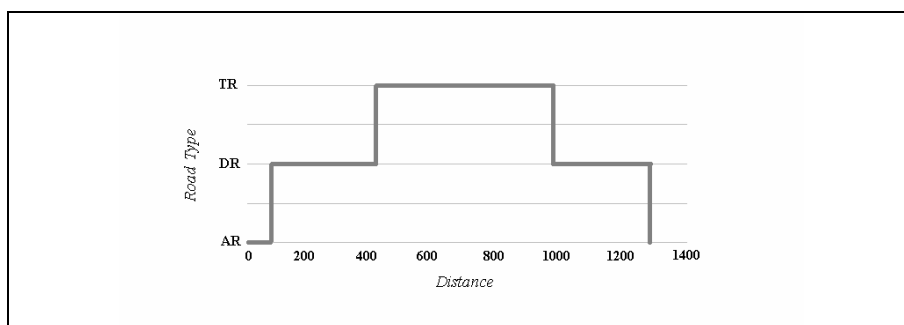


Figure 3.2. *Route diagram for an arbitrary route, in which AR = Access Road, DR = Distributor and TR = Through Road.*

Route diagrams provide a visual impression of the Sustainable Safety character of a route. As soon as we start comparing routes, the shortcomings of this visual representation become apparent. To get a quantitative assessment, we allocate a score to each route based on nine criteria. The authors drew up these criteria based on general knowledge of risks to road safety (Dijkstra et al., 2007). These criteria are all of a quantitative type and have the same 'direction': the lower the score for a criterion, the greater the road safety. We shall explain the nine criteria, one by one, in the following sections.



### 3.2.2.1. Number of transitions between road categories limited

An optimum route diagram has the right number of category transitions. In a network containing  $N$  number of road categories, a route should have a maximum of  $(N-1)$  upward transitions between categories and a maximum of  $(N-1)$  downward transitions between categories. An excessive number of transitions should incur a penalty, which can be expressed in the formula:

$$\begin{aligned} \text{If } O \leq (2N - 2) \text{ then } EO &= 0 \\ \text{If } O > (2N - 2) \text{ then } EO &= 2 + O - 2N \end{aligned}$$

in which  $O$  is the total number of category transitions in the route in question,  $N$  is the number of road categories in the network and  $EO$  is the number of extra transitions.

### 3.2.2.2. Nature of the transition is correct (not more than one step at a time)

It is important to make a distinction between upward and downward transitions. An upward transition involves moving to a higher category, a downward transition involves moving to a lower category. By considering the difference between the categories, the correctness of the transition can be assessed. The nature of the transition is calculated as follows:

$$AO = |C_j - C_i|$$

in which  $AO$  is the nature of the transition and  $C_j$  is the next category after the category  $C_i$  under consideration.

A category transition fulfils the second requirement if  $AO = 1$ . If  $AO > 1$ , the category transition does not meet the requirement. The number of faulty category transitions in a route is counted in this way.

### 3.2.2.3. As few missing road categories as possible

The number of road categories encountered in a route, in relationship to the number of road categories present in the network, forms the fourth requirement. This can be expressed in the formula

$$OWC = WCN - WCR$$

in which  $OWC$  is the number of missing road categories,  $WCN$  is the number of road categories present in the network and  $WCR$  is the number of road categories encountered in the route under consideration.

### 3.2.2.4. Proportion (in length) of access roads as low as possible

From a road safety viewpoint, through traffic in 30 k.p.h. (20 mph.) zones should be avoided. The proportion, in length, of access roads  $AL_{ETW}$  in relation to the total length  $L_{TOT}$  is calculated as follows:

$$AL_{ETW} = \frac{L_{ETW}}{L_{TOT}} \times 100\%$$

### 3.2.2.5. Proportion (in length) of distributor roads as low as possible

Distributor roads are the least safe when it comes to the risk of accidents. For that reason, the ratio in length of these roads should be kept as low as possible. The proportion, in length, of distributor roads  $AL_{ETW}$  in relation to the total length  $L_{TOT}$  is calculated as follows:

$$AL_{GOW} = \frac{L_{GOW}}{L_{TOT}} \times 100\%$$

### 3.2.2.6. Travel distance

The smaller the total distance  $L_{TOT}$  travelled on a route, the less risk to which a vehicle is exposed. The total distance  $L_{TOT}$  is equal to the sum of the distance over access roads  $L_{ETW}$ , the distance over distributor roads  $L_{GOW}$  and the distance over through roads  $L_{SW}$ . This is expressed as the formula

$$L_{TOT} = L_{ETW} + L_{GOW} + L_{SW}$$

### 3.2.2.7. Travel time

The total travel time  $R$  is calculated for each route on the basis of an empty network. This is done by totalling the length of the categories divided by their respective speed limits, expressed by the formula

$$R = \frac{L_{ETW}}{V_{ETW}} + \frac{L_{GOW}}{V_{GOW}} + \frac{L_{SW}}{V_{SW}}$$

### 3.2.2.8. As few turnings as possible across oncoming traffic

The number of left turns ( $LAB$ ) at junctions can be recorded for each route. Because turning left is seen as the most dangerous manoeuvre (Drolenga, 2005), the score declines as the number of these movements increases.

### 3.2.2.9. Low junction density on distributor road

The purpose of this requirement is to assess the route's potential for disruption on the distributor roads within it. The junction density  $KPD$  is defined as the number of junctions on distributor roads  $K$  per km of distributor road. This is expressed as the formula

$$KPD = \frac{K}{L_{GOW}}$$

### 3.2.2.10. Nine criteria summarised

The nine criteria including their dimensions are shown in *Table 3.2*. Some of these criteria are related to each other. For instance travel distance is related to travel time in an 'empty' network. As soon as the network gets saturated, this relationship will disappear. The proportion of a certain road category and travel distance seem to be mutually dependent, however, two routes having the same length of access roads will have different proportions of access roads when the total travel distances of both routes differ.

Criterion	Description	Unit
1	Number of transitions	Number of additional transitions
2	Nature of transitions	Number of wrong transitions
3	Missing road categories	Number of missing categories
4	Proportion of access roads	Percentage of total distance
5	Proportion of distributors	Percentage of total distance
6	Travel distance	Meters
7	Travel time	Seconds
8	Left turns	Number of left turns
9	Junction density	Number of junctions per kilometre

Table 3.2. *Nine criteria for route diagrams.*

### 3.2.3. *Requirements of the Sustainable Safety policy: route stars*

For each route we calculate the scores for the nine aforementioned criteria by collecting the data and applying the formulae. Using a multi-criteria analysis, we then try to arrange alternative routes in order of preference. Standardisation of the criterion scores is necessary if the different scores of the various routes are to be compared. The scores are standardised on the basis of interval standardisation. This means that the best alternative is awarded a score of 0, the worst a score of 1, and the other options are scaled between 0 and 1. This is done by reducing the score by the lowest score for the criterion in question and dividing this difference by the difference between the maximum score and the minimum score for the criterion in question. This is expressed as the formula

$$G_{ji} = \frac{C_{ji} - \min_j \{C_{ji}\}}{\max_j \{C_{ji}\} - \min_j \{C_{ji}\}}$$

in which  $G_{ji}$  is the standardised score of alternative  $i$  for criterion  $j$  and  $C_{ji}$  is the criterion score of alternative  $i$  for criterion  $j$ .

In determining the minimum and maximum scores for a criterion, not only the routes that are actually followed should be taken into account, but also the routes that are not followed but are nevertheless available in the infrastructure.

Routes can easily be compared by using stars to visually represent the standardised scores for the nine criteria. The nine points of a star represent the nine criteria. Each point shows '1 -  $G_{ji}$ ': the longer a point, the better the score for this route is in relationship to alternative routes. This means that the more complete the star is, the more sustainably safe the route is. The scores for the nine criteria on two routes are shown as an example in *Figure 3.3*.

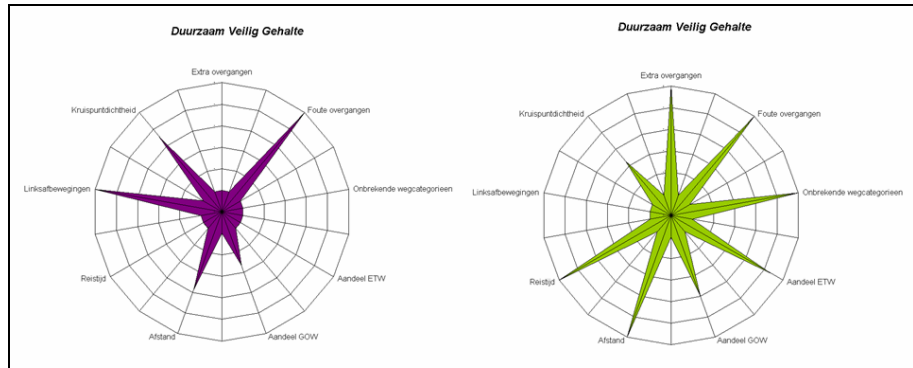


Figure 3.3. Route stars for two arbitrary routes.

The left-hand route (purple star) has the worst score for the first requirement (the number of additional transitions) because no point, or only part of a point, is visible. By contrast, the right-hand route (green star) has the best score for this requirement because the entire point is visible. Because the light coloured star is more complete than the dark coloured star, it may be concluded that the right-hand route fulfils the requirements of the Sustainable Safety policy more than the left-hand route.

#### Criteria weights

After the scores have been standardised, the weighting of the criteria can be determined. If each criterion is chosen to be of equal importance, then each of them counts with the same weight. If one or more criteria are considered more important, these may be allocated a greater weight than less important criteria. The sum of the weights of the criteria must always come to 1, so if all nine criteria are considered of equal importance, each criterion is given a weight of 1/9.

#### 3.2.3.1. Total score for a route

To arrive at a total score for each route, the standardised score is multiplied by the weight and added up over the nine criteria to give total scores (*weighted totalling method*). The outcome of this total score indicates the degree of unsafety. To arrive at a safety score, the unsafety score is deducted from 1 and multiplied by 100% so that the safety score will fall between 0 and 100%. This is expressed as the formula

$$VV_r = 100 - 100 \times \sum_{c=1}^C ss_c \times g_c$$

in which  $VV_r$  is the safety score of route  $r$ ,  $C$  is the number of criteria,  $ss_c$  is the standardised score for criterion  $c$  and  $g_c$  is the weight of criterion  $c$ .

#### 3.2.4. Sustainable Safety Level OD-relationship

Using the calculated safety scores of the various routes that are associated with a OD relationship and distribution of the vehicles over these routes, we calculate the safety level of a OD relationship. In doing this, it is important to also include the safety level of routes that are not selected (in this simulation). After all, traffic may well follow these routes in a subsequent simulation.

#### *Distribution of vehicles over routes*

The distribution of vehicles over the routes per OD relationship is indicated by calculating the percentage of the total number of vehicles per OD relationship that travel via route  $r$ . This is expressed by the formula:

$$V_{OD,r} = \frac{I_r}{I_{OD}} \times 100\% \quad (1)$$

in which  $V_{OD,r}$  is the percentage of vehicles that travel via route  $r$  from origin  $H$  to destination  $B$ ,  $I_r$  is the absolute number of vehicles that travel via route  $r$  and  $I_{OD}$  is the total number of vehicles that travel from origin  $H$  to destination  $B$ .

#### *Safety level OD*

The unsafety score for each route is multiplied by the percentage distribution of the vehicles following this route, and then added up over the various routes to give a total score for a OD relationship. The outcome of this total score indicates the degree of unsafety of the OD relationship. To arrive at a safety score, the unsafety score is deducted from 1 and multiplied by 100% so that the safety score will fall between 0 and 100%. This is expressed as the formula:

$$VV_{OD} = 100 - \sum_{r=1}^R \frac{(100 - VV_r) \times V_{OD,r}}{100}$$

or, in a more simple formula:

$$VV_{OD} = \sum_{r=1}^R \frac{VV_r \times V_{OD,r}}{100}$$

in which  $VV_{OD}$  is the safety score of OD relationship  $OD$ ,  $R$  is the number of routes associated with OD relationship  $OD$ ,  $VV_r$  is the safety score of route  $r$ , calculated using formula Y.2.10, and  $V_{OD,r}$  is the percentage of vehicles that travel via route  $r$  from origin  $H$  to destination  $B$  (Formula 1).

### 3.2.5. Sustainable Safety Level of OD-relationship given the infrastructure

In the Sustainable Safety Level of a OD relationship, discussed above in 3.2.4, both the route choice and the infrastructural characteristics of the routes are given factors. Improvements in the infrastructural characteristics can increase the Sustainable Safety level, as can another choice of route. In order to separate these two effects, which are probably interdependent, we introduce the Sustainable Safety Level of a OD relationship *given the (existing) infrastructure*. In this, we ignore the infrastructural inadequacies of the routes. This gives us more insight into the safety benefits that may be achieved by influencing the route choice of vehicles.

The safest route in a OD relationship, which does not have to have a safety level of 100 by definition, is standardised to the value of 100 and the least safe route is standardised to the value of 0. If all vehicles make use of the safest route, the safety level of the OD relationship under consideration is 100 *given the infrastructure* and no more benefit can be achieved by influencing route choice. If all vehicles make use of the least safe route, the safety level of the OD relation under consideration is equal to 0 *given the infrastructure*.

The standardised road safety score of a route  $r$  can be defined as follows:

$$VV_{rs} = \frac{VV_r - \min_r\{VV_r\}}{\max_r\{VV_r\} - \min_r\{VV_r\}} \times 100\%$$

By entering the standardised safety score of a route  $VV_{rs}$  instead of the non-standardised safety score  $VV_r$ , it is possible to define the safety score of a OD given the infrastructure as follows:

$$VV_{OD} = \sum_{r=1}^R \frac{VV_{rs} \times V_{OD,r}}{100}$$

See the *Appendix* for some examples of applications to OD relationships.

### 3.3. Vehicle-specific road safety indicators

#### 3.3.1. Introduction

In this section four vehicle-specific indicators will be presented. These indicators are related to the Time To Collision (TTC) which is the time to a collision with a vehicle that is in front (on road sections) or conflicting (at junctions) if neither vehicle changes its course or speed. In order to calculate these road safety indicators, the TTC at the vehicle level must first be calculated, distinguishing between vehicles that are on road sections or at junctions. The method for this is explained in *Section 3.3.2*. Based on the TTC at vehicle level, the four road safety indicators are calculated at vehicle level in *Section 3.3.3*:

- Number Of Conflicts (NOC);
- Time Exposed TTC (TET);
- Time Integrated TTC (TIT);
- Potential Collision Energy (PCE).

In calculating TTC values the smallest acceptable TTC, the so-called critical TTC value, plays an important role.

*Section 3.3.4* defines indicators which are not derived from the TTC. These indicators relate to the distance or the speed differences between vehicles: distance headway, time headway and speed.

In *Section 3.3.5*, the four road safety indicators for road sections and junctions are calculated on the basis of the results at vehicle level. In performing this calculation, a distinction can be made between absolute and relative measurements. The relative measurements at road section and junction level are used in *Section 3.3.6* to arrive at an indication of the safety of routes. *Section 3.3.7* gives an insight into the safety of an OD relationship using the safety of routes and the distribution of the vehicles over these routes.

#### 3.3.2. TTC at vehicle level

##### 3.3.2.1. Introduction

TTC is the time to a collision with a vehicle that is in front (on road sections) or conflicting (on junctions) if neither vehicle changes its course or speed. The TTC is an indicator for a traffic conflict and is therefore related to the accident risk. Low TTCs mean a higher accident risk and high TTCs mean a lower accident risk.

### 3.3.2.2. TTC on road sections and on junctions

In a micro-simulation model, a network can be divided into road sections and junctions. This is important because the method for calculating the TTC for a vehicle on a road section is different from calculating a TTC on a junction. The TTC for a vehicle on a road section is based on the vehicle in front; on a junction, the TTC is calculated on the basis of one or more vehicles coming from another arm of the junction. In addition, a vehicle on a road section can only have one TTC at any given time but on a junction a vehicle can have multiple TTCs simultaneously.

The border line between the end of a road section and the beginning of a junction is determined by the safe stopping distance, referred to henceforth and in the formulae by its Dutch abbreviation of VSA. The VSA for a vehicle  $i$  on road section  $j$  is defined as:

$$VSA_{ij} = \left( \frac{V_j}{3,6} \times rt_i \right) + \left( \frac{V_j^2}{2 \times 3,6^2 \times A_i} \right) \quad (2)$$

in which  $V_j$  is the speed limit in kph for road section  $j$ ,  $rt_i$  is the reaction time of vehicle (driver)  $i$  in seconds and  $A_i$  is the deceleration rate in  $m/s^2$  of vehicle  $i$ . This means the safe stopping distance is made up of a reaction distance and a braking distance (PIARC, 2004; p. 391).

