

METIS

A Smart, Safe & Green Navigation System

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Management Summary

Metis is a navigation system which is not only based on shortest or quickest routes, but also incorporates air quality, safety and noise pollution. Within some time constraints for the routes Metis advises the driver about the cleanest, the safest or most silence route. In the future it will be possible to combine these measures.

Many different stakeholders are involved in the Metis project. The key stakeholders are the Metis developers and the Dutch government. The Metis developers are interested in making a profitable product. Therefore they have to design a desired product. The Dutch government is interested in clean air, safe roads and less noise. These interests are similar to the aims of Metis. Therefore, the Dutch government could be willing to support Metis.

The Metis developers are interested in making a desired product. Are people interested in a device like Metis, and are they willing to pay extra in compare to a normal navigation system are important questions for the Metis developers. Therefore a user needs assessment by an online questionnaire is performed.

The results are mainly positive for the Metis producers. More than 70% of the people is interested in a navigation system which has some kind of externality implemented. Almost 80% of these people are especially interested in the traffic safety. There seems to be a broad market for navigation systems based on safety and fastest routes. On other nice result for the Metis developers is that people want to pay extra for a navigation system like Metis (with externalities implemented) in compare to a normal navigation system. On average people are willing to pay € 23 extra on average for an equipped system in compare to a normal navigation system. However, when one would only look at people willing to pay at all, the average amount is €43.

The Dutch government is interested in a system which limits the external effects of driving, so the impact on society is as small as possible. However, the mobility of the country is also at stake in this case. If drivers are rerouted because of the external effects, this should not lead to a major decrease of mobility. Therefore, the main assessment objectives in this case are the impact assessment and socio-economic evaluation.

Unfortunately the results of the impact assessment were not very logical and desired results. Some adaptations have to be made to make Metis effective product. When optimising for air quality, the total air pollution increases. This bias seems to be caused by an error in the methodology. Metis should further investigate on how to calculate the air quality. Although there is an promising result, because the peak values disappear. When looking at total values, the impact on noise pollution is non existent. This can be explained by the fact that the indicator for noise is highly dependent on the composition of the traffic and not so much on the road characteristics. In order to calculate noise pollution, more data is needed and a more complex model should be used. In the case of safety, scoring proofed to be difficult. An attempt has been made to calculate an average safety level, but this didn't result in the desired increase of safety levels. The method does reroute the traffic over the safest route, so their should be an increase is the total safety.

In a real world scenario a decrease of noise pollution is, based on the used definition, not yet feasible for Metis. Air quality could be increased on a local scale, as could the safety of the system. Based on the link loads, peaks in air pollution could be decreased with 5%. However, this does also leads to an increase of the less polluted roads which is higher because the rerouting is always a longer route.

Safety levels can increase with the use of Metis, because people will more actively comply to "Duurzaam veilig" guidelines for traffic safety. However, when rerouting to prevent one danger, the total exposure does increase.

Metis could also experience some risks in its deployment. One of the major risks of Metis is limiting data availability. The operations of Metis are dependent on the available data. Data that is available could also have a poor quality, that is a second risk. Mitigation strategies to overcome these risks consist of: cooperation with traffic information companies and building robust algorithms for the determination of the Metis routes. A third risk is that people do not want to drive on the cleanest, safest or most silent route because it will take longer. The existence of this risk is investigated in the user needs assessment. By advertising and campaigns this risk can be avoided. A fourth risk is the current economic situation, in a bad economic situation an environmental product will sell less. The government is the most important stakeholder which has an influence in this risk. The Dutch government could try to avoid this risk.

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1. Introduction

In times of economic recession little attention is paid to the environmental issues. But still car driving will cause externalities. Besides that, increasing intensities have bad influence on the traffic safety. The economic situation will change and people will care again about the environmental in some years from now. When the time is there, in 2020, car drivers are ready for a smart, safe and green navigation system. Metis would like to be such a navigation system. This report is a first step in the right direction for Metis to developing the product further. Metis is still in its developing phase and research about the deployment of such a system is needed. This report describes the results of this research project.

In order to get a good understanding about Metis the system and its context is described in the first two chapters. The market and its actor is investigated with a stakeholders analysis which is described in the third chapter. The key stakeholders of Metis are the Metis developers and the Dutch government. Converge is performed for these two key stakeholders. This is reported in the fourth chapter. CONVERGE implies that a user needs assessment and an impact assessment are needed. The user needs assessment is performed with a questionnaire. The questionnaire and its result are mentioned in the fifth chapter. The sixth chapter describes the impact assessment and its results. The impact assessment pointed out some possible points for improvement of Metis. Still if Metis is working fine there are some risks in the deployment phase. The four most important risks and the mitigation strategies are described in the seventh chapter. At the end the main conclusion and some recommendation of further investigations are given.

2. ITS concept

Metis is a navigation system which is not only based on shortest or quickest routes, but also incorporates air quality, safety and noise pollution. Metis is based on the CAN system (Van Delden & Reijnhoudt, 2008), but it takes multiple external effects into account. In this chapter, the system will be described in detail.

Transport systems layers

As presented in the course ITS 1, the system will first be positioned within the ITS context. Looking at the different transport system layers, Metis is concerned with the traffic market. Based on the individual's choice to make a trip from A to B by car, Metis will advise a certain use of the infrastructure (the route to take).

ICT Systems

When looking at the ICT system, there are three items to be taken into account: ICT components, ICT networks and ICT service management. In this case, networks and services are directly derivable from the components, so only the different components will be described. In Figure 1 the in-car part of the system is schematically presented.

Sensor

The navigation system works, as most systems do nowadays, based on the GPS positioning system. Next to this, floating car data (FCD) and induction loops are used to get information about current road conditions.

Communication

Based on current trends in navigation systems, the system will be equipped with GPRS. Using this two-way communication device, the system can be updated on trip. This is crucial when for instance incident or air quality data is updated. For general updates the system can be linked to the Internet via a PC. This will save time and costs compared to GPRS.

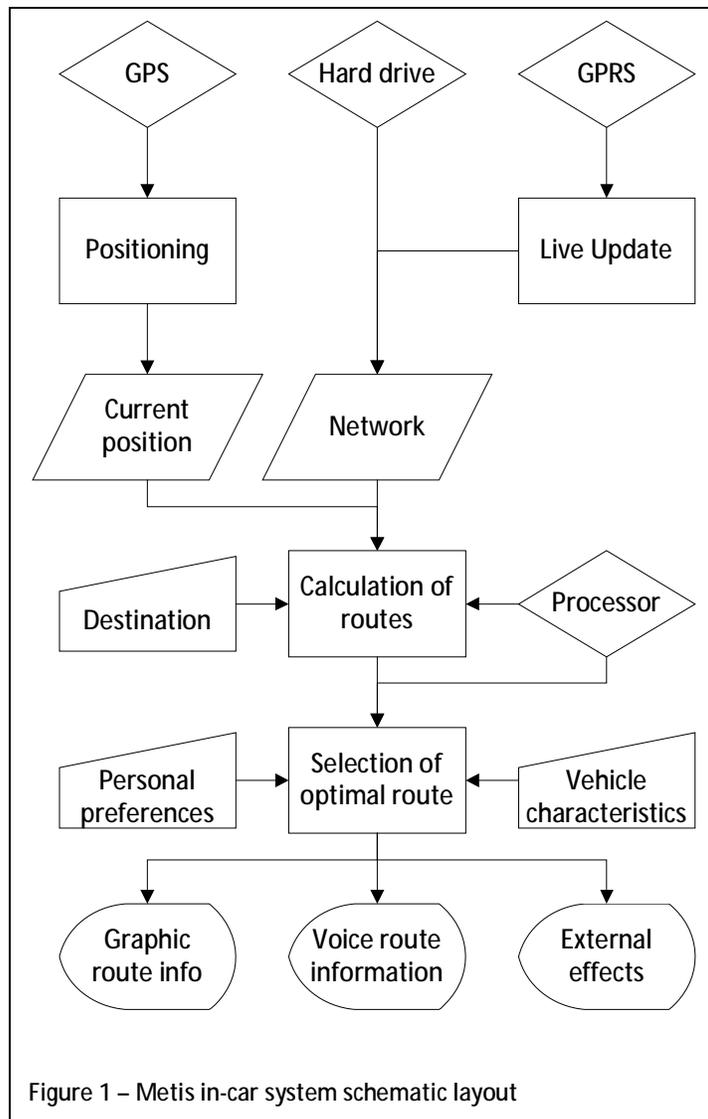


Figure 1 – Metis in-car system schematic layout

The GPRS system can also be used to send FCD to the traffic management centre. Induction loops make use of a fixed network to send their information.

Processing

The data available will be stored on a hard drive in the system. Based on the time stamp on information, the system can decide that an update of the information is needed. A processor will calculate the optimal route based on origin, destination, pre-set car properties, user preferences and external effects.

Actuators

Once the optimal route is calculated, this is presented on a screen, supported by audio. Also extra information on external effects can be displayed on the screen on demand. One can compare the layout of the system with a traditional navigation system.

Functional areas

According to the KAREN project, eight functional areas are defined (2004). Since the system is a navigation tool, the matching functional area is "Traveller Journey Assistance". Within this functional area, some distinction can be made between different functions. Metis makes use of three of the four functions: F 6.1 Define Traveller's GTP (General Trip Preferences), F 6.3 Support Trip and F 6.5 Prepare Trip Plan.

Since the system also incorporates safety aspects, there is a link with the functional area "Provide Safety and Emergency Facilities". Especially information about accidents that have occurred link with this area. From the viewpoint of the government, also the area "Manage Traffic" has close ties with Metis. Namely, Metis can be a tool for road operators to influence route choice for the minimization of (certain) external effects.

System details

The system has different options to calculate the optimal route. Next to the traditional shortest route, air quality, safety and noise pollution can be added to influence the route choice of Metis. This paragraph will discuss the different way these influences can be accounted for.

Local air quality

The developers of CAN system already set up a working system. In general, this system is incorporated in Metis. However, when the assessment of a route is based on a combination of air quality, safety and noise, it might be necessary to change the way the system deals with the impact on air quality.

Safety

In order to evaluate safety on a specific route, a method has to be developed. This is done based on a combination of basic information which is available for every link and incidents which are uploaded real-time. Basic information on a link can contain maximum speed, road type, road category, presence of schools in the neighbourhood, an indicator for the amount of accidents which happened on the link (based on BLIK), etc. Current incident information will reroute cars in order to not disturb

the place of the incident, this will also decrease the delay caused by an accident. The method to be developed will result in a risk indicator per link. This is used in calculating the safest route. When assessing the impact, this indicator is scaled by the amount of cars involved to get a risk factor.

Noise

Just as with safety, a method has been developed in order to specify the impact of the use of a certain link on noise pollution. This will be based on car properties (vehicle type), and road properties (location, maximum speed and intensities). A value for noise pollution can be calculated. However, the impact will not be the absolute amount of noise, but a factor which includes the amount of nuisance the presence of an extra car causes.

Optimal route

Based on the preferences of the driver, different routes can be presented. A driver who installs Metis has to set some parameters at start up, so the system can decide which optimum route is most suitable for the driver. Metis has five basis optima: shortest route, fastest route, "greenest" route, safest route and most silent route. Next to these, an optimum could be calculated which represents a compromise of the five other optima. How this compromise is reached, will not be determined in this research project. An additional research is recommended to determine the right proportion of each optimisation strategy for Metis.

3. Context description

Before the analysis of Metis started the context of Metis is described. The time scope and the current legislation about the air quality, traffic noise and traffic safety is described. Because Metis will (first) be implemented in the Netherlands, this research project focuses on the legislation in the Netherlands.

Time Scope

Like mentioned above, the spatial scope of this research project is the Netherlands. Metis will be introduced on the Dutch market, and the first model is based on the Dutch network. Therefore, with consumers is meant the Dutch consumer. The time scope is twelve years, because the intention is to have a feasible system in 2020 and introduce it on the market by that time.

Legislation

The Dutch government creates the legal context for implementation in the Netherlands. The regulations in the Netherlands are influenced by the regulations set up by the European Union. Therefore, the legislation of the European Union and the Dutch government are important. The main regulations are described below in the tables below.

Clean air regulation		
	Maximal amount on average per year	Maximal amount per day
PM ₁₀	40 µgram/m ²	50 µgram/m ²
NO ₂	40 µgram/m ²	200 µgram/m ² (RIVM, 2008)

Table 1 - Clean air norms which should be reached in 2011 (PM₁₀) and 2015 (NO₂) according to VROM (2008).

Traffic Safety regulation and measures	
Regulations	Safety belts are obliged, there are European speed limits for heavy weighted vehicles (European Commission, 2000). In the Netherlands, speed limits are formulated for every vehicle and on every road. These are just some examples of the existing regulations on traffic safety.
Aim	The aim of the European Commission and the Dutch government is to halve the number of the road casualties. The total amount of casualties was 791 in 2007. A measure to reach this aim in the Netherlands, is protecting fragile road users (Ministerie Verkeer & Waterstaat, 2008).

Table 2 - Traffic safety regulations of the European Union and the Dutch government

Traffic Noise regulations	
Maximum noise produced by a passenger car (EU)	74 dB(A)
Maximum noise produced by a urban bus (EU)	78 dB(A)
Maximum noise produced by heavy lorry (EU)	80 dB(A) (European Commission, 1996)
Maximum traffic noise on the house front (NL)	48 dB (Integrale wet geluidshinder, 2007)

Table 3 - Traffic noise regulations in the Netherlands and Europe

4. Stakeholders Analysis

Stakeholders of Metis are groups or organisations who are affected by Metis. All the stakeholders involved in Metis are grouped in four groups and listed below. Of each stakeholder, the interest and the possible actions with regard to Metis are described.

