ASSESSING THE SAFETY OF ROUTES IN A REGIONAL NETWORK

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Submitted to the 3rd International Conference on Road Safety and Simulation, September 14-16, 2011, Indianapolis, USA

ABSTRACT

In the Netherlands, the concept 'Sustainable Safety' 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. An important requirement that follows from this vision is that the quickest route and the safest route should coincide. This paper focuses on the design of a method which enables the planner to establish the safety effects of existing route choice, and also those of changes in route choice. The traffic safety assessment is carried out by quantifying the safety level of a route on the basis of those characteristics of the route that are assumed to be related to safety. This paper examines the quantitative relationship between the assessment of the route's safety level and the conflicts (at junctions) involving vehicles travelling along that route. These conflicts are detected in a micro-simulation model. Different routes in a regional network which were travelled by the modelled vehicles were used for the analysis.
This method of quantifying the safety level of routes will make it possible to evaluate road network structures from a safety perspective. It is expected that by optimizing the design of the network and by influencing route choice a (more) sustainably safe traffic system can be achieved.

Keywords: safety, road network, assessment, simulation model

INTRODUCTION

In the Netherlands, the concept 'Sustainable Safety' (Koornstra et al., 1992; Wegman & Aarts, 2006) is the leading vision in road safety policy and research. The main goal of a sustainably safe road transport system is that only a fraction of the current annual number of road crash casualties will remain. It is of great importance for a sustainably safe traffic system that, for each of the different road categories, road users know which behaviour is required of them and what they may expect from other road users. Their expectations should be supported by optimizing the recognizability of the road categories.
The main principles concerning the road infrastructure in a sustainably safe traffic system are functionality, homogeneity, recognizability/predictability, and forgivingness.
The functionality of the traffic system is important to ensure that the roads are used in accordance with the intended use. This principle has resulted in a road network with only three categories: through roads, distributor roads, and access roads. Each road or street may have only one function; a distributor road, for example, may not have any direct dwelling access.

The homogeneity principle is intended to avoid large differences in speed, direction, and mass by separating traffic types and, if that is not possible or desirable, by making motorized traffic drive slowly. According to the recognizability principle, the design of the road and its environment should enhance the predictability of any traffic situation that may occur. If crashes are unavoidable, the severity of the consequences should be minimised by specific facilities on or near the road; this is the forgivingness principle.
Sets of requirements have been specified for each principle. For the present paper the following requirements are relevant: journeys should follow safe roads as much as possible, journeys should be as short as possible, and the quickest and safest route should coincide (CROW, 1997).

ROUTE CHOICE AND ROAD SAFETY

Many studies have focussed on the Sustainable Safety requirements; Wegman & Aarts (2006) give an extensive overview of these studies. However, very little attention has been paid to the consequences of the functional requirements, particularly the route choice issues (Hummel, 2001). Therefore, current SWOV research focuses on the road safety effects of route choice and route management measures.
An important requirement in a sustainably safe road network is that the chosen road type is in accordance with the desired functional division of traffic over the road network. Sustainable Safety also requires residential areas to be 'as large as possible'. This requirement influences the mesh width of the distributor roads (Van Minnen, 1999; Krabbenbos et al. 2002). The connections between residential areas depend on the numbers of inhabitants as well as on the types and presence of facilities. The potential transportation demand determines the necessity and capacity of the connections. The resulting roads and intersections are normative for the composition of a sustainably safe road network (Dijkstra, 2011).
The consequence of requiring the safest and quickest route to coincide is that cars will be led through residential areas as these areas comprise very safe streets. This can be prevented by an additional requirement stating that a route should only follow access roads at its beginning and end, and that the rest, the vast majority of the route, should be along through-roads. In order to achieve such a route choice, the journey time of a route going through residential areas must be longer than that of a route that follows through-roads. In addition, the route choice can be influenced by in-vehicle guidance or indications alongside the road, and possibly also by the layout of the road and its environment.