#### *Reaction time*

The reaction time is the time between receiving information and undertaking an action in response to this information. Lamm et al. (1999) note that the reaction time varies from driver to driver and is a function of alertness, complexity and anticipation. The driver's alertness relates to the individual's physical condition; tiredness can play a role in this, as can talking to a passenger. In addition, the extent to which a problem is anticipated determines the reaction time. When a driver on a motorway suddenly perceives a problem, the reaction time will be longer than when a driver is approaching a junction; in the latter situation, the chance of a problem is higher and the driver can anticipate it. The relationship between the reaction time in seconds and the complexity in bits for an average driver and a 'slow' driver (85 percentile) is shown in a chart in Lamm et al. (1999). A 'bit' is the quantity of information required to choose between two apparently equal options. The chart shows that even for a zero-bit decision, in which there is only one alternative, time is required to take action and that the reaction time also increases in line with the number of bits. If we consider the 85 percentile driver, the reaction time for an anticipated, zero-bit decision is 1 second; for an anticipated, one-bit decision it is 1.75 seconds. In the case of an unanticipated, zero-bit decision, the 85 percentile driver has a reaction time of 1.5 seconds and for a one-bit decision a reaction time of 2.5 seconds.

#### *Deceleration rate*

The braking distance is a vehicle property. For a car, the average deceleration rate is  $4 m/s^2$ . For a van, the average is  $3.7 m/s^2$ ; for a medium-size (15-tonne) lorry it is  $3.2 m/s^2$  and for a big (38-tonne) lorry an average deceleration rate of  $3.0 m/s^2$  is conceivable.

### Safe Stopping Distance

As an example we assume a reaction time of 1 second and a deceleration rate of 4 m/s<sup>2</sup>. Safe stopping distances for a number of different speed limits are shown in *Table 3.3*. The safe stopping distance is made up of a reaction distance and a braking distance.

Speed limit (kph)	Reaction time (m)	Braking distance (m)	VSA (Safe Stopping Distance; in m)
30	8.3	8.7	17.0
50	13.9	24.1	38.0
70	19.4	47.3	66.7

Table 3.3. *Safe Stopping Distances at different speed limits for a reaction time of 1 second and a deceleration rate of 4 m/s<sup>2</sup>.*

### 3.3.2.3. TTC on road sections

For vehicles that are on road sections and whose distance to the next junction is greater than the safe stopping distance for the road section in question, we check whether there is any vehicle in front<sup>1</sup> of them.

#### *Vehicle in front*

If a vehicle has another vehicle in front of it, the TTC for vehicle *i* at point in time *t* in relation to a leading vehicle *i-1* is calculated using the formula below (Minderhoud and Bovy, 2001):

$$TTC_i(t) = \frac{X_{i-1}(t) - X_i(t) - l_i}{V_i(t) - V_{i-1}(t)} \quad \text{if } d_{ij}(t) \geq VSA_j$$

in which *X* is the position, *l* is the length, *V* is the speed, *d<sub>ij</sub>* is the distance of vehicle *i* to the end of road section *j* and *VSA<sub>j</sub>* is calculated using *Formula 2*. The TTC can only be calculated if the following vehicle is moving faster than the leading vehicle. If the leading vehicle moves faster than the following vehicle, the TTC is negative. No collision will take place, because the leading vehicle is moving away from the following vehicle and the distance between them is therefore constantly increasing. If the vehicles are moving at the same speed, the TTC is zero, so no collision will take place in this situation either.

#### *No vehicle in front*

If no vehicle is driving ahead of the subject vehicle, there is no TTC at that moment and the vehicle is designated as 'free'.

### 3.3.2.4. TTC on junctions

The TTC for a vehicle approaching a junction is either a TTC that is calculated in interaction with a vehicle in the same direction or one or more TTCs based on a vehicle in one or more conflicting directions. Vogel (2003) makes a distinction between 'passive' and 'active' vehicles.

<sup>1</sup> A vehicle in front may already be within the safe stopping distance from a junction



### Passive vehicles

A vehicle is designated as passive if there is a leading vehicle (a vehicle whose distance to the junction is less than that of the subject vehicle) on the same arm of the junction. The TTC for a passive vehicle is calculated on the basis of the vehicle ahead and therefore in the same way as for vehicles whose distance to a junction is greater than the safe stopping distance (Formula 2).

### Active vehicles

An active vehicle is one that comes into conflict with a vehicle in a conflicting direction or with multiple vehicles in various conflicting directions simultaneously.

### Conflicting streams

The conflicting directions in relation to a vehicle are determined by the type of junction (3-arms or 4-arms) and the manoeuvres (turning right, left or going straight ahead) of both the subject vehicle and of the potentially conflicting vehicle. The potential conflicting directions (arms of the junction) are numbered anti-clockwise. Figure 3.4 shows a number of examples for a vehicle *i* (arrowed in Figure 3.4) driving at a crossroads (on the left-hand side in Figure 3.4) and a T junction (on the right-hand side).

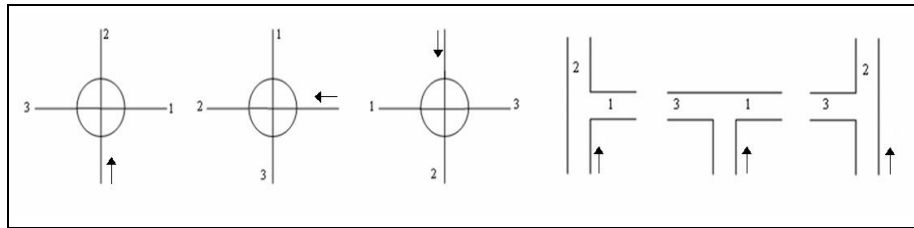


Figure 3.4. Numbering of arms.

The designation of the arms corresponds to the manoeuvre that the vehicle is executing: RT = right turn, SO = straight on and LT = left turn. In Table 3.4, the potential conflicts for vehicle *i* located on arm *n* and executing manoeuvre *m* are defined in relation to vehicle *j* on arm *n* and executing manoeuvre *o*.

### Time required to conflict zone

Per time step *t*, the time required by both active vehicles to reach the conflict zone is estimated by dividing the distance to the conflict zone by the speed (the dimensions of the conflict zone are determined by the width of both vehicles). This is expressed as the formula below (Van der Horst, 1990):

$$AT_i(t) = \frac{d_i(t)}{V_i(t)}$$

in which  $AT_i$  is the time required by vehicle *i* to reach the conflict zone at point in time *t*,  $d_i$  is the distance to the conflict zone at point in time *t* and  $V_i$  is the speed at point in time *t*.

Manoeuvre <i>m</i>	Arm <i>n</i>	Manoeuvre <i>o</i>	Type of conflict
RT	2	Left turn	Converging
RT	3	Straight on	Converging
SO	1	Right turn	Converging
SO	1	Straight on	Side
SO	1	Left turn	Side
SO	2	Left turn	Frontal
SO	3	Straight on	Side
SO	3	Left turn	Converging
LT	1	Straight on	Converging
LT	1	Left turn	Side
LT	2	Right turn	Converging
LT	2	Straight on	Frontal
LT	3	Straight on	Side
LT	3	Left turn	Side

Table 3.4. *Conflicting directions.*

#### *First vehicle*

Using the estimated arrival times per step in time, it is possible to calculate which vehicle will arrive first at the conflict zone; this is the vehicle with the lowest AT as calculated with the formula given above. The vehicle that will arrive first is designated vehicle *i* and the second vehicle is designated vehicle *k*.

#### *Clearance time*

For the vehicle that will arrive first (vehicle *i*), the time required to leave the conflict zone is calculated. This required time is the difference between the moment when the vehicle is estimated to enter the conflict zone ( $AT_i$ ) and the moment when the vehicle is estimated to leave the conflict zone. The required clearance time  $TO$  for vehicle *i* at point in time *t* is equal to (Van der Horst, 1990):

$$TO_i(t) = \frac{l_i + b_k}{V_i(t)}$$

in which  $l_i$  is the length of vehicle *i*,  $b_k$  is the width of vehicle *k* and  $V_i(t)$  is the speed of vehicle *i* at point in time *t*.

This formula can be used for all converging conflicts. In some types of conflicts this formula is also valid, for example, in a frontal conflict (SO versus LT in *Table 3.4*) both vehicles could hit each other at a very small angle.

#### *Collision course*

Active vehicles are on a collision course if the difference between the arrival times of the two vehicles *i* and *k* is less than the required clearance time of vehicle *i*:

$$AT_k(t) - AT_i(t) < TO_i(t)$$

If this is the case, the TTC is equal to the arrival time of the second vehicle:

$$TTC_{i,k}(t) = AT_k(t)$$

If the difference between the arrival times of the two vehicles is greater than the required clearance time of the first vehicle, then the vehicles are not on a collision course and the TTC is not calculated.

*Free vehicles*

A vehicle is free if no other vehicles are present in potentially conflicting directions. There is no TTC for a free vehicle.

3.3.3. From TTC to road safety indicators at vehicle level

3.3.3.1. Introduction

If a vehicle's TTC gets lower than a certain critical value, this can be considered an unsafe situation and is designated a 'conflict situation'. Minderhoud and Bovy (2001) conclude that different values are used for critical TTCs in different studies. According to Archer (2005), a TTC of less than 1.5 seconds is the critical value for road safety in urban areas. In his analysis, Van der Horst takes into account TTC values that are less than 2.5 seconds. Various critical values of TTC can therefore be argued for. Lu et al. (2001), in their study of TTC at junctions, distinguish three accident risk classes based on three critical TTC values. If these are translated into the minimum TTC value of conflicts, we arrive at three different conflict levels.

Risk level	Description
Low	1,5 sec ≥ TTC < 2,0 sec
Moderate	1,0 sec ≥ TTC < 1,5 sec
High	TTC < 1,0 sec

Table 3.5. Conflicts according to the risk level, depending on the TTC value (Lu et al., 2001).

In addition to the number of conflicts (NOC), the following sections illustrate three other road safety indicators: the duration in time of conflicts (TET), the 'intensity' of conflicts (TIT) and the potential collision energy (PCE).

3.3.3.2. Number of conflicts (NOC)

In most cases, there is other traffic on a road section or at a junction; we then speak of an 'encounter'. This is a situation in which two vehicles approach each other in time and space, and in which they can mutually affect each other's behaviour. In the vast majority of encounters, a controlled adjustment in direction or speed is sufficient to allow the encounter to pass off smoothly and without mishap. A conflict is the term used to refer to a traffic situation in which two or more road users approach each other in such a way that a collision threatens and that there is a real chance of physical injury or material damage if they do not change course or speed. FHWA (2003) defines a conflict as an observable situation in which two or more vehicle approach each other in time and space and there is a risk of collision if their movements remain unchanged.

We formulate the number of conflicts  $NOC_i$  in which vehicle  $i$  becomes involved as follows:

$$NOC_i = \sum_{n=0}^T \delta_i(\zeta_n)$$

in which  $\delta_i(\zeta_n)$  = 1 if  $0 \leq TTC_i(\zeta_n) \leq TTC^*$  and  $TTC_i(\zeta_{n+1}) > TTC^*$   
 = 0 otherwise.

In this formula,  $TTC_i$  is the TTC for vehicle  $i$  at point in time  $t$  as calculated in Section 3.3.2.3,  $TTC^*$  is the critical TTC value,  $\zeta_0$  is the point in time when vehicle  $i$  enters the network and  $\zeta_T$  the point in time when the vehicle leaves the network.

The example shows the TTC progress of a vehicle during the time period  $H$  (Minderhoud & Bovy, 2001). In this, the TTC goes below the critical value twice and vehicle  $i$  is therefore involved in two conflicts.

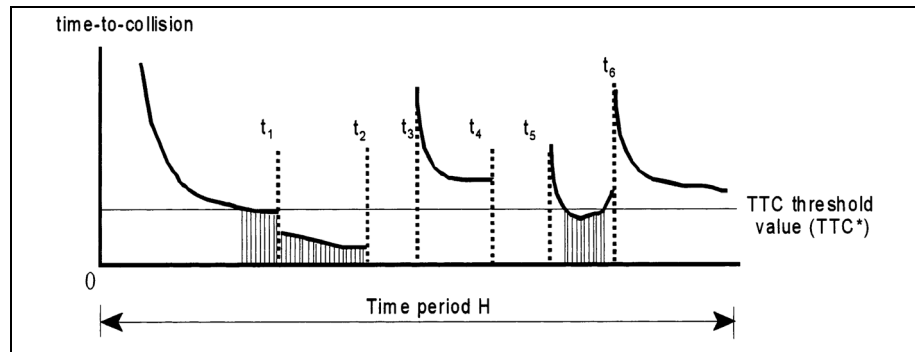


Figure 3.5. Number of conflicts given arbitrary fluctuations of TTC (Minderhoud & Bovy, 2001).

The total number of conflicts for a vehicle during its journey through the network can be calculated; one may also opt to distinguish between conflict types, i.e. conflicts on road sections and at junctions. The latter can be further subdivided into frontal conflicts, transverse conflicts and converging conflicts.

Dividing the minimum TTC values in the conflict situations into a number of classes gives an indication of the safety on road sections, at junctions, on routes and in an entire network.

The road safety indicators discussed below – following distance, vehicle spacing, time headway and speed – are not derived from the TTC but they are closely related to it because it is itself derived from the distance between two vehicles and their respective speeds.

### 3.3.3.3. Time Exposed Time To Collision (TET)

The TET (Time Exposed Time-to-collision) indicates the length of time that a vehicle's TTC is below a critical value ( $TTC^*$ ) during a certain time period (Minderhoud & Bovy, 2001). The TET is therefore the sum of the moments that a vehicle has a TTC that is below the  $TTC^*$ . This means that the lower the TET is, the less time that the vehicle is in a conflict situation and thus the safer the situation is.

The example in *Figures 3.5 and 3.6* shows the TTC progress of a vehicle during the time period  $H$ . The time that the TTC of this vehicle drops below the  $TTC^*$  (horizontal line) is shown by the shading in vertical lines. The sum of these moments gives the value of the TET indicator. This is expressed as the formula:

$$TET_i^* = \sum_{t=0}^T \delta_i(t) \cdot \tau_{sc}$$

in which  $TET_i^*$  = TET value for vehicle  $i$   
 $\delta_i(t)$  = 0 and  
= 1 if  $0 \leq TTC_i(t) \leq TTC^*$   
 $\tau_{sc}$  = time interval (sec.)

### 3.3.3.4. Time Integrated Time To Collision (TIT)

A disadvantage of the TET indicator is that any TTC value that is lower than the critical value is not included in the calculation. As an example, let us take a situation (*Figure 3.6*) in which a critical  $TTC^*$  of 3 seconds has been set: a TTC that has a value of 1 second for a period of 3 seconds has the same weighting in the calculation of the TET indicator as a TTC that has a value of 2 seconds for a period of 3 seconds. The first situation is more dangerous than the second situation. In order to properly reflect the impact of the TTC value, the TIT indicator was developed.

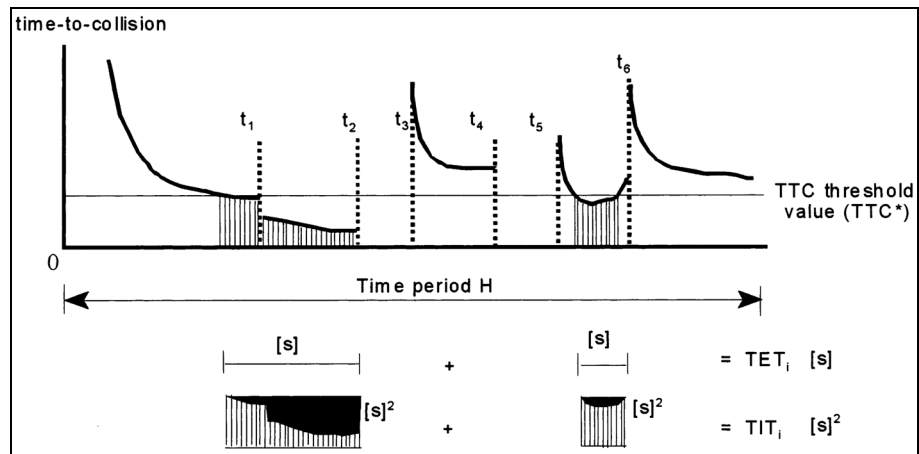


Figure 3.6. *Time Integrated Time To Collision at arbitrary fluctuations of TTC (Minderhoud & Bovy, 2001).*

The Time Integrated Time-to-collision (TIT) calculates the surface area between the  $TTC^*$  and the TTC that occurs. This is expressed as the formula

$$TIT_i^* = \sum_{t=0}^T [TTC^* - TTC_i(t)] \cdot \tau_{sc} \quad \text{for } 0 \leq TTC_i(t) \leq TTC^*$$

### 3.3.3.5. Potential Collision Energy (PCE)

Another way of reflecting the impact of a conflict is via the potential collision energy. This indicates how much energy is released in the event of a

collision between the vehicles that are in conflict with each other. The potential collision energy is built up from the weights and speeds of the vehicles involved and the way in which they collide: the type of conflict. On road sections, only longitudinal conflicts (1 in *Figure 3.7*) are identified. At junctions, a distinction is made between frontal (2), converging (3) and transverse conflicts (4).