- Development of Metis
 - Metis developer
 - Traffic information companies
- Governments
 - Dutch government
 - European Union
- Road users
 - Car drivers
 - Other road users
- Others
 - Residents along the road
 - Road operator
 - Environment organisations
 - Car industry

Development of Metis

The developer of Metis is a commercial company and wants to make a profit. The developer wants Metis to be a famous and desired product, such that people know the system and want to buy the system. To provide these elements the developers of Metis could advertise. To make Metis a desired product, Metis has to be developed such that it suffice the desires of the consumers for a reasonable price. The product should satisfy the user needs.

Traffic information companies are companies that gather traffic information. The traffic information companies could provide this information to the Metis developers, enabling them to use the actual traffic data for optimising the routes. The traffic information companies are interested in maximising their profit, therefore their possible action is providing traffic information at a favourable cost/quality ratio.

Governments

The Dutch government sets up the legal context for implementation in the Netherlands. The regulations in the Netherlands are influenced by the regulations set up by the European Union. Both interests are important for the implementation of Metis in the Netherlands.

The interest of the European Union is to provide a clean, safe and silent Europe for all European citizen. To provide such an area the European Union has stated the regulations mentioned in the previous chapter. Besides legislation, the European Union has other possibilities to provide a clean, safe and silent area, for instance recommending and supporting. The European Union will focus in the future more on recommendation and support (European Commission, 1996).

The interest of the Dutch government is to provide a situation in the Netherlands with a clean air, safe traffic situation, and less traffic noise in which the mobility of the Dutch people is high. The main possible actions of the Dutch government are supporting, recommending and legislating. A very

rigorous legislative kind of action, but not desirable action of the government is to obligate Metis in every car.

Road users

Car drivers are potential users of Metis. The interest of the car drivers is to have a comfortable drive to their desired location. The comfort of a trip is dependent on many different factors, and the perception of comfort is different for every driver. The comfort of a trip could include the amount of air pollution, traffic noise, and safety effects produced by the driver himself. Drivers with this definition of comfort could act to buy Metis. Drivers that are not interested in Metis could collaborate to obstruct Metis becoming obliged in all cars.

Other road users are pedestrians, cyclist and children playing at the street. One of the main common interests of this group is to use the road in a safe and efficient manner and experience as little air pollution and noise as possible. Metis will support in providing a clean, safe and silent road. Therefore, the road users could form action groups to convince the government to support or obliged Metis by demonstrating and agitating.

Others

Residents along the road want to live as comfortable as possible. This means that they want to suffer as little as possible of traffic noise and traffic pollution and they desire a safe street. Therefore the interest of the residents is that their street is as clean, safe and silent as possible. These people are interested in a high penetration rate of Metis or even Metis becoming obliged. Therefore, they could form action groups just like the road users to convince the government to support or obliged Metis by demonstrating and agitating.

The road operator in the Netherlands is Rijkswaterstaat. Their mission is to manage the traffic in a safe and fast manner and provide reliable and useful information about the traffic (Rijkswaterstaat, n.d.). To fulfil this mission, Rijkswaterstaat could support investigation on the area of traffic information and traffic safety. The Metis project is in line with the mission, therefore Rijkswaterstaat could invest in the Metis project. They could also work together with Metis by provide accurate traffic data to the Metis developers.

Environmental organisations are interested in the environment; the environment should suffer as little as possible of the traffic pollution and traffic noise. One of the aims of Metis is to minimise the air pollution and noise by traffic. The environment organisation could support the development of Metis. They could also try to convince the government to support or obliged Metis by demonstrating and agitating.

The car industry is interested in maximising their profit. If the people are interested in Metis, the car industry could take action by build Metis in their cars.

5. Key Stakeholders

Metis is still in its development phase. It will only become a success, if it is developed in a desired way. Development of the system in a desired way is one of the actions of the Metis developers. Therefore the developers are a key stakeholder in this development phase.

The government is the second key stakeholder, because the most stakeholders can only influence the system by influencing the government. The government needs to have a founded opinion such that it will not be influenced by wrong arguments.

Based on the main stakeholders identified, the CONVERGE method (CONVERGE project, 1998) is applied. The results of using CONVERGE are described below. Based on these findings, two assessments will be applied, an user needs assessment and an impact assessment.

Metis developer

The user needs of the Metis developer, the assessment objectives and expected impacts are determined using CONVERGE.

Definition of User Needs

For the producer of Metis, the prime target is the generation of profit. Being a commercial company, a product has to be profitable in order to be interesting for the company. Like mentioned in the stakeholder analysis, potential Metis users should have a willingness to pay for the benefits of Metis which is high enough to develop the system.

Defining Assessment Objectives

Since profit is the main interest of the Metis developer, the financial assessment and user acceptance assessment are most important to them. Also, the technical feasibility is of interest for the developer. Thus a third assessment category is the technical assessment.

Assessment category	Assessment objectives
Financial	<ul style="list-style-type: none">• Reducing of production cost• Allowing for profit after initial purchase by user
User acceptance	<ul style="list-style-type: none">• Adapting to user needs
Technical	<ul style="list-style-type: none">• Developing technical feasible system• Using state of the art technologies• Creating a durable system• Allowing for updates of system• Making system upgradable

Table 4 – Assessment objectives of Metis developer

Pre-Assessment of Expected Impacts

The system has several expected impacts. In order to focus the assessment, an overview of the different impacts is created. These impacts are related to the assessment objectives mentioned above.

Impacts expected	Target group	Magnitude
Device sales	Metis developer	++
Device purchase	Car drivers	++
Device use	Car drivers	++
Advice compliance	Car drivers	++
Technological advance	Metis developer	+

Scale: 0 uncertain, + a little impact, ++ a big impact

Table 5 – Expected impacts (1)

Dutch government

Just as presented for the Metis developer, the user needs of the Dutch government, their assessment objectives and the expected impacts are described in this paragraph.

Definition of User Needs

The Dutch government has a major interest in the system, since the system benefits the society as a whole. External effects like air pollution, noise pollution and public safety are main interests of the Dutch government. The government will want a system which limits these external effects, so the impact on society is as small as possible. However, the mobility of the country is also at stake in this case. If drivers are rerouted because of the external effects, this should not lead to a major decrease of mobility.

Defining Assessment Objectives

For the Dutch government, the potential impact on the traffic situation is very interesting. As is the socio-economic impact of the system, since the system could get close ties with a road pricing scheme. Therefore, the main assessment objectives in this case are the impact assessment and socio-economic evaluation.

Assessment category	Assessment objectives
Impact	<ul style="list-style-type: none"> • Reducing air pollution • Reducing noise pollution • Increasing road safety • Limiting negative impact on mobility
Socio-economic	<ul style="list-style-type: none"> • Utilizing possibilities of combination with pricing scheme • Making a system affordable for everybody

Table 6 – Assessment objectives of the national government

Pre-Assessment of Expected Impacts

As was done for the assessment objectives of the Metis developer, the expected impacts based on the assessment objectives of the government are presented.

Impacts expected	Target group	Magnitude
Increased local air quality	Local residents & Government	+
Decreased local noise pollution	Local residents & Government	+
Increased road safety	Local residents & Government	++
Increased trip costs (time & money)	Car drivers	+
More efficient use of road pricing scheme	Government	+

Scale: 0 uncertain, + a little positive, ++ positive

Table 7 – Expected impacts (2)

Assessment

Within the scope of the project, two assessments are carried out. In order to get an insight in the feasibility of the system, a user needs assessment is carried out. This is especially important for a potential developer. The main focus of the national government is the impact of the system on traffic. Therefore, a impact assessment has been carried out. These two assessments are described in the next chapter (User Needs Assessment) and chapter 7 (Impact Assessment).

6. User needs assessment

As follows from the CONVERGE method, the user needs assessment is one of the major assessments to be carried out for the Metis developer. In this chapter, this assessment will be set up and carried out.

Assessment method

The focus of the assessment for the Metis developer will be on the user acceptance. This is done using a questionnaire which ask potential future users about their attitude towards the Metis system. Table 8 gives an overview of the assessment method used. An explanation of this overview will be provided afterwards.

Definition of Indicators	Willingness to buy the system, willingness to use the system, compliance to advise, attitude towards external effects
Reference Case	Situation without the system
Data Collection	Send questionnaire to potential users
Conditions of Measurement	<ul style="list-style-type: none">• Indirect measurement• Valid, understandable questionnaire
Statistical Considerations	<ul style="list-style-type: none">• Sample of at least 100 respondents• 95% confidence level in analysis• Diverse, representative target group
Measurement Plan	<ul style="list-style-type: none">• Use questionnaire via internet• Run test on fellow students• Start questionnaire half December, wait four weeks for results
Integrity of Measurement	<ul style="list-style-type: none">• Justification bias - Answers might be biased towards a publicly preferable answer

Table 8 – Overview of the user acceptance assessment method

Indicators

The Metis developer will mostly be interested in the willingness of future users to buy the system. A questionnaire will be conducted, determining the attitude of people towards the system. People will be introduced to the system, after which they will be asked whether or not someone would buy the system. Since the producer can gain future revenues from additional services, they will also be interested in the actual use of the system. Therefore, this is added to the questionnaire as well.

As input for the impact assessment (next chapter) a penetration rate as well as the compliance to the given advice are of interest. Based on the willingness to pay, a penetration rate can be estimated. In order to find out the compliance to the advice, additional questions are added.

Another aspect of interest are the technical user preferences. This will concern the trade off between the different effects and peoples attitude towards the effects.

Data collection

The data is collected using a questionnaire. As stated in the project setup, some major risks are located in this part of the research. The questions should be understandable and valid (meaning that e.g. all answers can be filled in, in the case of an multiple choice question). In order to test if the questionnaire is valid, a trial version has been put to the test by some fellow students.

The questionnaire is carried out using an online application. By sending people an e-mail with a link to the questionnaire, people are asked to fill it out and forward the e-mail to other potential interested users.

Statistical considerations

In order to have a representative sample size, at least 100 respondents are needed. According to Moll,(n.d.) this is the adequate sample size for a 95% confidence level and a tolerance of 10%. When lowering this tolerance, the sample size rapidly increases. 7% Tolerance, results in 200 respondents, 5% even to 400 respondents. Because of practical considerations and the limited scale of the project, 10% tolerance will suffice. After the data clearance, the response of 136 people is used.

Also, attention should be paid to the composition target group. Students seem easy to reach, but do not represent the entire group of potential users. The target group is defined just as Van Delden en Reijnhoudt (2008) did, based on traveller miles which are studied by the DVS in the MON survey (2007).

Questionnaire design

The questionnaire is build up in four parts. The first part is used to get some general information about the target group. The second part is about externalities. Then some questions about the market potential of the system. Finally, in the fourth part, questions about the compliance to the system are asked. The questionnaire is set up using the web application ThesisTools. Because of practical considerations for the respondents, the questionnaire is set up in Dutch. In appendix A an English overview of the questions is given.

Questionnaire assessment

The analysis of the questionnaire consists of four steps. First, the data will be corrected in order to prevent logical errors and filter out not completed questionnaires. Next, the respondents will be compared to the target groups as it was defined beforehand. Then, the user interest and the compliance rate will be assessed.

Data cleansing

The first step in the data processing, is checking whether enough questions are answered. When no user attributes where filled in (3 times) or just the user attributes where given (9), this is not the case. Therefore these respondents are deleted.

Question 7 could potentially be answered wrong, when someone would select one of the options as well as " none of the above". If this occurred, the respondent probably was not answering the questions seriously and therefore deleted (0).

Question 1 could define whether someone is to young and therefore without the target group (0). Since this wasn't the case, the age group 0-18 is not taken into consideration for the analysis. Since there are only two respondents in the group 75+, little can be said about this group. Therefore, it is omitted when a distinction between age groups is made.

Question 8, about paying extra for a equipped navigation system, was multi interpretable. It was unclear whether one should specify the new total price or just the amount to pay extra. Therefore,

the answers are modified. When the specified amount was below the original price of € 150 (119), no change was made. When the amount was equal or higher (27), € 150 was subtracted from the given amount. After this correction was carried out, an outlier analysis is applied. This resulted in the exclusion of all records (2) which differ more than three times the standard deviation from the mean. These people stated that they would pay € 350 extra on a system which costs € 150. This seems highly questionable.

In general, the term traffic safety could, hindsight, have been better explained. There is some confusion since generally the Dutch term “externe veiligheid” is used in stead of “verkeersveiligheid” (which is used in the questionnaire) in cases where it is about the safety of others and not so much your own safety. One respondent pointed out this difference. Others indeed made remarks which indicated that they assumed it was their own safety which was included in the route advise. Since there is no clear indicator to distinguish between those two, no changes have been made. In general, all figures about traffic safety should be carefully interpreted since probably people are more willing to improve their own safety than the safety of the system (which thus will lead to an overestimation of the results).

Target group

In order to get a good representation of the population, a target group was specified based on MON data about the amount of miles travelled by different groups of drivers. In the figures below, the user attributes of the respondents are compared to the MON distribution. When comparing the age distribution, the most important difference is the size of the group 18-29. The other groups differ slightly, but this is highly under the influence of the difference in the first group. This is depicted in Figure 2 and Figure 3.

