A method to assess road safety of planned infrastructure

Jan van der Sluis & Theo Janssen

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Case study of Maastricht in the framework of the European research project DUMAS, Workpackage 9

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Jan van der Sluis & Theo Janssen
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SWOV Institute for Road Safety Research, The Netherlands

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Author(s):	Jan van der Sluis & Theo Janssen
Research manager:	Theo Janssen
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SWOV Institute for Road Safety Research
P.O. Box 1090
2260 BB Leidschendam
The Netherlands
Telephone 31703209323
Telefax 31703201261

Summary

This case study of Maastricht was part of Workpackage 9 ‘Town studies’ of the research project Developing Urban Management And Safety (DUMAS), commissioned by the European Commission.
One of the main objectives of DUMAS was to develop an assessment framework to encourage the use of objective measures in urban safety management initiatives. The objective of the 'Maastricht Town Study' was to develop a generally applicable methodology for assessing the influence on traffic safety of local initiatives, taking the 'Maastricht case' as a typical case.

The town of Maastricht is situated in the South of the Netherlands, and it was chosen for this study because it has some serious problems, concerning a motorway running through the city. This motorway not only has a through-function, but is also used as distributor road. Besides the mobility and accessibility problem, the situation also involves a major environmental problem of air pollution and noise nuisance. To solve these problems, three alternative plans have been prepared.

These three infrastructure plans have been analysed as to their traffic safety consequences by estimating the number of injury accidents in the year 2010. The three variants were named after the most important intervention: the ‘Traverse variant’, the ‘Northern Bridge variant’, and the ‘Eastern Diversion variant’ (by-pass). In the analysis, not only the effects of the measures concerning infrastructures were taken into account, but also the predicted accident reduction, due to the introduction of the ‘sustainable safety’ principles, was included.

At this moment, the introduction of ‘sustainable safety’ plays an important role in the Netherlands to improve road safety and is therefore one of the main institutional issues. A sustainably safe road traffic system is one in which the road infrastructure has been adapted to the limitations of human capacity, through proper road design. The key to arriving at a sustainably safe road system lies in the systematic and consistent application of three safety principles:

- functional use of the road network by preventing unintended use of roads;
- homogeneous use by preventing large differences in vehicle speed, mass and direction;
- predictable use, thus preventing uncertainties among road users, by enhancing the predictability of the road’s course and the behaviour of other road users.

The three safety principles require the specification of the intended function of each *road* and *street*. Roads are built with as major function the so-called traffic function, enabling people and goods to travel. Three options are distinguished:

- the flow function, enabling high speeds of long-distance traffic and, frequently, high volumes;
- the distributor function, serving districts and regions containing scattered destinations;

- the access function, enabling direct access to properties alongside a road or street.

Based on the distinguished road functions, five road categories have been defined: through-road, distributor road, urban and rural, and access road, urban and rural.

To assess the road safety consequences of the three plans concerning infrastructure in Maastricht, a quantitative method has been introduced. The method consist of three steps:

STEP 1: Determination of national safety indicators per road category;
STEP 2: Calculation of local safety indicators and comparison with national indicators;
STEP 3: Estimating the number of accidents for different scenarios in the prognosis year with a new set of sustainable safety indicators per road category.

The basic formula used in these three steps is:

$$N_{acc} = indic * v\_k$$

in which: N_{acc} = number of injury accidents [-]
indic = safety indicator [-/10^6 km] per road category
v_k = vehicle kilometres [10^6 km] on this road category

In the first step, 'indic' is calculated for each of the five defined road categories, based on a representative sample of the national road network in a reference year. In the second step, the first step is repeated for the studied road network in the reference year. Then the national safety indicators are compared with the local safety indicators, resulting in a correction factor for each national safety indicator. In the third step, local safety indicators are estimated for the prognosis year by applying the correction factors on a set of estimated national sustainable safety indicators in the reference year. Subsequently, the number of injury accidents is estimated with the corrected safety indicators for all considered variants in the prognosis year.

In order to apply the described method, one needs to gather accident data, road category data, and traffic volume data. Basically, all information needed was available for the Maastricht case. However, to perform the required calculations, it is necessary that all data is linked to one digital map only. Unfortunately this was not the case. Each data type, categorisation data, traffic volume data, and accident data was linked to its own map. The development of a common map and the data manipulation is described extensively. It was found impossible to perform the second step of the method in the Maastricht case. As a consequence, the number of injury accidents in the prognosis year was estimated by using uncorrected national safety indicators.

In the Maastricht case, the estimated numbers of injury accidents were not significantly different for the three infrastructure variants studied. However, in the case of the Eastern Diversion variant, the number of kilometres driven over the total network is smaller than for the other two variants. This may have environmental advantages.

The quantitative results of the method presented is very useful for policy makers to identify traffic safety consequences of local infrastructure plans. The method is particularly suited for comparing the traffic safety effects of a number of alternatives to solve one particular traffic problem. The setup of the method is relatively simple and probably applicable in other countries as well. Clearly, national safety indicators should be available, to be able to apply the described method.

Contents

1. Introduction

1.1. DUMAS project

This report has been prepared by SWOV Institute for Road Safety Research as part of Workpackage 9 ‘Town Studies’. This workpackage was part of the third phase of the research project ‘Developing Urban Management And Safety’ (DUMAS). The DUMAS project was commissioned by the European Commission in order to consider current practices of Urban Safety Management (USM) and to produce frameworks for the design and evaluation of cost-effective and successful urban safety initiatives. DUMAS also aimed to fill in some of the gaps in knowledge regarding USM.

The objectives of DUMAS have been elaborated in three phases:

1. The first phase was set up to collect, collate and report on research findings and current practice relevant to USM. This has produced 'state-of-the-art' reports of individual countries and an overall summary.
2. The second phase was set up to investigate specific issues in more detail. These include the role of traffic management, accident data collection and analysis, speed management, vulnerable road users, political factors and linking safety with other initiatives such as the environment.
3. The third phase was set up to involve towns and cities in partner countries, in which safety initiatives have been or are being implemented. The experiences are monitored and brought into the DUMAS frameworks. It is intended that this will allow us to identify the differences between countries and produce frameworks that can be adapted to a range of situations.

The main contractor of the DUMAS project is the Transport Research Laboratory TRL, United Kingdom, in cooperation with the following partners:

Institut National de Recherche sur les Transports et leur Sécurité, INRETS	Research Organisation	France
SWOV Institute for Road Safety Research	Research Organisation	The Netherlands
Danish Road Directorate	Research Organisation	Denmark
Development and Engineering Consultants Ltd.	Industry	Greece
Universitá Degli Studi di Brescia UdB	Education	Italy
Bundesanstalt für Straßenwesen BASt	Research Organisation	Germany
Kuratorium für Verkehrssicherheit KfV	Other	Austria
Centrum Dopravniho Vyzkumv S.a.	Research Organisation	Czechia

The DUMAS project was dealing with the subject of how traffic safety can be improved locally as part of some package, meeting wider urban objectives. In that, urban safety management often is, by its nature, not a particular objective or directly measurable subject. Yet, the DUMAS project strived to base advice on objective measures wherever possible. In this respect, one of the main objectives of DUMAS was to develop an assessment framework to encourage the use of objective measures in urban safety management initiatives.

Measurable objectives and measured results are at the heart of this. For this purpose the development of local safety assessment methodologies and the application of such tools at the local level is required.

The purpose of Workpackage 9 was to develop and test methodologies in a range of towns. Therefore, cooperation has been sought with a sample of towns for two purposes:

1. to use the experiences of towns which were already in the process of carrying out research and safety initiatives, to help developing the framework during Workpackages 2 to 8 of the DUMAS project.
2. to apply as many elements of the design and evaluation framework as possible with the objective of:
   i) assessing the present safety situation in these towns,
   ii) identifying further safety improvements that could be made,
   iii) comparing the predicted safety benefits with those measured.

1.2. The Dutch town study

For the Dutch contribution, SWOV has decided to perform a case study on Maastricht. Maastricht is a municipality in the south of the Netherlands with about 150,000 inhabitants.

The objective of the 'Maastricht town study' is to develop an eventually generally applicable methodology for assessing the influence on traffic safety of local initiatives. In that, one has to realise that traffic safety is influenced by the road network as a structure, as well as by the design (including measures concerning infrastructures, traffic management, rules and regulations, etc.) of its roads and junctions. Obviously, both points of view have to be taken into account.

1.3. The report

The setup of this report is as follows. In the next chapter, Institutional issues, the Dutch sustainably safe road system and the functional road categorisation are discussed. In the third chapter the problems in Maastricht are described in detail. The methodology developed is covered in the fourth chapter. Chapter five concerns a description of the data used for the analysis. In the sixth chapter the data manipulation is dealt with, as well as the problems that are encountered by combining data from several sources. In chapter seven the performed analysis is treated, which is concluded in chapter eight. In the last chapter some conclusions are drawn and some recommendations concerning the methodology are made.

2. Institutional issues

2.1. History

The Netherlands have a long history in the field of improvements with regard to environmental and road safety measures in (existing) residential areas. As in other countries, the massive growth in car ownership and use, meant that motorised traffic in the Netherlands took an increasingly dominant position. Activities typical to residential areas were crowded out, while the urban dweller felt increasingly threatened by motorised traffic and by high speeds.

In newly designed areas the design principles based on the separation of different types of traffic (such as the American Radburn principle and the Swedish SCAFT guidelines) were only used on a rather limited scale in the Netherlands.

During the seventies, an entirely different principle was developed for residential areas in the Netherlands: total integration of the different transport modes. The concept has also become internationally known by the Dutch word ‘woonerf’. Motorised traffic - excluding through-traffic - is accepted but is subordinate to the other ‘woonerf’ users. In a ‘woonerf’ motorised traffic is permitted to drive at walking pace (5-8 km/h). Separate provisions for pedestrians (such as sidewalks) are absent. In 1976 the ‘woonerf’ achieved legal status.

The ‘woonerf’ concept has greatly influenced thinking on the improvement of road safety and environmental aspects in the Netherlands. The ‘woonerf‘ led indeed to a substantial reduction in the number of injury accidents.
In some projects, injury accidents reductions of about 70% were reported. However, the application of the ‘woonerf’ often remained restricted to only a limited amount of and relatively small areas. As reasons for this, the following was given: very strict legal design requirements, the high construction costs and the extra physical space needed for realisation.

From these first experiences we learned that two features were essential: reducing driving speeds and reducing through traffic. From accident studies it turned out that the collision speed should remain below 30 km/h, because then the probability of a serious injury will be minimal. Since 1983, Dutch road authorities can install a legal limit of 30 km/h on roads or in zones within built-up areas. Based on a recent survey it could be concluded that 300 out of 700 Dutch municipalities have realised one or more ‘30 km/h-zones’. To guide Dutch municipalities to design effective speed-restricting and through-traffic-preventing measures, a handbook was developed. Recently the effect on the number of injury accidents has been studied and it was determined that the number of serious injury accidents had dropped by more than 30% (although a wide dispersion of effects was observed from almost no effect to more than 50% reduction).

A rough estimate at this moment is that 10% of the network of roads in the built-up areas has the status of 30 km/h-areas. The general opinion is that within urban areas approximately 80% of the road network could be given the status of 30 km/h-streets.

Two recent developments in the Netherlands also deserve attention. Firstly, streets which qualify for a 30 km/h status do not receive it due to the high costs. Secondly, for the same reason, those areas which have the 30 km/h status are relatively small. These are reasons to a) investigate to what extent a more low-cost design for 30 km/h-areas would lead to large-scale implementation, and b) determine if such a low-cost design is equally effective as the first design and thus be more efficient.

Intensive stimulation to foster implementation of large-sized 30 km/h-zones is recommended. This stimulation should probably fit in a more integral approach and the concept of ‘sustainable safety’ could possibly act as a framework.

2.2. Sustainably safe road system

The Dutch Government has set quantitative targets for road safety. These are a reduction in the number of road deaths of 50% and in the number of road injuries of 40% by the year 2010, compared with the levels of 1986. Various indicators suggested, however, that road safety in the Netherlands was not showing enough significant signs of improvement and it is no longer certain that the targets for the year 2010 will be met, even if the traditional policy continues to be followed.

New, innovative road safety policy was required and in 1990 the SWOV Institute for Road Safety Research was invited by the Dutch Government to develop a scientifically supported, long-term concept of a considerably safer road traffic system.
In a sustainably safe road traffic system a) road infrastructure has been adapted to the limitations of human capacity through proper road design, b) vehicles are technically equipped to simplify driving and to give all possible protection to vulnerable human beings, and c) road users have been properly educated, informed, and - where necessary - deterred from undesirable or dangerous behaviour. Human should be the reference standard and road safety problems should be tackled at its roots.
The key to arrive at a sustainably safe road system lies in the systematic and consistent application of three safety principles:

1. functional use of the road network by preventing unintended use of roads;
2. homogeneous use by preventing large differences in vehicle speed, mass, and direction;
3. predictable use, thus preventing uncertainties amongst road users, by enhancing the predictability of the road’s course and the behaviour of other road users.

Stimulated by a discussion in the Dutch Parliament, the concept of sustainable road safety has been adopted by the Dutch Government as an official part of its policy. Many stakeholders at other governmental levels and in the ‘road safety community’ supported the concept, although some doubts have been heard about financing the implementation and about possible side effects. Furthermore, it has been observed that safety professionals translate the vision differently in practice.

The starting point of the concept of 'sustainable safety' is to drastically reduce the probability of accidents in advance, by redesigning the infrastructure. Where accidents still occur, the process which determines the severity of these accidents should be influenced in such a way that serious injury is virtually excluded (Transport Research Centre AVV ,1996).

2.3. Road categorisation

The three safety principles (functional use, homogeneous use and predictable use) require the specification of the intended function of each *road and street*. Roads are built with one major function in mind: to enable people and goods to travel, the so-called traffic function. Three options can be distinguished:

- the flow function, enabling high speeds of long distance traffic and, frequently, high volumes;
- the distributor function, serving districts and regions containing scattered destinations;
- the access function: enabling direct access to properties alongside a road or street.