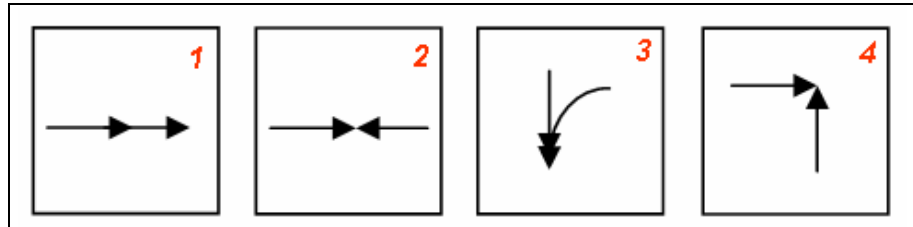


Figure 3.7. *Conflict types.*

#### *Longitudinal conflict*

In order to calculate the potential impact energy  $PCE_T$  at point in time  $t$  in the event of a longitudinal conflict between vehicle  $i$  and vehicle  $k$ , the kinetic energy of one vehicle is deducted from that of the other. This is expressed as the formula

$$PCE_T(t) = \frac{1}{2} (m_i \cdot v_i^2(t) - m_k \cdot v_k^2(t))$$

#### *Frontal conflict and transverse conflict*

In order to calculate the potential impact energy  $PCE_T$  at point in time  $t$  in the event of a frontal or transverse conflict between vehicle  $i$  and vehicle  $k$ , the kinetic energy of one vehicle is added to that of the other. This is expressed as the formula

$$PCE_T(t) = \frac{1}{2} (m_i \cdot v_i^2(t) + m_k \cdot v_k^2(t))$$

in which  $m$  is the mass and  $v$  is the velocity.

#### *Converging conflict*

In order to calculate the potential impact energy  $PCE_T$  at point in time  $t$  in the event of a converging conflict between vehicle  $i$  and vehicle  $k$ , the kinetic energy of one vehicle is added to that of the other and correct the result by a factor to take into account the angle ( $45^\circ$ ) between the vehicles. This is expressed as the formula

$$PCE_T(t) = \frac{1}{4} (m_i \cdot v_i^2(t) + m_k \cdot v_k^2(t))$$

#### *Distribution of PCE between vehicles*

The total potential collision energy  $PCE_T$  that is released if vehicles  $i$  and  $k$  with a mass  $m$  collide at point in time  $t$  (calculated using the three formulae for  $PCE_T$ ), is distributed between the vehicles according to their masses. The lighter vehicle has to absorb the greater part of the potential collision energy

and the heavier vehicle has to absorb the lesser part. The potential collision energy PCE to be absorbed by vehicle  $i$  is calculated as follows:

$$PCE_i(t) = \frac{m_k}{m_i + m_k} * PCE_T(t),$$

and consequently for vehicle  $k$  as:

$$PCE_k(t) = \frac{m_i}{m_i + m_k} * PCE_T(t)$$

### 3.3.4. Indicators for distance headway, time headway and speed

The next sections will treat another three indicators regarding the safety at the vehicle level. These three indicators are not derived from the *TTC*, but have a close relationship with *TTC* because the components are also the distance between two vehicles and the speed difference between these vehicles. In a similar fashion to the way in which Minderhoud and Bovy (2001) developed the TET and TIT road safety indicators based on the *TTC*, we can also use indicators, aimed at the time period and the seriousness of the conflicts.

#### 3.3.4.1. Distance Headway

The distance headway is the distance between a vehicle and the vehicle in front of it. Distance headway can be viewed with reference to a 'safe distance', whereby a collision with a vehicle in front is impossible if the latter acts in an unexpected manner. If the distance headway is less than the safe distance, the situation is unsafe. The number of critical distance headways on a road section or on all the road sections combined can be a road safety indicator.

##### *Time Exposed Distance Headway (TEDH)*

The TEDH (Time Exposed Distance Headway) indicates the length of time that a vehicle's distance headway is below a critical value (distance headway\*) during a certain time period. The TEDH is therefore the sum of the moments that a vehicle has a distance headway that is below the distance headway\*. This means that the smaller the TEDH is, the safer a situation is. This is expressed as the formula:

$$TEDH_i^* = \sum_{t=0}^T \delta_i(t) \cdot \tau_{sc}$$

in which  $TEDH_i^*$  = TEH value for vehicle  $i$   
 $\delta_i(t)$  = 0 and  
= 1 if  $0 \leq \text{distance headway}_i(t) \leq \text{distance headway}^*$   
 $\tau_{sc}$  = time interval (sec.)

##### *Time Integrated Distance Headway (TIDH)*

The TIDH (Time Integrated distance Headway) calculates the surface area between the distance headway and the distance headway\* that occurs. This is expressed as the formula

$$TIDH_i^* = \sum_{t=0}^T [distance\ headway^* - distance\ headway_i(t)] \cdot \tau_{sc}$$

for  $0 \leq distance\ headway_i(t) \leq distance\ headway^*$

### 3.3.4.2. Time Headway

Vogel (2003) introduces time headway as an indicator for calculating road safety. The time headway is the time between a vehicle and the vehicle in front. If the time headway drops below a critical value, the situation becomes unsafe. The number of low time headways can serve as an indicator of road safety on road sections or on all the road sections in combination.

#### *Time Exposed Time Headway (TETH)*

The TETH (Time Exposed Time Headway) indicates the length of time that a vehicle's time headway is below a critical value (headway time\*) during a certain time period. The TETH is therefore the sum of the moments that a vehicle has a time headway that is below the time headway\*. This means that the smaller the TETH is, the safer a situation is. This is expressed as the formula:

$$TETH_i^* = \sum_{t=0}^T \delta_i(t) \cdot \tau_{sc}$$

in which  $ETH_i^*$  = TETH value for vehicle i  
 $\delta_i(t)$  = 0 and  
= 1 if  $0 \leq time\ headway(t) \leq time\ headway^*$   
 $\tau_{sc}$  = time interval (sec.)

#### *Time Integrated Time Headway (TITH)*

The TITH (Time Integrated Time Headway) calculates the surface area between the time headway and the time headway\* that occurs. This is expressed as the formula:

$$TITH_i^* = \sum_{t=0}^T [time\ headway^* - time\ headway_i(t)] \cdot \tau_{sc}$$

for  $0 \leq time\ headway_i(t) \leq time\ headway^*$

### 3.3.4.3. Speed

#### *Time Exposed Speed (TES)*

The TES (Time Exposed Speed) indicates the length of time that a vehicle's speed is above the speed limit (speed\*) for a road section during a certain time period. The TES is therefore the sum of the moments that a vehicle's speed is higher than the speed limit. This means that the smaller the TES is, the safer a situation is. This is expressed as the formula:

$$TES_i^* = \sum_{t=0}^T \delta_i(t) \cdot \tau_{sc}$$

in which  $TES_i^*$  = TES value for vehicle i  
 $\delta_i(t)$  = 0 and



$$\begin{aligned} &= 1 \quad \text{if } \text{speed}_i(t) \geq \text{speed}^* \\ \tau_{sc} &= \text{time interval (sec.)} \end{aligned}$$

#### *Time Integrated Speed (TIS)*

The TIS (Time Integrated Speed) calculates the surface area between the speed and the speed limit\* that occurs. This is expressed as the formula:

$$TIS_i^* = \sum_{t=0}^T [\text{speed}^* - \text{speed}_i(t)] \cdot \tau_{sc} \quad \text{for } 0 \leq \text{speed}_i(t) \leq \text{speed}^*$$

### 3.3.5. From vehicle level to road section/junction level

The scores of the various road safety indicators at vehicle level can be totalled for each road section or junction to produce an indication of the safety of a road section or junction. For example, the number of conflicts that occur on a road section during a certain period of time is a measure of the safety of that road section. If the absolute score is divided by an exposure index such as the number of vehicles passing per time unit, a relative measure is obtained. This makes it possible to compare a variety of road sections and various simulations.

In the following sections, the safety of road sections and junctions is defined in general terms. This implies that road safety can be assessed using a variety of indicators at vehicle level: the number of conflicts, the TET, the TIT and the potential collision energy. The method of arriving at road section/junction level is the same for all four road safety indicators.

#### 3.3.5.1. Road sections

##### *Absolute measure*

The unsafety VOV on road section  $m$  during time period  $T$  is equal to the sum of unsafety on the road, in which the number of vehicles  $I$  that pass through road section  $m$  during time period  $T$  are involved. This is expressed as the formula

$$VOV_{m,T} = \sum_{i=0}^I VOV_{i,m,T}$$

In this the unsafety VOV is formed by the number of conflicts (NOC), TET, TIT, and PCE, as well as by the other indicators (TEDH, TIDH, TETH, TITH, TES, TIS).

##### *Relative measure*

The relative unsafety RVOV for road section  $m$  during time period  $T$  is equal to the absolute unsafety (as calculated using the previous formula) divided by the number of vehicles  $I$  that pass through road section  $m$  during time period  $T$ .

This is expressed as the formula:

$$RVOV_{m,T} = \frac{VOV_{m,T}}{I_{m,T}}$$

### 3.3.5.2. Junctions

#### *Absolute measure*

##### Longitudinal conflicts

The unsafety  $VOV$  for longitudinal conflicts at junction  $n$  for manoeuvre  $m$  during time period  $T$  is equal to the total of the unsafety in which the  $I$  number of vehicles executing manoeuvre  $m$  at junction  $n$  during time period  $T$  are involved. This is expressed as the formula

$$VOV_{n,m,T} = \sum_{i=0}^I VOV_{i,n,m,T}$$

in which manoeuvre  $m$  can be a right turn, left turn or going straight on or specified in more detail: at direction level. At a 4-arm junction, 12 directions (4 arms times 3 directions) are involved; at a 3-arm junction, 6 directions (3 arms times 2 directions) are involved.

##### Converging, transverse and frontal conflicts

The relative unsafety  $RVOV$  for converging, transverse and frontal conflicts at junction  $n$  and manoeuvre  $m$  during time period  $T$  is equal to the total number of conflicts in which the  $I$  number of vehicles executing manoeuvre  $m$  at junction  $n$  during time period  $T$  are involved. Because a conflict between two vehicles takes place at the same junction and therefore counts as a conflict for both vehicles, the conflicts for the junction must be divided by 2. This is expressed as the formula

$$RVOV_{n,m,T} = \sum_{i=0}^I VOV_{i,n,m,T} \times 0.5$$

in which manoeuvre  $m$  can be a right turn, left turn or going straight on.

#### *Relative measure*

The relative unsafety  $RVOV$  for junction  $n$  during time period  $T$  is equal to the unsafety  $VOV$ , as calculated using one of the two foregoing formulae (for longitudinal or other conflicts), divided by the number of passing vehicles  $I$  executing manoeuvre  $m$  at junction  $n$  during time period  $T$ . This is expressed as the formula

$$RVOV_{n,m,T} = \frac{VOV_{n,m,T}}{I_{n,m,T}}$$

### 3.3.6. From road section/junction level to route level

A route  $r$  is defined as a chain of a number  $M$  of road sections and a number  $N$  of junctions that can be followed to reach destination  $j$  from origin  $i$ . To indicate the safety of a route, we use the relative unsafety of road sections and junctions. The general formula is given below.

#### 3.3.6.1. Unsafety of a route

The safety of a route  $r$  between origin  $i$  and destination  $j$  is equal to the sum of the unsafety  $VOV$  during time period  $T$  on the number  $M$  of road sections

and the number  $N$  of junctions (see the formulae for the absolute measures in *Sections 3.3.5.1* and *3.3.5.2* respectively), specified according to manoeuvre, that form part of the route. This is expressed as the formula:

$$VOV_{ij,r,T} = \sum_{m=0}^M VOV_{m,T} + \sum_{n=0}^N VOV_{n,m,T}$$

The relative measure is formulated as:

$$RVOV_{ij,r,T} = \frac{VOV_{ij,r,T}}{I_{ij,T}}$$

If a route is not used by any vehicle the  $RVOV$  can nevertheless be calculated. That is because other vehicles, following different routes, will be using the road sections of the route in question. Those vehicles will be part of the calculation of  $RVOV$ .

### 3.3.7. From route level to OD level

Using the road safety indicators as described in *Section 3.3.6*, it is possible to calculate the road safety of an OD pair for all the routes that are associated with that OD pair. Then, by making it clear how vehicles spread themselves over these routes, we can see to what extent vehicles select the safest route and how many do so. It is also important here to include the safety level of routes that are not (in this step) selected. After all, traffic may well follow these routes in a subsequent step. This produces a picture of the road safety of an OD pair. We then explain, step by step, how these calculations were arrived at.

#### 3.3.7.1. Distribution of vehicles over all routes

The distribution of vehicles over the routes per OD pair is indicated by calculating the percentage of the total number of vehicles per OD pair that travel via route  $r$ . This is expressed in the formula

$$V_{OD,r} = \frac{I_r}{I_{OD}} \times 100\%$$

in which  $V_{OD,r}$  is the percentage of vehicles that travel via route  $r$  from origin  $H$  to destination  $B$ ,  $I_r$  is the absolute number of vehicles that travel via route  $r$  and  $I_{OD}$  is the total number of vehicles that travel from origin  $H$  to destination  $B$ .

#### 3.3.7.2. Safety level at the OD level

In order to define the safety level of an OD pair, the scores for the number of conflicts, TET, TIT and potential collision energy are standardised. The standardised road safety score of a route  $r$  can be defined as follows:

$$VV_{rs} = \frac{VV_r - \min_r\{VV_r\}}{\max_r\{VV_r\} - \min_r\{VV_r\}} \times 100\%$$

in which the road safety score of a route  $VV_r$  is given by the number of conflicts, TET, TIT, PCE or by the other indicators (TEDH, TIDH, TETH, TITH, TES, TIS).

The safety score of an OD pair is then defined as follows:

$$VV_{OD} = \sum_{r=1}^R \frac{VV_{rs} \times V_{OD,r}}{100}$$

in which the standardised road safety score of a route  $VV_{rs}$  is given by the number of conflicts, TET, TIT, PCE or other indicators.

## 4. Application to a test network

### 4.1. Introduction

In this chapter we will discuss an application of the safety indicators (described in *Chapter 3*) in the S-Paramics micro-simulation package. In S-Paramics three one-hour simulations are performed in order to apply the indicators to an OD relationship with a variety of routes. The results for the road safety indicators from the three simulations are compared and contrasted to expose the effect on road safety of influencing route section. The simulations in S-Paramics are performed on a synthetic network located within an urban area and consist of *nodes*, *links* between the *nodes* and *zones* that generate and attract traffic.

### 4.2. Description of test network in Paramics

#### 4.2.1. Road types

The synthetic test network consists of 4 different road types:

- Footpaths (purple);
- Roads with a speed limit of 30 kph (in black);
- Roads with a speed limit of 50 kph (in blue);
- Roads with a speed limit of 70 kph (in red).

The network is depicted in *Figure 4.1*, in which the roads have been allocated a colour corresponding to the colour of the road type.