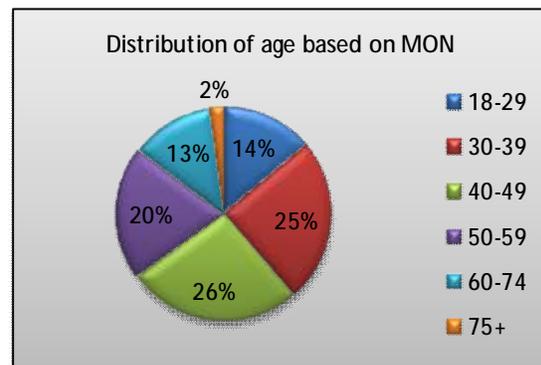
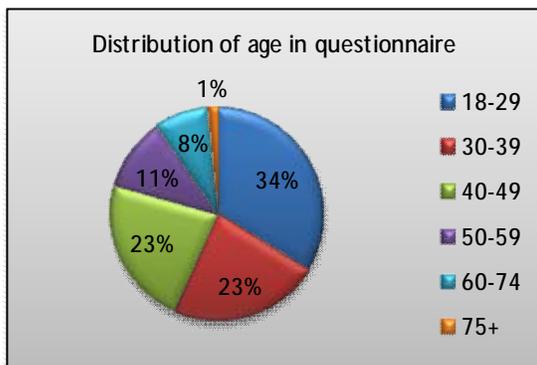


Figure 2 – Distribution of age in questionnaire

Figure 3 – Distribution of age based on MON

When comparing the distribution of sex, the respondents fit really well with the target group where 71% men. There is a difference of only three percent, as 68% of the respondents was male.

In order to fit the sample to the target group, a weighed average will be used when discussing the results. Since there is hardly a difference in the sex distribution and a considerable difference in the age distribution, the fitting will only take place based on age. The average of a group will be weighed by the theoretical percentage derived from the MON research (Figure 3).

Other questions about the composition of the sample where about driving experience and experience with navigation systems. The respondents are generally drivers who use their car

regularly. Use of navigation systems is very dependent of age; younger drivers have more experience than older drivers.

User interest

The main target of the questionnaire was to gain information about the willingness of users to buy a Metis system. In the questionnaire, a question was ask whether people would appreciate the use of a navigation system at all. Only a limited group (4%) doesn't want this, whereas the vast majority would like to use it sometimes (76%) or always (15%). Another 4% doesn't know.

When asked whether one would like to have some system implemented considering externalities, there is a strong relation between the people who are willing to use a navigation system and who would like to consider externalities. Figure 4 shows this relation. 29% of the respondents indicate that they don't want any kind of externality implemented in their navigation system. Only 29% of the people say to be interested in air quality, whereas the study of Van Delden & Reijnhoudt (2008) shows an incredibly higher percentage of 79%. There are two reasons which probably explain this difference. First, there is quite a difference in the age distribution and the driving experience of the target group. Second, this question has a considerable response bias. People will show preferred behaviour by not choosing no / none in such a question. In the Metis study people could choose between several options (air quality, noise pollution, traffic safety) which resulted in a lot of people choosing just for traffic safety. In the case of CAN, people could only choose for air quality, so all biased people chose air quality.

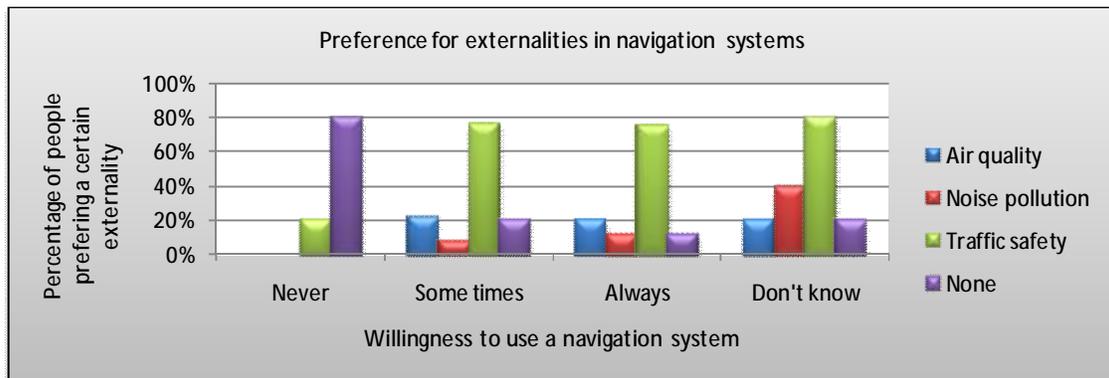


Figure 4 – Preference for externalities in navigation systems

When asked about the willingness to pay extra for such a system, people who intent to use a system are willing to pay more (Figure 5). Logically, people who don't want to use a navigation system also don't want to pay. In relation to sex, there is no significant difference. But when looking at age, younger people are less willing to pay (Figure 6).

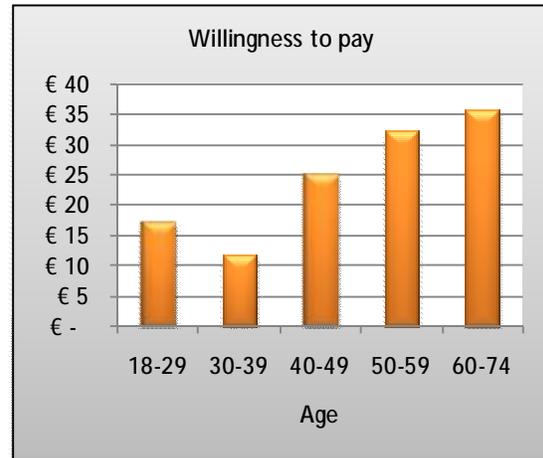
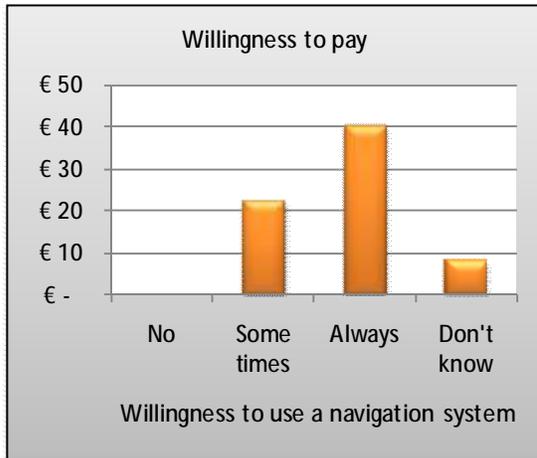


Figure 5 – Willingness to pay grouped by potential use Figure 6 – Willingness to pay grouped by age

On average people want to pay € 23 extra for an equipped system. However, when one would only look at people willing to pay at all, the average amount is €43. This seems like a promising result for a manufacturer, since there are actually people willing to pay considerably more for a system like Metis.

Compliance rate

As stated before, 92% of users likes to use a navigation system. However, not all of these users will follow the advice given by Metis. For modelling purposes, a compliance rate is desirable. Based on the results of the questionnaire, a figure will be estimate to indicate which percentage of users will actually use the routes presented by Metis. For this purpose, a filter is applied to exclude the respondents who indicated not to be willing to use a navigation system. Since there is only a limited amount of people interested in air quality and noise pollution, a correction factor for the different externalities will be applied.

Based on the stated number of minutes one wants to reroute, a graph can be made (Figure 7). This shows the cumulative percentage of people who is willing to reroute if trip has a percentage extra travel time. This is a linear interpolation between the different choices in the multiple choice questions. There are two attributes that differ between the lines: total trip length and trip reoccurrence. It should be noted that this rerouting is not directly linked to a specific externality.

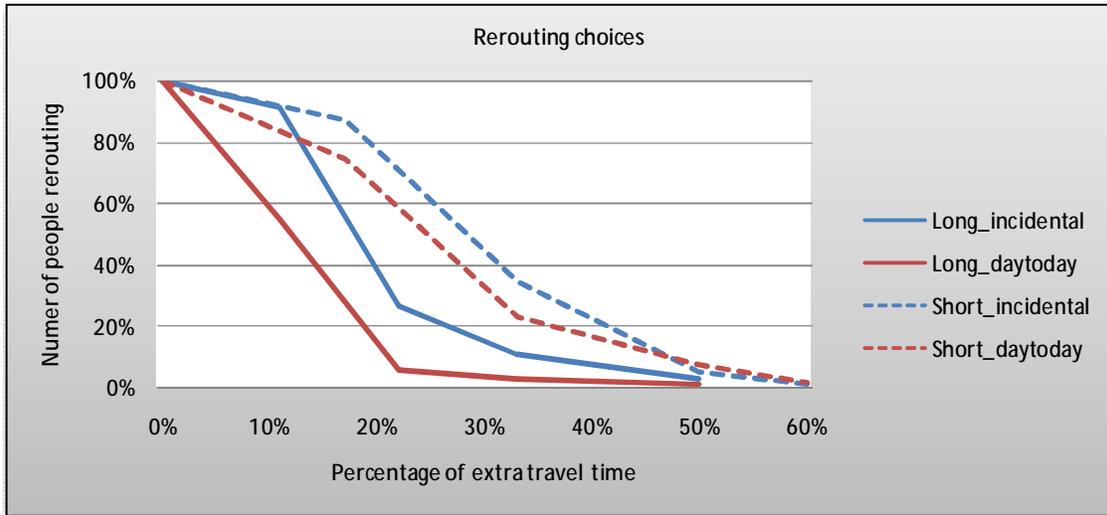


Figure 7 – Rerouting choices based on extra travel time

Now, a consideration has to be made whether a lot of people are rerouted a little or few people are rerouted a lot. Since the network used has few alternatives, the differences between the alternatives are relatively large. Since the distances in the network are rather small, the short route preferences (dotted lines) are used. All traffic is assumed to be day to day traffic (worst case scenario). In the model, a route will be set to be a valid alternative if the travel time is maximal 133% of the shortest route (in MatLab: ExtraTime = 0.33). This will result in 25% of the people who use a navigation system will reroute. Since the usage was defined to be 92%, the total compliance rate is 23%.

As said before, a correction factor will be applied based on interest in the different externalities. When looking at the different stated preferences, people highly prefer rerouting for traffic safety but don't care that much for noise pollution. This is shown in Figure 8. The percentages will be used as correction on the Metis factor. This results in the following figures for the fraction Metis (FM) in MatLab.

Air quality: FM = .06

Noise pollution: FM = .03

Traffic safety: FM = .20

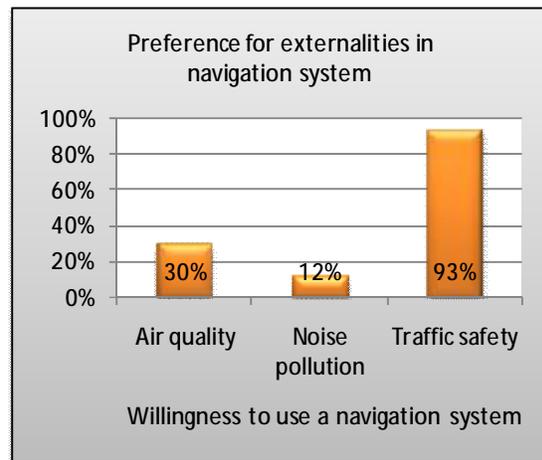


Figure 8 – Preferences for different externalities

7. Impact assessment

As follows from the CONVERGE method, the impact assessment is one of the major assessments to be carried out for the Dutch government. The impact assessment is executed by modelling the effects of Metis in a small network in Matlab.

Assessment method

The impacts of Metis on travel time, air quality, traffic safety and noise are assessed. Table 7 gives an overview of the assessment method used. Some explanation of this table and a short description of the network is given below.

Definition of Indicators	<ul style="list-style-type: none"> • Travel time in minutes • Air quality in a measure of both of concentrations of PM10 and NO2 • Traffic Safety in a score that compares possible routes • Noise in the amount of highly annoyed people by noise
Reference Case	Situation without Metis, using the shortest route criterion for assignment in a small network
Data Collection	Simulating the route choice on a small network
Conditions of Measurement	Controlled, a model is used
Statistical Considerations	The indicators used are not validated, because of the limited time available.
Measurement Plan	<ul style="list-style-type: none"> • Setup in MatLab before Christmas • Construct and run m-files early January • Finish half January
Integrity of Measurement	<ul style="list-style-type: none"> • A small network will not give complete overview • Reliability of fictive network • Reliability of reference case • Reliability of indicators • Reliability of implementation rate

Table 9 – Overview of the impact assessment method

Indicators

There are four different indicators. An indicator for: travel time, the air quality, traffic safety and traffic noise. The indicator for travel time is very straight forward, so it doesn't need any explanation. The other indicators are more complex and are explained below.

Air quality

It is obliged, in the Netherlands, to use the 'Standard Rekenmethode' when calculating air quality. Therefore, the yearly concentration PM₁₀ and NO₂ are estimated with the 'Standard Rekenmethode'. The concentration are multiplied by the length of a link and a bother fraction. This bother fraction is the highest at the locations where air pollution is the most unwanted. The formulas can be found in appendix B.

Traffic Safety

When talking about safety in a Metis context, safety is an externality. This means that it's not about the safety of the driver himself, but the safety of everyone around the car is at stake. Therefore, not only traditional indicators like traffic flow and accident statistics are important, but also potential conflicts with for instance crossing pedestrians or cyclists. The SWOV (Dijkstra & Drolenga, 2008)

published a report on safety of routes, based on several parameters. These parameters consist of two sets: road dependent and vehicle dependent. Since the model is not suitable for an evaluation on vehicle level, only the first set will be used. These characteristics are explained in appendix B

Next to the nine indicators (of which eight are used) of the SWOV, several other categories are introduced. The SWOV characteristics focus only on the road, whereas Metis is also interested in the surroundings. Especially the presence of vulnerable road users has an impact on the safety. Also, by the use of BLIK (accident data) information about past accidents are included in the factor. These characteristics also are described in appendix B.

Traffic Noise

The indicator for traffic noise is indicated by the total amount of people highly annoyed by the noise. This amount is formulated as the fraction highly annoyed people multiplied by the amount of people around the streets. When people are highly annoyed by noise is determined by the European Commission. According to the European Commission (2002), the fraction highly annoyed people is derived from transforming various annoyance scales to a 0 to 100 basis and using a cut-off at the scale value 72. The formulas for calculating this fraction for each link are given in appendix B.