Sustainable Safety wants to incorporate road safety in transportation planning. In the planning phase it should be determined whether the network will function according to the specified network requirements, especially those regarding safety. It is difficult to review the consequences of a traffic plan because of the large amount of data that plays a role in such plans. That is why planners often use traffic models and simulation models. The classic traffic models assign the total traffic volume to the road sections of the different networks. In micro-simulation models, however, it is possible to allow separate vehicles to follow a route through a network. The route choice of each simulated vehicle depends on a number of previously established preconditions and on various variables that are a function of in-vehicle equipment, facilities along the road, the driver's motive, time of day, and interaction with the rest of the traffic. In this way it is possible to determine in advance how the route choice will change when in-vehicle information is provided or when road facilities are planned. AVV (2002) gives a general overview of the features and possibilities for use of simulation models.

Modelling route choice will provide answers to the planning issues of Sustainable Safety; the safety effects of Sustainable Safety, however, are a separate issue to be dealt with.

Focus

This paper focuses on the design of a method that enables the planner to investigate the safety effects of existing route choice. Moreover, the method should predict the road safety effects of changes in the road network which result in different route choices.

MODELLING ROAD SAFETY - ROAD SAFETY IN A TRAFFIC MODEL

Many traffic policy measures are aimed at changing traffic behaviour, which in its turn, will affect road safety. Traffic behaviour on the level of road sections and junctions can generally be described by the number of vehicles, the travelling speeds, the headways, et cetera.
Road safety, however, can be described in various ways. The distribution of crashes over a road network largely depends on the distribution of traffic over that network; the more traffic there is, the more crashes there will be. Crash density and crash rate are common indicators to express the mutual relation (Janssen, 1994, 2005). Crash Prediction Models are another way of indicating road safety. Using Average Daily Traffic volumes and road characteristics as an input, the number of crashes or casualties can be calculated (FHWA, 2000; RIPCORD, 2006).
There are no crashes in a traffic simulation model, and therefore other road safety indicators, particularly simulated conflicts, have been introduced (FHWA, 2003). Such indicators will be dealt with in this paper. We will propose safety indicators that are focussed on a driver's route choice.

Road safety on the level of road sections and junctions is mostly expressed by the number of crashes. However, the number of crashes for a single road section or junctions is generally too small for an in-depth analysis to be performed. The number of traffic conflicts is much higher, therefore enhancing the possibilities for analyses. Studying conflicts presumes a relationship between a conflict and a 'real' crash. This relationship was studied extensively by Hydén (1987) and Svensson (1998).
When using a microscopic model, conflicts between vehicles will be an integral part of the simulation. The outcome will be used to compare the types of conflicts in a given simulation with the types of conflicts that are 'acceptable' in a sustainably safe road environment. For example, this means that conflicts with opposing vehicles at high speed differentials should be minimized.
Time To Collision (TTC) is an indicator for the seriousness of a traffic conflict. A traffic conflict is defined by FHWA (2003) as "an observable situation in which two or more road users approach each other in time and space to such an extent that there is a risk of collision if their movements remain unchanged". The TTC value differs between junctions and road sections. A TTC for road sections can only be relevant when one vehicle is following another one. A vehicle on a road section can therefore only have one TTC value. A TTC value for junctions is related to vehicles approaching each other on two different arms. A vehicle approaching a junction can have more than one TTC value, depending on the number of vehicles on the other arms.

TRAFFIC SIMULATIONS AND STUDY AREA

The study has been carried out in the western part of the Netherlands and the size of the area that was used is approximately 300 km^2. The area has a population density of 3,000 residents per square kilometre. By Dutch standards, the area contains one large town (475,000 inhabitants), two towns of medium size (64,000 and 118,000 inhabitants), and thirteen smaller communities (4,000 to 32,000 inhabitants). The area is traversed by two roads which are part of the national main road network (See *Figure 1*). A few regional roads run parallel to these two main roads.

Figure 1 Study area

The roads and the traffic in the study area have been modelled with the micro-simulation model S-Paramics (SIAS, 2005). The modelled network comprises the area's most important roads and streets, but residential roads have been omitted. The model consists of approximately 9,000 links and 4,500 nodes. A node connects at least two links, and may sometimes be an actual junction. The model contains more than 1,000 junctions and roundabouts. The model has been calibrated for morning rush-hour traffic on weekdays (6.00 a.m. to 10.00 a.m.). The traffic assignment during this period is in accordance with the observed flows. The calibration is particularly focused on the distribution of traffic over the two parallel main connections between the two most important urban centres in the area (Leiden/Katwijk and The Hague), using traffic counts and the observed lengths of queues.

