



Intelligent Route Guidance for Heavy Vehicles

FINAL SUMMARY REPORT



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LIST OF ABBREVIATIONS

SWIS	Straßenwetter-Informationssystem (Road weather information system)
TMC	Traffic Message Channel
HMI	Human Machine Interface
HGV	Heavy Goods Vehicle
WIM	Weigh in Motion
VSL	Value of Statistical Life
VMS	Vehicle Message Sign
PMS	Pavement Management Systems
ADAS	Advanced Driver Assistance System
GSM	Global System for Mobile Communication
GPRS	General Packet Radio Services
GPS	Global Positioning System
RDS	Radio Data System
TMC	Traffic Message Channel
FCD	Floating Car Data
ESAL	Equivalent Standard Axle Load (10 t or 100 kN)
EALF	Equivalent Axle Load Factor
WTP	Willingness to pay

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Executive Summary

The aim of the HEAVYROUTE project was to develop a first prototype of an advanced route guidance and driver support system for Heavy Good Vehicles (HGVs), based on the improvement in the generation and usage of digital maps, as a tool for deriving the safest and the most cost effective routes for road freight transports. As this includes reducing fuel consumption, it also implies a contribution to the reduction of green house gases.

Three main applications were developed based on vehicle/infrastructure interaction models together with detailed data on the vehicle itself, the infrastructure and the traffic. They are:

Pre-trip route planning

The pre-trip route planning is done in two steps. The first step is to derive **allowable (accessible) routes** based on the specific HGV characteristics and considering the preferred networks for HGVs. This requires that all relevant truck attributes are integrated in the digital map.

The second step was then to derive **recommended routes** considering the effects on fuel consumption, safety, environment (noise and emissions), road deterioration, etc. or rather the associated marginal costs that have been established.

For the calculation of the recommended routes, models developed in previous EU projects such as ARTEMIS for fuel consumption and emissions, and HARMONOISE for noise, as well as national models for road degradation and accident risk, were utilised and adapted. All these models require different types of road data for input. This means that access to data in national road databases (in Sweden NVDB) is necessary. For a fully developed European system it is therefore also essential that data collection and data formats should be harmonised and standardised.

All roads in the road network are furthermore divided into “homogeneous” links. A link based cost database including all effects, i.e. fuel consumption and emission costs, road damage costs, accident costs, etc., has been developed for the pre-trip routing application.

Navigation and dynamic on-trip route guidance

The first part of this application is to guide the driver according to the chosen recommended route. The second part is to inform the driver during the journey about important issues and critical situations. More specifically, in the latter case the current speed of the vehicle is compared with a maximum recommended speed calculated for roll-over risk as well as accident risk at black-spots.

A driving simulator study was also carried out to study which type of Human-Machine-Interface (HMI) has the greatest potential to improve safety. Displays showing only a warning symbol for roll-over risk as well as showing both warning symbol and recommended speed for avoiding roll-over were investigated. A comparison was made with the driver behaviour without the support of a warning system. In brief, both experienced and inexperienced drivers gained from having a warning system. It was sufficient to have the warning symbol, but inexperienced drivers preferred to also be given a recommended speed.

Monitoring and management of HGVs at bridges

The aim of this application is to avoid overload of a bridge. Management strategies were developed based on bridge load effect models and traffic micro simulations. When approaching a bridge, which is equipped with so called “Weigh in Motion” (WIM) sensors, the driver is instructed by a Variable Message Sign (VMS) how to drive. The driver may for example be requested to stop, change lane or keep a minimum distance to the vehicle in front.

All the above applications were tested and demonstrated in limited field trials conducted on test routes in Sweden, France and Austria. The purpose of the test in Sweden was to use and evaluate the navigation application, the on-board warning system and the fuel consumption model outcome in field. The evaluation on fuel consumption showed that calculated and actual measured fuel consumption correlated very well and thus could be used for routing. The field tests in France and Austria were done to evaluate traffic regulations due to actual load from HGVs on the bridge.

Social as well as private benefits

Case studies carried out on parts of the Swedish road network demonstrated that different cost functions would change routing and save costs both for users and for society. As is generally accepted, user cost is an important part of the transport cost and will thus strongly affect the routing. This also implies that the approach with a number of allowable routes will not limit efficient routing. However, although uncertain, it was concluded that road authorities are the biggest cost savers with up to 18% renewal cost saved. In the simulation this saving comes at the expense of the operators. It is obvious that the system involves a conflict between private and social interests/objectives. The conflict means that the market will not develop the most beneficial part of the HEAVYROUTE system. The welfare economic optimum can only be reached if incentive schemes are created that move these objectives closer to each other. Some alternative policy scenarios that can be developed to bridge this gap have been discussed.