Reference case

All the indicators are highly depended of the amount of traffic on a link. In the reference case, each individual will select their route by the Dijkstra algorithm. In the Dijkstra algorithm, the route choices are made using the shortest route principle. The traffic will be assigned using the incremental assignment method (13 steps). By using many (13) small steps the incremental assignment will approach the user optimum.

Data collection

In order to perform the impact assessment, a test network is needed. The network chosen for this assessment is the network of Nguyen and Dupuis (as cited in Huang & Li, 2007). This network is displayed in Figure 9 on the next page. This network has two origin nodes (1 & 4) and two destination nodes (2 & 3). Next to lengths, also indicators for the externalities have to be added to the network. Therefore, some context is added in the network. On the network a traffic flow will be assigned by an incremental assignment programmed in Matlab. A fraction of the people will be assigned on the routes advised by Metis, the others on the fastest route. The used Matlab files are attached in appendix C.

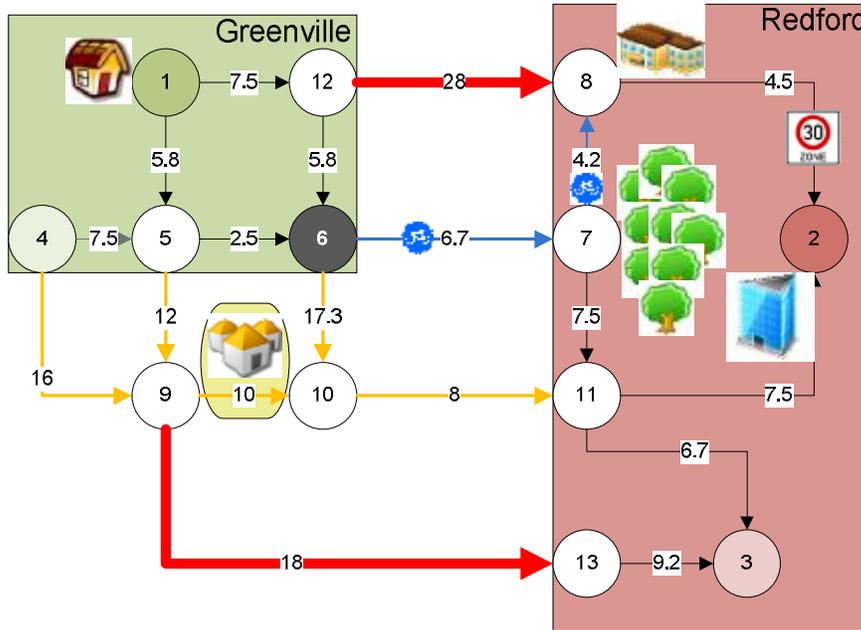


Figure 9 – Network with context

The several colours in the figure will be discussed briefly:

- There are two towns: Greenville, containing the origin(s), and Redford, containing the destination(s)
- There are two highways between the towns (the red links, 120 km/h)
- Between node 8 and 2, a 30 km/h zone with a school is located
- Cyclists from Greenville take the blue route to the school in Redford
- Between nodes 9 and 10, a little village is located with a 60 km/h zone
- According to BLIK, node 6 is a black spot with 6 or more accidents without injury
- When no other speed is mentioned, 50 km/h is the city limit, 80 km/h the rural limit
- 400 people travel from 1 to 2, 600 people from 1 to 3, 500 people from 4 to 2 and 300 people travel from 4 to 3.

Characteristics links

Other characteristics of the links need some explanation and will be given in this section.

Road type

The formulas of CAR uses a variable called road type to calculate the air quality. The different road types are explained by infomil (2007). The following road types are chosen for the links in our network: 3b for the links in Redford and Greenville, 4 for the link in the little village and 2 on the other roads.

Speed type

An other variable used by Car is the speed type. The speed types of the roads in Redford is chosen to be normal city traffic, in Greenville free flow city traffic, on the rural roads general rural and on the highways the speed type of normal highways is chosen. These are average speed types, so still congestion could occur.

In fact it is assumed that congestion does occur. Without any form of congestion the initial fastest route will stay the fastest route and rerouting will not save time. Because navigations system are manly used for rerouting in congested situation it is assumed that congestion would happen in our network. The influence of the intensities on the different speeds on the five types of roads is displayed in Figure 10.

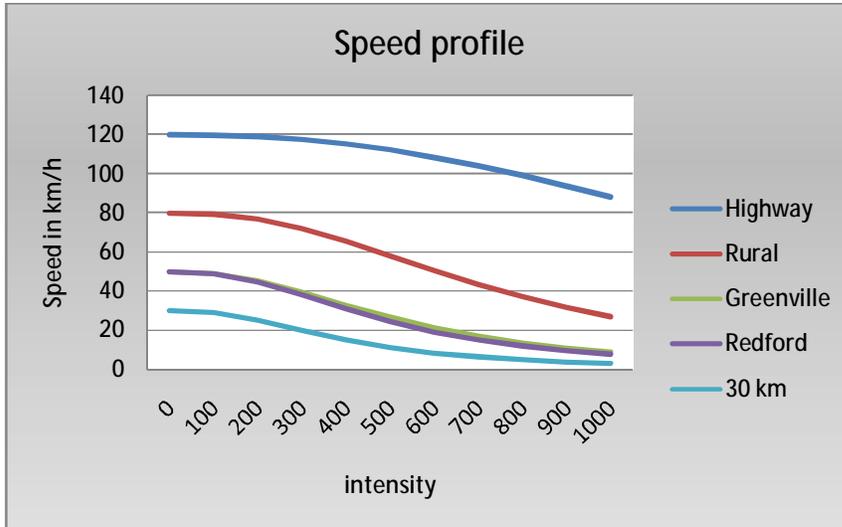


Figure 10 - Speed profile for the five different type of roads

The speed profile is translated to the travel times. A link with a free flow travel time of 9 minutes is used. The influence of the intensity on the travel times is displayed in Figure 11.

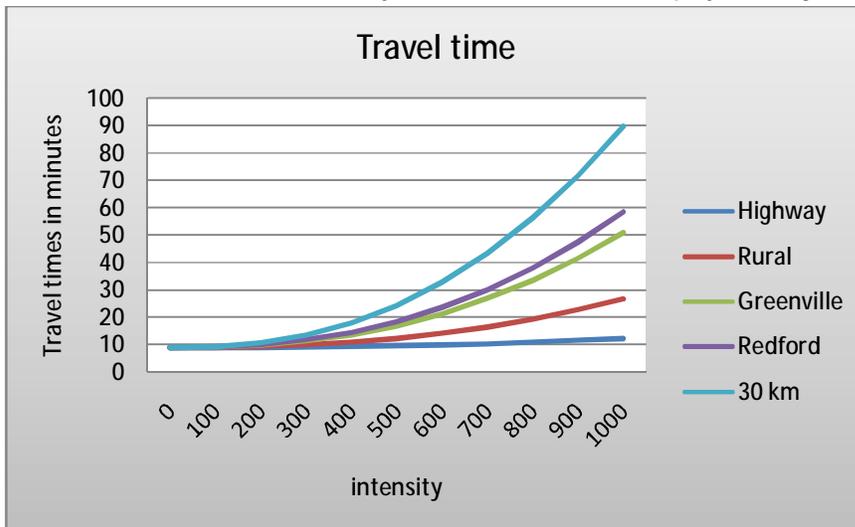


Figure 11 - Travel times on a road with a 9 minutes free flow travel time

Composition of the vehicles

The fractions of light, medium, heavy vehicles and the fraction busses need to be determined. These fractions are used for the calculation of the air and noise indicator. The fractions are determined using the vehicles kilometers of the year 2000 in the Netherlands(CBS, 2001). The vehicle kilometers of 2000 are given in Table 10.

Car	busses	Motor	delivery van	Special vehicle	tractor	trucks
100,925	610	1680	16,630	385	3290	3140

Table 10 - Vehicle kilometers (in millions) per vehicle type in 2000

The cars and motors are grouped together and are accounted for the group light vehicles. The delivery vans and the halve of trucks are grouped in the middle trucks class. The busses are simply the group busses. The other vehicles are placed in the group heavy trucks. An average distribution of vehicle types could be calculated using this categorisation. It is assumed that the distribution of vehicle type differs from each other in Greenville, Redford the highways and the rural roads. The chosen fractions for each vehicle type are displayed in Table 11.

	Light	Medium	Heavy	Busses
Greenville	0.82	0.14	0.03	0.01
Rural roads	0.83	0.13	0.04	0
Highways	0.79	0.15	0.06	0
Redford	0.78	0.18	0.02	0.02

Table 11 - Chosen vehicle type fraction for the impact assessment

Tree factor

The tree factor is a representation for the amount of trees along the road, see Infomil (2007) for more information on tree factors. The tree factor used are: 1.25 for links in Greenville, 1.5 for blue cycle route and near the park at the road from 7 to 8 and 7 to 11. All the other links have a tree factor of 1.

Bother measure

The bother measure is chosen to be 1 in Redford, 1.5 in Greenville, 1.2 in rural areas and 0.5 around the highways. This means that an amount of air pollution is the least worse around the highways. The bother measure is a useful tool. A street can easily be avoid by increasing the bother measure.

People around a link

The amount of people around a link is needed for the calculation of the noise indicator. A equal division of the people is assumed within the villages. Along the roads in Greenville are 500, in Redford 600, in rural areas 100 and along the highway 50 people.

Road category

As the ranking for safety of the SWOV is based on road categories of "Duurzaam veilig", these categories are added to the links. Greenville and Redford are all access roads. The highways are through roads . All other roads are ranked as distributer roads.

Number of crossings

Every link has two crossings. Next to that, roads in Greenville and Redford have two additional crossings. The little village between node 9 and 10 has one additional crossing.

Statistical considerations

The input used for determining the indicators is not validated, because a limited amount of time is available. The possible unreliability of the input has consequences for the reliability of the impact assessment. Therefore, a lot attention is paid to determining the formulas for the indicators.

Especially the indicator for safety is difficult, because little information about such indicators in the literature research was found.

Integrity of Measurements

A small network is used in this impact assessment. It is not possible to include all road situations in this network. The impact assessment will therefore not give a complete overview. Many different road situations are included in the network such that an almost complete overview can be given.

The validation of the impact assessment is dependent on the reliability of the used network, the indicators, the reference case, the assignment method and the used implementation rate. An unreliable network will not give a proper view of the impact of Metis in the Netherlands. Like mentioned at the statistical considerations, the indicators can also affect the validation of the results. In the reference case, it is assumed that the route choice is based on the shortest route principle. This could affect the reliability of the impact assessment, if the route choice is not based on the shortest route principle for a significant amount of people. The used assignment method is the incremental assignment, the assignment will differ if the step sizes are changed. Small step sizes are chosen to get accurate results. The implementation rate is determined using the results of the questionnaire, in the previous chapter is described which risks are involved in the questionnaire.

Results

The results of the MATLAB model are discussed first. Next, the results are extrapolated to the real traffic situation.

MATLAB Model

After running the MATLAB files, results can be compared. A comparison has been made between a theoretical implementation rate of 25% for all different optimisation strategies. Based on the results of the questionnaire (Chapter 6), the three different strategies are also compared to the reference case using their specific implementation rate. In Figure 12, the general results of the different strategies can be found.

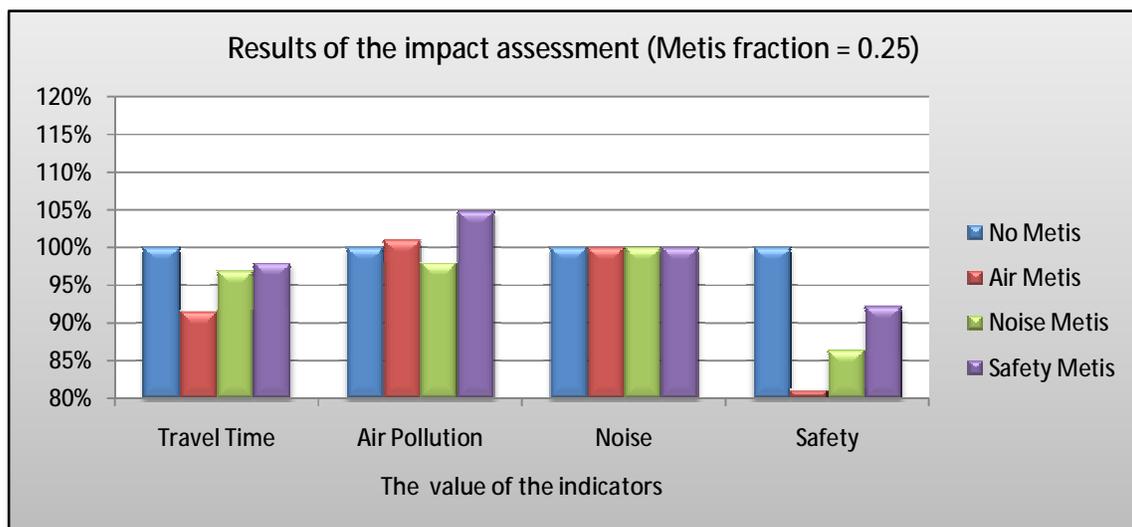


Figure 12 – Impact assessment general results

When looking at these data, it is surprising that the total travel time is not the lowest when optimizing only for travel time (no Metis). So far, no direct cause of this problem has been found. In MATLAB, the selection of the shortest route works fine, so the problem most occur some other way. There are however some possible explanations.

The assignment method might be too coarse, resulting in too large steps. Possibly, the optimum is not found this way. Since the small differences between the characteristics of the different routes, this might lead to some larger steps. Since the differences are rather small, there could be a link.