The model is tailored to the situation in 2005. As is typical in micro-simulation models, the model only represents the movement of motor vehicles.

S-Paramics determines and stores the positions of all vehicles, every second. From this data, the numbers of conflicts can be calculated, also for each second.

RELATION BETWEEN CRASHES AND CONFLICTS

The simulation model shows the passing vehicles per junction and the vehicles that may come into conflict with each other for this period. A sub-program then calculates the conflict numbers. These values for passing vehicles and conflicts may be too much subject to coincidence. During a following 'run', the values could be completely different. In order to control for this, 36 runs were carried out. This number of runs is much higher than usual and this was done to be sure about the variability in the numbers of conflicts and the numbers of passing vehicles. The resulting values were found to be sufficiently stable. The average values of the number of passing vehicles and conflict situations were calculated from these runs for each junction.
Dijkstra et al. (2010) showed that observed crashes and calculated conflicts are related to each other; see *Figure 2*. This quantitative relation was confirmed by using statistical testing procedures.

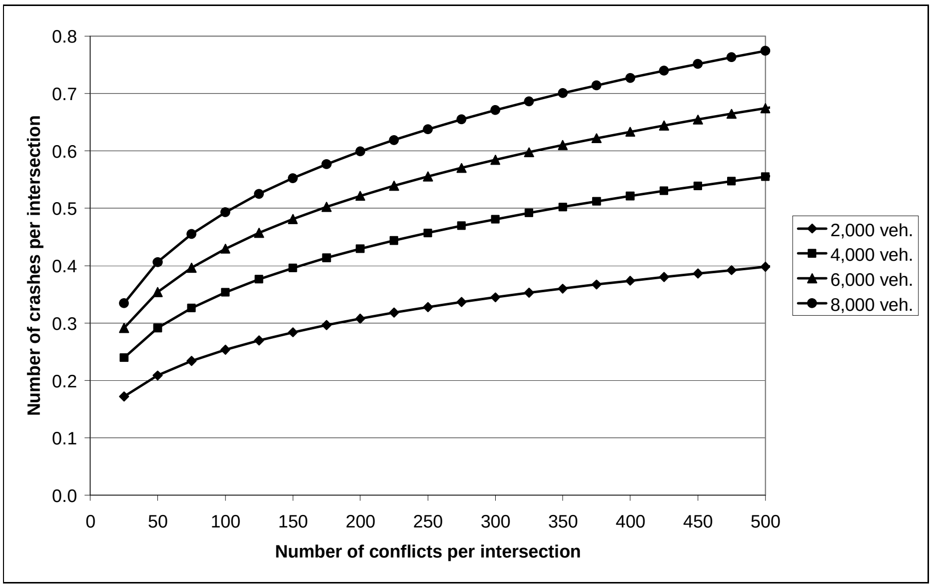

Figure 2 Number of observed crashes related to number of simulated conflicts

SAFETY REQUIREMENTS FOR A ROUTE

In the context of the Sustainable Safety vision, the exposure to safety risks is minimised if, for individual journeys, routes comply with the optimal sequence of road types, expressed in a route diagram (so-called SuSa steps), as depicted in *Figure 3*. A route starts at an Access Road (AR), switches to a Distributor Road (DR) and continues on a Through-Road (TR). When approaching the end of the trip, this sequence is followed in reverse order.
The route diagram of each route can be checked according to a series of criteria, nine in total, each representing requirements for a sustainably safe route choice (Dijkstra et al., 2007). Each criterion of the route diagram is important for the total safety level of a route; 'demerit points' are given when a criterion does not meet the requirements. These criteria and requirements will be described below:

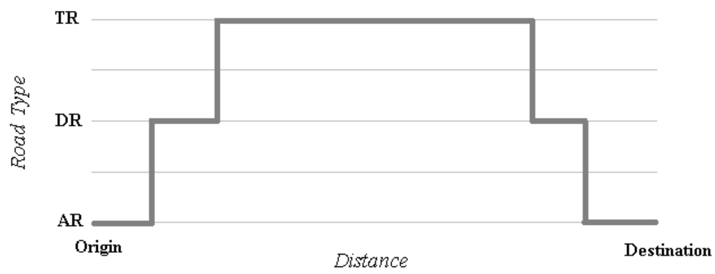

Figure 3 Route diagram or SuSa steps

1. *The number of transitions between road categories:*
   An optimal route diagram should have the correct number of road type transitions. A route with, for example, three categories should only have four transitions (two transitions upward and two downward). Having too many transitions results in demerit points, according to the equation:

   $$AT = T - (2RCP - 2)$$

   where *T* is the total number of category transitions along the route concerned, *RCP* the number of road types in the route, and *AT* the number of additional transitions.