Besides a traffic function, streets and roads in urban areas should allow people to move around the vicinity of their house safely and comfortably. We call this function residential function and this function could well be combined with the access function.

The concept of sustainably safe road transport comes down to the removal of all function combinations by making the road mono-functional, i.e. by creating categories of roads: pure through-roads, pure distributor roads and pure access roads. Multi-functionality leads to contradictory design requirements and also to higher risks. *Table 2.1* indicates the risk levels of different road types and from this we can learn that applying the safety principles, as has been done on motorways and in 30 km/h-zones, lead to relatively low risks.

Road type	Speed limit (km/h)	Mixed traffic	Intersecting/ oncoming traffic	Injury rates per 10^6 km
Residential areas	30	Yes	Yes	0.20
Urban street	50	Yes	Yes	0.75
Urban artery	50/70	Yes/no	Yes	1.33
Rural road	80	Yes/no	Yes	0.64
Express road or road closed to slow vehicles	80	No	Yes	0.30
Trunk road	100	No	Yes/no	0.11
Motorway	100/120	No	No	0.07

Table 2.1. *Injury rates in the Netherlands (1986) on different road types.*

The differences between the existing approach to categorise a road network and the sustainably safe approach are depicted in *Table 2.2*.

<table>
<tr><th colspan="2">Common practice of today</th><th colspan="2">Sustainably safe practice</th></tr>
<tr><th>Existing types of roads</th><th>Traffic function</th><th>Traffic function</th><th>Sustainably safe types of roads</th></tr>
<tr><td>Motorway</td><td rowspan="4">↑ increasing through and decreasing access</td><td rowspan="2">Through</td><td>Ia. Motorway</td></tr>
<tr><td>Trunk road</td><td>Ib. Trunk road</td></tr>
<tr><td>Main distributor</td><td rowspan="2">or
Distributor
or</td><td>IIa. Distributor road (rural)</td></tr>
<tr><td>Local distributor</td><td>IIb. Distributor road (semi-urban)</td></tr>
<tr><td>District artery</td><td rowspan="4">↓ decreasing through and increasing access</td><td rowspan="4">Access</td><td rowspan="2">IIIa. Access road (rural)</td></tr>
<tr><td>Neighbourhood artery</td></tr>
<tr><td>Residential street</td><td rowspan="2">IIIb. Access road (urban)</td></tr>
<tr><td>Woonerf</td></tr>
<tr><td colspan="2">Residential function</td><td colspan="2">Residential function</td></tr>
</table>

Table 2.2. *Common practice and sustainably safe practice of categorising roads and streets.*

Based on our existing knowledge, functional requirements for design criteria have been developed for a sustainably safe traffic system (Van Minnen & Slop, 1994). Later, these functional requirements have been made operational in ‘draft guidelines’ by a CROW working committee (CROW, 1997).

To pay lip service to the concept of sustainable safety is one point, to put this concept into practice is another. The concept cannot be handed over to just those who are interested in the concept and rely on their individual willingness to come to implementation, and leaving those who are not interested aside. The concept requires an active participation of all road authorities in the country and of the whole road safety community as well.

Consultation of those policy makers involved in traffic safety on national, regional and local level has learned that an integral implementation of a sustainably safe traffic system is not possible at the moment. Therefore, the decision-making will take place in two steps or phases.
The first phase is described in the Start-up Programme Sustainable Safety and consists of a coherent package of measures in relation to infrastructure and education which can be implemented quickly, accompanied by some supporting measures. Furthermore, preparations will be made for decision-making about the second phase of the implementation.
Phase 1 will be carried out in the period from 1997-2001. In 2000 decision-making will take place about phase 2: the integral implementation of sustainable safety.

In the first phase, local authorities, provinces, and water boards make as soon as possible -within their own region and responsibility - a distinction between through-roads, distributor roads, and access roads. The main criterion in the distinction between distributor roads and access roads is that on all roads within an access area driving with motor vehicles is (made) inferior to all other traffic functions.

The central government stimulates timely a change of the rules to make it possible to put the speed limit within urban areas to 30 km/h.
It will be possible for road authorities to put the speed limit to 50 or 70 km/h by way of exception.

One of the most important lessons that can be learned from demonstration projects is how to get broad support, not only from politicians, policy makers, road authorities etc. Far more important is the support of the people who are concerned: the road user. Another important lesson is that the promotion of a sustainably safe traffic system cannot depend on one single initiative, e.g. the reconstruction of one single road. There always has to be a plan in which such a reconstruction can be seen in relation to the consequences for all other connecting roads in the area.

Once a plan is performed, monitoring the process is of utmost importance. Such monitoring shows at regular times whether or not the (intermediate) goals that have been set are reached. Monitoring makes it possible to control the process by everyone who is concerned.

As economy is an important factor of our society and because there is a relation between economy and infrastructure, it is important to commit the industry when realising the plans. Once convinced about the necessity of sustainable safety, the industry will also be willing to pay for the realisation.

Traffic has to be regarded as a system with infrastructure, regulations, vehicles, and traffic participants as the main elements of the system. All those elements must be attuned to one another within the concept of sustainable safety. That tuning is a matter of coordination between performance, formula, regulations, and usage.
A sustainably safe functional use of the road network takes into account: choice of routes, different kind of vehicles, traffic flow, accessibility, and intensity. A regular traffic flow can be achieved by the application of a correct formula and proper traffic regulations. It also means that low speeds can be enforced at crossroads. By taking into consideration the identification of traffic situations, the willingness of traffic participants to accept traffic rules and the simplicity of the layout of traffic situations, predictable traffic behaviour can be realised. Therefore, realisation of a sustainable road traffic safety system always has to begin with the drawing up of a categorising plan. Functional demands are necessary to achieve this and a step-by-step plan must be followed in order to realise the required mapping out of the roads.

Sustainable safety begins with drawing up a categorising plan by all those road authorities who are responsible for the construction and maintenance of roads. The very first step is to agree on the function individual roads have to fulfil. The categorisation of roads starts on paper. The expertise of different kinds of people has to be combined, so that a blueprint can be made as to the function of every road to be built in the future. In this plan, every road in an area is designated one category only, and the functional requirements for that road category are already specified. After that, the real work starts: it must be ensured that the roads and streets are designed in such a way that they optimally meet the corresponding functional requirements.

A sustainably safe road infrastructure has to fulfil operational as well as functional requirements. The functional requirements are meant particularly for the road authorities. They result in differentiation and the assignment of functions of roads. A rough outline of these functional requirements can be given:

- The flow function requires a design which allows high speeds. This means that no oncoming, crossing or intersecting traffic is permitted. The speed and mass differences between traffic travelling in the same direction should be minimal. Stationary objects located alongside the carriageways should be kept at a safe distance, or protected by conductive or energy-absorbing means.

- The distributor function results in a relatively high density of junctions. This hinders flyover solutions. Slow and fast-moving traffic should be kept separate wherever possible by applying separate frontage access. It should not be possible to cross the verges between the main carriage-way and the parallel road. In addition, oncoming traffic must be avoided as much as possible. At locations where slow and fast-moving traffic intersect, the driving speed should be either low, or traffic flows should be separated in time. Roads with a distributor function should prohibit parking as much as possible, and hazardous obstacles should be removed or screened off. The design applied for this approach will vary, depending on whether it concerns a rural area or an urban area.

- The access function is meant for roads where origins and destinations are immediate adjacent to the road and where it is allowed to enter or leave the road to reach these destinations or leave the origins. All sorts of traffic mix on the same carriageway; motor vehicles should drive slower than 30 km/h.

- A residential function for areas means that pedestrians, playing children, cycles and parked cars can use the same area. The roads in these areas should be designed in such a way that the residential function is immediately recognisable, and prohibit driving speeds of more than 30 km/h within urban areas or 40 km/h within rural areas. The possibility of conflicts between slow and fast traffic may still exist, but the low speed allows good anticipation and avoidance of hazards. Furthermore, any accident that does occur should not have serious consequences.

Based on assessments of the Dutch situation, it can be concluded that simply by ‘upgrading’ the roads that currently tend towards a flow function, even without introducing the envisaged design, and by ‘downgrading’ the roads that currently have a mixed flow and access function, it is possible to realise a redistribution of traffic and hence safer roads, so that the road accident risk will be reduced by at least one third.

2.4. Functional and operational requirements

Operational requirements form the bridge between the functional require-ments and the actual design and regulations of the road system. They result in recommendations for design and regulations that guarantee the distinction between the different road categories. Essential is the possibility

for the road user to recognize the road situation, leading to predictable behaviour.
Operational criteria follow from the twelve principal requirements for a sustainably safe road network:

1. Realise residential areas that are as large as possible.
2. Make a minimal part of the trips over unsafe roads.
3. Make trips as short as possible.
4. Make the shortest routes also the safest routes.
5. Prevent searching for destinations.
6. Make road categories recognisable.
7. Reduce the number of traffic solutions and make them uniform.
8. Prevent conflicts on oncoming traffic.
9. Prevent conflicts with crossing traffic and pedestrians.
10. Separate different means of transport.
11. Reduce speeds where conflicts could occur.
12. Avoid obstacles along roads.

To be able to work with them, the functional requirements have been translated into operational criteria. In *Table 2.3* this is done for the requirements 5 to 12, the numbers 1 to 4 being of a different order. The crosses indicate which operational criteria are relevant per functional requirement.

Operational criteria	Functional requirements							
	5	6	7	8	9	10	11	12
Speed limit		x						
Signing		x						
Longitudinal marking		x	x					
Cross section		x	x					
Road surface		x	x					
Access control		x		x	x		x	
Separation of carriageway		x	x	x	x			
Crossing (on road sections/mid block)		x			x		x	
Parking facilities		x		x	x			x
Bus stops		x		x	x			x
Emergency facilities		x	x					x
Clear zone	x							x
Bicycles		x	x			x		
Mopeds		x	x			x		
Slow motorised vehicles		x	x			x		
Speed reducing measures		x					x	
Lighting		x						x
Type of junction		x	x	x	x		x	
Leaving or entering a road category		x	x					

Table 2.3. *The functional requirements translated into operational criteria, for the requirements 5 to 12.*

Recently, functional requirements have been made operational in ‘draft guidelines’. Examples of these guidelines for roads outside and inside built-up areas are presented in the *Tables 2.4 and 2.5.*

Design criteria	Roads outside built-up areas		
	Through- road	Distributor road	Access road
Speed limit	120/100	80	60
Longitudinal marking	Complete	Partly	No
Cross section	2x1 (or more)	2x1 (or more)	1
Road surface	Closed	Closed	Open
Access control	Yes	Yes	No
Carriageway separation	Yes, physical	Yes, visual, to be crossed over	No
Crossing between junctions	At grade	At grade	Grade
Parking facilities	No	No	Parking space or on the carriageway
Stops for public transport	No	Outside the carriageway	On carriageway
Emergencyfacilities	Emergency lane	In verge or on hard shoulder	No
Obstacle-free zone	Large	Medium	Small
Cyclists	Separated	Separated	Depending
Mopeds	Separated	Separated	On carriageway
Slow motorised traffic	Separated	Separated	On carriageway
Speed-reducing measures	No	Appropriate measures	Yes

Table 2.4. *Guidelines for rural roads.*

Design criteria	Roads inside built-up areas		
	Through-road	Distributor road	Access road
Speed limit		70/50	30
Longitudinal marking		Partly	No
Cross section		2x1 (or more)	1
Road surface		Closed	Open
Access control		No/limited	Yes
Carriageway separation		To be crossed over	No
Crossing between junctions		At grade	Grade
Parking facilities		No	Parking space or on the carriageway
Stops for public transport		Outside the carriageway	On carriageway
Emergency facilities		In verge or on hard shoulder	No
Obstacle-free zone		Medium	Small
Cyclists		Separated	Depending
Mopeds		Separated/on carriageway	On carriageway
Slow motorised traffic		On carriageway	On carriageway
Speed-reducing measures		Yes	Yes

Table 2.5. *Guidelines for urban roads.*

2.5. Categorisation step-by-step

In almost every country the existing road network will turn out to be an autonomous result of developments in the past. For example, it is possible that certain villages have been united to form one big town. It is also possible that when doing this, connecting roads between the villages became part of the urban area of the new town without losing their original function. So, it is imaginable that such a development led to roads whose function, design and usage are not attuned to each other. In practice this will often be the case. Now the question presents itself: how to change from an existing road network to a sustainably safe road network without being to expensive?

Such a change should be made step-by-step. The first step is to categorise the roads, which means that every road must be given a certain function. Thereafter, the proper design should be defined on basis of the operational criteria. When giving a function to a road, it is important to build up a logical road network based on the three categories of roads: flow, distribution, and access.

Roads are designed and constructed to make it possible to travel. When designing new roads and reconstructing existing roads, not only traffic safety is important, but also the physical space, the budget, the function of the road, the flow capacity, and environmental issues are. In the sustainable safety concept, categorising should be considered as a ‘wishful dream’ which previously has to be attuned to other ‘wishes’ like accessibility, environmental problems and physical planning. As such, all parties can have their advantage from an early cooperation between the different policy areas.

The wish for a sustainably safe road system by categorising the road network therefore can be realised step-by-step:

Step 1. Establish conditions and starting points not only from a sustainably safe point of view, but take also into account conditions and starting points from other policy areas.
Step 2. Formulate the goals for the residential areas and for the main transport modes.
Step 3. Unite and attune the goals.
Step 4. Apply operational criteria.
Step 5. Adjust goals if necessary.
Step 6. Compare sustainably safe goals with goals in other policy areas.
Step 7. Deliberate and choose.

Such a step-by-step plan can be considered as an iterative process when it shows that not all conditions for one separate step can be fulfilled. In that case it will turn out to be necessary to return to a former step.

By doing so, the categorised road network is achieved. After this image is established, choices can be made and those choices can be brought into practice in plans.