Another possible flaw could be the presentation of total scores, which represents some sort of system optimum. When calculation however, the user optimum is used. When looking at individual values of links, it can be seen that the values of air pollution lie closer together. With an implementation rate of 6%, the following figures are found:

	No Metis	Air Metis (6%)
Maximum	110.2174	104.4219
Minimum	0.000986	6.516428
Average	47.39976	47.70718

Table 12 – Link score characteristics

As could be expected, the average value is higher (as can be seen in Figure 12). However, the maximum decreases and the minimum increases.

Of course, there could also be a programming error in the m-file. However, extensive checking has revealed no errors, so there is probably a methodological problem. Due to time constraints, the data shown in Figure 12 is used for the analysis.

Air quality

When optimising for air quality, the total air pollution increases. As can be seen in Table 12, the peak values disappear. This is a beneficial result, since it limits the peaks in the pollution. The calculation method used for CAN (Van Delden & Reijnhoudt, 2008) is more detailed and showed a positive effect on local air quality. Since this method also uses a background concentration, this is not used in the model. When developing Metis, the data availability should be increased so the CAN method can be used.

When talking about air quality, one should always keep in mind that rerouting will increase driving mileage; resulting in a higher total emission of exhaust. The method presented is aimed at local air quality.

Noise pollution

When looking at total values, the impact on noise pollution is non-existent. This can be explained by the fact that the indicator for noise is highly dependent on the composition of the traffic and not so much on the characteristics of the link. Therefore, Metis will not give a different advice in a case with such a limited amount of cars and routes. In order to calculate noise pollution, more data is needed and a more complex model should be used.

Since the interest for noise is very limited and the calculation rather difficult, the willingness to pay for the acquisition of enough data will probably lower than the costs. Therefore, implementing noise pollution into Metis is not beneficial.

Safety

In the case of safety, scoring proved to be difficult. Instead of a value per link, there is a value per route. An attempt has been made to calculate an average safety level, but this didn't result in the desired increase of safety levels. The method does reroute the traffic over the safest route, so their should be an increase in the total safety.

As is the case for the above mentioned indicators, safety is dependent on the flow on a link. Since this also influences the problem with the travel times, it is hard to say where the problem in the case of safety occurs.

The user interest in safety is highest of all examined externalities, the benefits probably outweigh the costs for data needed. The current method should be extended in order to incorporate flow based indicators. In the current model, all routes have a fixed safety level, whereas in practice the situation is unsafe when more cars travel on a link (to a certain extent).

Real world

The data found with the MATLAB Model don't give a solid basis to extrapolate to the traffic situation in practice. What can be seen is that the consideration of externalities leads to a different route choice. These routes will always be longer, so the total travel time increases. Since there is a maximum extra travel time of 33%, the total travel time in the network could increase with maximal 6% ($33\% * 20\%$ (implementation rate)).

Decrease of noise pollution is, based on the used definition, not feasible. Air quality could be increased on a local scale, as could the safety of the system. Based on the link loads, peaks in air pollution could be decreased with 5%. However, this does also lead to an increase of the less polluted roads which is higher because the rerouting is always a longer route. Safety levels can increase with the use of Metis, because people will more actively comply to "Duurzaam veilig" guidelines for traffic safety. However, when rerouting to prevent one danger, the total exposure does increase.

8. RAID

The purpose of RAID is to identify the main obstacles, constraints and recommend specific measures (European Commission, 1999). These measures are called mitigation strategies.

Risk Identification

To identify the risks of the deployment of Metis, the deployment scenario is described. The four most important risks for Metis are described below.

Deployment scenario

Like mentioned in the context description, Metis will be implemented in the Netherlands in 2020. In 2020 Metis should be known, desired and a good working product. Before 2020, Metis will be tested by a small group of car drivers. In this test phase will Metis not be able to have the full desired dataset. Therefore, Metis could advice the cleanest, safest and most silence route for a restricted amount of trips. The test target group will consist of people in a certain area. Less data is needed to advice about the fastest routes. Therefore is Metis able to calculate the fastest route for the whole Netherlands in the test phase and not only for a restricted amount of routes.

Risk one

A lot of different data is needed for Metis to get reasonable results for the air, safety and noise optimisation. Like mentioned in the previous chapter, for the determination of indicators, data is needed like: environmental pollution, amount of people in a street, current traffic flow on the links, tree factor, composition of the traffic on the road etc.. A risk is that the data is not available for Metis, or that the data has low quality. Non available data will be discussed in the next section. Low quality data affects the reliability of the advised routes. Low quality data would lead to errors, which are maybe difficult to observe by the Metis users, but if the errors are observed, people will loose their thrust in Metis and worse think Metis is useless. This risk has a high probability of occurrence, because there is always some kind of an error in data. Data will never be an exact image of the reality. The level of impact is also high because if Metis is not able to calculate the actual cleanest, safest and most silence route and the people find out, Metis is ruined. This risk has a red rating.

Risk two

A second risk of the deployment of data is that data is not available for Metis. Without data or parts of data, Metis is not able to advice about the Metis routes. Even if a small of data is missing, Metis could not calculate the 'right' routes. This could lead to inconvenience, annoyance and a lost of thrust in Metis. The needed data for Metis *is* available for some companies, so Metis does not need to produce the data. But Metis has to convince the companies to share the data with Metis. Therefore the probability of occurrence is medium. The level of impact of this risk is high, because a lost of thrust in Metis could lead to the ruin of Metis. This risk has an orange rating.

Risk three

A third risk of Metis is that almost nobody wants to drive a few minutes longer for some externality. If people are not willing to reroute they will think Metis is useful and will not buy Metis. It is not very likely that this risk will happen, because of the results of the questionnaire. In the questionnaire 25% was willing to reroute if the route was less than 33% longer (for short day to day traffic). Still it is possible that the respondents gave desired answers. Maybe they are not willing to reroute or less

willing to reroute in reality. Therefore the probability of occurrence of this risk is medium. The level of impact is high, because less people will buy Metis. The rating of this risk is orange

Risk four

The fourth risk, a more current risk, is the current economic situation of the Netherlands. In a bad economic situation is less attention for environmental issues. The interest for an environmental friendly application will decrease. Besides that, sales will decrease in a bad economic situation. It is hard to predict the economic situation in 2020, but a bad economic situation will imply bad sales for Metis. The probability of occurrence is medium, because there is still some time for the economy to recover before 2020. The impact level is high because less people will buy Metis. The rating of this risk is orange

Mitigation Strategies

For each of the four risks a small mitigation strategy will be set up. The actions, the actors and the category of this mitigation strategy will be described.

Risk one

With low quality data, it is still possible to determine the cleanest, safest and most silence. But the routes are not as reliable as desired. Therefore a robust model has to be build which is not too sensible for errors in the data. Especially random errors could easily be filtered by using robust models for calculating the Metis routes. This action should be done by the Metis developers, the ones who developed the algorithm of Metis. This is a control risk mitigation strategy.

Risk two

The second risk is very similar to the first risk except that risk avoidance should be used. The developers of Metis should take action in an early phase to be sure that they will get data finally. Metis could cooperate in early phase with a traffic information company or other company with the needed data. The data companies are more willing to share data if they cooperate in the project. Therefore, the data companies need to be convinced that their cooperation with Metis is rewarding for them. Another mitigation strategy could be to offer a lot of money to the data companies, but this is a less safe option. Both actions are risk avoidance.

Risk three

The third risk could be avoided by advertising and campaigns. The Metis developers could advertise about how good Metis is for the community. The government could use campaigns to convince the people to drive more social. With campaigns the government is able to educate the people about the disadvantages of driving and their externalities. Such actions will persuade people to buy Metis. These actions are risk avoidance actions

Risk four

The fourth risk is harder to deal with. Metis developers have less influence on this risk. Metis developers could only convince people to buy Metis by advertising. But if even less people are buying cars because of the economic situation, it is obvious that the economic situation will affect the sales of Metis. The government could invest in the economy to avoid a situation in which the economic situation is still bad. But the government is not the only influence on an economic situation, the government is not able to solve the situation all by itself. These two actions of the Metis developer and the government are risk avoiding actions.

9. Conclusion & Recommendations

The main conclusion of this research project and recommendations for further research are given below.

Conclusions

In general, there is a market for navigation systems which incorporates traffic safety. People are interested in such a navigation system and they are willing to pay significant more for such a navigation system. People are less interested in navigation systems which incorporates only traffic noise and air pollution. The amount of people interested in a clean air navigation system was according to van Delden & Reinhoudt significant higher than the results of our questionnaire picture. This difference in results can be attributed to the manner the questions are described and at the different composition of the respondents. We believe our questionnaire gives a more realistic picture.

People are willing to pay extra for Metis, which is a promising result for potential development. When a system like Metis would enter the market, it should be commercially feasible. The results show that people are willing to pay on average €23 to get externalities implemented in their navigation system. If we only look at potential buyers of the system, the willingness to pay raises to €49. Therefore, we think a product like Metis can very well be put into the market.

When looking at the impact on traffic, the current model doesn't give very good results. However, based on the results it can be seen that optimisation for noise is not cost beneficial because of the high data demand. Since a shift route choice can be seen, optimising should be possible for air quality and safety. However, the results presented do not give a clear picture of the amount of impact this good give.

When looking at risks for the system, data presents by far the highest risks. A lot of attribute data is needed in order to get Metis up and running, otherwise the results will be less beneficial for the users. This low performance will lead to lower user interest and therefore less commercial feasibility. This is a huge threat to the potential for Metis to be developed.

Recommendation

Looking at the user needs assessment Metis is a promising product. People are really interested in a smart, safe and green navigation system. But before Metis can be introduced to the market, Metis has to be adopted by its potential users. The product has to use reliable and good indicators for the air quality, the safety and the noise of a route. The indicators should not need too much data, because the availability of data is a risk for Metis. Further research to such indicators is necessary for Metis. For example, the environmental air pollution does not contribute to the air indicator, this could be changed. The indicator for safety needs especially more attention, because many people are interested in a navigation system which incorporates the traffic safety.

When nice indicators are found an impact assessment should be done on a bigger network, with realistic characteristics. In a realistic network, the impact on a real world situation can be estimated better. Also the possibilities of using another assignment method in the impact assessment should be

investigated. In the incremental assignment, a bias between the real shortest route and the chosen shortest is always present.

Finally some additional research towards the combination of the four different optimisation strategies is recommended. The influence of the different optimisation strategies on the other indicators could be investigated to get some idea about the possibilities of a combination.

Before setting Metis into the market, it should be very well equipped with data. Since a lot of data is needed to get results on the different aspects, this will lead to a large investment beforehand. A well prepared partner (e.g. NAVTEQ, TeleAtlas) should be found in order to be able to handle these amounts of data and get the Metis system up and running.

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Appendix A – Questionnaire

Original Dutch version

Navigatiesysteem

Welkom bij deze enquête. In het kader van een onderzoek naar een mogelijk nieuw type navigatiesysteem, wordt deze enquête uitgevoerd. Het invullen van de enquête kost u minder dan tien minuten. Uw antwoorden zullen hierbij anoniem worden behandeld.

Bent u geïnteresseerd in de resultaten van het onderzoek, dan kunt u aan het einde van de enquête uw mailadres achterlaten. U krijgt dan eind januari ons eindverslag toegestuurd.

Voordat er inhoudelijk vragen gesteld worden, volgt er een aantal vragen over uw persoonlijke situatie.

1.	Wat is uw leeftijd?
	<input type="checkbox"/> 0-18
	<input type="checkbox"/> 18-29
	<input type="checkbox"/> 30-39
	<input type="checkbox"/> 40-49
	<input type="checkbox"/> 50-59
	<input type="checkbox"/> 60-74
	<input type="checkbox"/> 75+

2.	Wat is uw geslacht?
	<input type="checkbox"/> Man
	<input type="checkbox"/> Vrouw

3.	Hoe vaak bent u bestuurder van een auto?
	<input type="checkbox"/> Meerdere malen per week
	<input type="checkbox"/> Meerdere malen per maand
	<input type="checkbox"/> Meerdere malen per jaar
	<input type="checkbox"/> Nooit

4.	Heeft u ervaring met het gebruik van navigatie-apparatuur?
	<input type="checkbox"/> Nee
	<input type="checkbox"/> Ja, ik heb het wel eens gebruikt
	<input type="checkbox"/> Ja, ik gebruik het regelmatig

Nu volgen de inhoudelijke vragen. Er wordt hierbij gesproken over externe effecten. In deze enquête wordt aandacht besteed aan drie aspecten hiervan:

Luchtkwaliteit - Dit is afhankelijk van de uitstoot van uw auto. Deze uitstoot is gerelateerd aan bijvoorbeeld snelheid, rijstijl en wegtype. Ook de achtergrondconcentratie (hoeveelheid vervuiling van andere bronnen) is van belang.

Geluidsoverlast - Dit is afhankelijk van de mate waarin mensen hinder ondervinden van geluid. Dit is afhankelijk van bijvoorbeeld wegtype, bevolkingsdichtheid en achtergrondgeluid.

Verkeersveiligheid - Dit kan worden beperkt door bepaalde kwetsbare gebieden te mijden. Denk hierbij aan gebieden met hoge concentraties voetgangers of overstekende fietsers.