A number of different alternative scenarios to facilitate the implementation of a HEAVYROUTE system have been identified and considered within the project, such as:

- ▶ Change the preferences of the private operator – *be green with a Heavy Route system.*
- ▶ Tax the polluter (Pigouvian taxes) or subsidise the cleaner producer – *road charging reduction for users of the Heavy Route system.*
- ▶ Lift restrictions (for example weight and dimensions) – *longer and heavier vehicles with a HEAVYROUTE system.*

For moral or market reasons private companies may wish to behave more in line with the social objective – e.g. to behave green. Environmental lobbyist and individual preferences may create an environment where the market rewards firms that behave green. Following the advice on air pollution and accidents in HEAVYROUTE may thus be a prerequisite for better customer relations. The HEAVYROUTE system could be used to monitor this behaviour and used to issue a “Green HEAVYROUTE” certificate. The market for HEAVYROUTE would be limited to the number of operators that chooses to acquire a “Green HEAVYROUTE” certificate.

One could also envisage a system where users of a monitoring scheme of the HEAVYROUTE type could be allowed to pay the tax according to the monitored external cost in HEAVYROUTE (or other system). Other users, which do not have a HEAVYROUTE system, can still pay the tax according to the current blunt average taxation system. Obviously, only users with ‘well behaved’ costs functions will follow the advice of the HEAVYROUTE system. However, this will nevertheless increase the average cost for the users outside the system as the ‘well behaved’ operators will join

the HEAVYROUTE system. A cycle will be created that moves users voluntary into the system with tax differentiation. This will of course have consequences for Governments tax collection which have to be solved. The initial market share of HEAVYROUTE will in this case be limited to operators which today have a higher road tax than their actual social marginal cost.

And finally, a system can be foreseen that allows heavier and longer vehicles on a (limited) road network if their trips are informed by a HEAVYROUTE system. An increase in the length or weight may create an externality per vehicle (road damage, accidents etc). On the other hand the transportation and logistics costs will be reduced as the number of vehicles will be reduced (and probably outweigh the external costs). The legal requirement to allow these longer vehicles could be that they have to follow the advice of the system. In return they will reap the benefit of using longer and heavier vehicles.

1. Introduction

The transport of goods between EU Member states is set to increase by 50% between 2000 and 2020 (Europa, 2007). Road transport – which already conveys more than 70% of goods on land – can be expected to take the main part of this expansion. The increase of Heavy Goods Vehicles (HGVs) on the European road network will obviously have consequences for safety and congestion as well as for the environment. In addition, increasing gross weights and changing load configurations of HGVs are causing accelerated damage of bridges and pavements. Consequently, traffic management problems to maintain safety as well as to reduce congestion and the damage to the infrastructure can be foreseen from the viewpoint of **road operators**.

In addition, **truck operators** face the combined challenges of reducing ever increasing fuel costs, maximising efficiency and profitability whilst maintaining safety. **Truck drivers** have the additional tasks of charting a safe and appropriate route. Finding means to reduce the costs associated with the increasing traffic volumes is a major challenge for the road research community as well as the road authorities and operators.

The FP6 project HEAVYROUTE was based on the belief that one major support for all three of the above mentioned parties could come from the improvement in the generation and usage of maps for trucks in Europe. The use of mapping systems based in satellite guidance has increased dramatically and is providing major benefits to professional drivers. However, there are many stories of drivers finding themselves on inappropriate routes for their vehicle because the systems used were derived for passenger cars.

The aim of the project was to develop a first prototype of an advanced route guidance and driver support system for HGVs, based on the improvement in the generation and usage of digital maps, as a tool for deriving the safest and the most cost effective routes for road freight transports. As this includes reducing fuel consumption, it also implies a reduced impact on climate.

Together with all the major stakeholders, the HEAVYROUTE project worked to provide the tools, the systems and the data collection and interpretation processes that will effectively link Europe's road infrastructure via electronic mapping systems to the truck operators and drivers. This will provide a major boost to the efficiency, profitability and safety of the haulage sector whilst contributing to overall road safety, congestion and infrastructure asset management objectives.

Three main applications were developed based on vehicle/infrastructure interaction models together with detailed data on the vehicle itself, the infrastructure and the traffic.

Pre-trip route planning

Allowable routes were derived based on “HGV specific data” together with physical and legal restrictions on the infrastructure

Recommended routes were then derived based on arguments addressing fuel consumption, emissions, noise, safety, driver comfort and infrastructure maintenance costs.

Driving support

Real time driver warning and recommended driving to avoid critical situations (for example recommended speed to avoid roll-over).