2. *The nature of the transitions is correct:*
   The transitions between road categories should be ‘stepwise’; each step should lead to the ‘next’ category. It is important here to make a distinction between upwards and downwards transitions. In the case of an upwards transition, it is to a higher road type, and a downwards transition is to a lower road type. The distinction between road types allows us to examine whether the transition is correct. If the difference is 1 (upwards transition) or -1 (downwards transition), the transition is correct. If the difference is greater than 1 or smaller than -1, the transitions are incorrect. The equation for this is:

   $$NT = (C_j - C_i)$$

   where *NT* is the transition type, C_j the next category after the C_i category concerned.

   A road type transition meets this requirement if NT = 1 (upwards) or NT = -1 (downwards). If NT > 1 or NT < -1, it does not meet the requirement. We then add up the number of incorrect transitions along a route.

3. *Missing road categories:*
   Minimise the number of missing road categories. The number of road types covered in the route, compared with the number present in the network constitutes the fourth requirement, expressed in the equation:

   $$MRC = RCN - RCP$$

   where *MRC* is the number of missing road types, *RCN* the number of road types present, and *RCP* the number of road types covered in the route concerned.

4. *Access roads: keep length share as low as possible:*
   Access roads are only meant for direct access; the length of this road type should be minimised.
   From the safe route choice point of view, through-traffic should avoid 30 km/h zones. The part of the route travelled on an AR is expressed as a percentage of the total route length.

5. *Distributor roads: keep length share as low as possible:*
   Distributor roads have higher risks than through roads (Janssen, 2005) and should be used less frequently, their length share should be as low as possible. The part of the route that uses a DR is expressed as a percentage of the total route length.

6. *Keep the total travel distance as short as possible:*
   The shorter a route, the less exposure to crash risk. This relationship is supposed to be common knowledge. For each route the total distance travelled (from origin to destination) is calculated.

7. *Keep the total travel time as short as possible:*
   The shorter the journey time, the lower the exposure to risk for the individual user. Calculations of the journey times in the network have been made by dividing the length of the road segments by the speed limits of these road segments. The speed limits are regarded tot be the operating speeds in an 'empty' network. An alternative for this is to calculate the average journey times of the total number of passing vehicles on each road segment.

8. *Minimise the number of left turns:*
   Left turns are more dangerous than other manoeuvres (Dijkstra et al., 2007). The number of left turns at intersections can be counted and added up.

9. *Keep density of junctions as low as possible:*
   The amount of 'disturbance' should be kept to a minimum. The purpose of this requirement is to assess the route for disturbances present. In this way the intersection density is defined as the number of intersections per kilometre on each route. All intersections are included here, also those with streets and roads that have no car traffic.

Definition of the Sustainable Safety Score (DV score)

For each route we calculate the scores for the nine aforementioned criteria by collecting the data and applying the equations. Standardisation of the criterion scores is necessary if the different scores of the various routes are going 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 subtracting the lowest score from the score of 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 by the equation:

$$G_{ji} = \frac{C_{ji} - min_j\{C_{ji}\}}{max_j\{C_{ji}\} - min_j\{C_{ji}\}} \qquad (1)$$

where 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*.

To arrive at a total score for each route, the standardised score is multiplied by a weight factor g_c 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 be between 0 and 100%. This is expressed by the equation:

$$DVscore_r = 100 - 100 \times \sum_{c=1}^{C} ss_c \times g_c \quad (2)$$

where $DV\ score_r$ 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*.

RELATION BETWEEN CONFLICTS AND DV SCORE

Showing a direct relation between crash numbers and DV indicators in a comparable way is almost impossible. The reason being that the crash numbers for individual routes are very small: solid quantitative relations can therefore not be established. To bypass this problem the relations between conflict numbers and DV indicators are examined. If these relations appear to be strong, then the existence of a relationship between DV indicators and crash numbers is made plausible. The data on DV indicators and other route characteristics will also be used to analyse general assumptions regarding the safety of routes and route choice. Some of the data is the output of the micro-simulation model. This (dynamic) data is the average of ten runs and refers to data about the number of vehicles per route and per road section, the vehicle movements (in particular near intersections), the actual travel times, the departure and arrival times, and the speeds driven. The other data has been calculated using the previous data as an input.