5.	Wanneer u auto rijdt, zou u dan prijs stellen op een navigatiesysteem?
----	--

<input checked="" type="checkbox"/>	Nee, nooit
<input checked="" type="checkbox"/>	Ja, in sommige gevallen
<input checked="" type="checkbox"/>	Ja, altijd
<input checked="" type="checkbox"/>	Geen idee

6. Geef aan hoe belangrijk u de volgende aspecten van uw rit vindt.		Niet belangrijk	Heel belangrijk	Geen mening
Reistijd		<input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Brandstofkosten		<input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Luchtkwaliteit		<input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Geluidsoverlast		<input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Verkeersveiligheid		<input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Uitzicht langs de route		<input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input checked="" type="checkbox"/> <input checked="" type="checkbox"/> <input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

7.	<p>De huidige navigatiesystemen geven u vaak de snelste of kortste route. In de toekomstige situatie is mogelijk om ook rekening te houden met externe effecten zoals luchtkwaliteit, geluidsoverlast en verkeersveiligheid.</p> <p>Geeft hieronder aan welke aspecten u graag terug zou zien in uw navigatiesysteem naast de snelste/kortste route (meerdere antwoorden mogelijk).</p>
	<input type="checkbox"/> Luchtkwaliteit

<input type="checkbox"/>	Geluidsoverlast
<input type="checkbox"/>	Verkeersveiligheid
<input type="checkbox"/>	Geen van bovenstaande

Het restant van de vragen gaat over een navigatiesysteem dat is ingericht zoals u bij bovenstaande vraag heeft geantwoord. Dus een navigatiesysteem dat naast de snelste route rekening houdt met de gekozen aspecten. Houd u dit daarom in gedachten.

8.	Op het moment kost een basis navigatiesysteem voor Europa €150. Hoeveel euro bent u bereid te betalen voor een uitbreiding met de functionaliteiten die u bij de vorige vraag heeft ingevuld?
	<input type="text"/>

De volgende vragen gaan over de bereidheid om langer te reizen ten gunste van de door u gekozen negatieve externe effecten. Dit veroorzaakt dus:

- Betere luchtkwaliteit
- en/of
- Minder geluidsoverlast
- en/of
- Grotere verkeersveiligheid

9.	Veronderstel dat u met de auto een familielid gaat bezoeken. Normaal kost deze rit u anderhalf uur. Uw navigatiesysteem geeft een route aan die langer duurt dan anderhalf uur, maar deze route vermindert de negatieve externe effecten. Hoeveel extra tijd bent u bereid te rijden om deze vermindering te bereiken?
----	--

<input type="checkbox"/>	Ik ben hier niet toe bereid
<input type="checkbox"/>	Ik wil maximaal 1 uur en 40 minuten reizen
<input type="checkbox"/>	Ik wil maximaal 1 uur en 50 minuten reizen
<input type="checkbox"/>	Ik wil maximaal 2 uur reizen
<input type="checkbox"/>	Ik ben bereid langer dan 2 uur te reizen

10.	Veronderstel dat u met de auto naar het zwembad in de stad reist. Normaal kost deze rit u een half uur. Uw navigatiesysteem geeft een route aan die langer duurt dan een half uur, maar deze route vermindert de negatieve externe effecten. Hoeveel extra tijd bent u bereid te rijden om deze vermindering te bereiken?
<input type="checkbox"/>	Ik ben hier niet toe bereid
<input type="checkbox"/>	Ik wil maximaal 35 minuten reizen
<input type="checkbox"/>	Ik wil maximaal 40 minuten reizen
<input type="checkbox"/>	Ik wil maximaal 45 minuten reizen
<input type="checkbox"/>	Ik ben bereid langer dan 45 minuten te reizen

11.	Veronderstel dat u met de auto uw dagelijkse reis naar het werk maakt. Normaal kost deze rit u anderhalf uur. Uw navigatiesysteem geeft een route aan die langer duurt dan anderhalf uur, maar deze route vermindert de negatieve externe effecten. Hoeveel extra tijd bent u bereid te rijden om deze vermindering te bereiken?
<input type="checkbox"/>	Ik ben hier niet toe bereid
<input type="checkbox"/>	Ik wil maximaal 1 uur en 40 minuten reizen
<input type="checkbox"/>	Ik wil maximaal 1 uur en 50 minuten reizen

	<input type="checkbox"/> Ik wil maximaal 2 uur reizen
	<input type="checkbox"/> Ik ben bereid langer dan 2 uur te reizen

12.	Veronderstel dat u met de auto uw dagelijkse reis naar het werk maakt. Normaal kost deze rit u een half uur. Uw navigatiesysteem geeft een route aan die langer duurt dan een half uur, maar deze route vermindert de negatieve externe effecten. Hoeveel extra tijd bent u bereid te rijden om deze vermindering te bereiken?
	<input type="checkbox"/> Ik ben hier niet toe bereid
	<input type="checkbox"/> Ik wil maximaal 35 minuten reizen
	<input type="checkbox"/> Ik wil maximaal 40 minuten reizen
	<input type="checkbox"/> Ik wil maximaal 45 minuten reizen
	<input type="checkbox"/> Ik ben bereid langer dan 45 minuten te reizen

13.	Heeft u nog verdere op- of aanmerkingen dan kunt u deze hier achterlaten:
	

14.	Wilt u op de hoogte blijven van de resultaten, laat dan hier uw mailadres achter:
	<input type="text"/>

English version

Welcome, at this questionnaire. This questionnaire is set up for a research project to new possible types of navigation systems. The questionnaire will take you less than 10 minutes.

Your answers will be dealt with anonymous. The questions can be answered without considering technical possibilities and impossibilities.

You could give your e-mail address at the end of the questionnaire, if you are interested in the results of this research project. If you leave your e-mail address, the research report will be send to you at the end of January.

Before questions concerning the content are asked, a few questions about your personal situation will be asked.

1 What is your age?

0-18

18-29

30-39

40-49

50-59

60-74

75+

2 What is your sex?

Male

Female

3 How often do you drive a car?

Several times a week

Several times a month

Several times a year

Never

4 Do you have any experience using a navigation system as driver?

No

Yes, I have used it sometimes

Yes, I use the navigation systems regularly

The questions concerning the content will follow now. In this question the term extern effects will be used. Extern effect can be divided into three aspects:

Air quality – The air quality is depended of the emission of your car. The emission is related to for example the speed, driving behavior and road type. The environmental air pollution is also an important aspect of air quality.

Noise – The noise is depended of the degree in which people are inconvenience with the sound. This is depended of for example the road type, density of the population and environmental sound.

Traffic safety – Traffic safety can be reduced by avoiding certain areas. Think of areas with high concentrations of pedestrians or cyclists.

5 When driving in a car, would you like to have a navigation system?

No, never

Yes, sometimes

Yes, always

I do not know

6 Rate the importance of different aspects of your trip on a scale from 1 to 6.

Travel time

Fuel costs

Air pollution

Noise pollution

Traffic safety

View along the route

7 The current navigation systems provide the fastest route. In the future, it is also possible to consider the air quality, traffic safety and the noise pollution. Indicate below which aspect(s) you prefer besides the fastest route in a navigation system (multiple answers are possible).

Air quality

Traffic safety

Noise pollution

None of these aspects

The next questions will be about a navigation system which contains the preferred aspect indicated at the previous question. Suppose you have indicated the first box, the next questions will be about a navigation system that besides providing the fastest route also concerns the air quality. Remember therefore your answer to the previous question.

8 Currently, a basic navigation system for Europe costs 150 euro. How much extra would you be willing to pay for the system you indicated above as most preferable?

...

The following questions are about the willingness to take an other route that reduces the external effects. The external effects considers in these questions are the chosen aspect of question 7.

Suppose you are going to visit some relative. Normally this trip will take one hour and a half by car. The navigation system provides you an route which takes longer than one hour and a half, but the trip reduces the negative external effects

9 How long are you willing to reroute if this reduce external effects?

I am not willing to reroute

I am only willing to reroute if the new route takes me less than 1 hour and 40 minutes

I am only willing to reroute if the new route takes me less than 1 hour and 50 minutes

I am only willing to reroute if the new route takes me less than 2 hour

I am willing to reroute if the new route takes me more than 2 hour

Suppose you are going towards the swimming pool in your city by car. Normally this trip takes you 30 minutes. Your navigation system provides an route which takes longer than one hour. But the provided trip reduces the negative external effects.

10 How long are you willing to reroute if this reduce external effects?

I am not willing to reroute

I am only willing to reroute if the new route takes me less than 35 minutes

I am only willing to reroute if the new route takes me less than 40 minutes

I am only willing to reroute if the new route takes me less than 45 minutes

I am willing to reroute if the new route takes me more than 45 minutes longer

Suppose you are traveling toward your job. Normally this trip takes one hour and a half by car. Your navigation system provides a route which takes longer than one hour and a half by car. But the provided trip reduces the negative external effects.

11 How long are you willing to reroute if this reduce external effects?

I am not willing to reroute

I am only willing to reroute if the new route takes me less than 1 hour and 40 minutes

I am only willing to reroute if the new route takes me less than 1 hour and 50 minutes

I am only willing to reroute if the new route takes me less than 2 hour

I am willing to reroute if the new route takes me more than 2 hour

Suppose you are traveling toward your job. Normally this trip takes 30 minutes by car. Suppose the navigation system provides you an route which takes longer than one hour by car. But the provided trip reduces the negative external effects.

12 How long are you willing to reroute if this reduce external effects?

I am not willing to reroute

I am only willing to reroute if the new route takes me less than 35 minutes

I am only willing to reroute if the new route takes me less than 40 minutes

I am only willing to reroute if the new route takes me less than 45 minutes

I am willing to reroute if the new route takes me more than 45 minutes longer

13 Do you have any remarks or comments?

...

14 Would you like to be kept up to date on the results, please leave your e-mail address here.

...

Appendix B – Formulas to determine the indicators

The formulas used to determine the indicators for the impact assessment are described in this appendix.

Air indicator

The Air indicator is calculated on the basis of the concentration NO_2 and PM_{10} . These concentration are calculated using the formula of CAR. These concentrations represents the estimated year average concentration on one spot. Therefore is this concentration multiplied by the length of the link to calculate the link concentration. Metis do not want to minimize the total air pollution but the bother of the air pollution, therefore are the link concentrations multiplied by a bother measure. The values of the bother measure are described in Chapter Impact Assessment. The Air indicator is calculated per link by:

$$I_{AIR} = (C_{PM10} + C_{NO2}) \cdot LinkLength \cdot BM$$

- I_{AIR} : Indicator Air per link
- C_{PM10} : Yearly average concentration of PM_{10}
- C_{NO2} : Yearly average concentration of NO_2
- BM : Bother measure

The formulas used for determine the yearly concentration PM_{10} and NO_2 are all derived from InfoMil (2007). The average year concentration of PM_{10} is calculated by:

$$C_{PM10} = CT_{PM10} + CE_{PM10}$$

- C_{PM10} : Yearly average concentration of PM_{10}
- CT_{PM10} : Yearly average concentration of PM_{10} produced by traffic
- CE_{PM10} : Yearly environmental average concentration of PM_{10}

It is assumed that no double counts of environmental concentrations and concentration produced by traffic will appear in the developed network. Therefore, the total amount is just the sum of the environmental concentration and the concentration produced by the traffic. The average year concentration of NO_2 is a bit more difficult, see the formula below:

$$C_{NO2} = \frac{E_{NO2}}{E_{NOx}} \cdot CT_{NOx} + \frac{B(CE_{O3}) \cdot CT_{NOx} \cdot \left(1 - \frac{E_{NO2}}{E_{NOx}}\right)}{CT_{NOx} \cdot \left(1 - \frac{E_{NO2}}{E_{NOx}}\right) + K} + CE_{NO2}$$

- C_{NO2} : Yearly average concentration NO_2 ($\mu g/m^3$)
- E_{NO2} : Emission NO_2 ($\mu g/m/s$)
- E_{NOx} : Emission NO_x ($\mu g/m/s$)
- CT_{NO2} : Yearly average concentration of PM_{10} produced by traffic ($\mu g/m^3$)
- CE_{NO2} : Yearly environmental average concentration of PM_{10} ($\mu g/m^3$)
- CE_{O3} : Yearly environmental average concentration of O_3 ($\mu g/m^3$) (40 is chosen)
- B, K : Parameters determined by InfoMil (2007), chosen values 5 and 100.

The yearly amount of concentration produced by the traffic can be calculated with the following formula for both PM_{10} and NO_2 :

$$CT_{PM10} = 0.62 \cdot E \cdot \theta \cdot F_b \cdot F_{local}$$

- CT_X : Yearly concentration of X produced by traffic ($\mu\text{g}/\text{m}^3$)
 F_b : Tree factor
 F_{local} : Local wind factor
 θ : Diluting factor

The emission can be calculated using the formula below. The other parameters: F_b , F_{local} and θ are approximated according to InfoMil (2007).

$$E = \frac{1000 \cdot N}{24 \cdot 3600} \left[(1 - FS) \left((1 - (F_m + F_v + F_b)) E_p + F_m E_m + F_v E_v + F_b E_b \right) + FS \left((1 - (F_m + F_v + F_b)) E_{p,d} + F_m E_{m,d} + F_v E_{v,d} + F_b E_{b,d} \right) \right]$$

- E : Emission ($\mu\text{g}/\text{m}/\text{s}$)
 N : Amount of vehicles every twenty four hours (24 hours^{-1})
 FS : Fraction stagnated traffic
 F_{medium} : Fraction medium vehicles
 F_{heavy} : Fraction heavy vehicles
 F_{busses} : Fraction busses
 E_{light} : Emission factor for light vehicles (g/km)
 E_{medium} : Emission factor for medium vehicles (g/km)
 E_{heavy} : Emission factor for heavy vehicles (g/km)
 E_{busses} : Emission factor for busses (g/km)
 E_{*d} : Emission factor of vehicle type *, of congested traffic (g/km)

Emission factors

The values for the emission factors are displayed in the table below. These values are derived from a research of the emission factors performed by de Lange & Ligterink (2008). The emission factor for the year 2010 are used, the values are given in Table 13, Table 14 and Table 15.