2.6. Processing to sustainable safety

To make sustainable road safety work, the active support of road authorities is required. This means the active support of governmental, provincial and local road authorities. The concept of sustainable road safety cannot simply be handed down as a blueprint from the upper levels of government to the lower levels. The concept of sustainable road safety offers general guidelines and criteria from a basically theoretical perspective. It takes the knowledge and insight of local practitioners and road authorities and translates these guidelines or criteria into a plan that may work at a local level. Good implementation requires a safety and mobility analysis and new creative designs by local road authorities.

The negotiations about the Start-up Programme dealt with a number of subjects. First, there was a discussion about the measures concerning the infrastructure that should be undertaken in the period 1997-2001. The discussion involved issues such as: the uniform categorisation of certain roads within urban areas, the uniform amendment of the right-of-way rule on intersections in urban areas and a speed limit of 60 km/h instead of 80 km/h for low volume access rural roads. Agreement has been reached about a package of physical measures to support the preliminary categorisation: speed-reducing measures, roundabouts, bicycle paths/lanes etc.

Besides the preliminary categorisation of some road types and changes concerning the infrastructure, attention is also paid to a programme of flanking policy measures, e.g. publicity and education measures, the establishment of a sustainable road safety information centre, or - possibly - the development of special audits to evaluate road designs and assist in implementing them.

3. Problem description

3.1. General

Road safety is a quality aspect of road traffic and this aspect has to be balanced with aspects like level of service, access to destinations, environmental impact, costs etc., when it comes to decisions about what projects concerning the infrastructure one should invest in.

In decision-making on projects concerning the road infrastructure, road safety arguments have to be considered as explicitly as possible already in the planning phase.

Projects or programmes often fit within a transport and infrastructure policy or plan. As a rule, general goals and objectives are formulated, so that the extent to which these have been realized can be assessed. We suggest the appropriate instrument for this might be called a Road Safety Impact Assessment (RIA). A Road Safety Impact Assessment could be made on a more strategic level and on an individual project or scheme level. For both levels different tools are developed.

On a strategic level, we suggest to assess safety consequences of changes or redistributions of traffic over a road network due to infrastructure projects (new roads, new lay out of roads) by using a scenario technique. This technique uses the fact that different categories of roads (with different road and traffic characteristics) turn out to have different road safety records dependent on traffic volumes. By modelling road type, values of relevant safety indicators and traffic volumes, road safety impacts of different alternatives can be calculated.

Secondly, on a project level, we suggest to use an audit technique to make as explicit as possible the safety consequences of certain choices in the detailed planning and the design process and to optimize a road design. The primary objective of using an audit technique is to ensure that road safety is optimally incorporated during the design and realisation phase of infrastructure projects.

3.2. Road safety and network design

At best, traffic risks are only considered implicitly and qualitatively in current decision-making on projects concerning the infrastructure. This means that the consequences for road safety are not visible.
This can mean that - unintentionally, but also unwittingly - road safety is not given sufficient consideration in decision-making process. It also hampers rational consideration of alternative solutions.

The aim of the Road Safety Impact Assessment (RIA) method presented in this report is to provide an insight into the content and procedures of such a method, to be used in planning of infrastructure projects in a local or regional context (i.e. to compare different alternative road network routes and road categories). This possibility lies on a strategic level.

It is an instrument to make as explicit as possible the safety consequences of certain choices in the planning and the design process.

In short, we propose to assess safety impacts of changes in road infrastructures on a strategic level: the changes in the distribution of traffic over a certain road network due to changes of that network.

3.3. The town study Maastricht

The reason to choose Maastricht for this study is that the city faces some serious problems, concerning a motorway running through the city. This motorway not only has a through-function, but is also used as distributor road. Besides the mobility and accessibility problem, the situation also implies a major environmental problem of air pollution and noise nuisance. To solve these problems, three alternative plans have been prepared. In this report a methodology is described and tested to assess the road safety of those three plans.

The 'Rijksweg 2' or the A2 motorway partly runs through urban areas of the eastern districts of the city. A section of some 2 kilometres is still a kind of arterial highway and has to be upgraded: the 'A2-Passage Maastricht'. The A2 forms a part of the national network of motorways, as well as of the European network: the A2 is then called E25, running between Amsterdam and Genoa. In the north-south direction, it offers a connection with Belgium. Just north of the city, the junction with another motorway, the A79, running east-west, offers a connection between Belgium and Germany. Besides their national importance, the A2 and A79 are vital too for the regional traffic, as well as for the local traffic of Maastricht itself. As a consequence, there are several junctions between the A2 and A 79 motorways and the regional and local road networks. Both motorways, and in particular the 'A2-Passage' and its junctions, are often heavily congested. They constitute a barrier, blocking local, regional, and national through-traffic. Besides the mobility and accessibility problem, the situation also implies a major environmental problem of air pollution and noise nuisance.

In order to cope with the described problems, three alternative road trajectories and junctions are under study:

1. The traverse option: tunnelling of the ‘A2-Passage Maastricht’
2. The northern bridge option: An additional east-west connection in the northern district of the city, including a new bridge spanning the river Maas (Meuse).
3. The eastern diversion option.

With regard to the national road network, studies of the kind, called 'Tracé/MER-studies', are compulsory by law. They focus on mobility and environmental aspects, the latter also comprising the safety aspects of 'transport in general' (with topics like the effects of accidents with hazardous materials, road safety, rescue management, etc.).

In its most simple form, safety calculations are based on formulae like: 'safety level = road length * traffic volume * safety risk of the road type'. By implication, data of this kind have to be obtainable. In developing such a methodology, models are needed for forecasting changes in mobility and traffic volumes, resulting from modifications of the network. As a rule, models of this kind and the related maps do not cover both the region and the municipality. It is, however, required that the applied models and maps are compatible in a way that the 'before' and 'after' situation can be calculated from an identical starting point. It means that a common network has to be constructed as a reference for calculations. Major problems have occurred in this process, when a number of data sources needed to be combined.

4. Road Safety Impact Assessment (RIA) method

4.1. Introduction

As in any system, design characteristics determine to a large extent the safety characteristics of the road traffic system. Accidents, as they happen, are to a large extent built-in. If, for instance, two lanes rural roads allow and are designed for overtaking at speeds of around 90 km/h, the overtaking accident with differential speeds of around 150-200 km/h is bound to happen. Additionally, some secondary variants may be expected as a result of attempts to avoid the accident at the last moment, e.g. the ‘run off the road accident’ at around 90 km/h. By means of ergonomic road design, improved vehicle performance and driver training one may, to a certain extent, reduce the relative frequency of such accidents. Since this is an especially difficult task, placing high demands on the driver, it is next to impossible to reduce such relative frequency to values approaching zero.

Effective safety control, therefore, should be exercised in stages of planning and design rather than after the fact on the basis of implemented designs that have already been demonstrated to be unsafe.

This is, of course, a rather obvious notion, commonplace in other safety area's. One would not even think, for instance, of designing a nuclear power plant for energy production and subsequently improve on safety on the basis of the implemented design, or even on the basis of actual system failures. Regrettably, such an approach does characterize past and present states of affairs in road transport.

To change this situation one needs a procedure, a method, and content and strategy:
- procedure, either legal or administrative, to be able to effectively introduce safety considerations into the transport decision process;
- method, to be able to assess the safety consequences of transport-decisional alternatives;
- content and strategy, to be able to devise preferable or optimal safety alternatives.

Many plans concerning infrastructure and other projects are characterized by a basic tension between mobility objectives and safety requirements. This tension centres most of the time around driving speeds. Apart from requirements concerning traffic flow and volumes, mobility objectives demand relatively high speeds in order to realize acceptable travel times. At the same time, any increase in speed constitutes a progressive increase in built-up energy, of which the uncontrolled release progressively increases the probability of injury. Wherever traffic participants interact, either with each other or with obstacles in the immediate vicinity, safety essentially requires low (differential) speeds. The basic task is therefore, to design in such a way that, on the one hand, high speeds may be realized for at least part of the road network. On the other hand, interactions, encounters, conflicts etc. should be controlled in such a way that, if negotiated unsuccessfully, the corresponding accident does not result in major injury or death.

A basic rule-of-thumb might be that, in general, the uncontrolled encounter or conflict between unprotected slow-moving traffic and motorized traffic with differential speeds of more than 30 km/h should be avoided, as well as uncontrolled conflicts among motorized traffic with differential speeds of more than 50 km/h. Heavy vehicles pose a special problem that is not only to be solved by speed regulation, but is also, to a substantial degree, dependent on vehicle design.

Generally, the basic strategy should be that for a fairly limited length of roads, given a flow or distributor function, much more severe constraints should be put on the design specifications in order to combine mobility, speed and safety requirements. At the same time, major parts of the network should be redesigned or ‘downgraded' for the relative safety of low driving speeds. The combined process of upgrading and downgrading should thereby, apart from being a design for safety, also uphold the mobility function of the network as a whole.

Before turning to practical questions of how to implement road safety impact assessments, we will first have a more detailed look at scenario methods, specifically developed to assess the safety consequences of redistributions of traffic over a road network.

4.2. **Description of the method**

In general, road accidents are caused by a combination of factors, although relationships between accidents and those factors causing them, or contributing to the causes, are not well understood. The interaction between road, vehicle and the road user obscures the determination of accident causes. In qualitative terms, it is a well-known fact that physical features of a road network, together with the traffic volumes on that network are the main explanatory factors of the mean number of accidents happening on that network.

This enables us to develop a strategy or method to assess road safety impacts of changes of the road network itself and of its use on a macroscopic and mesoscopic level, i.e. on a national or a regional scale. The strategy finds its origin in the different relationships between traffic volumes and the number of road accidents for different types of roads. The method can be described in the following three steps:

1. The first step is to prepare the reference material. Establish a system of categories of road types for a representative national sample. Measure the road length per road type and try to measure or estimate the relevant national road safety indicators per road type. Three safety indicators are of relevance:
   - the number of injury (including fatal) accidents per kilometre of road length,
   - the number of injury accidents per million motor vehicle kilometres,
   - the severity of injuries per injury accident.

   Try to estimate the development in time of the road safety indicators.

2. In step two, the functional boundaries of a region are established. Per road type an inventory of all roads needs to be prepared. When possible, digitalize the road network, using a Geographic Information System. Try to make an estimation of traffic volumes based on traffic counts and, if necessary, on traffic model results. Locate registered accidents per road type (per link and junction), based on accident registration by the police. Design a procedure to compare regional and national road safety indicators (taking in mind the distributions of variables in the indicators).

3. For the same region used in step two, make an estimation of the road network and its traffic volumes for the prognosis year. This is the start of the third step. Make an estimation of the road safety indicators for the same year. Try to establish the road safety effects of changes of the road network and the traffic volumes.

4.3. The Dutch RIA method in more detail

In this section the steps are elaborated in more detail in a Dutch setting (Wegman et al., 1994). Clearly, the method should be adapted to the local situation when it is applied outside the Netherlands.

STEP 1.1. *Categorisation of a representative sample of the national road network*

The following road characteristics are used:
- number of carriageways,
- number of lanes per carriageway,
- number of directions per carriageway,
- existence of parallel facilities.

Furthermore, roads are discriminated according to the type of road user using the same physical space: fast motorized traffic, non-motorized vehicles, agricultural vehicles.

Using these criteria the following eight road categories outside urban areas are used:
- motorways with three lanes or more per carriageway,
- motorways with two lanes per carriageway,
- trunk roads with dual carriageway,
- trunk roads with one carriageway,
- all-purpose road with dual carriageway (no slow traffic),
- all-purpose road with one carriageway (no slow traffic),
- all-purpose road, one carriageway, two lanes,
- all-purpose road, one carriageway, one lane.

Inside urban areas the following categorization of roads is used:
- dual carriageway, two directions, two parallel lanes,
- dual carriageway, two directions, one parallel lane,
- dual carriageway, two directions, no parallel lane,
- one carriageway, two directions, two parallel lanes,
- one carriageway, two directions, one parallel lane,
- one carriageway, two directions, no parallel lane,
- one carriageway, one direction, two parallel lanes,
- one carriageway, one direction, one parallel lane,

- one carriageway, one direction, no parallel lane.

Of course, it is be possible that some of these road types do not occur in certain areas.

STEP 1.2. *Road safety indicator per road category*

Per type of road the following variables are measured to estimate road safety indicators on a national level:
- kilometres of road length,
- number of motorized kilometres travelled,
- number of all registered accidents,
- number of injury accidents,
- number of victims,
- number of deaths.

As road safety indicator are used:
- number of all accidents or injury accidents per kilometre per year per road type,
- number of victims per injury accident,
- number of deaths per 100 casualties.

Dutch road safety indicators per road type, for urban and rural roads are given in *Tables 2a* and *2b* in the *Appendix*.

STEP 1.3. *Relationship between road safety indicators and traffic volumes*

In *Table 1* of the *Appendix* a linear relationship is assumed between the number of (motorized) kilometres travelled and the number of injury accidents per kilometre road length, per road type (Janssen, 1991).

STEP 1.4. *Distribution of road safety indicators*

It is assumed that the number of injury accidents (nominator) follows a so-called Poisson distribution. This means that the number of observed injury accidents are within a confidence interval of twice the square root of the observed number.
The distribution in the denominator (the number of kilometres travelled) is seldom known per road type. Most of the times, these observations are based on measurements of a few hours per year.

STEP 1.5. *Development of national road safety indicators in time*

As can be observed from the national accident statistics, the number of casualties decreases in time. This reduction could be explained partly by the fact that road traffic had become safer over the years (better trained and more experienced road users, better cars, and better design of roads). It can also be explained by the increasing proportion of kilometres travelled on roads with low accident rates (motorways).
Unfortunately, we do not know the contribution of either of these factors. For this reason we propose, in the mean time, not to assume that the road safety indicators will remain constant during the years, but to assume that the reduction in fatality and injury rates in a country (to be estimated with so-called macroscopic accident models) are the same for all road types.

STEP 2.1. *Roads per road category*

An inventory has to be made of all roads in a certain region as a start of this second step, according the road types defined in STEP 1.1. If available, a Geographical Information system is used to support the process to estimate the impact of different scenarios and to visualize these impacts.