The conflicts on the intersections can be divided into frontal, longitudinal (rear-end), transversal (lateral), and converging conflicts. For the analysis, it is relevant to focus on conflicts that involve vehicles following the route. Only for transversal (lateral) conflicts, one of the vehicles is always certain to have been following the route to be analysed. For this reason, the analyses were limited to lateral conflicts.

Route types

Three types of routes can be distinguished:

1. Routes with both the origin and destination within the study area;
2. Routes with only the origin or destination within the study area;
3. Routes with neither the origin nor destination within the study area.

For the analyses, the route characteristics of the whole route are needed, from origin to destination. This data is only available for the first type of routes. For this reason the analyses in this paper only deal with 'type 1' routes (belonging to 11,659 OD pairs).

Another restriction is made for OD pairs only having one route. Within such a type of OD pair, it is obviously not possible to make a route choice. Therefore, these 5,078 OD pairs are also left out of the analyses.

The number of OD pairs with at least two routes and with both origin and destination within the study area amounts to 6,581. The total number of routes belonging to these OD pairs is 25,181; the resulting average number of routes per OD pair is 3.83.
For this network, the maximum number of routes observed within an OD pair is 34 routes.

Formulation of hypotheses

The hypotheses for analysing the routes and OD pairs focus on numbers of conflicts and on DV scores.
The most important hypotheses relate to the Sustainable Safety requirement that the shortest route should also be the safest route. The hypothesis is that within an OD pair the route with the shortest travel time will have the lowest safety indicator. In this analysis the safety indicator can be:

1. Number of conflicts.
2. Number of conflicts per kilometre (conflict density).
3. Number of conflicts per vehicle kilometre (conflict risk).

The following hypotheses relate to the DV scores. A hypothesis is formulated for the routes within an OD pair. Mind that a higher DV score is equivalent to a higher safety level.

4. The higher the DV score, the shorter the travel time.
5. The higher the DV score, the lower the number of conflicts.
6. The higher the DV score, the lower the number of conflicts per kilometre.
7. The higher the DV score, the lower the number of conflicts per vehicle kilometre.

The routes differ in length: the shortest route amounts to 62 metres, the longest one to 23.9 kilometres. The shorter routes may differ from the longer ones, since they might miss essential route characteristics. Therefore, the next hypothesis is:

8. Hypothesis 5 is best tested for longer routes instead of for all 25,181 routes.

These hypotheses will be tested according to a procedure explained below.

How the hypotheses are tested

Most of the hypotheses are tested in two ways. First, different combinations of two routes within an OD pair are compared. For instance, if an OD pair has three routes numbered 1 to 3, then routes 1 and 2 are compared, routes 2 and 3, and routes 1 and 3. For each comparison, the result will be a 'yes' or 'no' as the answer to the question whether the hypothesis is true. The number of tests is added up as well as the number of affirmative and negative answers. The total number for 'yes', related to the total number of tests is the input for a binomial test. A hypothesis which is tested for more than 10,000 cases is taken to be ‘true’ when at least 50.1 % of the answers are 'yes'.
The second way of testing the hypotheses is to perform a regression analysis for all routes within an OD pair. The most important element in this regression analysis is the *slope* of the tangent line. A hypothesis such as 'if A is bigger, then B is also bigger' will have a positive slope, while a hypothesis such as 'if A is bigger, then B is smaller' will have a negative slope.
These regression analyses are applied to the OD pairs having a maximum of eight routes. The remaining 370 OD pairs (with nine or more routes) are put aside because their contribution to the total result will be small while the calculation procedure will become more and more

complicated. Again, the hypothesis is true when the number of negative or positive slopes (depending on the type of hypothesis) in relation with the total number of tested OD pairs is more than 50.1%.
The first way of testing (pair-wise) is applied to all hypotheses; the second way (regression) is applied to a selected number of hypotheses.