PM ₁₀	City normal	City free flow	Rural road	Highway
E_{light}	0.055	0.054	0.034	0.04
E_{medium}	0.350	0.249	0.223	0.188
E_{heavy}	0.247	0.194	0.190	0.164
E_{busses}	0.412	0.282	0.281	0.202

Table 13: The emission factors PM₁₀ for 2010 in g/km.

NO ₂	City normal	City free flow	Rural road	Highway
E_{light}	0.1	0.1	0.06	0.07
E_{medium}	0.63	0.45	0.35	0.26
E_{heavy}	0.53	0.38	0.37	0.27
E_{busses}	0.8	0.58	0.51	0.3

Table 14: The emission factors NO₂ for 2010 in g/km.

NO _x	City normal	City free flow	Rural road	Highway
E_{light}	0.42	0.45	0.21	0.21

E_{medium}	8.24	5.9	4.87	3.98
E_{heavy}	7.87	5.66	5.43	4.06
E_{busses}	9.75	7.02	6.04	4.47

Table 15: The emission factors NO_x for 2010 in g/km

Traffic Safety

The appendix discusses the indicators for safety. First, two tables present the indicators used, their meaning and the way they are calculated. Then, the way the data for the network is defined is explained.

The first set of indicators is based on the study of the SWOV (Dijkstra & Drolenga, 2008).

SWOV General road safety indicators		
Number of transitions between road categories limited	Calculate the number of transitions	# < 4 0 # > 4 #-4
Nature of the transition is correct (not more than one step at a time)	Calculate the difference between to following links	Count number of times step size > 1
As few missing road categories as possible	Count the number of categories used	3 – number of categories used
Proportion (in length) of access roads as low as possible	Calculate the length of route on access road	Percentage of total route length
Proportion (in length) of distributor roads as low as possible	Calculate the length of route on distributor road	Percentage of total route length
Travel distance	Calculate total distance	Total distance
Travel time	Calculate travel time	Total travel time
As few turnings as possible across oncoming traffic	The number of left turns made on the route	Not used, since the network is a graph. Therefore, it has no definition of left and right.
Low junction density on distributor road	Count the number of junctions passed	Total number of junctions divided by total distance

Table 16 – SWOV General road safety indicators

The next four characteristics are added in order to include data about the surroundings of the road.

METIS Extra road safety indicators		
Black spots	Count the number and type of black spots	# of black spots + # of black spots with fatalities
Bicycle conditions	Calculate length of different types of bicycle paths multiplied by an impact factor	0 * km's with bicycle path + 1 * km's with bicycle lane + 2 * km's on road cycling
Pedestrian conditions	Calculate number of pedestrian crossings	3 * count of zebra paths + count of pedestrian intersections
Schools	Binary indicator which states if	0 or 1

a schoolzone is present (only used during school hours)

Table 17 – Metis extra road safety indicators

Since the score of safety is a value without a unit, the scores of the different characteristics are only for ranking purposes. In order to be able to compare different routes based on all 12 characteristics used, all scores are standardised using interval standardisation. This way the highest scoring alternative gets a 1 as score, and the lowest scoring alternative gets a 0. There is no weight factor applied, since all characteristics are assumed to be equally important. This assumption has been made because no objective way to rate the different characteristics is available. This way, the maximum score of a route is 12.

Normalising the scores is done using the formula presented below:

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

In this formula, G_{ji} is the standardised score of alternative i for criterion i . C_{ji} is the normal score of alternative i for criterion i . Since it is preferable to associate a high score with high safety, the scores are all inversed in the summation for the total score, as can be seen in the next presentation.

$$S_j = 12 - \sum_{i=1}^{12} G_{ji}$$

Remarks

Based on the SWOV report (Dijkstra & Drolenga, 2008), also vehicle specific criteria should be used. In the model used, this was not possible, therefore it is not used. This results in a static safety level for each route, whereas in reality the safety level will depend on the number of cars on a stretch of road.

When realising Metis, this could be taken into account by using historical data to predict certain parameters. However, also very accurate real time data would be needed to implement all criteria. For instance the Potential Collision Energy (PCE) which is calculated based on the encountering vehicles and their weights and speeds.

Traffic noise

The indicator for traffic noise is the total amount of highly annoyed people. This amount is calculated with the following formula:

$$TN = H \cdot P$$

TN: Indicator traffic noise, the total amount of highly annoyed people

H: Fraction highly annoyed people

P: Amount of people around the road

The fraction highly annoyed people can be derived with the following formula (European Commission, 2002):

$$H = 9.868 \cdot 10^{-4} \cdot (L_{den} - 42)^3 - 1.436 \cdot 10^{-2} \cdot (L_{den} - 42)^2 + 0.5118 \cdot (L_{den} - 42)$$

L_{den} : The total amount of traffic sound in dB_A .

L_{den} is a measure to express the noise and is defined in terms of the average levels during day, evening and night. A penalty of 5 dB is applied to noise in the evening and a 10dB penalty is applied to noise in the night. The definition of L_{den} in terms of the day noise (LD), evening noise (LE) and night noise (LN) is given below:

$$L_{den} = 10 \cdot \log \left[\frac{12}{24} \cdot 10^{LD/10} + \frac{4}{24} \cdot 10^{(LE+5)/10} + \frac{8}{24} \cdot 10^{(LN+10)/10} \right]$$

A formula from Gündoğru et al (2005) is used to calculate the traffic noise at day, evening and night. In this formula is the traffic noise depended of the traffic volume, the traffic composition, the road gradient and the ratio of building height to the road width in m/m. The formula is formulated below.

$$L_{eq} = 60.3 \left(\log \left(\frac{n_{car} \cdot 10^{7.5} + n_{busses} \cdot 10^{8.5} + n_{trucks} \cdot 10^{8.5}}{n_{total}} \right) \right)^{0.14} G^{0.016} R^{0.0046}$$

L_{eq} : The average sound pressure level in dB_A

N_{total} : The total traffic flow

N_{car} : Amount of cars

N_{busses} : Amount of busses

N_{trucks} : Amount of trucks

G: Road gradient in m/m

R: Ratio of building height to the road with (including sidewalk and front gardens)

A road gradient of 1 is assumed because in the Netherlands is very flat. The ratio of building height is difficult to determine, but the value does not have much influence on the total. For instance $10^{0.0046} = 1.01$ and $0.1^{0.0046} = 0.99$ so the ratio of building heights is fixed at 1 for each link.

Appendix C – m-files

In this appendix, an overview is given of the m-files used. The m-files: DataNetwork, TravelTime, ShortestRoutes and KShort are not given because these are some basic m-files which are not the key ingredients of Metis. The use of these four m-files are explained briefly. In DataNetwork, the characteristics (amount of nodes, links the demanded on the OD, etc) of the network will be loaded. In TravelTime are the travel times of each link given a certain flow calculated. In ShortestRoutes the shortest routes for the OD pairs will be calculated. In KShort the k shortest routes are calculated, in our case is a value of 10 used for k.

Reference case

The first step is to calculate the values for reference case. In this situation, the steps of the incremental assignment (y) are the general steps, plus the steps later used for the assignment of Metis users. In order to get an equilibrium, the assignment is iterative (Q iterations).

```
function [Results] = Incremental(FM)
%FM = Fraction Metis Users

Network = DataNetwork;
Infinity = Network.Infinity;
Flow=Network.Flow;
y=[(1-FM)*0.3 (1-FM)*0.2 (1-FM)*0.1 (1-FM)*0.1 (1-FM)*0.1 (1-FM)*0.1 (1-FM)*0.05 (1-FM)*0.05 0.4*FM 0.3*FM 0.2*FM 0.1*FM];
Y=length(y);
Q=29;
x=zeros(Q+1,19); %initial flow on links
UsedRoutes=[];

for q=1:Q
    for j=1:Y
        if q >= 2 && j == 1
            UsedRoutes=[];
            UsedRoutesLoads=[];
        end
        Routes= ShortestRoutes(x(q,:));
        NewRoutes=Routes.UsedLinks;
        UsedRoutes=[UsedRoutes; NewRoutes];
        for R = 1:4
            for i=1:19
                x(q+1,i)=y(j)*Flow(R)*NewRoutes(R,i)+x(q+1,i);
            end
            UsedRoutesLoads(j,R)=y(j)*Flow(R);
        end
    end
    x(q+1,:) = (x(q,:) + x(q+1,:))/2;
end
X = x(Q+1,:);
Results.X=X;
```

Once the flow is calculated (X), the indicators for the different external effects as well as the total travel time are calculated. Since this last part is fairly similar for all types of assignment, it is omitted in the following paragraphs.

```

aa=Kshort(10,X);
a=Network.Alinks;
b=Network.Blinks;
c=Network.Clinks;
d=NoiseIndicator(X);
e=AirIndicator(X);
f=SafetyIndicator(X);
TotalNoise=0;
TotalAir=0;
TotalSafety=0;
TotalTime=0;
for i=1:19
    t(i)=a(i)+c(i)*b(i)*X(i).^(c(i)-1);
    TotalTime=t(i)*X(i)+TotalTime;
    TotalNoise=TotalNoise+d.Noise(i);
    TotalAir=TotalAir+e.Air(i);
end
%Calculate how much traffic is assigned to different routes in order to calculate total safety
SortedUsedRoutes = zeros(Y,19,4); %All routes used in different assignment steps (8 incremental, 1 metis)
for s=1:Y %Loop for all incremental steps
    SortedUsedRoutes(s,:,1) = UsedRoutes(4*(s-1)+1,:);
    SortedUsedRoutes(s,:,2) = UsedRoutes(4*(s-1)+2,:);
    SortedUsedRoutes(s,:,3) = UsedRoutes(4*(s-1)+3,:);
    SortedUsedRoutes(s,:,4) = UsedRoutes(4*(s-1)+4,:);
end

RouteSafety = zeros(1,4); %Total Safety on a route
for i=1:4 %Loop ODS
    for s = 1:Y %Loop for all assigninment steps
        for k = 1:10 %Loop through possible shortest routes
            if SortedUsedRoutes(s,:,i) == aa.UsedLinks(k,:,i)
                RouteSafety(i) = RouteSafety(i) + f.Safety(i,k)*UsedRoutesLoads(s,i);
            end
        end
    end
end
end

%Total score is sum of routes devided by 1800 (total trips)
TotalSafety = sum(RouteSafety)/1800;

Results.TotalTime=TotalTime;
Results.x=X;
Results.TotalNoise=TotalNoise;
Results.TotalAir=TotalAir;
Results.TotalSafety=TotalSafety;
Results.UsedRoutes=UsedRoutes;
%Results.UsedMRoutes=UsedMRoutes;
Results.SortedUsedRoutes=SortedUsedRoutes;
Results.Total= [TotalTime TotalAir TotalNoise TotalSafety];

```

Air Quality

The assignment for Air Quality start just like the reference case. However, the extra iterative step is omitted and the result of the reference case is used as primary input. Also, the Metis users are separated from the non-Metis users. In another incremental assignment (M), the Metis users are added to the system.

```
ExtraTime=0.33; %Allowable extra travel time by questionnaire 33%
%Calculating actual route times
aa=Kshort(k,X);
TT=Traveltime(X);
RouteTimes = zeros(4,k);
for i=1:4
    for ks=1:k
        for j=1:19
            RouteTimes(i,ks)=TT.t(j)*UsedLinks(ks,j,i)+RouteTimes(i,ks);
        end
    end
end
for i=1:4
    for ks=1:k
        for j=1:19
            if RouteTimes(i,ks) == 0
                RouteTimes(i,ks) = Infinity;
            end
        end
    end
end
%Selecting routes wit route times that lie witin limits
for i=1:4
    r(i)=1;
    [C I]=min(RouteTimes(i,:));
    MetisRoutes(r(i),:)=UsedLinks(I,:,i);
    for j=1:k
        if RouteTimes(i,j)<(1+ExtraTime)*RouteTimes(i,I)
            r(i)=r(i)+1;
            MetisRoutes(r(i),:)=UsedLinks(j,:,i);
        end
    end
end
for h=1:M
    % Determine Metis values for routes
    b=AirIndicator(X);
    Air=zeros(4,k);
    for i=1:4
        for j=1:r(i)
            for n=1:19
                Air(i,j)=Air(i,j)+b.Air(n)*MetisRoutes(j,n,i); % determine air on each route
            end
        end
    end
    for i=1:4
        for j=1:k
            if Air(i,j)==0
                Air(i,j)=Infinity; %set value to infinity for too long routes
            end
        end
    end
    %Select optimal route
    for i=1:4
```

```

[C I]=min (Air (i,:));
RouteChoice(i)=I;
end
%Calculate new flows
UsedMRoutes=[];
for i=1:4
    UsedMRoutes=[UsedMRoutes;MetisRoutes(RouteChoice(i),:,i)];
    for n=1:19
        X(n)=X(n)+m(h)*Flow(i)*MetisRoutes(RouteChoice(i),n,i);
    end
    UsedRoutesLoads(Y+h,i)=m(h)*Flow(i);
end
end
end

```

In order to calculate air quality, a separate m-file is used:

```

for i=1:19
    if x(i)==0
        Air(i)=0;
    else
        %amount of traffic / 3600 and not 24*3600 because hour average is used
        Epm(i)=(1000*x(i))/3600*(light(i)*pmlight(i)+ medium(i)*pmemium(i)+heavy(i)*pmeheavy(i)+busses(i)*pmebusses(i));
        En2(i)=(1000*x(i))/3600*(light(i)*nelight(i)+ medium(i)*nemedium(i)+heavy(i)*neheavy(i)+busses(i)*nebusses(i));
        Enx(i)=(1000*x(i))/3600*(light(i)*nxelight(i)+ medium(i)*nxemedium(i)+heavy(i)*nxehavy(i)+busses(i)*nxebusses(i));
        PM(i)=0.62*Epm(i)*diluting(i)*tree(i)*regio*bother(i);
        CTNx(i)=0.62*Enx(i)*diluting(i)*tree(i)*regio;
        NO2(i)=En2(i)/Enx(i)*CTNx(i)+(0.6*40*CTNx(i)*(1-(En2(i)/Enx(i))))/(CTNx(i)*(1-(En2(i)/Enx(i)))+100)*bother(i);
        Air(i)=(NO2(i)+PM(i))*km(i);
    end
end
end
Indicator.Air=Air;