STEP 2.2. *Traffic volumes per road category*

An inventory has to be made of the traffic volumes per road type in a self-chosen reference year.

STEP 2.3. *Accidents per road category*

Based on information from a national accident database, all accidents have to be allocated to the road network. A procedure has to be developed how to decide on accidents on junctions of two roads in two different road categories.

STEP 2.4. *Road safety indicator per road category*

One should compare road safety indicators for a certain area based on regional data with ‘mean' national data, a procedure of validation. If the national indicators differ from the regional indicators, one should try to find explanations that account for the differences found. Generally however, it is recommended to use national road safety indicators.

STEP 3.1. *Road network per road category and estimation of traffic volumes*

The third step deals with a year in the future: e.g. 2010 or 2025. For this prognosis year, all the relevant changes of the road network have to be added to the reference network: road length and road type are important. Using traffic forecasting techniques, one has to estimate the traffic volumes per road type.

STEP 3.2. *Estimation of road safety indicators*

Road safety indicators per road type do not remain constant over the years, but are expected to improve. An estimation has to be made on the values of the different indicators for the prognosis year. Estimations of indicators per road type have to correspond with road accident developments on a macroscopic level. Or, the other way around, from macroscopic developments, road safety indicators per road type could be derived.

STEP 3.3. *Estimation of road safety effects*

When assuming values of road safety indicators per road type, and using the outcome of STEP 1.5, including the results of STEP 3.1, one can estimate the effects on road safety.

STEP 3.4. *Assessment of road safety impact*

The results of different scenarios are compared to each other and these results are compared with the road safety objectives as well. Policy conclusions must be drawn and the results might contribute to public debate and to political decisions.

5. Data

In the Maastricht case, the method has been applied slightly differently from the way the method has been described in section 4.3. The differences are caused by the fact that not all data available could be transformed into the required format for the Maastricht area. In the following, the available data, its format, and the implications for the application of the method will be described for each step. As the reference year 1995 has been chosen and the future year for which each of the three plans concerning the infrastructure will be assessed (year of evaluation) has been set to 2010.

5.1. STEP 1: Basic data

For the reference year the categorisation of the network as described in section 4.3 at STEP 1.1 was not available for the Maastricht area. The consequence of not having this road categorisation is that the known national traffic safety indicators couldn’t be used, since these indicators refer to the road categories described in STEP 1.1. This problem has been tackled as follows.

Available was a map with a road categorisation based on the principles of sustainable safety as described in the guidelines of the Netherlands Centre for Research and Contract Standardization in Civil and Traffic Engineering CROW. This categorisation data has been gathered by a consultant in the framework of the Start-up Programme Sustainable Safety 1997-2000. All municipalities within the Province of Limburg were asked to categorise their network. In the guidelines five categories are identified: through-road (1), distributor road in rural area (2), access road in rural area (3), distributor road in urban area (4) and access road in urban area (5). The figures in brackets will be used in the legend of some maps presented in the *Appendix*. For some unknown reasons, the municipalities have not delivered the information in accordance with the guidelines, since they have added other categories. Frequently used categories are ‘other road in urban areas’ and ‘other road in rural areas’.
The consultant has linked the information gathered from the municipalities to a digital map. This map was geographically based on the map of the National Road Database NWB (See section 5.2), but no direct link between both maps was available. A section of the resulting map is shown in *Figure 2* of the *Appendix*.

Having this categorisation data, one needs national safety indicators related to the categories used, that predict the number of injury accidents in the reference year. Since there exists more or less a relationship between the road categories presented in STEP 1.1 and the sustainably safe road categories, one can determine such road safety indicators for the sustainably safe road categories based on the national road safety indicators. The result of this work is given in *Table 2a* in the *Appendix*. In this table for each of the five road categories four indicators are given: Injury accidents per kilometre road length, injury accidents per million vehicle kilometres, casualties per injury accident, and fatalities per 100 casualties.

5.2. STEP 2: Research area in the reference year

This step concerns the verification of the national safety indicators determined in the previous step in the research area, for the reference year. Therefore one needs a safety indicator per road category, the road categories, traffic volume data and accident data for the research network. The safety indicators and road category data are the same as presented in the previous step.

Traffic volume data for the reference year has been calculated by the Department of Public Works of the province Limburg. They used a computer programme called TRIPS. The traffic flow model used in TRIPS has been calibrated with measured traffic flow data. In *Figure 3* of the *Appendix* a TRIPS map is shown concerning the traffic flow in terms of the average daily traffic in the reference year.

Accident data is needed to verify the national safety indicators for the Maastricht case. The verification is performed by comparing the actual number of accidents with the number of accidents predicted by the multiplication of the safety indicators with traffic volume and road length for a reference period of time. Doing this, one needs at least accident data over a period of three years. As reference period the years 1994-1996 have been chosen.

In the Netherlands, accident data is recorded by the police and archived in an electronic data base by the Netherlands Transport Research Centre (AVV), Department for Statistics and Data Management. The accidents are stored in a relational database, containing information on the type of accident, involved vehicles, involved occupants, accident outcomes etc. The location of the accident is linked to a digital map which is known as the National Road Database NWB. This map gives a detailed representation of the whole Dutch road network.
In *Figure 4* in the *Appendix* a section of the NWB map is shown with the accidents over the period 1994-1996.

To perform the required calculations for STEP 2, it is necessary that all data is linked to one digital map only. Unfortunately this is not case. Each data type, categorisation data, traffic volume data, and accident data is linked to its own map. These problems are discussed in chapter 6. Furthermore, a problem occurred with the accident map; this is also treated in more detail in chapter 6.

5.3. STEP 3: Research area in the prognosis year

The categorisation of the network under study is equivalent to the categorisation as shown in section 5.1.
Traffic volume data concerning the three developed plans for Maastricht have been calculated for the year 2010. Also these calculations have been performed by the Department of Public Works of the province Limburg with computer programme TRIPS. A TRIPS map of each plan is shown in the *Appendix*, the traverse option in *Figure 5*, the northern bridge option in *Figure 6* and the eastern diversion option in *Figure 7*.

The 2010 risk indicators have been estimated, in relation to the sustainably safe road categories. The results of the estimation are shown in *Table 2b* in the *Appendix*.

6. Data manipulation

Basically, all information needed for the analysis with the described method is available. Furthermore the data is linked to digital maps. Unfortunately, these maps represent reality in a different way. The method requires that the data is available on the level of road sections. This means that a common network has to be constructed as a reference for calculations. It is decided to use the NWB map as the basis for the development of a common digital map to link the collected data. The reason for this is that the NWB map is the most accurate representation of reality. Therefore the length parameter, necessary for the analysis, can be derived with great accuracy from this map. In the following four sections the development of a common map and the data manipulation is reported separately for each of the four types of data. All the data manipulation and calculations have been performed with SAS.

6.1. Road categorisation

The road category data, collected by a consultant, has been linked to a map which is geographically identical to the NWB map. Unfortunately the consultant did not include a key to link their map directly to the NWB map. Therefore, a SAS programme has been written to link both maps to each other. The programme is based on the assumption that both maps have identical coordinates for each road section. The result of the programme is shown in *Figure 8* in the *Appendix*, showing the road category data linked to the NWB map. Comparison of the maps in *Figure 2* and *Figure 8* shows that the programme worked satisfactorily, since both maps are identical.

6.2. Risk indicators

This information has a one-to-one relationship to the road categorisation data and therefore this data can be linked one-to-one to the map prepared according to the previous section.

6.3. Accident data

A quite unexpected problem has occurred with the accident data. In 1999 the digital map (NWB), to which the accidents are linked, has been updated by the data supplier the Netherlands Transport Research Centre (AVV), Department for Statistics and Data Management. The update consisted of a more accurate representation of the real situation in the digital map. The consequence is that approximately one third of the collected accidents is linked to so-called expired road sections. In *Figure 9* in the *Appendix*, the problem is visualised. The present network is drawn in orange and the expired network in gray. All accidents linked to a present road segment are coloured green, while an accident linked to an expired road segment is coloured red.

The database doesn’t contain historic information in such a sense that an expired road section has a link to the present presentation of that road section. The present road sections are used to build the common map for the analysis and therefore a computer algorithm is required to link the expired road section to present road sections. To perform this linking manually is not regarded as an option, due to the quantity of accidents concerned and the complexity of the matter. The latter can be seen in *Figure 10* of the *Appendix* where a small detail of the map of *Figure 9* is enlarged. To link the accidents related to an expired road section to an actual road section, one needs to use both data from the accident file as geographic data.

The matter is found to be rather complicated, and as yet the algorithm has not been completed. For the analysis, the consequence is that it is impossible to correct the national risk indicators for the year 1995 for the local situation. Therefore, the uncorrected national safety indicators are used instead.

6.4. **Traffic volume data**

The traffic volume data is linked to TRIPS maps, that are geographically completely different from the NWB map. The only way to link the volume data to the NWB map was to manually link the TRIP road segments to NWB road sections. To link all TRIPS segments would be too much work and therefore it was decided to reduce the number of links which had to be linked. In the first place all TRIPS segments lying in Belgium and Germany were dropped. Furthermore, the TRIPS maps covered a much larger area then the Maastricht area. To reduce the number of TRIPS segments to be linked to the NWB map, a research area was defined, including all major roads which are connected to the ‘A2-Passage Maastricht’.

Since there are four TRIPS maps, one for the reference year and one for each of the three variants, linking with the NWB map has to be done also four times. However, the four TRIPS maps are identical to a large extent. Only those parts where new roads are planned are different. To reduce the amount of work, a map was constructed, containing all TRIPS segments which are geographically identical in the four TRIPS maps. This map, named ‘core’ is shown in *Figure 11* in the *Appendix* with the NWB map in the background. The segments which are not presented by the core map are shown in *Figure 12-15* in the *Appendix*, covering the remaining part of the 1995 map, the traverse map, the northern bridge map and the eastern diversion map respectively.

The last way in which the number of data to link manually were reduced, concerns the core map. A TRIPS segment is only included in the research network if the traffic volume in this segment deviates in one of the 2010 variants more than 5% from the mean traffic volume of the three 2010 variants of this segment. The segments of which the traffic volume differs less than 5% with the mean value, do not significantly contribute to the difference in safety calculated for the three variants. The segments dropped in this way are coloured orange in the map presented in *Figure 11* in the *Appendix*.

After preparing the maps showed in *Figures 11-15* of the *Appendix*, the actual linking of the TRIPS segments could be performed. To do this, a SAS programme was written, creating a user interface for doing the job. Clearly, segments that represent road trajectories which don’t exist in the 1995 situation cannot be linked to NWB segments. Those TRIPS segments have been copied to the maps containing the NWB segments linked to

TRIPS segments. Therefore, the resulting maps, one for the reference year and three for the prognosis year used for the analysis, are built up partly by NWB segments linked to TRIPS segments, and by TRIPS segments which could not be linked to a NWB segment. The road categories have been added manually to those TRIPS segments which could not be linked to a NWB segment. The resulting maps are shown in *Figures 16-19* in the *Appendix*. The codes used in the legends of these figures are described in *Table 3* in the *Appendix*.

For each segment in the maps of *Figures 16-19* we now have the following information available:
- road category (and therefore also the traffic safety indicator),
- segment length,
- traffic volume.

Except for the accident data, all required data for applying the described method is available. The analysis of the data will be discussed in the next chapter.

7. Analysis

As stated in the previous chapter, it was found impossible to correct the national safety indicators for regional effects, since the accident data couldn't be manipulated into the necessary format. Hence, STEP 2 of the described method cannot be applied. Therefore, the national safety indicators will be used for the whole analysis.

Having the data as described in the previous chapter, one can calculate the estimated number of injury accidents in the reference year and in the prognosis year for the three infrastructure plans as follows.

In each of the four cases the number of injury accidents is calculated for each segment in the map with the following formula:

$$nr\_of\_acc = veh\_kilo * s\_ind \quad (1)$$

with:

nr_of_acc : number of injury accidents [-]
veh_kilo: vehicle kilometres (=traffic volume* length of segment) [km]
s_ind: safety indicator [number of injury accidents per million vehicle kilometres]

In *Table 7.1*, a summary statistic is given of the calculated number of injury accidents, for each road category and for the total research network.

Road category	1995	'Traverse' in 2010		'Bridge' in 2010		'East' in 2010	
	Number	Number	%	Number	%	Number	%
1	35	33	94	32	92	30	87
2	30	16	53	16	53	16	53
3	14	15	111	14	105	12	88
4	175	77	44	87	50	79	45
5	52	38	72	37	70	35	68
Total	306	179	58	186	61	173	57

Table 7.1. *Number of injury accidents for the three variants, grouped by road category, in absolute numbers and as a percentage of the number of injury accidents in the reference year 1995.*

As can be seen from *Table 7.1*, the number of injury accidents decreases for the 2010 variants, compared to the number of injury accidents in the reference year. In the traverse variant the number of injury accidents counts 58% of the number of injury accidents in the reference year In the northern bridge variant this percentage equals 61% and for the eastern diversion variant 57%. The calculated number of injury accidents of the three prognosis year variants doesn't differ significantly, using the rule-of-thumb that the difference should be larger then $2\sqrt{n}$ where n is the number of observations.

Equation 1 shows that the accident reductions can be explained by the two variables by which the number of injury accidents has been calculated. These are the vehicle kilometres and the applied safety indicator.

Starting with the latter, it is obvious that the number of injury accidents for the 2010 variants decreases due to the lower values of the national safety indicators of the prognosis year compared to the reference year. In *Table 7.2* the safety indicators for each road category are obtained from the *Tables 2a and 2b* in the *Appendix*. The indicators for the prognosis year have been expressed in *Table 7.2* as a percentage of the value of the indicator in the reference year. For example the safety indicator for through-roads in 2010 counts only 68% of the indicator in the reference year.