Varying the DV scores

The DV scores for the hypotheses are calculated according to *Equation 2*, using equal weights for all criteria. However, it is very likely that the criteria are not equally important regarding their relationship with the safety indicators. That is why a series of DV scores will be tested. These DV scores are listed in *Table 1*. The scores DV1 to DV7 are used to test whether the systematic addition of a criterion gradually produces a better result. DV8 and DV9 are used to test the assumption that the number of left turns and the intersection density are strongly related to the conflict indicators.

Table 1 Criteria with different weights, resulting in a series of DV scores

	DV	wghDV	DV1	DV2	DV3	DV4	DV5	DV6	DV7	DV8	DV9
Number of transitions	0,11	0.11	1.00	0.50	0.33	0.25	0.20	0.17	0.14	0.00	0.00
Nature of transitions	0,11	0.11	0.00	0.50	0.33	0.25	0.20	0.17	0.14	0.00	0.00
Missing road categories	0,11	0.11	0.00	0.00	0.33	0.25	0.20	0.17	0.14	0.00	0.00
Proportion of access roads	0,11	0.05	0.00	0.00	0.00	0.25	0.20	0.17	0.14	0.00	0.00
Proportion of distributors	0,11	0.12	0.00	0.00	0.00	0.00	0.20	0.17	0.14	0.00	0.00
Travel distance [kilometres]	0,11	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.14	0.00	0.00
Travel time [minutes]	0,11	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00
Left turns	0,11	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00
Intersection density (per km)	0,11	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	1.00
Sum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

ANALYSING SCORES, NUMBERS OF CONFLICTS, AND TRAVEL TIMES

The hypotheses 1 to 8 will be tested below, first by pair-wise comparisons, followed by the regression analyses.

Pair-wise comparisons

The pair-wise comparisons are intended to give a clear insight into the mutual relationships between the routes within an OD pair. Not all routes within an OD pair are compared to each other. The comparisons are structured according to the system in *Table 2*: consecutive routes (i+1 and i) are compared to each other as well as routes i+2 and i ($i \leq 9$). This limitation has a merely practical motivation: it reduces the number of operations. However, this approach still results in many comparisons, more than enough for satisfactorily executing the binomial tests.

A methodological drawback to this procedure regards routes that are included in two or more tests. This can be observed in *Table 2*: e.g., route 1 (in OD pair A -B) is involved in two tests. Therefore, these tests are not considered to be completely independent. To check the effect of this dependency, the sequence of the routes within an OD pair was randomly changed in some tests. A second drawback regards routes that have some road sections in common: the overlapping of routes. This will also harm the assumption of independency in a statistical test. On the other hand, from a traffic and transport point of view the entire route has to be considered instead of only part of it. Although consideration of a shorter part may result in the desired independency (of another part of another route), the essence of the route concept is that the route with all its characteristics should be investigated. That is why the routes are analysed in their entirety, not as parts. Regression analyses are supposed to partially overcome these drawbacks. The results of the pair-wise comparisons are expressed as percentages; the hypothesis is true if the percentage is at least 50.1.

Table 2 Procedure for testing routes

Row number	OD pair	Route, serial number	Comparing routes
1	A - B	1	-
2	A - B	2	2 to 1
3	A - B	3	3 to 2 and 3 to 1
4	A - B	4	4 to 3 and 4 to 2
5	A - B	5	5 to 4 and 5 to 3
6	A - B	6	6 to 5 and 6 to 4
7	A - B	7	7 to 6 and 7 to 5
8	A - B	8	8 to 7 and 8 to 6
9	A - B	9	9 to 8 and 9 to 7
10	A - B	10	10 to 9
11	A - B	11	11 to 10
12	A - B	i+1	i+1 to i
13	A - C	1	-
14	A - C	2	2 to 1
15	A - C	3	3 to 2 and 3 to 1

Hypothesis 1, 2, and 3

These hypotheses are relevant to the Sustainable Safety requirement 'the shortest route should also be the safest route'. The procedure for testing routes was different from the procedure depicted in *Table 2*. For the following procedure, only OD pairs having no more than five routes were analysed. *Table 3* shows the results for travel time in an empty network. Only hypothesis 1 (number of conflicts) can be confirmed. The hypotheses for conflict density and the conflict risk cannot be confirmed.