Monitoring and management of HGV's at bridges

Advice on speed, minimum vehicle spacing and/or lane change to keep appropriate loading of bridges

The activities in HEAVYROUTE were focused on the following objectives:

System conception and user requirements

- ▶ Assessment of state-of-the-art in fleet management and HGV guidance systems/services
- ▶ Identifying stakeholder and user requirements on an advanced HGV management and route guidance system
- ▶ Identifying factors that influence the “route optimization”
- ▶ Deriving a system architecture concept

Databases and vehicle/infrastructure interaction models

- ▶ Inventory of available static, periodic and dynamic road, bridge and traffic data in national databases
- ▶ Inventory of available effect models for deriving the “optimum” route and reducing impacts on the infrastructures

Route guidance and driving support

- ▶ Design and development of innovative route guidance and driver support applications for HGVs based on database contents and effect models

Traffic simulation and effects of management strategies

- ▶ Traffic simulation and assessment of possible effects and future scenarios from traffic management solutions implemented on European scale using route guidance solutions, particularly taking into account critical sections (bridges, ferries, tunnels, cities)
- ▶ Simulation of traffic flows due to different management strategies using economical incentives (price differentiation, etc) and legislative means.

Dissemination and clustering of results

- ▶ Effective communication of the objectives and results of the project to road authorities and fleet operators. Road authorities will need to be convinced of the benefits to them – the business case - of providing their data (and where necessary collecting new data) that is needed for the mapping functions.

2. User Requirements

To construct and plan a future routing, guidance and navigation system for HGV's according to needs of the users, stakeholders and the environment, it was necessary to gather and analyse the user and stakeholder requirements. First of all qualitative interviews were made with all relevant stakeholders to get a broad impression of the requirements and needs concerning routing, guidance and navigation systems for HGVs. Based on these interviews two questionnaires were developed for a quantitative survey targeted at the end users, meaning truck drivers and planners in logistics companies.

2.1 Interviews

Stakeholders from a wide variety of sectors were interviewed: HGV drivers, planners and representatives of logistics companies, management, road authorities, road safety engineers and experts in areas of traffic, roads, bridges and or telecommunications (Forward, 2007). Some input was also provided from former projects in Germany and Belgium.

The results from the interview study illustrate the problems experienced with route guidance systems in the past, along with the potential benefits and disadvantages of such systems, and the requirements for any future implementation to be realised.

Problems encountered in the past

Interviewees' experiences of past problems associated with HGV management and route guidance can be grouped into four broad categories of problems affecting: i) *driving performance* (e.g., jack-knifing, overloading); ii) *route quality* (e.g., traffic jams, dangerous roads, low/unknown tunnel heights); iii) *cargo discharge and take-over* (e.g., warehousemen not discharging goods, conditions at the cargo-transfer site), and iv) *the navigation system per se* (e.g., too much choice, interoperability concerns, a lack of information from other countries). In a sense, the experiences of interviewees suggest that there is a general lack of both static and dynamic/real-time information associated with present systems.

Perceived benefits of a route guidance system

Interviewees endorsed the potential for intelligent route guidance systems to provide a wide range of benefits and effects. The expected *economic benefits* of an intelligent HGV guidance system related to less fuel consumption, less driving time, less wear and tear on roads (and vehicles), as well as fewer accidents taking place. Not unrelated to these benefits is the expectation that there would be less time spent in congested traffic conditions, fewer unloaded trucks on roads, and a better optimisation of transport. The perceived *environmental benefits* had to do with less pollution and less wear and tear of tyres. Fewer trucks were also expected to be on roads. However, the concern was raised that the environmental benefits may come at the expense of longer transportation times (presumably through the avoidance of sensitive areas, urban areas and the like). Finally, the *societal effects* of an intelligent HGV route guidance system were less overwhelmingly positive. While there was the expectation of increased cooperation and pan-European harmonisation of rules, together with the provision of better information to reduce accidents and assist the driver to find the correct route, there was also a concern that there would be less communication between drivers and that they would be permanently monitored.

Future implementations

Interviewees were asked about the constraints that might apply to the future implementation of a HGV management and route guidance system. Interviewees mentioned the need for some degree of obligation or a decision at the European level, as well as the need for a cost-benefit analysis to be conducted. There was also mention of the need to protect driver privacy (i.e., the system should not be used to track and act as an informer on driver behaviour). Finally, the economic case was seen as important to assisting implementation. More specifically, interviewees believed that fiscal advantages were needed and that the system should not be too expensive.

2.2 Survey

More than 170 responses to the questionnaires were received. In the questionnaire, drivers and planners were requested to rate the importance of various types of information and support that could potentially be provided in the form of an intelligent HGV management and guidance system. The first part of the results deals with the responses from drivers, the second part with those responses from planners, with the third part comparing and contrasting responses from these two groups.