Road category	1995	2010	
	Safety indicator	Safety indicator	%
1	0.062	0.042	68
2	0.196	0.086	44
3	0.443	0.313	71
4	0.966	0.390	40
5	0.930	0.549	59

Table 7.2. *National safety indicators (injury accidents per million vehicle kilometres) per road category for the reference year and the prognosis year. The prognosis year indicators are also presented as a percentage of the reference indicators.*

Comparison of the last column of *Table 7.2* with the % columns in *Table 7.1* shows that the reduction of the number of injury accidents is lower than when the safety indicator would be the only contributor of the reduction. For example, for the eastern diversion variant the number of injury accidents on through-roads (category 1) is estimated as 87% of the number of injury accidents in the reference year on through-roads. The 2010 safety indicator however is only 68% of the value in the reference year. The difference is caused by the increase in vehicle kilometres driven on through-roads. This is shown in *Table 7.3*.

Road category	1995	'Traverse' in 2010		'Bridge' in 2010		'East' in 2010	
	Million vehicle kilometres	Million vehicle kilometres	%	Million vehicle kilometres	%	Million vehicle kilometres	%
1	563	778	138	762	135	725	129
2	155	189	122	189	121	186	120
3	31	48	157	46	149	38	124
4	181	197	109	223	123	203	112
5	56	69	123	67	119	65	115
Total	986	1281	130	1286	130	1217	123

Table 7.3. *Vehicle kilometres (in millions) for the three variants, grouped by road category, in absolute numbers and as a percentage of the number of vehicle kilometres in the reference year 1995.*

On through-roads, the growth in vehicle kilometres for the eastern diversion variant is 29% of the vehicle kilometres on through-roads in 1995.
The overall reduction of 13% (=100%-87%) in the number of injury accidents (see *Table 7.1*) was calculated using the percentages in *Equation 1*: 87% equals (129%*68%)/100.
These percentages in relation to the reference year are given in *Table 7.4* for all road categories and variants.

Road category	Safety indicator	Traverse		Bridge		East	
		Vehicle kilometres	Injury accidents	Vehicle kilometres	Injury accidents	Vehicle kilometres	Injury accidents
1	68	138	94	135	92	129	87
2	44	122	53	121	53	120	53
3	71	157	111	149	105	124	88
4	40	109	44	123	50	112	45
5	59	123	72	119	70	115	68
Total		130	58	130	61	123	57

Table 7.4. *Safety indicators, vehicle kilometres, and injury accidents in 2010 for all road categories and variants, given as percentages of the value of the reference year 1995.*

The difference in the number of injury accidents per road category between the three 2010 variants is caused by the differences in vehicle kilometres only, since the safety indicators used for all three variants are the same. The eastern diversion variant scores best since drivers are apparently able to choose shorter routes to reach their destinations. The result is that the traffic volume produced is lower for the eastern diversion variant then is case in the other two variants. Furthermore, in the traverse (157%) and northern bridge(149%) variant relatively more traffic is routed on rural distributor roads than in the eastern diversion variant (124%). This road category has a relatively high safety indicator (0.313).

8. Results of case study

The method described in Chapter 4 has been applied to the Maastricht case. Three infrastructure variants have been analysed on their traffic safety consequences by estimating the number of injury accidents in the year 2010. The three variants were named after the most important intervention; the traverse variant, the northern bridge variant, and the eastern diversion variant. Not only the effects of the measures concerning infrastructures were taken into account, but also the predicted accident reduction, due to the introduction of the principles of a sustainably safe traffic system, was included. The effects of the sustainably safe traffic were accounted for by the introduction of different safety indicators for the reference year and the prognosis year.

From a traffic safety point of view one cannot give a preference for one of the three variants based on the results. The differences in the predicted number of injury accidents in 2010 for the three variants are too small. The predicted number of injury accidents in 2010 is 179 for the traverse variant, 186 for the northern bridge variant, and 173 for the eastern diversion variant. It is possible that the differences would have been larger when all TRIPS segments would have been included in the analysis. During the data manipulation, a number of TRIPS segments have been excluded, to reduce the amount of work necessary to link the TRIPS map to the NWB map.

When the results are interpreted from a broader point of view than traffic safety alone, there might be a preference for the eastern diversion variant, since this variant produces the lowest vehicle kilometres of the three variants.

9. Conclusions and recommendations

The road safety assessment method is very useful for policy makers to identify traffic safety consequences of local infrastructure planning. Traffic safety should be one of the parameters included in the evaluation of plans concerning the infrastructure. In the Netherlands, a traffic safety analysis is currently not required by law, contrary to environmental issues which have to be analysed in a so-called MER procedure.

The method presented in this report is particularly suited for comparing the traffic safety effects of a number of alternatives to solve one particular traffic problem. In a case in which only one plan has to be evaluated, one can use a variant in the prognosis year in which no changes of the infrastructure are applied to determine the effects of the suggested measures.

The setup of the method is relatively simple and probably applicable in other countries as well. However, application of the method in the Dutch situation is found to be rather complicated, mainly because the required data was not available in the correct format. This is caused by the fact that the data initially was compiled for other purposes than to be used in the suggested method.

In the Netherlands, the determination of national safety indicators is not the problem, since the SWOV has been doing this already for some years. However, it might be a problem in other countries, in which this type of research has not been performed. The determination of the safety indicators by applying the method will then give similar data problems as described in this report for regional safety indicators in the Maastricht case: each data type was linked to its own digital map, whereas application of the method requires that all data is linked to one digital map only.

When the described method will be used more frequently, it is necessary to adapt the data format of data obtained from different sources to the requirements of the method. This means that all data should be linked to one digital map on road segment level. For the Dutch situation this means that the NWB map should be used as a basis for the data gathering. Clearly, a general solution has to be found for the problem of present and expired road sections, which is a built-in lacuna in the data model behind the NWB map.

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Appendix Tables and maps

Road type	Kilometres of road	Motor vehicles per day	Motor vehicle kilometres (x10^6)
MW>41	242	81252	7177
MW 41	1761	31451	20216
MR 2c	197	16957	1220
MR 1c	2108	5877	4522
AR 2c	252	18314	1683
AR 1c	6537	4927	11756
LR 2l	11719	1396	5970
LR 1l	31702	314	3631
AU	11519	4471	18798
LU	32142	649	7619
WE	1339	318	155
Total	99519	2278	82748

Table 1a. *Dutch road network 1986.*

Road type	Injury accidents	Casualties	Fatalities
MW>4l	476	698	30
MW 4l	1500	2157	111
MR 2c	182	282	17
MR 1c	475	653	79
AR 2c	455	550	40
AR 1c	3540	4826	239
LR 2l	3055	3802	224
LR 1l	3102	3880	217
AU	25010	27207	477
LU	5754	7517	94
W	32	37	0
Total	43581	51610	1529

Table 1b. *Dutch accident data 1986.*

Road type	Injury accidents per		Casualties per injury accident	Fatalities per 100 casualties
	100 km of road	motor vehicle kms ($x10^9$)		
MW>4l	197	66	1,47	4.31
MW 4l	85	74	1,44	5.13
MR 2c	93	150	1,55	5.94
MR 1c	23	105	1,38	12.12
AR 2c	181	270	1,21	7.22
AR 1c	54	301	1,36	4.96
LR 2l	26	512	1,24	5.90
LR 1l	10	854	1,25	5.60
AU	217	1330	1,09	1.75
LU	18	755	1,31	1.26
WE	2	205	1,16	1.26
Total	44	527	1,18	2.96

Table 1c. *Dutch road safety indicators per road type, for urban and rural roads (SWOV)*.

Explanation of abbreviations used in *Tables 1a-1c*:

MW>4l: motorway; more than four lanes
MW 4l: four-lane motorway
MR 2c: dual carriageway trunk road
MR 1c: single carriageway trunk road
AR 2c: dual carriageway rural arterial
AR 1c: single carriageway rural arterial
LR 2l: two-lane rural local road
LR 1l: one-lane rural local road
AU: urban arterial
LU: urban local road
WE: `woonerf' and 30 km/h-zone

Area	Road category	Injury accidents per km road length	Injury accidents per million vehicle kms	Casualties per injury accident	Fatalities per 100 casualties
Rural	Through-road	72	62	147	385
	Distributor	47	196	139	382
	Access road	13	443	129	394
Urban	Distributor	160	966	112	121
	Access road	30	930	120	107

Table 2a. *Safety indicators in the Netherlands for 1995, SWOV*.

Area	Road category	Injury accidents per km road length	Injury accidents per million vehicle kms	Casualties per injury accident	Fatalities per 100 casualties
Rural	Through-road	50	42	148	340
	Distributor	21	86	138	329
	Access road	8	313	129	355
Urban	Distributor	113	390	112	109
	Access road	6	549	129	72

Table 2b. *Safety indicators in the Netherlands for 2010, SWOV*.

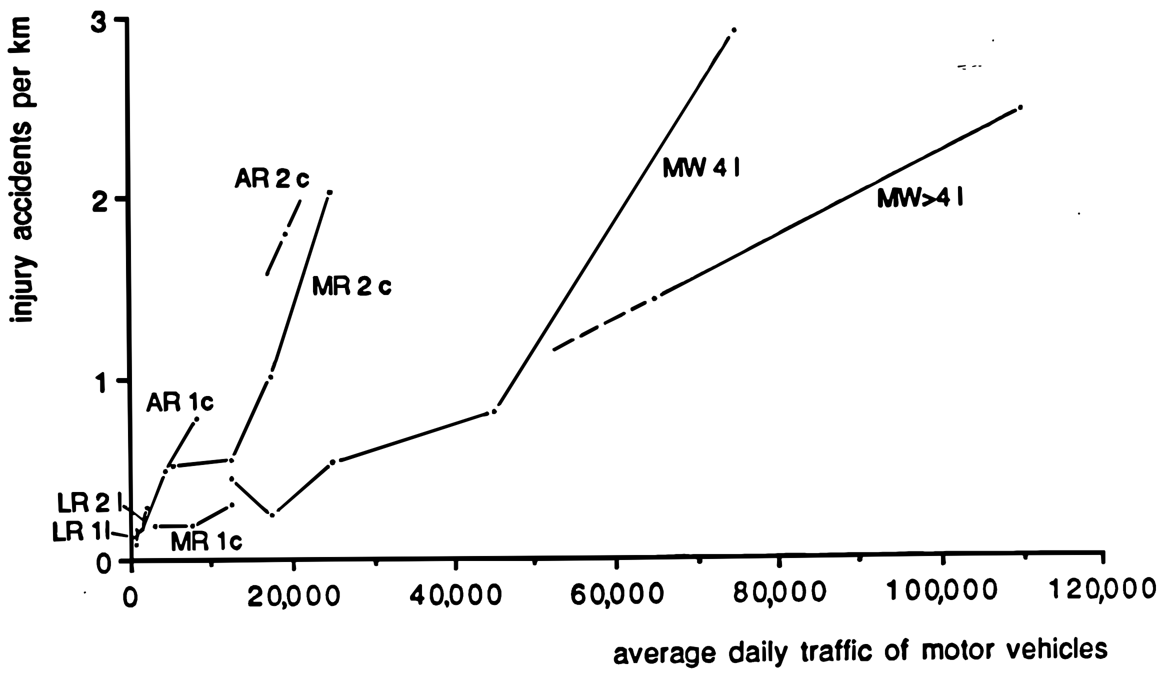

Figure 1. *Indicators on rural roads in the Netherlands, 1986 (SWOV).*

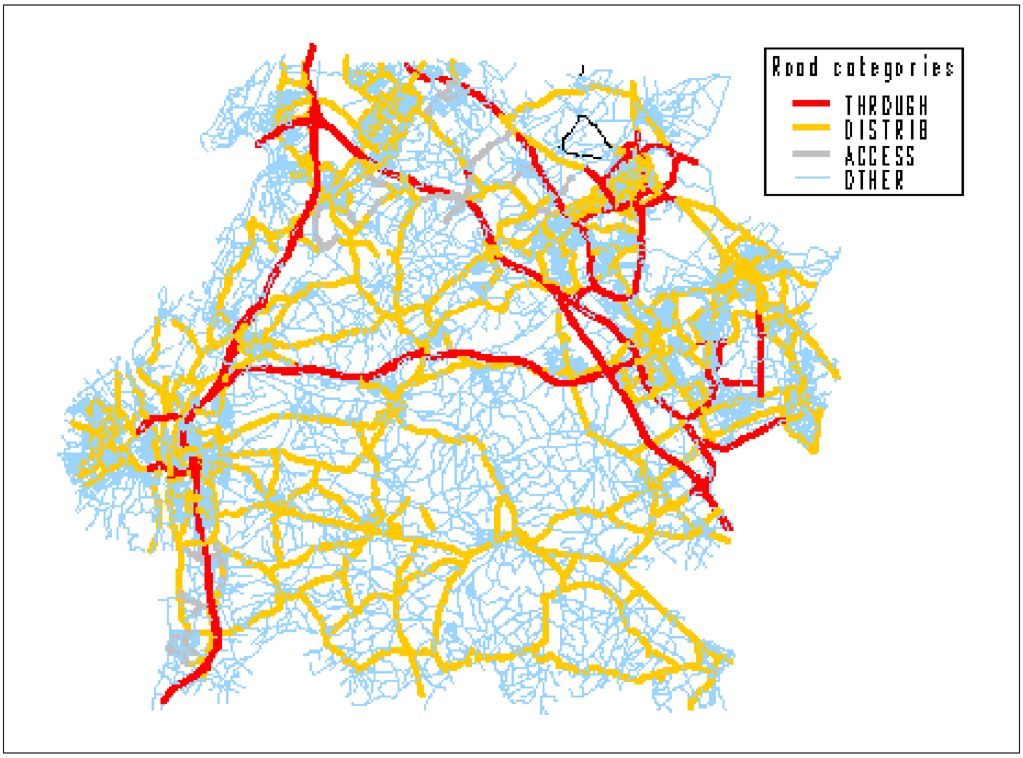

Figure 2. *Map of collected road categories*.