Table 3 Results for hypotheses 1, 2, and 3 (percentages 'true' of the total number of tests)

Travel time in empty network	Number of route pairs tested	Hyp. 1 (conflicts)	Hyp. 2 (conflict density)	Hyp. 3 (conflict risk)
OD pairs with 2 or 3 routes	4,013	59	41	49
OD pairs with 2, 3 or 4 routes	4,946	56	38	46
OD pairs with 2, 3, 4 or 5 routes	5,469	55	40	46

Hypotheses 4 to 8

Hypotheses 4 to 8 have been tested for both DV score and wghDV score. The tests in *Table 4* follow the procedure according to *Table 1*. The test for hypothesis 4 (*Table 5*) follows a procedure analogously to the tests for hypotheses 1 to 3.
All hypotheses are accepted. The hypotheses regarding the safety indicators (5 to 8) show the best results for the number of conflicts (DV score) and the conflict risk (wghDV score). The results are satisfactory for both score types (DV and wghDV). Hypothesis 8 is accepted, although it results in the same percentage as the corresponding test with all routes. So the longer routes do not differ from the entire set of routes.

Table 4 Results for hypotheses 5 to 8 (percentages that verify the hypothesis)

Hypothesis	Test results	
	DV score	wghDV score
5 (number of conflicts)	67	65
6 (conflict density)	57	63
7 (conflict risk)	62	67
8 (longer routes)	67	-
Number of route pairs tested (for hypothesis 8: 13,397 routes)	28,077	28,528

In a second test procedure, the original sequence of routes within an OD pair was changed in order to find any effect on the test results. However, the effect on the test results appeared to be very small. There may be an effect of routes taking part in two or more tests, but this effect could not be found in repeating the tests after having changed the sequence of routes within the OD pair.

Table 5 Results for hypothesis 4 (percentages that verify the hypothesis)

	Number of route pairs tested	DV score	wghDV score
OD pairs with 2 or 3 routes	4,013	75	62
OD pairs with 2, 3 or 4 routes	4,946	73	58
OD pairs with 2, 3, 4 or 5 routes	5,469	69	56

Alternative DV scores

The original DV score is split up systematically into scores with different weights. The results of the DV score and wghDV score for the hypotheses 10 - 12 are compared with the results of the DV1 - DV9 scores; see *Table 6*. Only the DV8 score and DV9 score show a somewhat better result than the (wgh)DV scores. The good results for the DV9 score are remarkable, considering that this score only consists of one criterion (intersection density). The DV9 score will, therefore, be looked at more closely in the next section.

Table 6 Results for hypotheses 10, 11, and 12 (percentages that verify the hypothesis)

Type of score	Criteria or criterion	Number of route pairs tested	Hyp. 10 (conflicts)	Hyp. 11 (conflicts density)	Hyp. 12 (conflict risk)
DV	all	28,077	67	57	62
wghDV	all but crtn. 6	28,528	65	63	67
DV1	crtn. 1	700	58	52	45
DV2	crta. 1 - 2	3,441	45	38	25
DV3	crta. 1 - 3	5,359	48	54	53
DV4	crta. 1 - 4	27,356	46	52	58
DV5	crta. 1 - 5	14,148	53	59	62
DV6	crta. 1 - 6	28,193	60	50	53
DV7	crta. 1 - 7	28,161	61	49	53
DV8	crta. 8 - 9	26,928	64	67	67
DV9	crtn. 9	27,486	65	69	70

Compared to other score types, the route pairs tested for DV1 to DV3 are rather few (*Table 6*). This is caused by the large number of OD pairs showing exactly the same score for all routes. These OD pairs are left out of the testing procedure resulting in rather few pairs remaining for the test.

Regression analysis

A regression analyses will be applied to the most important hypotheses, in particular hypothesis 1 (travel time, conflicts), 5 (DV score, conflicts), 6 (DV score, conflict density), and 7 (DV score, conflict risk).
Starting with hypothesis 1, both travel time indicators will be analysed: 'travel time in empty network' and 'travel time in model'. *Table 7* contains the percentages of OD pairs with a *positive* slope, for each number of routes per OD pair. All of these percentages are below 50.0 percent, except for the OD pairs with four and five routes; see also *Figure 4*.
Given these results, the conclusion must be that hypothesis 1 has to be rejected. Of course, these are the results for the current network. Changing the network in the right direction may improve the results.