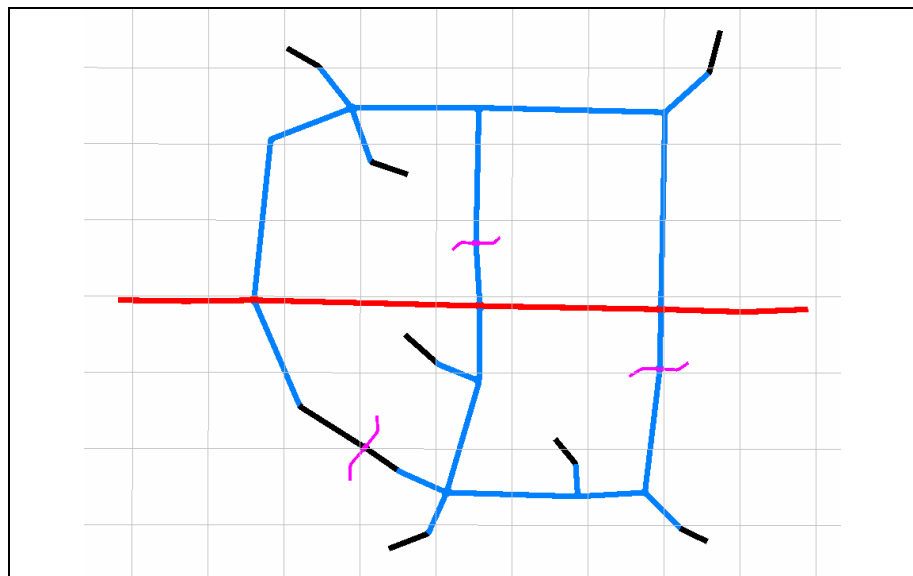


Figure 4.1. Road types in a test network.

A 70 kph priority road (in red) with an external zone at each end (generating traffic without origin and destination within the network) runs straight through the network. Vehicles that do not enter/leave the network via these external zones always make use of 30 kph zones (in black). For these vehicles, a route through the network therefore always begins and ends on 30 kph

roads. Three pedestrian crossings are also simulated; these are identifiable as the 3 purple footpaths that cross the roads. Two of the pedestrian crossings are on 50 kph roads and the third is in a 30 kph zone.

#### 4.2.2. Nodes

In the illustration below, the nodes are numbered. This numbering system is used in the output to indicate which road section or junction is involved.

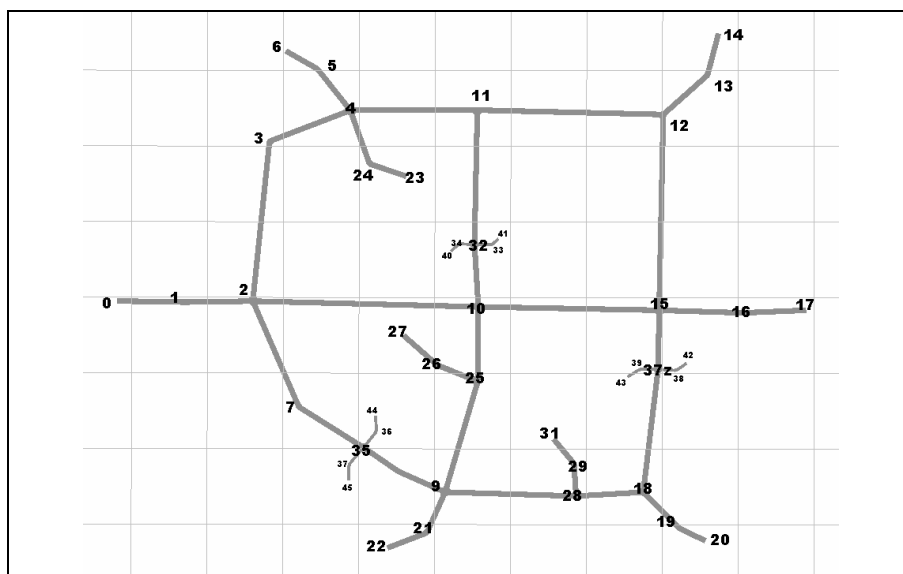


Figure 4.2. Nodes in the test network.

The 4-arm junctions 2, 10 and 15 are priority junctions. At the other 4-arm junctions (4 and 9) and the 3-arm junctions (11, 12, 18, 25 and 28) traffic from the right has priority.

Pedestrians have priority at the pedestrian crossings (nodes 32, 35 and 37z).

The road sections in the network are indicated by a combination of start and end nodes. For example, traffic moves from node 2 to node 10 via road section 2-10. Traffic in the other direction drives on road section 10-2.

#### 4.2.3. Zones

Zones generate and attract vehicles onto and from the network. In the synthetic test network there are two external zones (orange circles) and seven internal zones (green circles). In addition, there are six pedestrian zones (red circles) that have been created to simulate three pedestrian crossings.

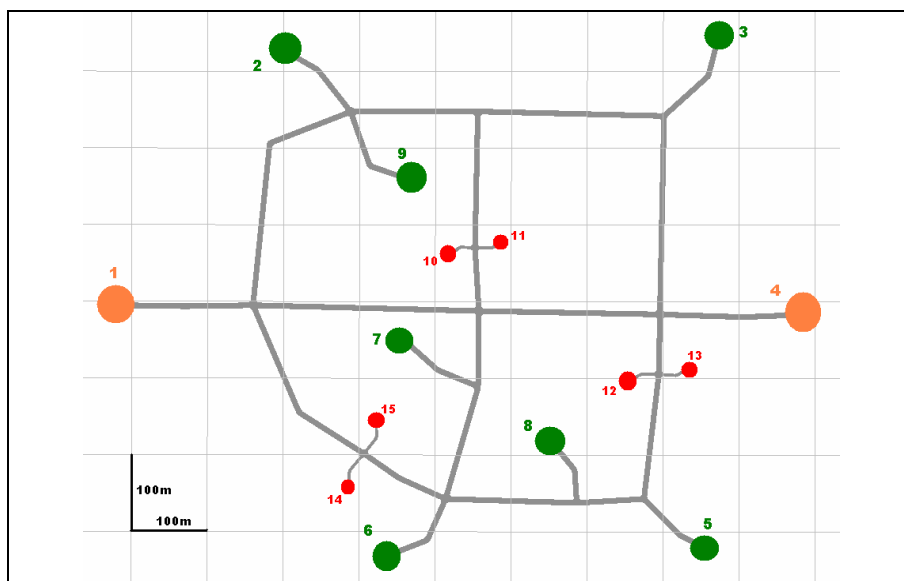


Figure 4.3. Zones in the test network.

The zones are used to draw up the OD matrix. In this matrix, the number of vehicles is entered for each OD relationship. The following types of traffic are distinguished in the matrix:

- A Through traffic: both the origin and the destination are in external zones;
- B Outgoing traffic: the origin is in an internal zone and the destination in an external zone;
- C Incoming traffic: the origin is in an external zone and the destination in an internal zone;
- D Internal traffic: both the origin and the destination are in internal zones;
- E Pedestrians: origin and destination are both in pedestrian zones.

Table 4.1 shows the relationships between the various zones for the motor vehicles, including the type of traffic (A, B, C or D). Table 4.2 shows the relationships between the zones for the pedestrians (type E).

Origin	Destination								
	1	2	3	4	5	6	7	8	9
1	-	C	C	A	C	C	C	C	C
2	B	-	D	B	D	D	D	D	D
3	B	D	-	B	D	D	D	D	D
4	A	C	C	-	C	C	C	C	C
5	B	D	D	B	-	D	D	D	D
6	B	D	D	D	D	-	D	D	D
7	B	D	D	B	D	D	-	D	D
8	B	D	D	B	D	D	D	-	D
9	B	D	D	B	D	D	D	D	-

Table 4.1. OD pairs for motor vehicles in the test network.

Origin	Destination					
	10	11	12	13	14	15
10	-	E	-	-	-	-
11	E	-	-	-	-	-
12	-	-	-	E	-	-
13	-	-	E	-	-	-
14	-	-	-	-	-	E
15	-	-	-	-	E	-

Table 4.2. OD pairs for pedestrians in the test network.

#### 4.2.4. OD relationship and associated routes

The various road safety indicators can be applied for each OD relationship in the network. In this report, OD relationship 2-5 is used by way of illustration; here, there are six possible routes that can be selected (numbering in line with *Figure 4.2*):

- R1. Node 4-11-12-15-18;
- R2. Node 4-11-10-15-18;
- R3. Node 4-11-10-9-18;
- R4. Node 4-2-10-15-18;
- R5. Node 4-2-10-9-18;
- R6. Node 4-2-9-18.

#### 4.3. Route choice in S-Paramics

In the three simulations, attempts were made to influence route choice using different methods. Before discussing these, we shall first describe the route choice model in S-Paramics.

In S-Paramics, each vehicle tries to find the shortest route from the road section on which it is located to its destination zone. The shortest route is the one for which the general journey costs are lowest. Each time a vehicle enters a new road section, the route is evaluated again on the basis of the general journey costs that are 'stored' in route tables.

##### 4.3.1. Road hierarchy

The road hierarchy in a network can be used to change the journey costs on special road sections for familiar and unfamiliar vehicles. The road hierarchy in a network is made up of major and minor road sections.

###### *Major road sections*

Major road sections are equipped with signs; the journey costs of familiar and unfamiliar vehicles are the same.

###### *Minor road sections*

There are no signs on minor road sections and the familiar vehicles view the journey costs on minor road sections as being the same as the actual costs. Unfamiliar vehicles have a lower consciousness of minor road sections; they view the journey costs on these road sections as being twice the actual costs. These 'penalty costs' make it less likely that these unfamiliar vehicles



will choose routes along minor road sections and they will therefore tend to stay on the signed road sections (i.e. the major road sections).

#### *Familiarity*

Familiarity with the road network has a fundamental influence on route choice in a hierarchical road network. If this directly influences the quantity of routes passing along routes with and without signs, it is important to properly calibrate the level of familiarity.

The standard familiarity value for all vehicles is 85%. This means that 85% of the vehicles make *no* distinction between the costs of *major* and *minor* road sections. The other 15%, the unfamiliar vehicles, view the costs on *minor* road sections as higher and will be more inclined to travel along *major* road sections.

The level of familiarity can be set separately for each vehicle type. For example, if a model includes taxis, it would be quite possible to set the familiarity at 100% because taxi drivers usually know the road network well.

#### 4.3.2. General costs

The general journey costs and the road category can be set for each individual road section.

#### *General journey costs of a road section*

The journey costs of an individual road section can be calculated using the general cost comparison. This represents a combination of factors that drivers take into consideration when choosing between various routes. The most important factors are time and distance. If a toll is charged for using certain parts of a road, these costs will also be taken into account.

The general journey costs *GK* of a road section are measured in time, distance and (if imposed) toll charges and can be weighted by means of coefficients, depending on the road category and the familiarity of the road users with the road network. The formula for calculating the *GK* is:

$$GK = a * T + b * D + c * P$$

in which *a* is the time coefficient (seconds), *b* is the distance coefficient, *c* is the toll coefficient (minutes per unit of money), *t* is the journey time in minutes, *d* is the link length and *p* is the toll price. The standard value is 1 for *a*, 0 for *b* and *c*.

The general journey costs *GK* of a road section can be set to the same (*generic*) value for all vehicles or they can be set *by vehicle type*.

By way of example, the general journey costs associated with a 1-kilometre road section with a journey time of 120 seconds for different coefficients *a*, *b* and *c* are shown in *Table 4.3*.

a	b	c	GK
1	0	0	120
0	1	0	60
0.5	0.5	0	90

Table 4.3. Example of general journey costs *GK* for different coefficients *a*, *b* and *c*.

### General journey costs of a road category

In addition to calculating the general journey costs of an individual road section as described above, we can also calculate the general journey costs for a road category. This determines the general journey costs for all road sections that fall into a certain road category. This is done in precisely the same way as described above.

If an individual road section falls into a category for which the general journey costs are e.g. 2 and, furthermore, it is allocated a specific value of e.g. 3 that applies only to this road section, then the final general journey costs are 6 (GK of the category multiplied by GK of the individual road section).

For a minor road section, the costs are 6 for familiar vehicles and 12 for unfamiliar vehicles. *Table 4.4* gives some examples of how GKC (general journey costs of category) and GKWs (general costs of an individual road section) influence the costs for familiar and unfamiliar vehicles.

Link type	GKC General Costs of Category	GKW General Costs of an Individual Road Section	Familiar	Unfamiliar
Major	1	1	1	1
Minor	1	1	1	2
Major	2	1	2	2
Minor	2	1	2	4
Major	2	2	4	4
Minor	2	2	4	8
Major	3	2	6	6
Minor	3	2	6	12

Table 4.4. Example of general journey costs for familiar and unfamiliar vehicles on major and minor road sections for a combination of GKC and GKWs.

### 4.3.3. Route tables

The route tables are filled in using the general journey costs of the road sections. The route costs are equal to the sum of the general journey costs of the road sections that form part of the route. Route tables give vehicles the opportunity to calculate the costs of a route choice at each junction along the route. When a vehicle approaches a junction, it consults the relevant route table and, after deciding whether to apply *perturbation* and/or *dynamic feedback*, the vehicle selects the route that has the lowest journey costs to the destination.

As standard there are two route tables in a model in S-Paramics: one table contains the costs for vehicles that are familiar with the road network (familiar vehicles) and the other table contains the costs for vehicles that are unfamiliar with the road network (unfamiliar vehicles). Familiar vehicles have a different perception to unfamiliar vehicles of a route through the network. This is achieved by making use of a road hierarchy in the network and by calibrating familiarity.

In addition, a separate route table can be created for each type of vehicle, thereby producing a set of route tables. Each route table is calculated each time that a simulation is started.

#### 4.3.4. Allocation methods

The following allocation methods are possible in S-Paramics:

- All-or-nothing allocation;
- Stochastic allocation;
- Dynamic allocation;
- Stochastic Dynamic allocation.

##### *All-or-nothing allocation*

In a one-off operation based on an empty network at the start of a simulation, the *all-or-nothing* allocation determines the general journey costs for all possible routes associated with a OD relationship. The route with the lowest general journey costs is seen as the *shortest* route. All vehicles that travel from a given origin to a given destination will then make use of this shortest route.

##### *Stochastic allocation*

In the stochastic allocation, *perturbation* is used. Application of this perturbation means that a variance is applied to the general journey costs of a route whenever vehicles have to choose between routes and do not want to make use of an *all-or-nothing* allocation.

When a route choice has to be made, a vehicle calculates the general journey costs  $GK$  of each possible route and then takes a random perturbation of these costs according to the formula below to calculate the new generalised journey costs  $GK_{new}$ . The route with the lowest new general journey costs  $GK_{new}$  is chosen.

$$GK_{new} = GK + (GK * var/ 100)$$

in which  $-perturbation \leq var \leq + perturbation$ .

The variance  $var$  can be calculated in one of two ways: by means of the Percentage algorithm or the Square Root algorithm.

##### Percentage algorithm

With the Percentage algorithm, the probability is taken into account that the new general journey costs lie within a margin of P% above or below the actual costs  $GK$ .

A *perturbation* level of 5 (standard) leads to a variance of 5% on the general journey costs  $GK$ .

##### Square Root algorithm

The Square Root algorithm perturbs the general journey costs by making use of the *Burrell* technique, based on the following comparison:

$$C' = C + (((N - 5) * P) / 500) * \sqrt{C}$$

in which  $C'$  is a random journey time,  $C$  is the actual journey time,  $N$  is a random number (from 0 to 10) and  $P$  is the perturbation factor (whole number >0).

If the *perturbation factor*  $P$  is equal to 100, then the costs will vary by up to  $\pm \sqrt{C}$ .

### *Dynamic feedback allocation*

In the dynamic feedback allocation, road users who are familiar with the road network take into consideration the congestion in the network when calculating the journey costs of a road section and of routes.

Where an all-or-nothing allocation calculates the journey costs on the basis of an empty road network, the dynamic feedback allocation calculates the journey costs of a road section on the basis of the delay imposed by congestion in a constantly revised (dynamic) cost calculation.

Road sections that have low journey costs based on calculation for an empty network, and will therefore attract a lot of traffic, will in the course of time produce higher journey costs due to higher concentrations and possibly even congestion. As a result, alternative routes become more attractive. If the congestion decreases, the journey costs of these road sections will decline and become more attractive again.

In the dynamic feedback allocation, the various route tables are constantly recalculated for each feedback interval.

### Feedback interval

The frequency of the feedback can be set using the *feedback interval*. This means that the journey costs are recalculated every 1, 5 or 10 minutes (for example) and are used to redetermine the route choice for each individual vehicle.