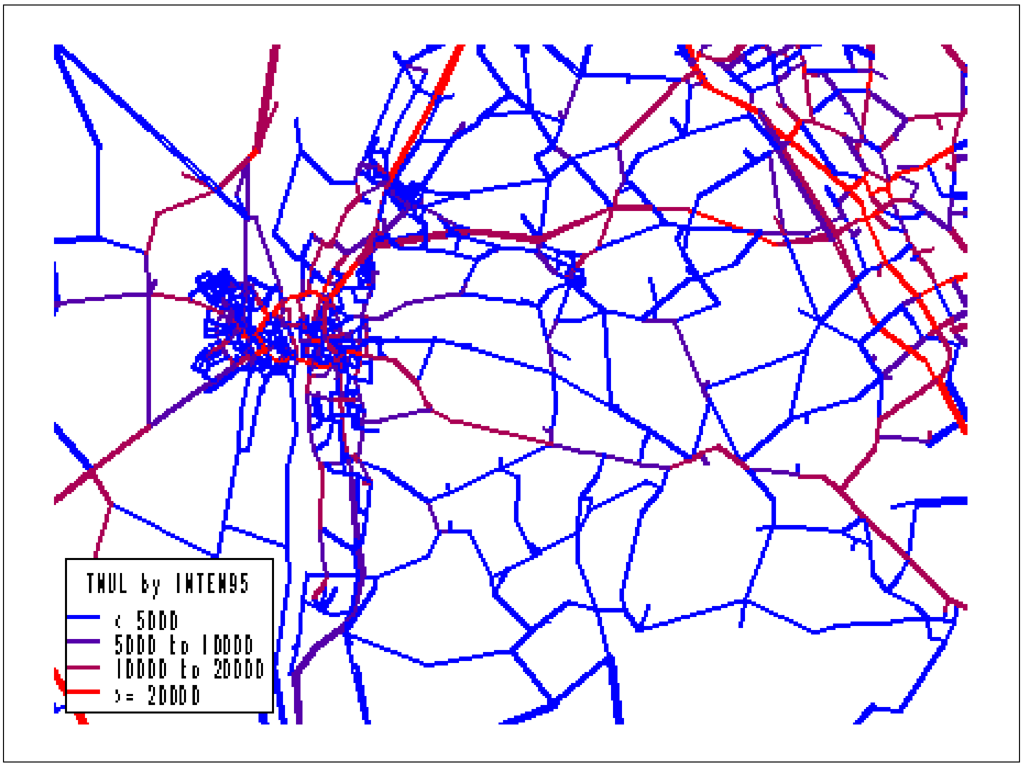

Figure 3. *TRIPS map with the average daily traffic flow in the reference year.*

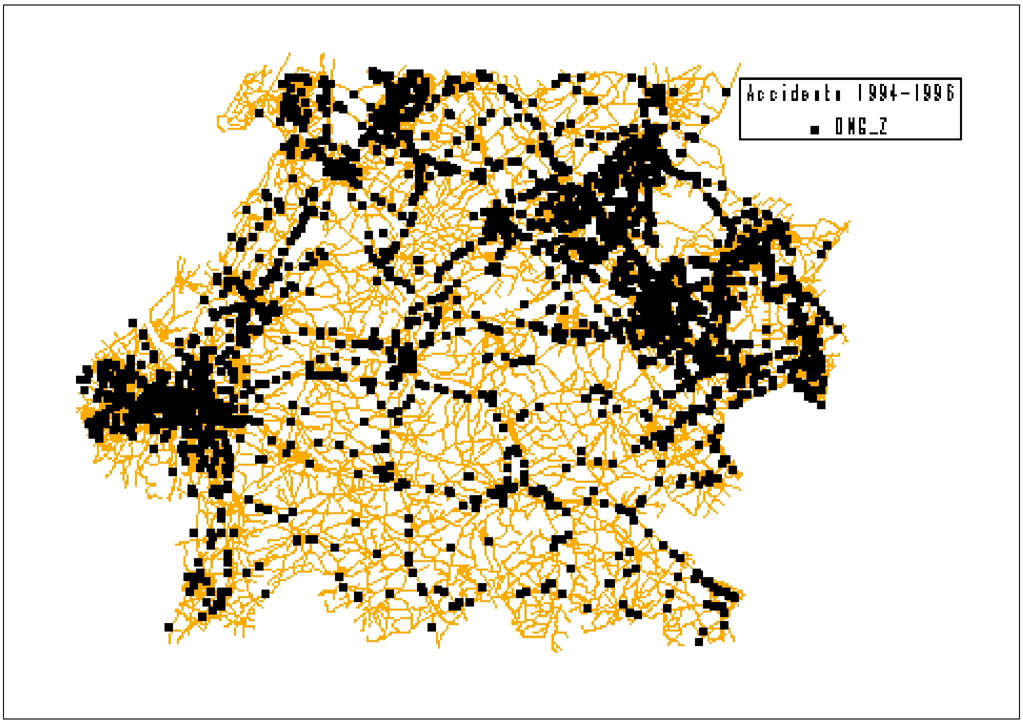

Figure 4. *Section of the NWB map with accidents over the period 1994-1996.*

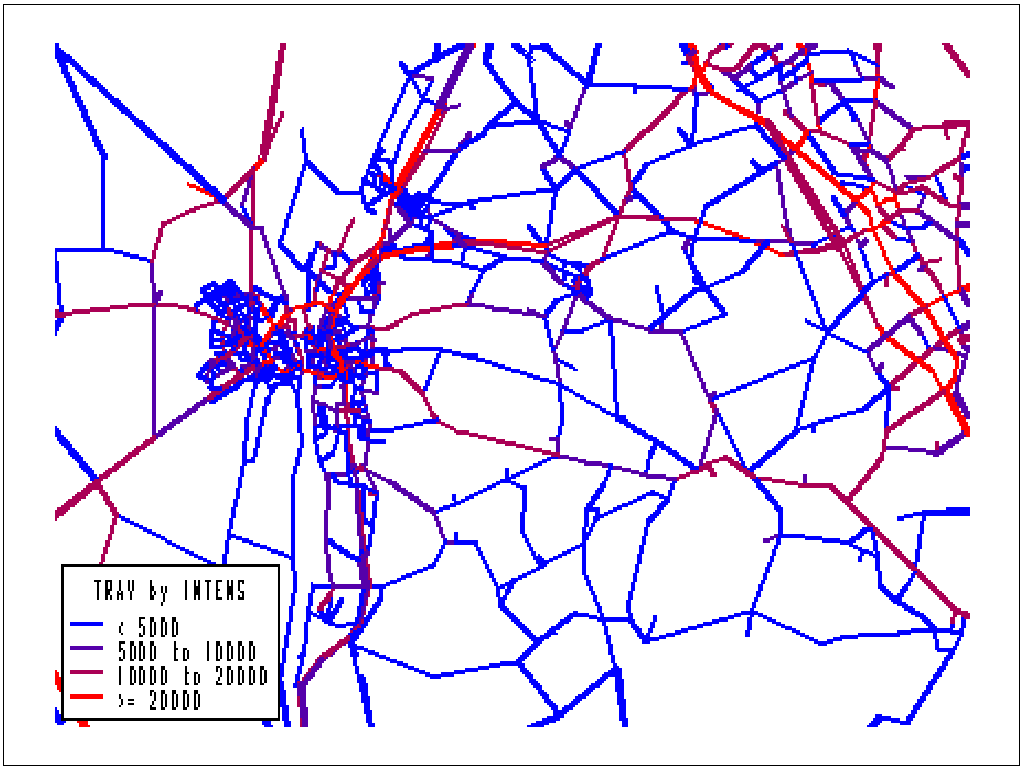

Figure 5. *TRIPS map with the daily traffic flow in the year 2010 for the traverse variant.*

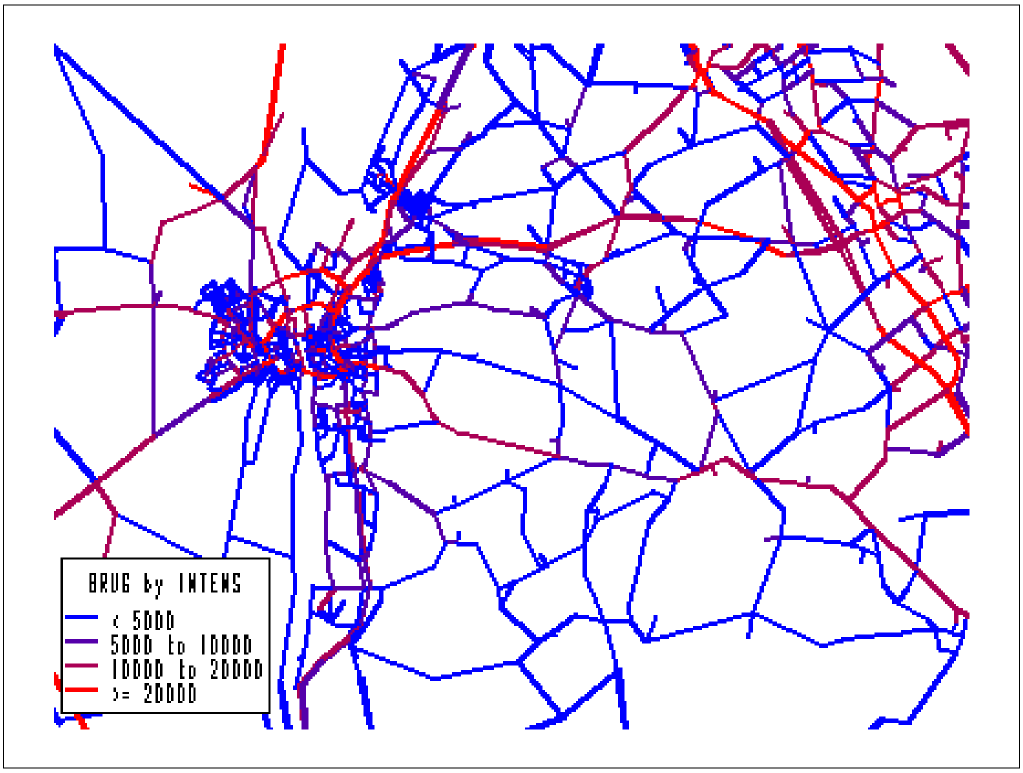

Figure 6. *TRIPS map with the daily traffic flow in the year 2010 for the northern bridge variant.*

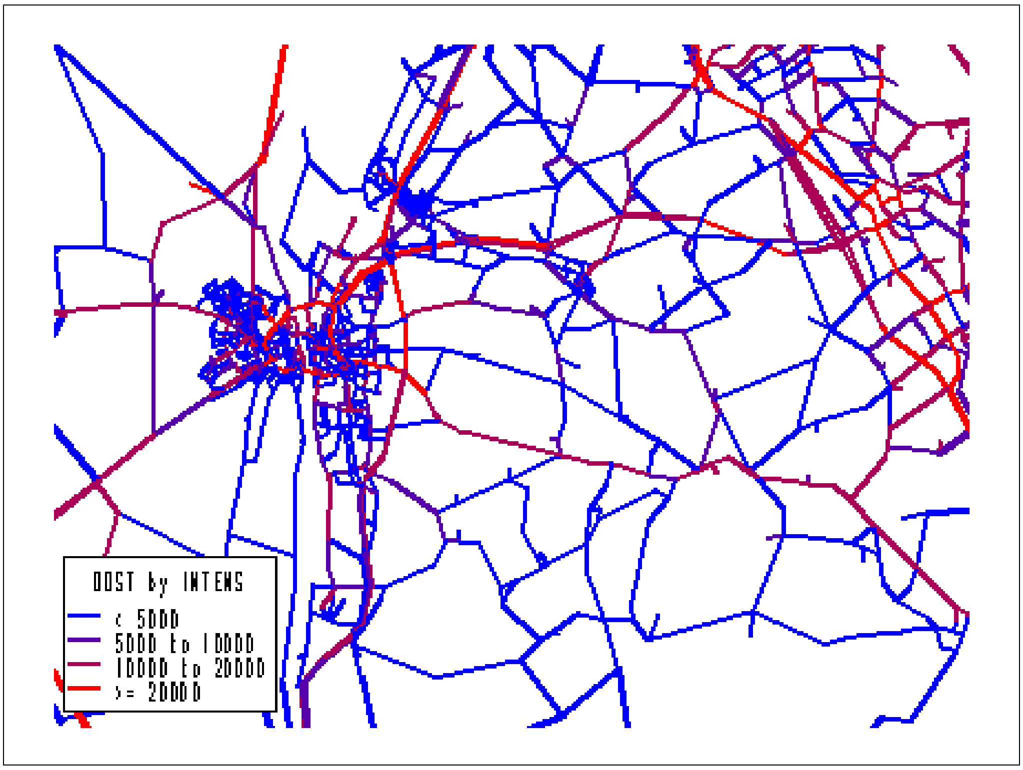

Figure 7. *TRIPS map with the daily traffic flow in the year 2010 for the eastern diversion variant.*