```

Traffic safety

Like with the air quality is the assignment for traffic start just like the reference case. However, the extra iterative step is omitted and the result of the reference case is used as primary input. Also, the Metis users are separated from the non-Metis users. In another incremental assignment (M), the Metis users are added to the system. Another additional thing about traffic safety is that the traffic safety cannot be calculated for each link separately, but for each route. Therefore an other optimization strategy is used. Also, the safety is maximized in stead of minimized.

```

ExtraTime=0.33; %Allowable extra travel time by questionnaire
%Calculating actual route times
aa=Kshort(k,X);
TT=Traveltime(X);
RouteTimes = zeros(4,k);
for i=1:4
    for ks=1:k
        for j=1:19
            RouteTimes(i,ks)=TT.t(j)*UsedLinks(ks,j,i)+RouteTimes(i,ks);
        end
    end
end
end
for i=1:4
    for ks=1:k
        for j=1:19
            if RouteTimes(i,ks) == 0
                RouteTimes(i,ks) = Infinity;
            end
        end
    end
end
end

```

```

end
end
%Selecting routes wit route times that lie witin limits
for i=1:4
r(i)=1;
[C I]=min(RouteTimes(i,:));
MetisRoutes(r(i),:)=UsedLinks(i,:i);
for j=1:k
if RouteTimes(i,j)<(1+ExtraTime)*RouteTimes(i,I)
r(i)=r(i)+1;
MetisRoutes(r(i),:)=UsedLinks(j,:i);
end
end
end
for h=1:M
% Determine best Metis route
b=SafetyIndicator(X);
Safety=b.Safety;
for i=1:4
for ks=1:r(i)
for j=1:k
if MetisRoutes(ks,:)=UsedLinks(j,:i);
MetisRouteSafety(ks,i) = Safety(i,j);
end
end
end
end
%Select optimal route
for i=1:4
[C I]=max (MetisRouteSafety(:,i));
RouteSafety(i)=C;
RouteChoice(i)=I;
end
%Calculate new flows
UsedMRRoutes=[];
for i=1:4
UsedMRRoutes=[UsedMRRoutes;MetisRoutes(RouteChoice(i),:,i)];
for n=1:19
X(n)=X(n)+m(h)*Flow(i)*MetisRoutes(RouteChoice(i),h,i);
end
UsedRoutesLoads(Y+h,i)=m(h)*Flow(i);
end
end
end

```

In order to calculate the traffic safety the following m-file is used:

```

for hb=1:od %loop OD-relations
for k=1:ks %loop routes
for n=1:ns %loop links
i = K(hb,n,k);
if i==0
break
else
%Link based attributes
SafetyLength(hb,k)=SafetyLength(hb,k)+length(i);
SafetyTraveltime(hb,k)=SafetyTraveltime(hb,k)+time(i);
SafetyETW(hb,k)=SafetyETW(hb,k)+etw(i);
SafetyGOW(hb,k)=SafetyGOW(hb,k)+gow(i);
SafetyCrossings(hb,k)=SafetyCrossings(hb,k)+crossings(i);
SafetyBicycles(hb,k)=SafetyBicycles(hb,k)+0*bcpath(i)+1*bclane(i)+2*bcroad(i);
SafetySchool(hb,k)=SafetySchool(hb,k)+school(i);

```

```

SafetyPedestrian(hb,k)=SafetyPedestrian(hb,k)+pedestrian(i);
SafetyBlackSpots(hb,k)=SafetyBlackSpots(hb,k)+blackspots(i);
%Route based attributes
SafetyCatCountDum(hb,k,category(i)) = 1; % Dummy to check whether a category is used or not
if n > 2
    if category(i)~= category(i-1)
        SafetyTranCount(hb,k)= SafetyTranCount(hb,k)+1; %Number of category transitions
        if abs(category(i) - category(i-1)) > 1
            SafetyTranWrong(hb,k)= SafetyTranWrong(hb,k)+1; %Number of transitions >1 category level
        end
    end
end
end
end
if K(hb,1,k) ~= 0
    SafetyCatCount(hb,k)=3-sum(SafetyCatCountDum(hb,k,:)); % Number of categories not used
    SafetyCrossings(hb,k)= SafetyCrossings(hb,k)/SafetyLength(hb,k);
    SafetyPercentageETW(hb,k)=SafetyETW(hb,k)/SafetyLength(hb,k);
    SafetyPercentageGOW(hb,k)=SafetyGOW(hb,k)/SafetyLength(hb,k);
    dummy = 2*(SafetyCatCount(hb,k) - 1); % number of transitions minimal needed
    if SafetyTranCount(hb,k) <= dummy
        SafetyTranCount(hb,k) = 0;
    else
        SafetyTranCount(hb,k) = SafetyTranCount(hb,k) - dummy;
    end
end
end
% Normalizing scores
for k=1:ks % loop for all routes
    if K(hb,1,k) ~= 0
        Indicator.SafeScoreLength(hb,k) = (SafetyLength(hb,k)-min(SafetyLength(hb,1:hbl(hb))))/(max(SafetyLength(hb,1:hbl(hb)))-min(SafetyLength(hb,1:hbl(hb))));
        Indicator.SafeScoreTraveltime(hb,k) = (SafetyTraveltime(hb,k)-min(SafetyTraveltime(hb,1:hbl(hb))))/(max(SafetyTraveltime(hb,1:hbl(hb)))-min(SafetyTraveltime(hb,1:hbl(hb))));
        Indicator.SafeScorePercentageETW(hb,k) = (SafetyPercentageETW(hb,k)-min(SafetyPercentageETW(hb,1:hbl(hb))))/(max(SafetyPercentageETW(hb,1:hbl(hb)))-min(SafetyPercentageETW(hb,1:hbl(hb))));
        Indicator.SafeScorePercentageGOW(hb,k) = (SafetyPercentageGOW(hb,k)-min(SafetyPercentageGOW(hb,1:hbl(hb))))/(max(SafetyPercentageGOW(hb,1:hbl(hb)))-min(SafetyPercentageGOW(hb,1:hbl(hb))));
        Indicator.SafeScoreCrossings(hb,k) = (SafetyCrossings(hb,k)-min(SafetyCrossings(hb,1:hbl(hb))))/(max(SafetyCrossings(hb,1:hbl(hb)))-min(SafetyCrossings(hb,1:hbl(hb))));
        Indicator.SafeScoreBicycles(hb,k) = (SafetyBicycles(hb,k)-min(SafetyBicycles(hb,1:hbl(hb))))/(max(SafetyBicycles(hb,1:hbl(hb)))-min(SafetyBicycles(hb,1:hbl(hb))));
        if max(SafetySchool(hb,1:hbl(hb)))-min(SafetySchool(hb,1:hbl(hb)))== 0 % workaround since there is only 1 schoolzone which is not reachable when travelling to destination 3
            Indicator.SafeScoreSchool(hb,k) = (SafetySchool(hb,k)-min(SafetySchool(hb,1:hbl(hb))))/(max(SafetySchool(hb,1:hbl(hb)))-min(SafetySchool(hb,1:hbl(hb))));
        else
            Indicator.SafeScoreSchool(hb,k) = 0;
        end
        Indicator.SafeScorePedestrian(hb,k) = (SafetyPedestrian(hb,k)-min(SafetyPedestrian(hb,1:hbl(hb))))/(max(SafetyPedestrian(hb,1:hbl(hb)))-min(SafetyPedestrian(hb,1:hbl(hb))));
        if max(SafetyCatCount(hb,1:hbl(hb)))-min(SafetyCatCount(hb,1:hbl(hb))) ==0 % workaround to prevent error in case this variable is equal for all alternatives
            Indicator.SafeScoreCatCount(hb,k) = (SafetyCatCount(hb,k)-min(SafetyCatCount(hb,1:hbl(hb))))/(max(SafetyCatCount(hb,1:hbl(hb)))-min(SafetyCatCount(hb,1:hbl(hb))));
        else
            Indicator.SafeScoreCatCount(hb,k) = 0;
        end
        Indicator.SafeScoreTranCount(hb,k) = (SafetyTranCount(hb,k)-min(SafetyTranCount(hb,1:hbl(hb))))/(max(SafetyTranCount(hb,1:hbl(hb)))-min(SafetyTranCount(hb,1:hbl(hb))));
        if max(SafetyTranWrong(hb,1:hbl(hb)))-min(SafetyTranWrong(hb,1:hbl(hb))) == 0 %workaround since number of wrong transitions can be zero for all routes

```

```

Indicator.SafeScoreTranWrong(hb,k) = (SafetyTranWrong(hb,k)-
min(SafetyTranWrong(hb,1:hbl(hb))))/(max(SafetyTranWrong(hb,1:hbl(hb)))-min(SafetyTranWrong(hb,1:hbl(hb))));
else
Indicator.SafeScoreTranWrong(hb,k) = 0;
end
Indicator.SafeScoreBlackSpots(hb,k) = 0;
if max(SafetyBlackSpots(hb,1:hbl(hb))) > 0
Indicator.SafeScoreBlackSpots(hb,k) = (SafetyBlackSpots(hb,k)-
min(SafetyBlackSpots(hb,1:hbl(hb))))/(max(SafetyBlackSpots(hb,1:hbl(hb)))-min(SafetyBlackSpots(hb,1:hbl(hb))));
end
% Calculate total score, use "1 - score" so high scores indicate high safety
Indicator.Safety(hb,k) = 12 -
(Indicator.SafeScoreLength(hb,k)+Indicator.SafeScoreTravelttime(hb,k)+Indicator.SafeScorePercentageETW(hb,k)+Indicator.SafeScorePerce
ntageGOW(hb,k)+Indicator.SafeScoreCrossings(hb,k)+Indicator.SafeScoreBicycles(hb,k)+Indicator.SafeScoreSchool(hb,k)+Indicator.SafeScor
ePedestrian(hb,k)+Indicator.SafeScoreCatCount(hb,k)+Indicator.SafeScoreTranCount(hb,k)+Indicator.SafeScoreTranWrong(hb,k)+Indicator.
SafeScoreBlackSpots(hb,k));
end
end
end
end

```

Traffic Noise

Again the assignment of the traffic start just like the reference case. However, the extra iterative step is omitted and the result of the reference case is used as primary input. Also, the Metis users are separated from the non-Metis users. In another incremental assignment (M), the Metis users are added to the system.

```

ExtraTime=0.33; %Allowable extra travel time by questionaire
%Calculating actual route times
aa=Kshort(k,X);
TT=Traveltime(X);
RouteTimes = zeros(4,k);
for i=1:4
for ks=1:k
for j=1:19
RouteTimes(i,ks)=TT.t(j)*UsedLinks(ks,j,i)+RouteTimes(i,ks);
end
end
end
for i=1:4
for ks=1:k
for j=1:19
if RouteTimes(i,ks) == 0
RouteTimes(i,ks) = Infinity;
end
end
end
end
%Selecting routes wit route times that lie witin limits
for i=1:4
r(i)=1;
[C I]=min(RouteTimes(i,:));
MetisRoutes(r(i),:,i)=UsedLinks(I,.,i);
for j=1:k
if RouteTimes(i,j)<(1+ExtraTime)*RouteTimes(i,I)
r(i)=r(i)+1;
MetisRoutes(r(i),:,i)=[UsedLinks(j,.,i)];
end
end
end
end

```

```

for h=1:M
% Determine Metis values for routes
b=NoiseIndicator(X);
Noise=zeros(4,k);
for i=1:4
    for j=1:r(i)
        for n=1:19
            Noise(i,j)=Noise(i,j)+b.Noise(n)*MetisRoutes(j,n,i); % determine noise on each route
        end
    end
end
for i=1:4
    for j=1:k
        if Noise(i,j)==0
            Noise(i,j)=Infinity; %set value to infinity for too long routes
        end
    end
end
%Select optimal route
for i=1:4
    [C I]=min(Noise(i,:));
    RouteChoice(i)=I;
end
%Calculate new flows
UsedMRRoutes=[];
for i=1:4
    UsedMRRoutes=[UsedMRRoutes;MetisRoutes(RouteChoice(i),:,i)];
    for n=1:19
        X(n)=X(n)+m(h)*Flow(i)*MetisRoutes(RouteChoice(i),n,i);
    end
    UsedRoutesLoads(Y+h,i)=m(h)*Flow(i);
end
end
end

```

In order to calculate the traffic noise the following m-file is used:

```

for i=1:19
    light(i)=NoiseData(i,1);
    medium(i)=NoiseData(i,2);
    heavy(i)=NoiseData(i,3);
    busses(i)=NoiseData(i,4);
    people(i)=NoiseData(i,5);
    if x(i)==0
        H(i)=0;
        Noise(i)=H(i)*people(i);
    else
        Leq(i)=60.3*(log10((x(i)*light(i)*10^7.5+(busses(i)+medium(i)+heavy(i))*x(i)*10^8.5)/x(i)))^0.14;
        H(i)=(9.868*10^(-4))*(Leq(i)-42)^3-(1.436*10^(-2))*(Leq(i)-42)^2+0.5118*(Leq(i)-42);
        Noise(i)=H(i)*people(i);
    end
end
end
Indicator.Noise=Noise;

```