### Feedback factor

To avoid excessive variance in the route choice during the simulation period, a feedback factor is used. This factor takes into account the degree of change in the journey costs and is used to recalculate the choice of route. It is applied as follows:

$$V_{new} = a * V_{current} + (1 - a) * V_{previous}$$

in which  $a$  is the feedback coefficient,  $V$  the costs of a given movement (from link to link),  $V_{new}$  the costs to be used for route choice calculations,  $V_{current}$  the costs from the current feedback period and  $V_{previous}$  the costs from the previous feedback period.

A high feedback factor leads to a higher proportion of delays that are fed back in the simulation and therefore to a greater chance of route revision. The standard setting for the feedback factor is 0.50.

### *Stochastic dynamic allocation*

The stochastic dynamic allocation uses both *perturbation* and *feedback* and is therefore the dynamic feedback allocation together with a varying perception of the actual general journey costs (*perturbation*). It is used in precisely the same way as the stochastic allocation.

## 4.4. Coefficients and factors used in the simulations I, II and III

Three simulations, referred to as simulations I, II and III, were performed. The standard values for the coefficients ( $a=1$ ,  $b=0$ ,  $c=0$ ) were used for the general journey costs function in all three simulations. Only the journey time is therefore taken into consideration in the choice of route. In addition, a *familiarity* factor of 85 is used: this means that 85% of the vehicles make no distinction between the costs of *major* and *minor* road sections; these vehicles are therefore familiar with the road network. The 50 kph and 70 kph

road sections are set as *major* road sections and the 30 kph ones are set as *minor* road sections.

In simulation I, the stochastic, all-or-nothing allocation with a *perturbation* factor of 15 is used.

In simulation II, the vehicles have a route information system that gives the current situation on the road network every minute. Based on this current situation, the vehicles estimate the journey time and use this to select a certain route. The allocation used is the dynamic feedback allocation, with a feedback interval of 1 minute and a feedback factor of 0.5.

In simulation III, the concentration on the main artery (70 kph road) is doubled and the vehicles still have a route information system that gives the current situation on the network every minute. The same allocation (dynamic feedback) and the same settings as for simulation II are therefore used in simulation III. The only change is in the OD matrix: the number of vehicles moving from zone 1 to zone 4 and vice versa is doubled.

#### 4.5. General road safety indicators

##### 4.5.1. Route diagrams

The route diagrams described in *Section 3.2.2* are shown in *Figures 4.4* to *4.9* for the six routes of OD pair 2-5 in the test network.

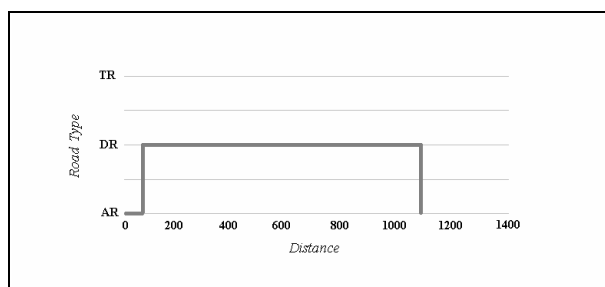


Figure 4.4. *Route diagram route 1.*

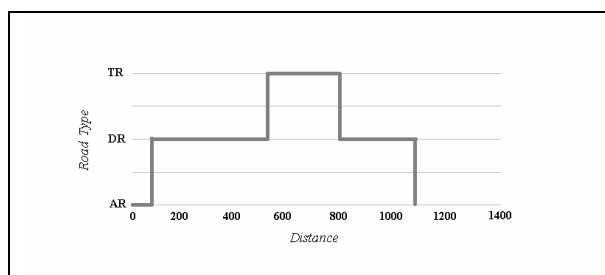


Figure 4.5. *Route diagram route 2.*

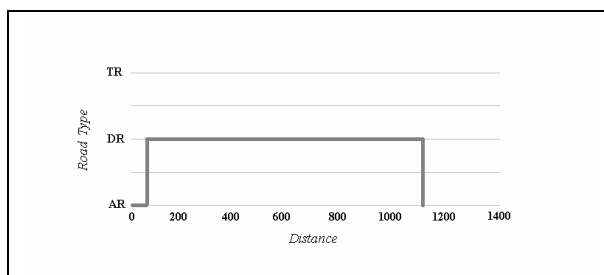


Figure 4.6. Route diagram route 3.

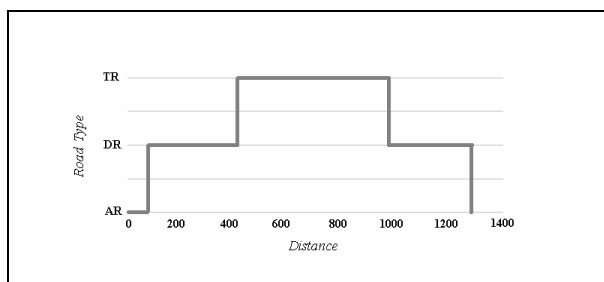


Figure 4.7. Route diagram route 4.

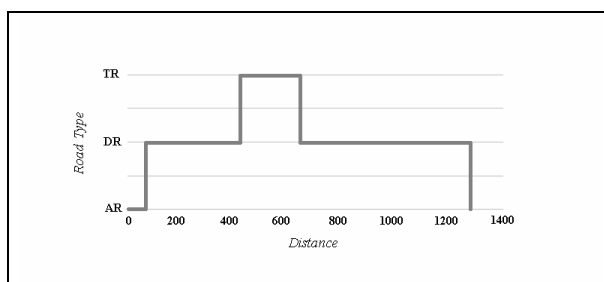


Figure 4.8. Route diagram route 5.

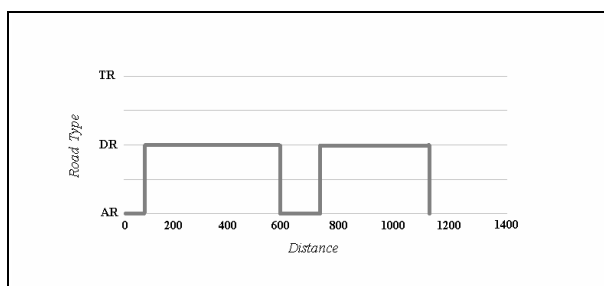


Figure 4.9. Route diagram route 6.

A visual evaluation of the diagrams in *Figures 4.4 to 4.9* results in three routes that meet the qualitative criteria as described in *Section 3.3.3*: routes 2, 4 and 5 use Access Roads at the beginning and end, and follow, although not for a greater part of the total length, the Through Road. This visual evaluation does not allow for a distinction between these routes 2, 4, and 5.

#### 4.5.1.1. Sustainable Safety level of routes

For the six routes, data were collected in order to calculate the scores for the nine Sustainable Safety criteria as described in *Sections 3.2.2.1 to 3.2.2.9*.

The scores calculated for the nine Sustainable Safety criteria are shown in *Table 4.5*.

Criterion	Description	Route number					
		1	2	3	4	5	6
1	Number of transitions	0	0	0	0	0	2
2	Nature of transitions	0	0	0	0	0	0
3	Missing road categories	1	0	1	0	0	1
4	Proportion of access roads	7.9	8.5	8.3	6.7	6.6	20.6
5	Proportion of distributors	92.1	68.9	91.7	53.1	71.6	79.4
6	Travel distance	1142	1055	1087	1334	1366	1192
7	Travel time	87	75	83	90	96	98
8	Left turns	2	3	2	2	2	0
9	Junction density	5.7	6.9	8	5.6	6.1	6.3

*Table 4.5. Calculated scores for each route.*

The standardised scores were calculated according to the formula in *Section 3.2.3* and are shown in *Table 4.6*.

Criterion	Description	Route number					
		1	2	3	4	5	6
1	Number of transitions	0.00	0.00	0.00	0.00	0.00	1.00
2	Nature of transitions	0.00	0.00	0.00	0.00	0.00	0.00
3	Missing road categories	1.00	0.00	1.00	0.00	0.00	1.00
4	Proportion of access roads	0.09	0.14	0.12	0.01	0.00	1.00
5	Proportion of distributors	1.00	0.41	0.99	0.00	0.47	0.67
6	Travel distance	0.28	0.00	0.10	0.90	1.00	0.44
7	Travel time	0.52	0.00	0.35	0.65	0.91	1.00
8	Left turns	0.67	1.00	0.67	0.67	0.67	0.00
9	Junction density	0.04	0.54	1.00	0.00	0.21	0.29

*Table 4.6. Standardised scores for each route.*

The route stars (introduced in *Section 3.2.3*) are shown for each route in *Figures 4.10 to 4.15*.

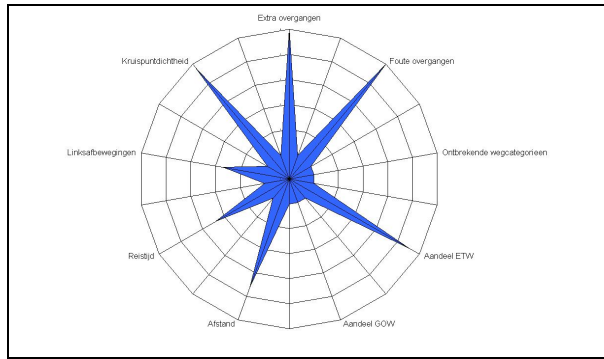


Figure 4.10. *Route star route 1.*

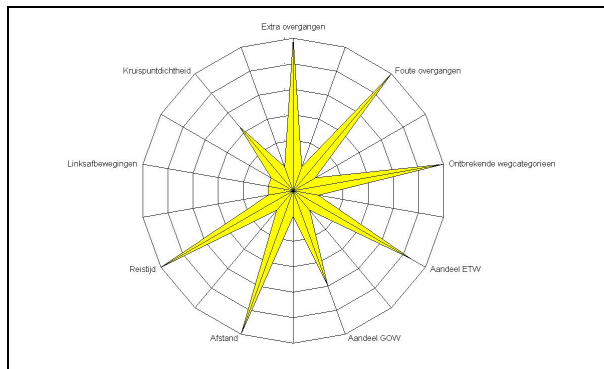


Figure 4.11. *Route star route 2.*

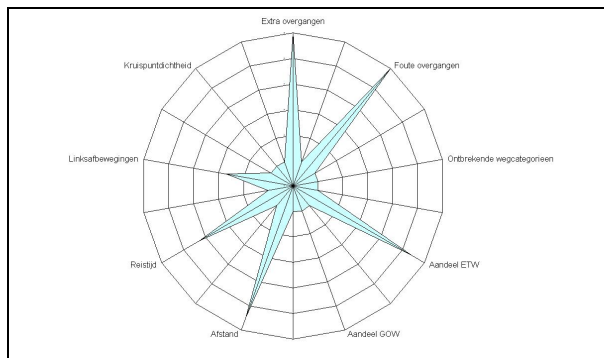


Figure 4.12. *Route star route 3.*

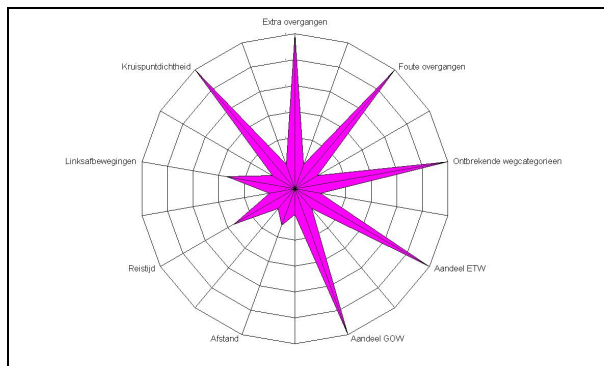


Figure 4.13. *Route star route 4.*



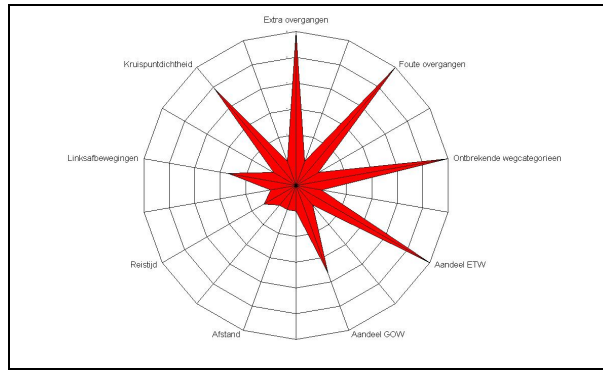


Figure 4.14. *Route star route 5.*

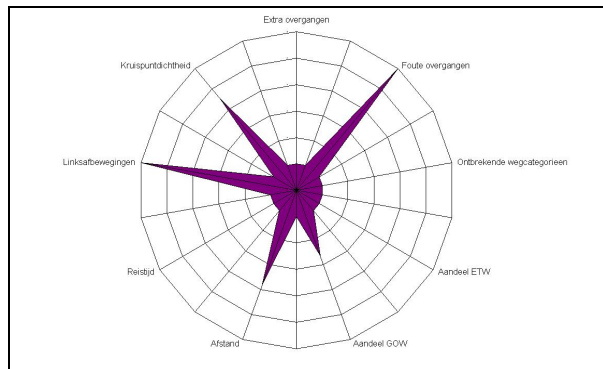


Figure 4.15. *Route star route 6.*

#### 4.5.2. *Weight and total score*

It was decided to give all the criteria equal weighting (see *Section 3.2.3* for the weights of criteria). Each criterion is therefore given a weight of 1/9 that is multiplied by the standardised scores. By adding up this product per route across the nine criteria, a total per route is arrived at: the unsafety score. The Sustainable Safety level is then determined using the formula described in *Section 3.2.3.1*.

Criterion	Description	Weight	Route number					
			1	2	3	4	5	6
1	Number of transitions	1/9	0.000	0.000	0.000	0.000	0.000	0.111
2	Nature of transitions	1/9	0.000	0.000	0.000	0.000	0.000	0.000
3	Missing road categories	1/9	0.111	0.000	0.111	0.000	0.000	0.111
4	Proportion of access roads	1/9	0.010	0.016	0.013	0.001	0.000	0.111
5	Proportion of distributors	1/9	0.111	0.046	0.110	0.000	0.052	0.074
6	Travel distance	1/9	0.031	0.000	0.011	0.100	0.111	0.049
7	Travel time	1/9	0.058	0.000	0.039	0.072	0.101	0.111
8	Left turns	1/9	0.074	0.111	0.074	0.074	0.074	0.000
9	Junction density	1/9	0.004	0.060	0.111	0.000	0.023	0.032
	SUM	1	0.400	0.232	0.470	0.248	0.362	0.600
	Sustainable Safety level		60%	77%	53%	75%	64%	40%

Table 4.7. Sustainable Safety level of each route, given the weights of each criterion.

#### 4.5.3. Ranking order of routes

Based on the Sustainable Safety level, it is possible to create a ranking order of routes. Routes 2 and 4 are virtually equal, followed by route 5, which in turn is closely followed by route 1. Routes 3 and 6 are at the bottom of the steps, the latter trailing by a considerable distance.

Ranking	Route	Sustainable Safety level
1	2	77%
2	4	75%
3	5	64%
4	1	60%
5	3	53%
6	6	40%

Table 4.8. Ranking of routes according to the Sustainable Safety level.

Routes 2 and 4 appear to be equally safe, given their score of 77 and 75 percent respectively. The lower score of route 5 is mainly because of the longer part of the route on Distributor Roads, the total route length, and, because of this, the travel time. So the nine criteria show differences between routes which can not easily be perceived when only 'looking' at the diagrams.

The test shows no differences for the criterion on the nature of the transitions between road categories: in this network vehicles never skip a road category when changing to another road. This is because our test network was intentionally set up with a structure which does not allow for skipping categories. In a real-life network these kinds of transitions will be present, and consequently will result in a 'negative' score on this criterion.

In this test all criteria have the same weight, However, crash evaluations of the variables used in the criteria can cause a change in the weighing of the criteria, for example, left turns at junctions cause more crashes than other manoeuvres, the weight for this criterion could therefore be raised.

#### 4.5.3.1. From route level to OD level

Using the Sustainable Safety levels of the routes and the distribution of the vehicles over the routes in the three simulations, the safety level of OD relationship 2-5 is calculated for each simulation.

From the simulation results we can see that all vehicles choose route 2 in simulation I. In simulations II and III, the vehicles distribute themselves over several routes. In simulation II, 39% choose route 2, 36% route 1 and 25% route 4. In simulation III, the vehicles even took 4 routes: 60% chose route 2, 20% route 1, 13% route 6 and 7% route 4.