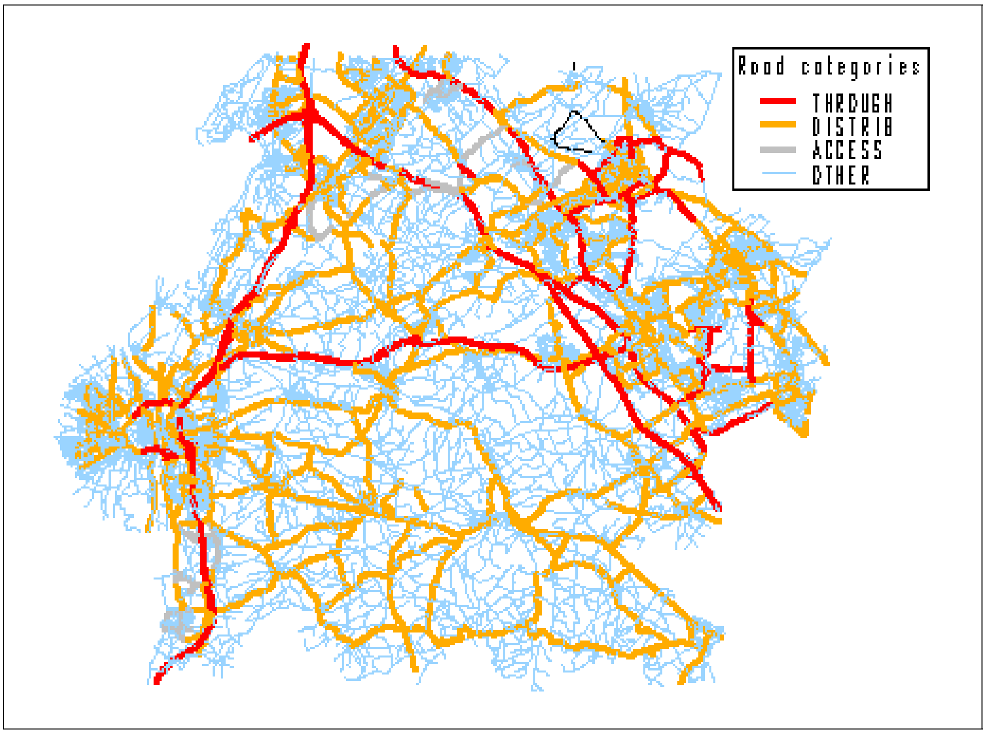

Figure 8. *Road categories linked to the NWB map.*

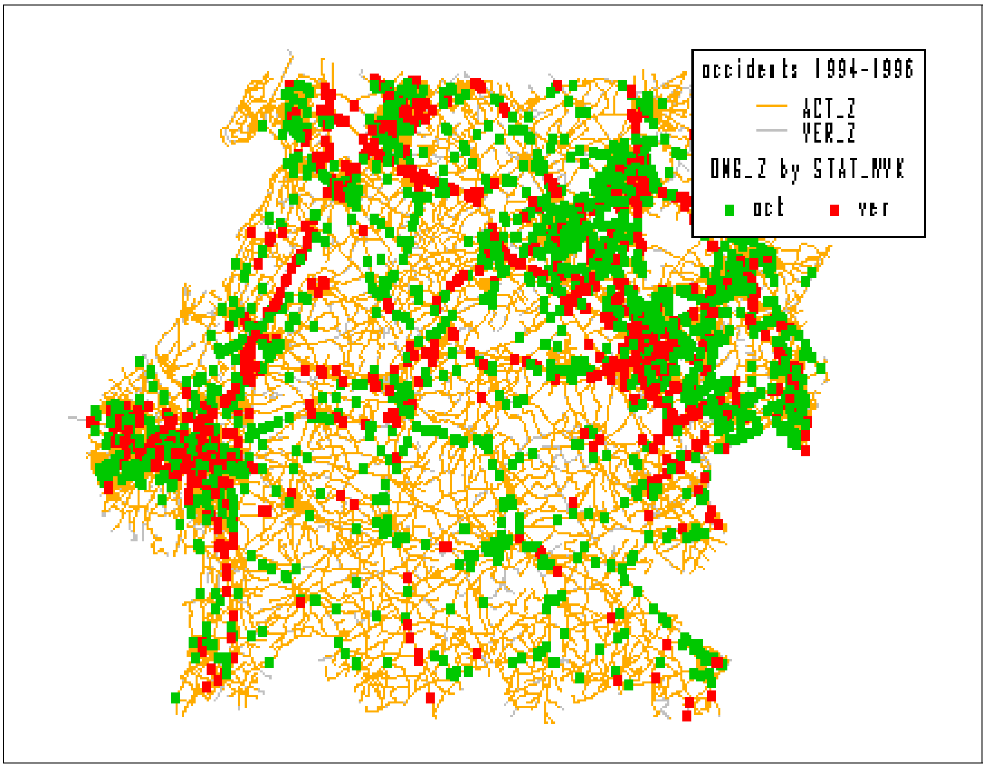

Figure 9. *NWB map with accidents over the period 1994-1996. The present NWB network is drawn in orange, the expired road sections are drawn in grey. Accidents linked to the present road sections are coloured green, accidents linked to expired road section are coloured red*.

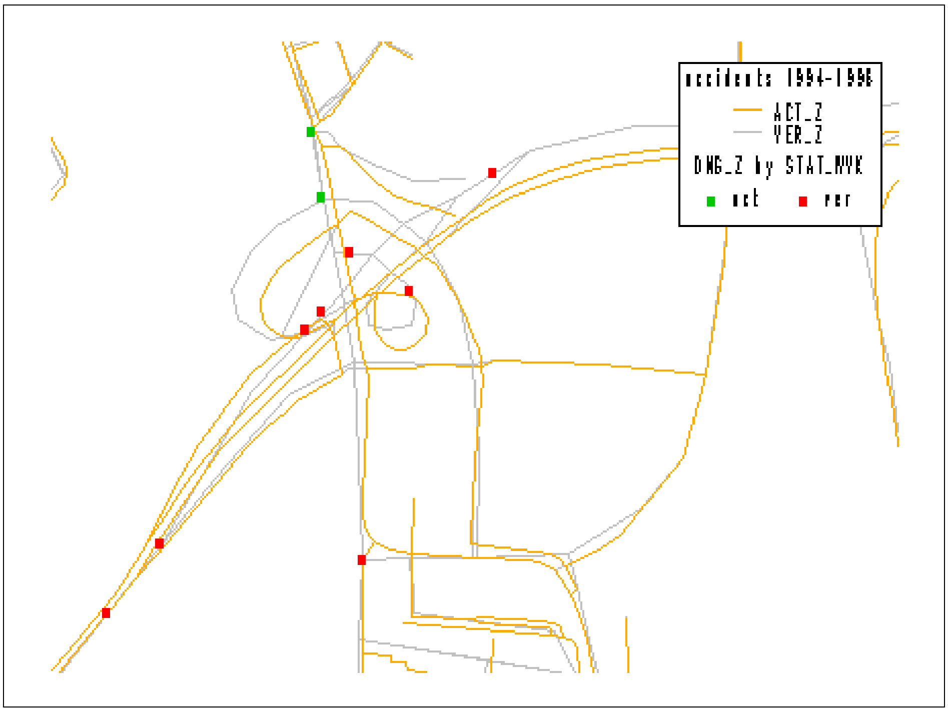

Figure 10. *Detail of NWB map with accidents over the period 1994-1996. The present NWB network is drawn in orange, the expired road sections are drawn in grey. Accidents linked to the present road sections are coloured green, accidents linked to expired road section are coloured red.*

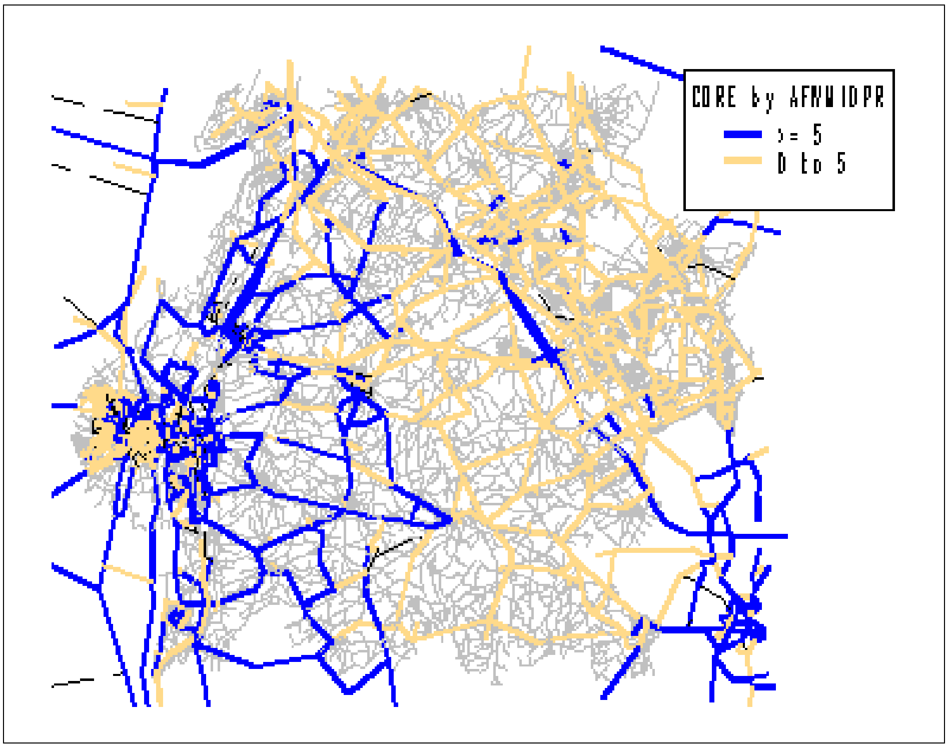

Figure 11. *Core map, geographically identical segments of the four TRIPS maps with NWB map in the background. Blue and orange lines represent the road segments of which the estimated traffic volume in one of the three variants deviates more than 5% from the average traffic volume of this segment according to the three variants.*

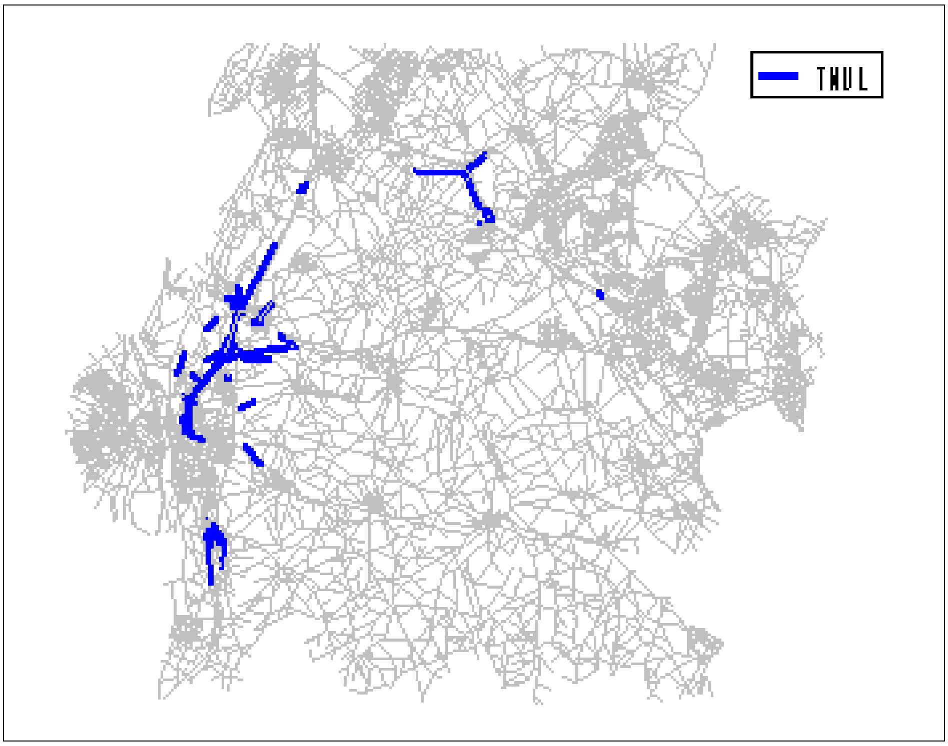

Figure 12. *TRIPS segments of reference year not contained by core map.*

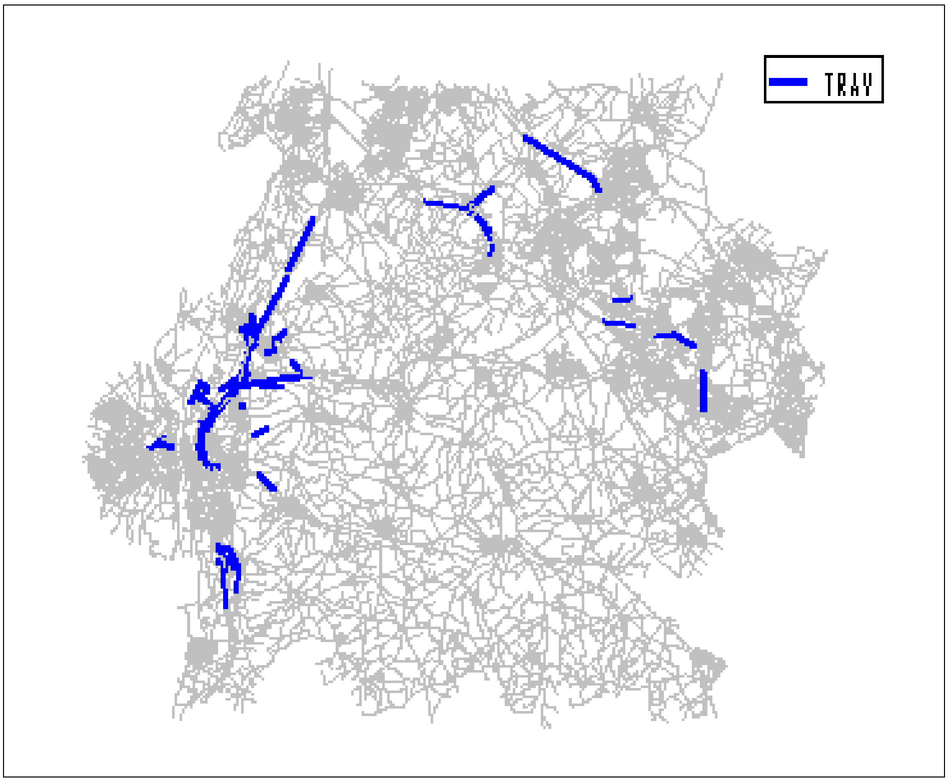

Figure 13. *TRIPS segments of traverse variant not contained by core map.*

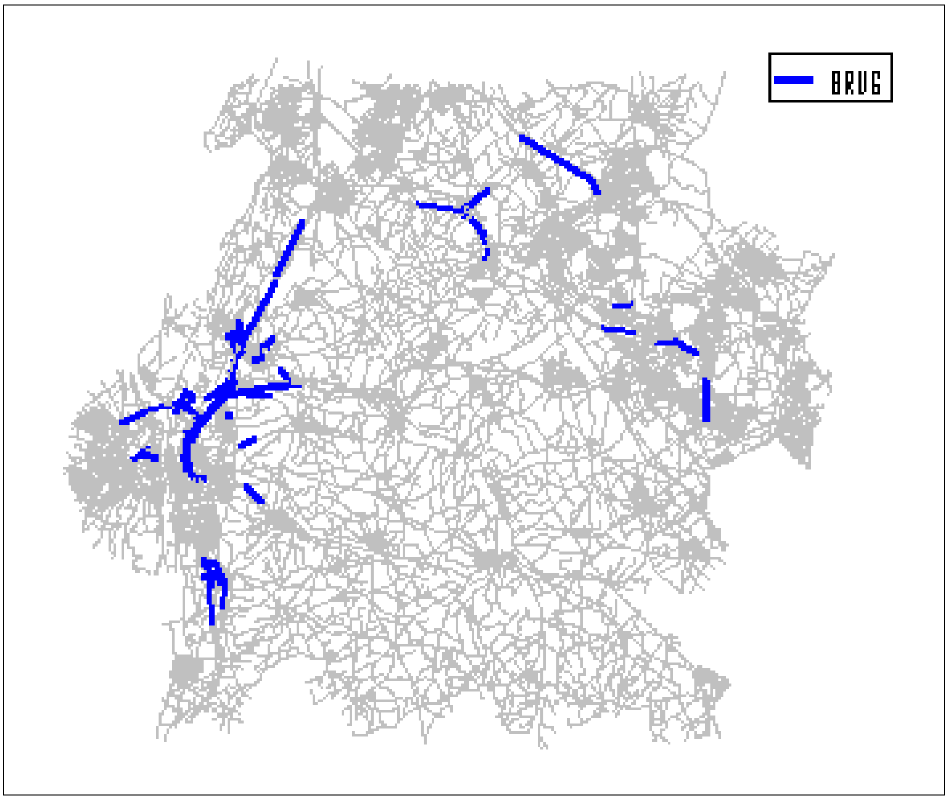

Figure 14. *TRIPS segments of northern bridge variant not contained by core map.*