Table 7 Variable Travel time in empty network, results for hypothesis 1

Number of routes within OD pair	Is the slope according to hypothesis 1?
2	45.8
3	45.2
4	52.5
5	52.6
6	44.6
7	42.2
8	48.1
2 - 8	47.1

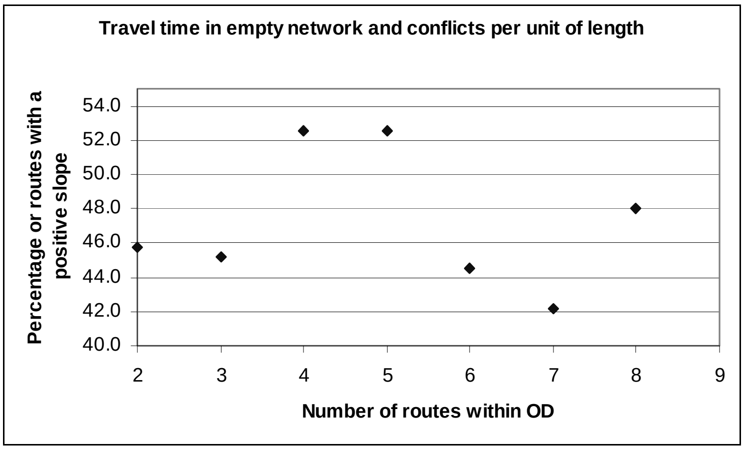

Figure 4 Percentage of OD pairs with a positive slope, for different numbers of routes per OD pair

The next hypotheses 5, 6 and 7, deal with the relationships between the DV score types and the conflict safety indicators. Hypothesis 10 was tested for DV score and wghDV score. The resulting percentages of OD pairs with negative slopes are given in *Table 8*. Both score types show percentages far above 50%. This hypothesis is therefore accepted.
The percentages for hypothesis 6 are above 50 percent, except for the DV score of an OD pair with two routes. Therefore, this hypothesis is also accepted.
Finally, hypothesis 7 is tested for three score types: DV score, wghDV score and DV9 score. The previous results learned that the DV9 score had a good result in pair-wise comparisons. Possibly this good result will show up in the regression analysis as well. The DV scores prove not to perform very well. The wghDV score and DV9 score perform much better. The results for the DV9 score, however, are not better than those for the wghDV score. The hypothesis is accepted for both the wghDV score and the DV9 score. Looking at the results for the DV score more closely, the OD pairs with two routes appear to have a high share of OD pairs with a horizontal slope (15% of 2,685 routes). This percentage is much higher than in the other analyses (mostly around 1 percent). If these OD pairs with a horizontal slope are left out of the analyses, then the percentage of routes with negative slopes rises from 44.7 to 52.6. The percentage for all OD pairs (2 to 8 routes) rises from 49.4 to 53.1 percent. In this way, the hypothesis can also be accepted for the DV score. Leaving out the OD pairs with horizontal slopes hardly affects the percentages for wghDV score.

Table 8 Results for hypothesis 5 (number of conflicts)

Number of routes within OD pair	DV score	wghDV score
2	61.3	64.3
3	74.8	74.5
4	79.5	77.7
5	80.9	77.1
6	78.0	76.7
7	81.7	79.4
8	81.4	82.9
2 - 8	70.8	71.3

CONCLUSIONS AND RECOMMENDATIONS

Simulation models are a useful tool for understanding the relation between transportation demand, traffic flow and detailed movements of vehicles.

Traffic safety in simulation models can be described by indicators using the time-to-collision between conflicting vehicles.

The traffic safety of a route can be described by a set of criteria (DV score) that indicates the degree to which the Sustainable Safety requirements are met.

The results show a direct relation between the DV score and the number of conflicts. An earlier study showed a quantitative relation between the number of conflicts and the number of crashes. Therefore, we may conclude that the DV score and the number of crashes are related indirectly.

The method of quantifying the safety level of routes will allow evaluation of road network structures from a safety perspective. It is expected that by optimizing the design of the network and by influencing route choice a (more) sustainably safe traffic system can be established. Ultimately, this method will provide road authorities and traffic engineers with a tool that enables them to include traffic safety in the planning and design phase of a project.

Micro-simulation models like S-Paramics, only represent the movement of motor vehicles. For safety studies other road users also need to be modelled.

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