Route	Sustainable Safety level	Simulation I		Simulation II		Simulation III	
		Distribution of traffic	Unsafety score	Distribution of traffic	Unsafety score	Distribution of traffic	Unsafety score
1	60%	0%	0%	36%	14.4%	20%	8%
2	77%	100%	23%	39%	8.9%	60%	13.8%
3	53%	0%	0%	0%	0%	0%	0%
4	75%	0%	0%	25%	6.25%	7%	1.75%
5	64%	0%	0%	0%	0%	0%	0%
6	40%	0%	0%	0%	0%	13%	7.8%
<i>Sum</i>		<i>100%</i>	<i>23%</i>	<i>100%</i>	<i>29.6%</i>	<i>100%</i>	<i>31.4%</i>

Table 4.9. Distribution of traffic as well as unsafety score for each route of OD pair 2-5.

Using the formula in Section 3.3.7.2 it is possible to calculate the safety level of OD relationship 2-5. Table 4.9 shows, for each simulation, the distribution of the vehicles over the routes and the percentage contribution of each route to the total unsafety of the OD relationship under consideration.

The degree to which the vehicles safely distribute themselves over the routes in a OD relationship amounts to  $(100 - 23 =) 77\%$  in simulation I,  $(100 - 29.6 =) 70.4\%$  in simulation II and  $(100 - 31.4 =) 68.6\%$  in simulation III. It may therefore be concluded that the distribution of traffic over the routes most closely follows the principles of the Sustainable Safety policy in simulation I.

If we base our calculations on the existing infrastructure, it appears that route 2 best fulfils the Sustainable Safety criteria. This is standardised at 100% in line with the formula in Section 3.2.5. Because route 6 complies least with the Sustainable Safety criteria, it is standardised at 0%.

Route	Sustainable Safety level	Standardized Sustainable Safety level	Simulation I		Simulation II		Simulation III	
			Distribution of traffic	Unsafety score	Distribution of traffic	Unsafety score	Distribution of traffic	Unsafety score
1	60%	54%	0%	0%	36%	16.6%	20%	9.2%
2	77%	100%	100%	0%	39%	0%	60%	0%
3	53%	35%	0%	0%	0%	0%	0%	0%
4	75%	95%	0%	0%	25%	1.25%	7%	0.35%
5	64%	65%	0%	0%	0%	0%	0%	0%
6	40%	0%	0%	0%	0%	0%	13%	13%
Sum			100%	0%	100%	17.9%	100%	22.6%

Table 4.10. *Distribution of traffic as well as safety score for each route of OD pair, given the infrastructure.*

The standardised scores and the recalculated unsafety scores per route are shown in *Table 4.10*.

The degree to which the vehicles distribute themselves in accordance with the Sustainable Safety principle over the given infrastructure for OD relationship 2-5 is  $(100 - 0) = 100\%$  in simulation I,  $(100 - 17.9) = 82.1\%$  in simulation II and  $(100 - 22.6) = 77.4\%$  in simulation III.

#### 4.5.4. Measures of seriousness and risk

During the simulations using S-Paramics, the traffic intensity for each road section was recorded. By combining the length of the road section with the intensity, we can calculate the 'level of exposure', expressed in millions of vehicle kilometres driven in a year. The duration of each simulation was a full hour (see *Section 4.1*).

We add up the calculated number of injury accidents on the road sections that form part of a route. The results for the six routes in each simulation are shown in the table below. Route 6 is the safest route in simulations I and II; in simulation III, route 4 is the safest.

Route	Simulation I	Simulation II	Simulation III
	Number of accidents with injury (*10 <sup>-5</sup> )	Number of accidents with injury (*10 <sup>-5</sup> )	Number of accidents with injury (*10 <sup>-5</sup> )
1	4.68	4.74	4.94
2	4.68	4.94	4.86
3	6.61	6.66	6.64
4	2.45	2.58	2.97
5	3.80	4.29	4.74
6	2.37	2.44	3.15

Table 4.11. *Number of accidents with injury on each route, calculated with key figures.*

#### 4.5.5. *TTC at vehicle level*

For each vehicle that was present in the network for one hour in the S-Paramics simulation, we calculated the TTC with a time interval of 0.5 seconds as described in Section 3.3.2.3. For this purpose, a safety module was written in the SAS statistical package. This module produces safety indicators, including the TTC values (Drolenga, 2006).

#### 4.5.6. *From TTC to road safety indicators at vehicle level*

##### 4.5.6.1. Introduction

The road safety indicators at vehicle level are calculated on the basis of the TTCs at vehicle level and an assumed critical TTC value of 2 seconds. The road safety indicators will be explained with reference to the TTC progress of a given vehicle.

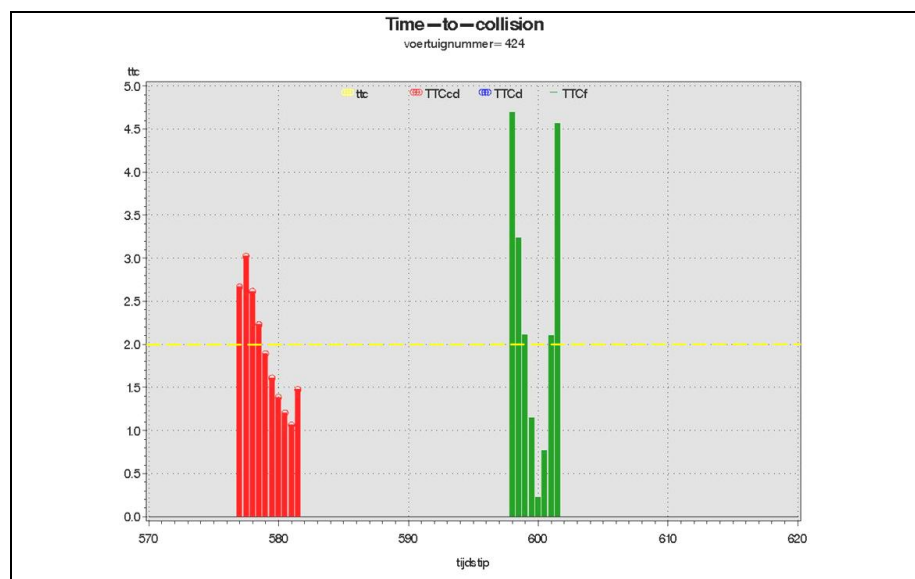


Figure 4.16. *TTC values for an arbitrary vehicle in a given period of time.*

The TTC values between 0 and 5 seconds are shown on the vertical axis of Figure 4.16. The time (in 0.5 second intervals) is shown on the horizontal axis. The beginning and the end of the horizontal axis (570 seconds and 620 seconds) indicate the moments when the subject vehicle enters and leaves the network. The vehicle's journey has therefore taken exactly 50 seconds. In this example, there are 2 situations in which the subject vehicle encounters another vehicle and in which a critical situation may arise. The dotted yellow line indicates the critical TTC value. The red bars (on the left) indicate a converging encounter and the green bars (on the right) indicate a frontal encounter, both of them at a junction. In addition, yellow bars indicate TTCs on road sections and blue bars indicate the TTC of transverse conflicts on road sections. The subject vehicle apparently encounters no vehicles on road sections or transversely conflicting vehicles at junctions.

#### 4.5.6.2. Number of conflicts (NOC)

In Section 3.3.3.2, the situation is referred to as a conflict if the TTC declines below the critical TTC value. From the TTC progression of the subject vehicle in Figure 4.16, it may be concluded that the vehicle gets involved in two conflict situations during its journey through the network. The left-hand part represents a converging conflict and the right-hand part represents a frontal conflict.

By way of example, two junctions are compared to each other in Figure 4.17. In this example the number of conflicts is distinguished according to the number of risks, determined by the minimum TTC value in a conflict situation.

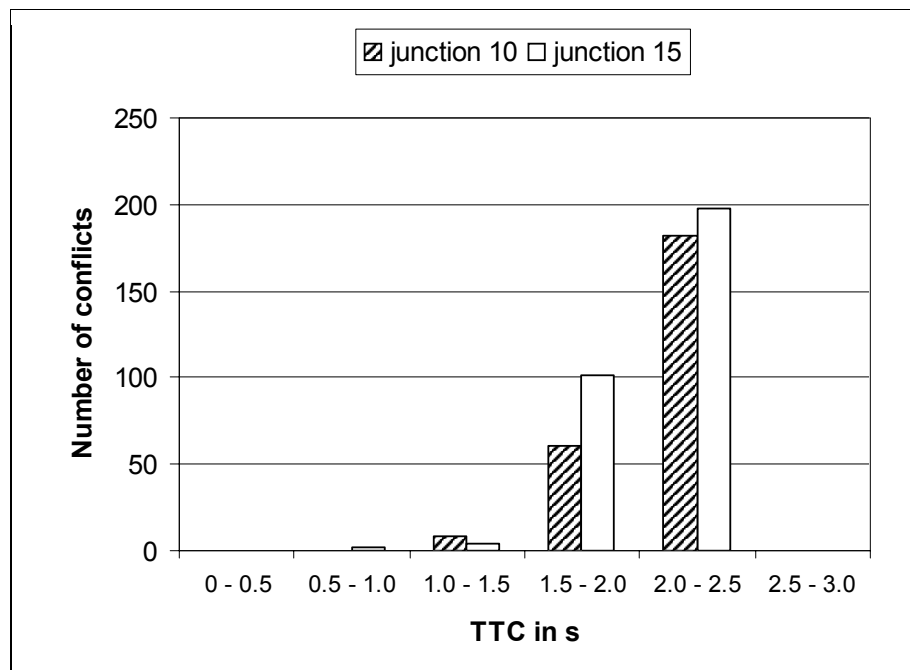


Figure 4.17. Junctions 10 and 15: number of conflicts for lowest values of TTC.

#### 4.5.6.3. Time Exposed Time To Collision (TET)

Figure 4.18 gives a close-up of Figure 4.16 where the TTC goes below the critical TTC value. For a converging conflict, the time that the TTC goes below the critical value (the TET) is 3 seconds; for a frontal conflict it is 1.5 seconds.

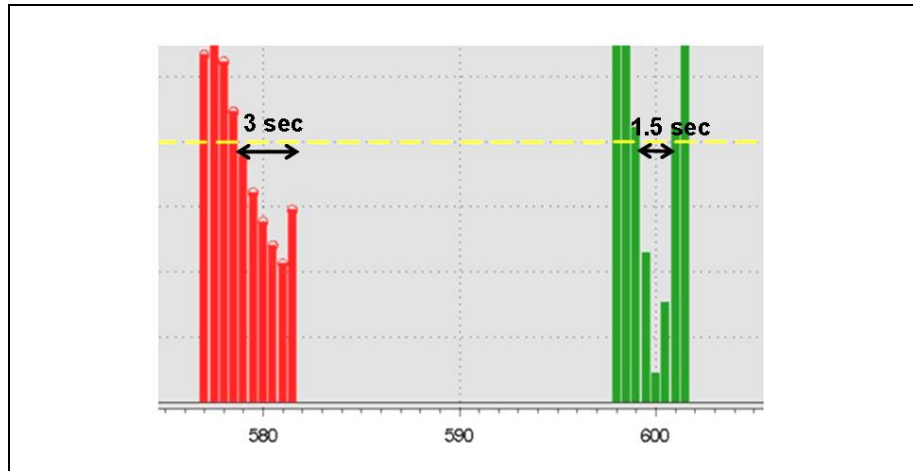


Figure 4.18. *Time Exposed Time To Collision (TET) for the vehicle from Figure 4.16.*

#### 4.5.6.4. Time Integrated Time To Collision (TIT)

For a converging conflict, the time that the TTC goes below the critical value multiplied by the TTC (the TIT) is  $1.65 \text{ sec}^2$ ; for a frontal conflict it is  $1.95 \text{ sec}^2$ .

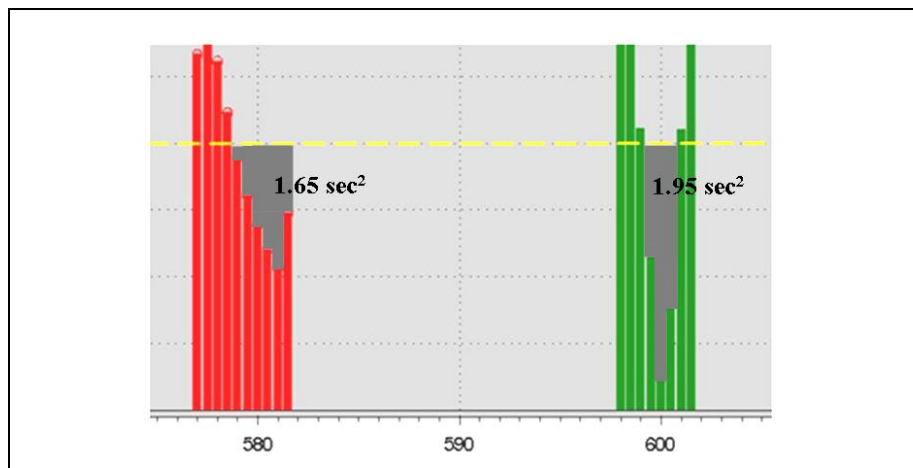


Figure 4.19. *Time Integrated Time To Collision (TIT) for the vehicle from Figure 4.16.*

#### 4.5.6.5. Potential Collision Energy (PCE)

The weight of the subject vehicle is 900 kg. In the converging conflict, the weight of the other vehicle is the same at 900 kg. In the frontal conflict, however, the subject vehicle is the smaller and the other vehicle has a weight of 2250 kg. In addition to the speed of the subject vehicle (speed I) and that of the conflicting vehicle (speed II), the total collision energy and the total collision energy that the subject vehicle has to absorb are calculated. These are shown in the tables below for the converging and the frontal conflict respectively. In these, the total collision energy and the proportion of the collision to be absorbed by the subject vehicle are calculated using the

formulae in Section 3.3.3.5. The results for the converging conflict are shown in Table 4.12 and those for the frontal conflict in Table 4.13.

Time	Speed I (kph)	Speed II (kph)	Total PCE KJ	PCE I KJ
579	28.8	49.6	1159	580
579.5	30.9	49.8	1222	611
580	32.7	49.9	1277	638
580.5	34.3	50.0	1328	664
581	36.3	50.0	1392	696
581.5	30.5	50.0	1217	609

Table 4.12. Potential Collision Energy for a converging conflict.

Time	Speed I (kph)	Speed II (kph)	Total PCE KJ	PCE I KJ
599.5	20.8	42.4	2442	1744
600	15.1	46.2	2771	1978
600.5	9.9	49.0	3045	2174

Table 4.13. Potential Collision Energy for a frontal conflict.

The potential collision energy of the subject vehicle in relation to the total potential collision energy is shown in the figure below. The left-hand image shows the converging conflict and the right-hand image shows the frontal conflict.

The sum of the potential collision energy that the subject vehicle has to absorb over the duration of the conflict is 3798 KJ for the converging conflict and 5896 KJ for the frontal conflict.

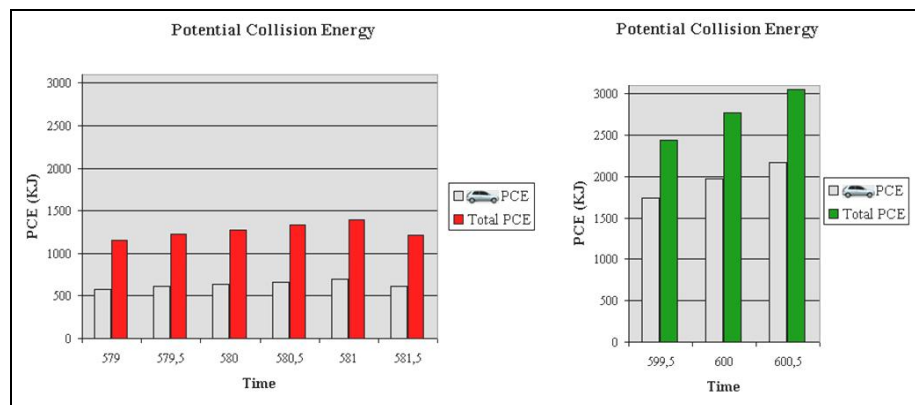


Figure 4.20. Potential Collision Energy for a converging and a frontal conflict to be absorbed by the vehicle from Figure 4.16.



#### 4.5.6.6. Distance headway

The number of distance headways on two sample road sections (road sections 25-26 and 3-4) are presented in *Figure 4.21*.