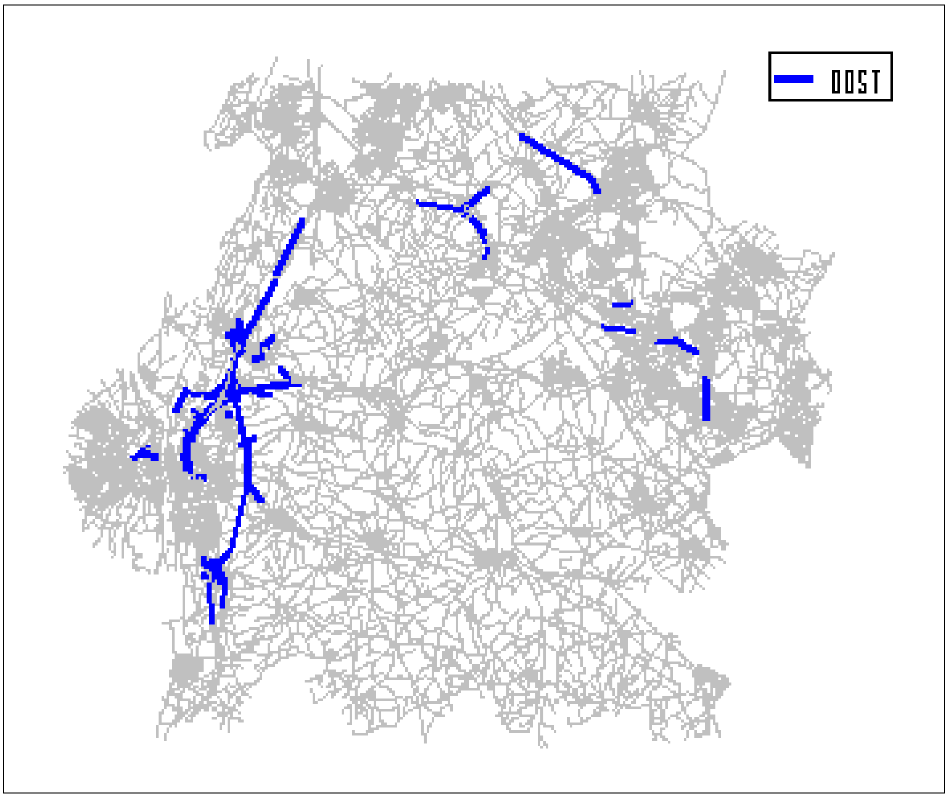

Figure 15. *TRIPS segments of eastern diversion variant not contained by core map.*

Code	Road category
1	through-road
2	rural distributor road
3	rural access road
4	urban distributor road
5	urban access road

Table 3. *Codes used in legends of the maps in Figures 16-19.*

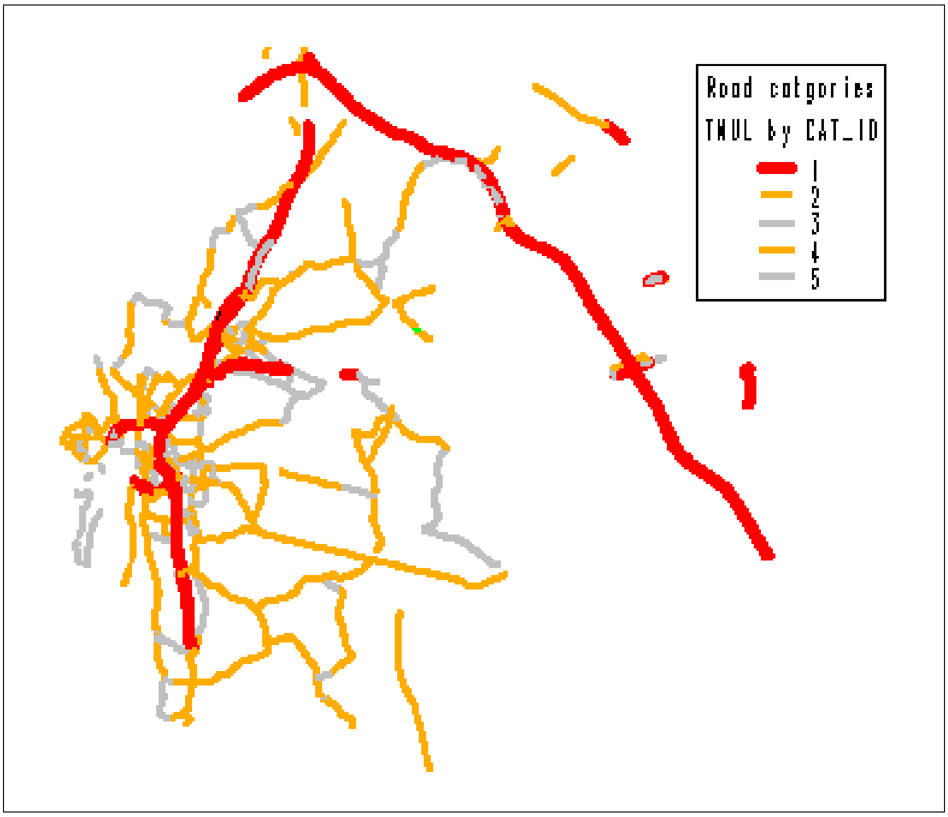

Figure 16. *Road categories for the analysis in the reference year.*

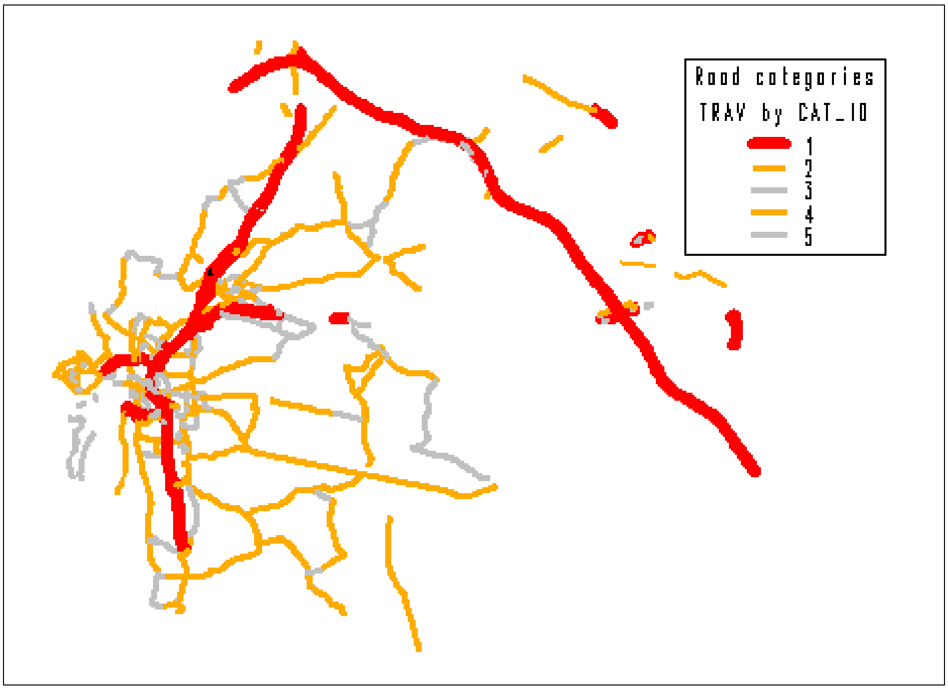

Figure 17. *Road categories for the analysis in the prognosis year of the traverse variant*.

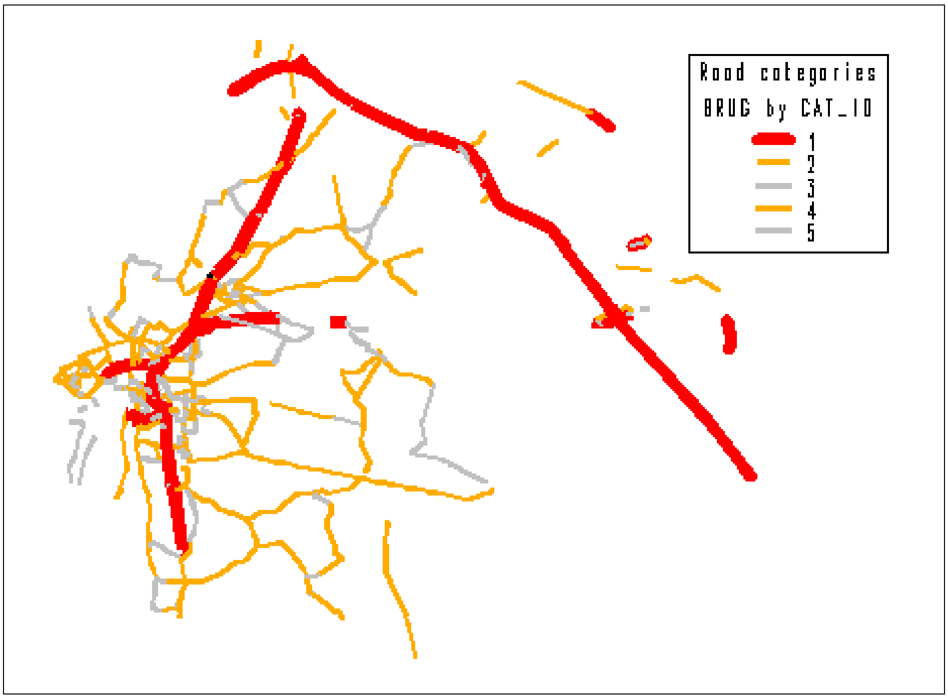

Figure 18. *Road categories for the analysis in the prognosis year of the northern bridge variant.*

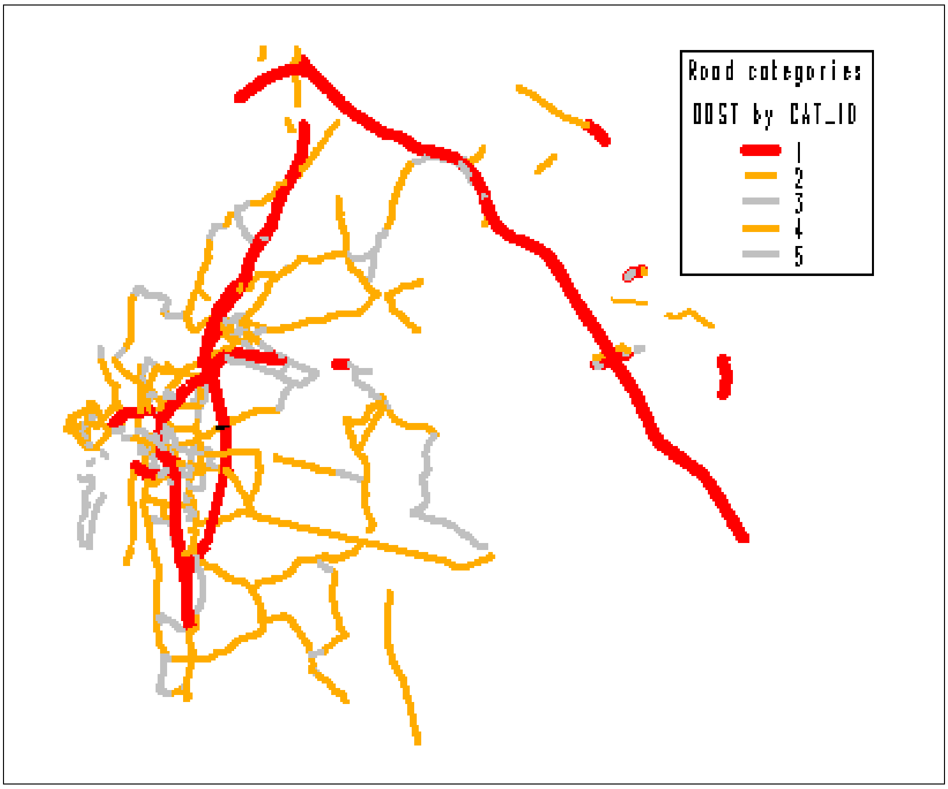

Figure 19. *Road categories for the analysis in the prognosis year of the eastern diversion variant.*