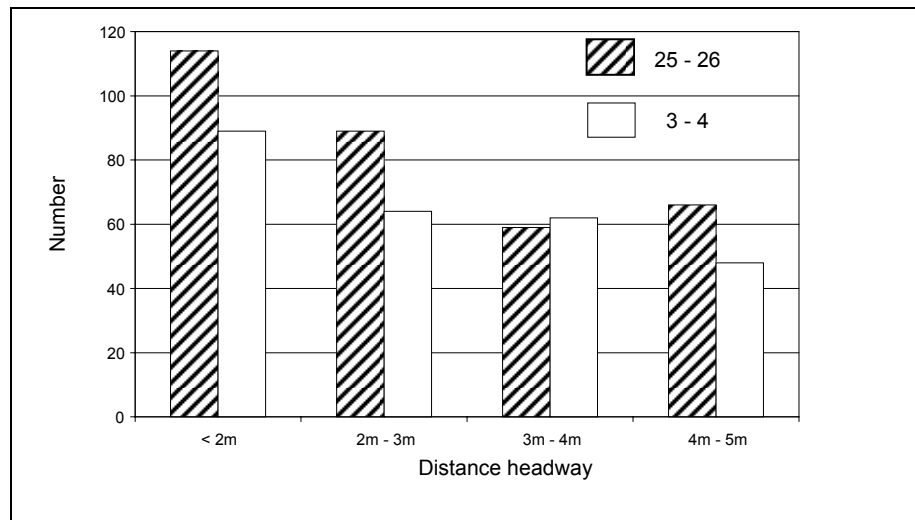


Figure 4.21. *Distance Headways for road sections 25-26 and 3-4.*

#### 4.5.6.7. Time headway

The number of time headways on 2 sample road sections (road sections 25-26 and 3-4) are presented in *Figure 4.22*.

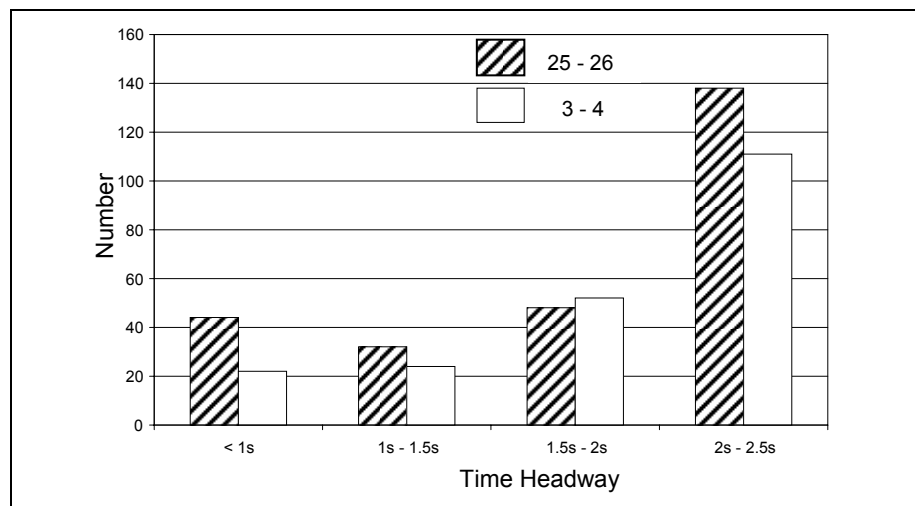


Figure 4.22. *Time Headways for road sections 25-26 and 3-4.*

#### 4.5.6.8. Speed

*Figure 4.23* shows the speed progression of a given vehicle in the simulation. The speed in kph is shown on the vertical axis. The time (in 0.5 second intervals) is shown on the horizontal axis. The beginning and the end of the horizontal axis (212480 seconds and 212640 seconds) indicate the moments when the subject vehicle enters and leaves the network. The

vehicle's journey through the network has therefore taken exactly 160 seconds. The red line indicates the speed of the subject vehicle on road sections. This line becomes green whenever the vehicle is within the safe stopping distance from a junction. The blue, dotted line indicates the speed of the vehicle in front (if present). The orange spheres next to the horizontal axis show the manoeuvre being executed at a junction. The black spheres indicate a bend in a road section where no junction is involved.

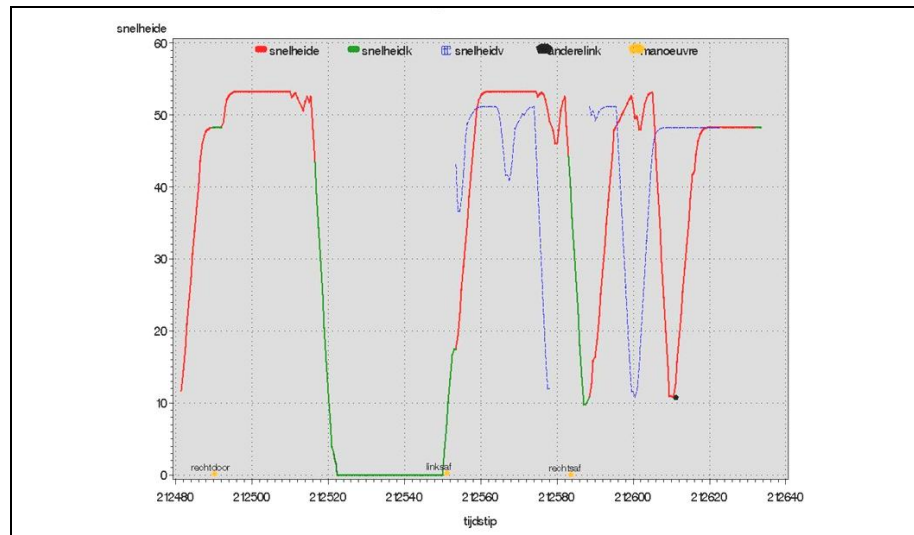


Figure 4.23. Progression of speed for an arbitrary vehicle.

In the example, it can easily be seen that the vehicle enters the network at 10 kph, accelerates to about 48 kph to carry straight on at a junction, after which it accelerates to about 54 kph and then brakes until it comes to a halt. At this point the vehicle has to wait a while before turning left at a junction onto a road section where it once again accelerates to about 54 kph and where it finds a vehicle in front of it. At a certain moment, the vehicle in front brakes drastically in order to perform its manoeuvre at a junction. A number of seconds later, the subject vehicle does the same: it brakes and turns right at a speed of 10 kph. There is also a vehicle in front on the new road section; while the subject vehicle is still accelerating to 54 kph, the vehicle in front brakes to take a bend in a road section. Slightly later, the subject vehicle does the same, after which both vehicles ride one behind the other (at about 48 kph) and leave the network one after the other.

The tendency of the vehicle in this simulation to exceed the speed limit (50 kph) depends on the settings in S-Paramics. With the normal settings, driving speeds are at or close to the set speed limit. By adjusting the 'aggression value', we can make more vehicles drive faster than the limit (and allow them to overtake).

#### Time Exposed Speed (TES)

Figure 4.24 gives a close-up of Figure 4.23 where the speed exceeds the 50 kph speed limit. The time that the speed exceeds the speed limit (the TES) is equal to the sum of 23 seconds, 18 seconds, 2 seconds, 4 seconds and 3 seconds: 50 seconds.

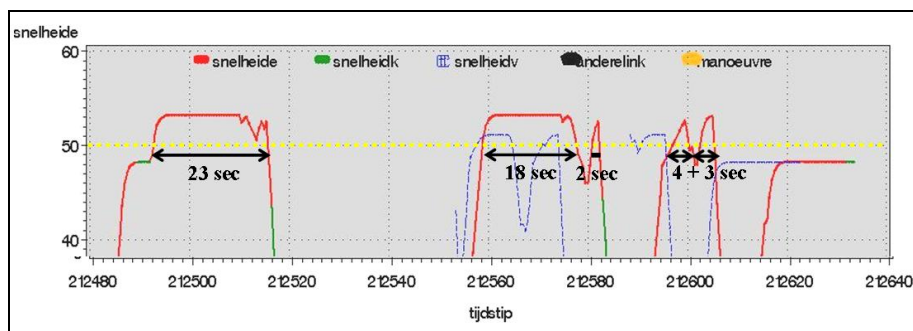


Figure 4.24. *Time Exposed Speed (TES)* for the vehicle from Figure 4.23.

#### *Time Integrated Speed (TIS)*

If the total distance (in metres) for the times that the vehicle exceeds the speed limit is calculated – the TIS – the impact is taken into account. The TIS for the subject vehicle is equal to the sum of 25.4 metres, 21.1 metres, 0.4 metres, 0.8 metres and 1.9 metres: 49.6 metres.

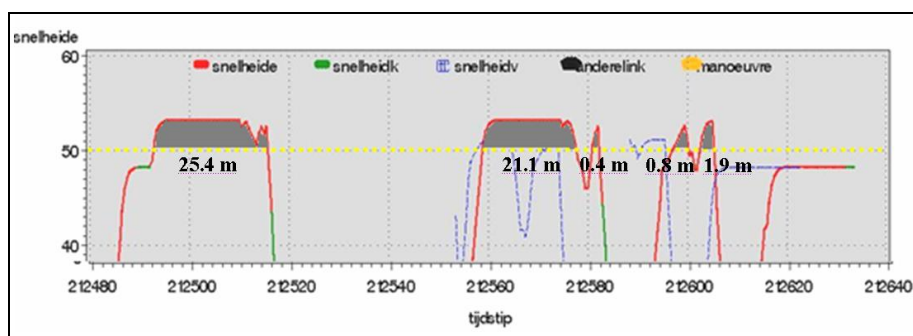


Figure 4.25. *Time Integrated Speed (TIS)* for the vehicle from Figure 4.16.

#### 4.5.7. From road section/junction level to route level

Using the definition of a route in Section 3.3.6 the road safety indicators of the six routes are calculated on the basis of the ratios of the road sections and junctions that form part of the route. In the following sections, the final results for the road safety ratios in the three simulations will suffice.

##### 4.5.7.1. Results of simulations I, II and III

The four conflict indicators do appear to differ from each other: the sequence of routes is hardly ever the same; see Tables 4.14, 4.15 and 4.16.

The level of the Conflict Vehicle Ratio is dependant on the amount of traffic in the network, the more traffic, the more conflicts. The volumes in simulation III are highest, which results in higher CVR's.

The TExTVR values are also subject to the volumes in the network: the more traffic, the more exposure to conflicts. The sequence of routes only changes for routes 1 and 6 in simulations I and II. The changes between the three simulations apparently do not influence the scores of TExTVR very much. This is not true for the TInTVR values which show many changes in the sequences of the routes. Furthermore the level of the values do not change when the volumes go up. The TInTVR is very much influenced by the nature (seriousness) of the interactions between vehicles, not by the

amount. The differences between the simulations are not specifically focussed on changing this nature.

Finally, the PCEVR values, are much higher in simulation III than in the other two simulations. That is because of more traffic on the Through Road, driving at higher speeds, resulting in potentially more collision energy in each conflict.

Each of the conflict indicators appears to have its own surplus value for assessing the safety of routes in a network. More research is needed to find out the pros and cons of using these indicators in more complex networks.

#### *The effect of pedestrian crossings*

In general, TExTVR and TInTVR have a different ranking of routes. A clear example of this are routes 2 and 5 in simulation I. Routes 2 and 5 are third and last respectively for the TExTVR but score the other way round for TInTVR. The explanation for this can be found by making a distinction between intersections and road segments for both TExTVR and TInTVR. Route 5 contains more intersections with a higher crash rate than route 2, i.e. intersections with longer lasting and more severe conflicts. The difference in higher risk intersections also plays a role for the TInTVR, but this difference is annulled by a striking difference in the TExT on road segments. Further examination of the data made us realise that this situation occurs on road segments with a pedestrian crossing. The conflicts with a vehicle in front who allows a pedestrian to cross over are evidently not long lasting, but they are more serious. Route 2 passes two pedestrian crossings, route 5 does not pass any, which is why route 5 scores better than route 2 for TInTVR.

#### *Number of crashes*

The total number of crashes (during one hour) was also calculated for each route (*Tables 4.14e, 4.15e and 4.16e*). When transforming these hourly numbers to the number of accident per year, we find a crash level varying between 0.2 to 0.6 crashes. The crash level of route 3 is highest in every simulation, this route was not to be found the least safe for the other safety indicators. Higher volumes on a route can cause more crashes, while the other indicators can still be more favourable because these are weighed by the amount of vehicles.

#### 4.5.8. *From route level to OD level*

Using the scores for the 6 routes and the distribution of the vehicles over these routes, the safety level of OD relationship 2-5 is calculated in the three simulations. For this purpose, the road safety ratios are standardised using the formula in *Section 3.2.5*. These standardised values are presented per road safety indicator and per simulation in the tables below.

Route	Conflict Vehicle Ratio	Distribution of vehicles (%)
6	0.42	-
1	0.47	-
4	0.62	-
5	0.67	-
2	0.69	100
3	0.74	-

**Table 4.14a**  
**Simulation I**

Route	Time Exp. TTC Vehicle Ratio	Distribution of vehicles (%)
6	0.71	-
1	0.84	-
2	1.10	100
3	1.12	-
4	1.12	-
5	1.14	-

**Table 4.14b**

Route	Time Int. TTC Vehicle Ratio	Distribution of vehicles (%)
6	0.12	-
1	0.19	-
5	0.21	-
3	0.23	-
4	0.24	-
2	0.26	100

**Table 4.14c**

Route	Potential Collision Energy Vehicle Ratio	Distribution of vehicles (%)	Route	Number of crashes *10 <sup>-5</sup>	Distribution of vehicles (%)
6	146	-	6	2.37	
1	168	-	4	2.45	
3	206	-	5	3.80	
2	228	100	2	4.68	100
5	246	-	1	4.68	
4	268	-	3	6.61	

**Table 4.14d**

**Table 4.14e**

Route	Conflict Vehicle Ratio	Distribution of vehicles (%)
1	0.51	36
2	0.58	39
6	0.65	-
3	0.68	-
4	0.79	25
5	0.89	-

**Table 4.15a**  
**Simulation II**

Route	Time Exp. TTC Vehicle Ratio	Distribution of vehicles (%)
1	0.94	36
2	1.02	39
6	1.14	-
3	1.19	-
4	1.51	25
5	1.68	-

**Table 4.15b**

Route	Time Int. TTC Vehicle Ratio	Distribution of vehicles (%)
1	0.17	36
6	0.19	-
2	0.20	39
3	0.23	-
4	0.25	25
5	0.28	-

**Table 4.15c**

Route	Potential Collision Energy Vehicle Ratio	Distribution of vehicles (%)	Route	Number of crashes *10 <sup>-5</sup>	Distribution of vehicles (%)
6	146	-	6	2.44	-
2	195	39	4	2.58	25
1	198	36	5	4.29	-
3	213	-	1	4.74	36
4	252	25	2	4.94	39
5	270	-	3	6.66	-

**Table 4.15d**

**Table 4.15e**

Route	Conflict Vehicle Ratio	Distribution of vehicles (%)
1	0.72	20
6	0.75	13
2	0.83	60
3	0.86	-
4	1.14	7
5	1.17	-

**Table 4.16a**  
**Simulation III**

Route	Time Exp. TTC Vehicle Ratio	Distribution of vehicles (%)
1	0.96	20
2	1.24	60
6	1.32	13
3	1.37	-
4	1.74	7
5	1.87	-

**Table 4.16b**

Route	Time Int. TTC Vehicle Ratio	Distribution of vehicles (%)
1	0.23	20
5	0.24	-
3	0.26	-
4	0.26	7
2	0.28	60
6	0.28	13

**Table 4.16c**

Route	Potential Collision Energy Vehicle Ratio	Distribution of vehicles (%)	Route	Number of crashes *10 <sup>-5</sup>	Distribution of vehicles (%)
6	262	13	4	2.97	7
1	363	20	6	3.15	13
3	450	-	5	4.74	-
5	554	-	2	4.86	60
2	582	60	1	4.94	20
4	686	7	3	6.64	-

**Table 4.16d**

**Table 4.16e**

#### 4.5.8.1. Conflict Vehicle Ratio Route (CVR)

The table below shows the percentage contribution of each route to the total unsafety (here in the form of the Conflict Vehicle Ratio) of the subject OD relationship 2-5 in the three simulations.

The degree to which the vehicles distribute themselves safely over the routes of OD relationship 2-5 is considerably worse in simulation I (15.6%) than in simulations II and III (74.4% and 78%) respectively.

Route	Simulation I				Simulation II				Simulation III			
	CVR	CVR <sub>s</sub>	V <sub>r</sub>	Safety score	CVR	CVR <sub>s</sub>	V <sub>r</sub>	Safety score	CVR	CVR <sub>s</sub>	V <sub>r</sub>	Safety score
1	0.47	84.4%	0%	0.0%	0.51	100.0%	36%	0.0%	0.72	100%	20%	0%
2	0.69	15.6%	100%	84.4%	0.58	81.6%	39%	7.2%	0.83	75.6%	60%	14.6%
3	0.74	0.0%	0%	0.0%	0.68	55.3%	0%	0.0%	0.86	68.9%	0%	0%
4	0.62	37.5%	0%	0.0%	0.79	26.3%	25%	18.4%	1.14	6.7%	7%	6.5%
5	0.67	21.9%	0%	0.0%	0.89	0.0%	0%	0.0%	1.17	0%	0%	0%
6	0.42	100.0%	0%	0.0%	0.65	63.2%	0%	0.0%	0.75	93.3%	13%	0.9%
			100%	84.4%			100%	25.6%			100%	22%

Table 4.17. Standardized Conflict Vehicle Ratios for each route.

#### 4.5.8.2. Time Exposed Time To Collision Vehicle Ratio Route (TETVR)

The table below shows the percentage contribution of each route to the total unsafety (here in the form of the Time Exposed Time To Collision Vehicle Ratio) of the subject OD relationship 2-5 in the three simulations.

The degree to which the vehicles distribute themselves safely over the routes of OD relationship 2-5 is considerably worse in simulation I (9.3%) than in simulations II and III (76.5% and 70.4%) respectively.

Route	Simulation I				Simulation II				Simulation III			
	TETVR	TETVR <sub>s</sub>	V <sub>r</sub>	Safety score	TETVR	TETVR <sub>s</sub>	V <sub>r</sub>	Safety score	TETVR	TETVR <sub>s</sub>	V <sub>r</sub>	Safety score
1	0.84	69.8%	0%	0.0%	0.94	100.0%	36%	0.0%	0.96	100.0%	20%	0.0%
2	1.10	9.3%	100%	90.7%	1.02	89.2%	39%	4.2%	1.24	69.2%	60%	18.5%
3	1.12	4.7%	0%	0.0%	1.19	66.2%	0%	0.0%	1.37	54.9%	0%	0.0%
4	1.12	4.7%	0%	0.0%	1.51	23.0%	25%	19.3%	1.74	14.3%	7%	6.0%
5	1.14	0.0%	0%	0.0%	1.68	0.0%	0%	0.0%	1.87	0.0%	0%	0.0%
6	0.71	100.0%	0%	0.0%	1.14	73.0%	0%	0.0%	1.32	60.4%	13%	5.1%
			100%	90.7%			100%	23.5%			100%	29.6%

Table 4.18. Standardized Time Exposed Time To Collision Vehicle Ratios for each route.

#### 4.5.8.3. Time Integrated Time To Collision Vehicle Ratio Route (TITVR)

The table below shows the percentage contribution of each route to the total unsafety (here in the form of the Time Integrated Time To Collision Vehicle Ratio) of the subject OD relationship 2-5 in the three simulations.

The degree to which the vehicles distribute themselves safely over the routes of OD relationship 2-5 could not be any worse in simulation I (0%); this is because all vehicles select the least safe route. In simulation II it is much better at 71.2%. Because the 60% of the vehicles in simulation III select the least safe route, the degree to which the vehicles distribute themselves safely over the routes is fairly poor at 22.8%

Route	Simulation I				Simulation II				Simulation III			
	TITVR	TITVR <sub>s</sub>	V <sub>r</sub>	Safety score	TITVR	TITVR <sub>s</sub>	V <sub>r</sub>	Safety score	TITVR	TITVR <sub>s</sub>	V <sub>r</sub>	Safety score
1	0.19	50.0%	0%	0.0%	0.17	100.0%	36%	0.0%	0.23	100.0%	20%	0.0%
2	0.26	0.0%	100%	100.0%	0.20	72.7%	39%	10.6%	0.28	0.0%	60%	60.0%
3	0.23	21.4%	0%	0.0%	0.23	45.5%	0%	0.0%	0.26	40.0%	0%	0.0%
4	0.24	14.3%	0%	0.0%	0.25	27.3%	25%	18.2%	0.26	40.0%	7%	4.2%
5	0.21	35.7%	0%	0.0%	0.28	0.0%	0%	0.0%	0.24	80.0%	0%	0.0%
6	0.12	100.0%	0%	0.0%	0.19	81.8%	0%	0.0%	0.28	0.0%	13%	13.0%
			100%	100.0%			100%	28.8%			100%	77.2%

Table 4.19. Standardized Time Integrated Time To Collision Vehicle Ratios for each route.

#### 4.5.8.4. Potential Collision Energy Vehicle Ratio Route (PCEVR)

The table below shows the percentage contribution of each route to the total unsafety (here in the form of the Potential Collision Energy Vehicle Ratio) of the subject OD relationship 2-5 in the three simulations.

The degree to which the vehicles distribute themselves safely over the routes of OD relationship 2-5 is worse in simulation I (32.8%) than in simulations II and III (48.1% and 43.0%) respectively.

Route	Simulation I				Simulation II				Simulation III			
	PCEVR	PCEVR <sub>s</sub>	V <sub>r</sub>	Safety score	PCEVR	PCEVR <sub>s</sub>	V <sub>r</sub>	Safety score	PCEVR	PCEVR <sub>s</sub>	V <sub>r</sub>	Safety score
1	168	82.0%	0%	0.0%	198	58.1%	36%	15.1%	363	76.2%	20%	4.8%
2	228	32.8%	100%	67.2%	195	60.5%	39%	15.4%	582	24.5%	60%	45.3%
3	206	50.8%	0%	0.0%	213	46.0%	0%	0.0%	450	55.7%	0%	0.0%
4	268	0.0%	0%	0.0%	252	14.5%	25%	21.4%	686	0.0%	7%	7.0%
5	246	18.0%	0%	0.0%	270	0.0%	0%	0.0%	554	31.1%	0%	0.0%
6	146	100.0%	0%	0.0%	146	100.0%	0%	0.0%	262	100.0%	13%	0.0%
			100%	67.2%			100%	51.9%			100%	57.0%

Table 4.20. Standardized Potential Collision Energy Vehicle Ratios for each route.

## 5. Conclusions and recommendations

This exploratory study elaborates four different methods of determining the effects of route choice on road safety:

- (qualitative) route diagram (Sustainable Safety Steps);
- quantitative safety criteria (route star);
- various conflict measures via a micro-simulation model;
- measures of severity and risk (key safety indicators).

The results of the methods used do not all point in the same direction with regard to the effects of route choice on road safety. The explanation for this and the usefulness of the methods both require further study.

The micro-simulation model used here, S-Paramics, offers many possibilities for:

- determining route choice by individual vehicles;
- calculating road safety effects (via conflict measures and safety criteria);
- modelling different ways of influencing route choice.

The results of the micro-simulation model with respect to route choice have not yet been compared to observations in the real world. It is partly for that reason that this exploratory study has not yet provided a definitive answer to the question of whether micro-simulation models are suitable tools for this kind of (route choice) research.

More research is needed into the modelling of (serious) conflicts between road users. Observations of real conflicts are also important.

Previous studies into the effects of altering the road structure, did not focus on the effects of changing the mesh of the network. These effects can be studied by using micro-simulation models. This type of model can also show the effect of different systems of road categorization.

The safety criteria for route choice are suitable for incorporation in software for route planners.

The safety indicators in this report can be used in the planning stage as well as in existing situations. For applying the route diagram and the route star only a limited set of road characteristics are needed, a simulation model is not required.

The conflict indicators are only an output of a micro-simulation model. They can well be used for comparing the (safety) effects of routing alternatives.



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## Appendix

### Examples of calculations using the sustainable safety level of a OD relationship given the infrastructure (Section 3.2.5)

This *Appendix* shows some examples that illustrate the difference between the Sustainable Safety Level for a OD relationship and the Sustainable Safety Level for a OD relationship *given the infrastructure*. To this end, there are three main sections relating respectively to a OD relationship with two routes, a OD relationship with three routes and a OD relationship with four routes. Within each main section, two variants are examined by means of varying the distribution of the vehicles over the various (unchanging) routes.

#### Example of OD relationship with two routes

In a given OD relationship, two routes (routes 1 and 2) are utilised. The majority of the vehicles (85%) select route 2; route 1 attracts 15% of the vehicles. Of the two routes, route 1 best fulfils the Sustainable Safety criteria with a Sustainable Safety Level of 72% in contrast to a Sustainable Safety Level of 20% for route 2.

The contributions of the routes ( $VV_{OD,r}$ ) to the unsafety of OD are calculated in *Table 1* using the formula in *Section 3.2.4*. The road safety  $VV_r$  is converted into a measure of unsafety ( $100 - VV_r$ ), multiplied by the percentage number of vehicles ( $V_{OD,r}$ ) that select the route in question, and divided by one hundred. The sum of these route contributions forms the total degree of unsafety in the OD. In this case, it is 72.2%. The Sustainable Safety Level is then  $(100-72.2=)$  **27.8%**.

Route	$VV_r$	$V_{OD,r}$	Unsafety level
1	72%	15%	4.2%
2	20%	85%	68%
		100%	72.2%

Table 1.

To calculate the Sustainable Safety Level given the infrastructure, we first standardise the Sustainable Safety Levels of the routes using the formula in *Section 3.2.5*. In this case, route 1 (the safest) is allocated a standardised Sustainable Safety Level of 100, and route 2 (the least safe) is allocated a standardised Sustainable Safety Level of 0 (see also *Table 2*). The standardised Sustainable Safety Levels of the routes are then converted into a measure of unsafety ( $100 - VV_{rs}$ ), multiplied by the percentage number of vehicles ( $V_{OD,r}$ ) that select the route in question, and divided by one hundred. The sum of these route contributions forms the total degree of unsafety in the OD *given the infrastructure*. In this case, it is 85%. The Sustainable Safety Level *given the infrastructure* is then  $(100 - 85 =)$  **15%**.

Route	$VV_{rs}$	$V_{OD,r}$	Unsafty level
1	100%	15%	0%
2	0%	85%	85%
		100%	85%

Table 2.

*Different distribution of traffic over the routes*

In the subject OD relationship, the same routes continue to exist but the distribution of vehicles over these routes changes. This has consequences both for the Sustainable Safety Level and the Sustainable Safety Level *given the infrastructure* for the subject OD relationship. In *Table 3* it can be seen that 85% of the vehicles now travel via route 1 instead of route 2. The remaining vehicles select route 2. Given the unchanged Sustainable Safety Level of the routes, we arrive at a Sustainable Safety Level for the subject OD relationship of  $(100 - 35.8 =) 64.2\%$ . This score is considerably higher than for the other distribution, because many more vehicles select the safest route.

Route	$VV_r$	$V_{OD,r}$	Unsafty level
1	72%	85%	23.8%
2	20%	15%	12%
		100%	35.8%

Table 3.

In *Table 4*, the Sustainable Safety Levels of the routes are standardised using the same method as described above. This produces a total OD unsafety of 15%, which means a Sustainable Safety Level *given the infrastructure* for the OD relationship of **85%**.

Route	$VV_{rs}$	$V_{OD,r}$	Unsafty level
1	100%	85%	0%
2	0%	15%	15%
		100%	15%

Table 4.

**Example of OD relationship with three routes**

In this example, three routes are followed in a OD relationship selected at random. The majority of the vehicles (65%) choose route 3, 3.25% choose route 2 and 10% choose route 1 (see also *Table 5*). Route 1 scores best in the Sustainable Safety criteria with a Sustainable Safety Level of 72. Route 2 scores 55% and route 3 is the least safe with a score of 20%.

In *Table 5*, the contributions of the various routes to the total OD unsafety are calculated in the same way as in the example with the two-route OD relationship. It can clearly be seen that route 3 makes the biggest contribution to the unsafety because numerous vehicles select this, the least safe route. A total OD unsafety of 66% produces a Sustainable Safety Level of **34%** for the OD relationship.

Route	$VV_r$	$V_{OD,r}$	Unsafty level
1	72%	10%	2.8%
2	55%	25%	11,25%
3	20%	65%	52%
		100%	66.05%

Table 5.

In *Table 6*, the Sustainable Safety Levels of the various routes from *Table 5* are standardised. The safest route (route 1) is allocated a standardised Sustainable Safety Level of 100%. The least safe route (route 3) gets 0% and route 2 is in the middle at 67%.

Using these standardised Sustainable Safety Levels of the routes, we arrive at a Sustainable Safety Level for the OD relationship *given the infrastructure* of **26.8%**.

Route	$VV_{rs}$	$V_{OD,r}$	Unsafty level
1	100%	10%	0%
2	67.3%	25%	8.17%
3	0%	65%	65%
		100%	73.17%

Table 6.

*Different distribution of traffic over the routes*

In the subject OD relationship, the same three routes continue to exist but the distribution of vehicles over these routes changes. This has consequences both for the Sustainable Safety Level and the Sustainable Safety Level *given the infrastructure* for the subject OD relationship. In *Table 7* it can be seen that the majority (65%) of vehicles select route 1, the safest route. However, 10% of the vehicles select the least safe route, route 3. This results in a much higher Sustainable Safety Level for the relevant OD relationship: **62.6%**.

Route	$VV_r$	$V_{OD,r}$	Unsafty level
1	72%	65%	18.2%
2	55%	25%	11,25%
3	20%	10%	8%
		100%	37.45%

Table 7.

Using these standardised Sustainable Safety Levels of the routes in *Table 8*, we arrive at a Sustainable Safety Level for the OD relationship *given the infrastructure* of  $(100 - 18.2) = \mathbf{81.8\%}$

Route	$VV_{rs}$	$V_{OD,r}$	Unsafty level
1	100%	65%	0%
2	67.3%	25%	8.17%
3	0%	10%	10%
		100%	18.17%

Table 8.

### Example of OD relationship with four routes

In this example, four routes are followed in a OD relationship selected at random. The majority of the vehicles (45%) choose route 4, 4.27% choose route 1, 23% choose route 2 and a small minority (5%) selects route 3 (see also *Table 9*).

Route 1 scores best in the Sustainable Safety criteria with a Sustainable Safety Level of 72. Route 2 scores 55% and route 4 is the least safe with a score of 20%. Route 3 scores 33%.

In *Table 9*, the contributions of the various routes to the total OD unsafety are calculated in the same way as in the examples with the two-route and three-route OD relationship. It can clearly be seen that route 4 makes the biggest contribution, due to the fact that numerous vehicles select this, the least safe route. A total OD unsafety of 57% produces a Sustainable Safety Level of **43%** for the OD relationship.

Route	$VV_r$	$V_{OD,r}$	Unsafty level
1	72%	27%	7.56%
2	55%	23%	10.35%
3	33%	5%	3.35%
4	20%	45%	36%
		100%	57.26%

Table 9.

In *Table 10*, the Sustainable Safety Levels of the various routes from *Table 9* are standardised. The safest route (route 1) is allocated a standardised Sustainable Safety Level of 100%. The least safe route (route 4) gets 0% and routes 2 and 3 are in the middle with 67% and 25% respectively.

Route	$VV_{rs}$	$V_{OD,r}$	Unsafty level
1	100%	27%	0%
2	67.3%	23%	7.51%
3	25%	5%	3.75%
4	0%	45%	45%
		100%	56.26%

Table 10.

Using these standardised Sustainable Safety Levels of the routes, we arrive at a Sustainable Safety Level for the OD relationship *given the infrastructure* of **43.7%**.

#### *Different distribution of traffic over the routes*

In the subject OD relationship, the same four routes continue to exist but the distribution of vehicles over these routes changes. This has consequences both for the Sustainable Safety Level and the Sustainable Safety Level *given the infrastructure* for the subject OD relationship. In *Table 11*, it can be seen that even more traffic selects the most dangerous route, route 4 (80%). This results in an even lower Sustainable Safety Level for the relevant OD relationship: **25%**.

Route	$VV_r$	$V_{OD,r}$	Unsafety level
1	72%	2%	0,56%
2	55%	7%	3.15%
3	33%	11%	7.37%
4	20%	80%	64%
		100%	75.08%

Table 11.

Using these standardised Sustainable Safety Levels of the routes in *Table 12*, we arrive at a Sustainable Safety Level for the OD relationship *given the infrastructure* of  $(100 - 90.5) = 9.5\%$

Route	$VV_{rs}$	$V_{OD,r}$	Unsafety level
1	100%	2%	0%
2	67.3%	7%	2.28%
3	25%	11%	8.25%
4	0%	80%	80%
		100%	90.53%

Table 12.