1. **Drivers**

Pre-trip route planning

Drivers were asked how important it was for them that the pre-trip route planning considered a number of different factors before choosing the best route. The results showed that drivers believed height restrictions on bridges and in tunnels, as well as weight restrictions on bridges, to be of the utmost importance when planning a route. The same applied to information regarding European road works and the arrival/opening hours at the place of delivery. All factors were seen as relatively important with the exception of routes with fewest curves/slopes and routes with best evenness quality.

Support during the journey

The majority of drivers believed support during the journey in the form of various recommendations and en-route information to be important. The exception to this general rule is information and recommendations regarding the nearest services and amenities, notably hotels, workshops, and restaurants, which were regarded as less important. However, information about parking lots and secure resting places was something a large proportion found important.

An overwhelming majority of drivers considered information on environmental conditions to be an extremely important form of support during the journey, particularly information on accidents, congestion, worksite locations, temporary lorry bans, and the presence of any unsuitable infrastructure. Related to this, was drivers' indication that guidance on any alternative route (presumably as a response to unexpected, poor environmental conditions) was very important. With regard to rules and regulations the most important aspect was maximum axle loads.

HGV monitoring and management during the journey

Drivers were also asked about the importance of communication with the head office and other drivers, and if it was *acceptable* that head office had access to certain en-route information about them and their vehicle during the journey. The results show that most drivers see the importance of en-route communication between the head office and their

HGV, although the communication with other drivers appeared to be more important. During the journey drivers could be warned about different obstructions on the road, with drivers finding it especially important to be warned about congestion. Nevertheless, the results also demonstrate that levels of acceptability for access to driver and vehicle information by the head office are relatively low amongst drivers, particularly for information regarding speed and adherence to the selected route. (As shown below in the section dealing with planner responses, this is precisely the type of information planners consider to be very important).

2. Planners

Pre-trip route planning

Planners' responses with respect to the importance of factors considered in pre-trip route planning were assessed. Planners believed height restrictions on bridges and in tunnels, information regarding European road works, and the arrival/opening hours at the place of delivery to be particularly important in the planning of a route. Even so — excluding routes with fewest curves/slopes, routes with best evenness quality and roundabout dimensions — all other factors were still seen to be important or very important by the majority of planners in the context of pre-trip route planning.

HGV monitoring and management during the journey

In general, the majority of planners seemed to consider as most important any information that ensured the safe transport of the goods without necessarily reverting to the micromanagement of individual drivers. This is why, for example, driver location, adherence to the selected route, delays and adherence to resting-time rules were considered important, while less important was driver speed. Similarly, upon detection of tiredness or resting-time violations planners wished to be able to communicate alerts to drivers, they wished to communicate information about new routes or even warn drivers of any loading/unloading difficulties; but less important was the communication of alerts when drivers violated speed regulations. Planners also wished to know about the general location of the vehicle, its axle loads, and whether or not the HGV was overloaded.

3. Drivers and planners compared

While questions were individually tailored to drivers and planners alike, there was considerable overlap in the questions posed to both groups, thereby enabling a comparison of responses. Only results significant at the (Bonferroni-corrected) level of $p < 0.05$ or less are reported.

With regard to pre-trip planning, information about parking at place of delivery was considered more important by drivers than by planners. Thereafter, all significant differences arose in the area of en-route HGV management and monitoring. While a comparison is not exactly appropriate given the measurement of acceptance (by drivers) on the one hand and of importance (for planners) on the other, it is nevertheless the case that *planners believed access to such information was more important than drivers' acceptance of such access to information*. This finding applied to the physical condition of drivers (and, related to this, the ability to communicate an alert to drivers in the case of detected tiredness), driver speed, adherence to the selected route as well as to resting-time rules, whether any delays are experienced, driver location (for transport security), the general location of the vehicle, and vehicle axle loads.

3. Vehicle-infrastructure Interaction Models and Databases

In order to calculate a route in a digital road network a graph representing the spatial structure of the area under investigation (e.g. Europe) containing all relevant segments and nodes is necessary. Furthermore weights per segment, such as distance, travel time, costs or combinations of them must be established in order to calculate shortest paths or route with smallest “resistances”. In HEAVYROUTE these weights are expanded to include new types of data as explained below.

The innovative idea with HEAVYROUTE is to use effect models (vehicle –infrastructure models) to estimate marginal costs for a specific HGV to find lowest cost route. These models have to be supported by new data not currently used for routing applications.

For the HEAVYROUTE applications two types of data are particularly relevant: data on road (surface) conditions which are periodically captured by road authorities and dynamic data, in particular on traffic and weather conditions.

Periodic data is data that represents features that might change dynamically but is measured and presented in time intervals of around one to three years. Road condition data is considered as periodic data in HEAVYROUTE.

For a fully implemented HEAVYROUTE the provision and support of data have to be considered. The basic digital network is provided by companies like Navteq, Tele Atlas and AND. The new information needed by HEAVYROUTE is collected and managed by national governments, by regional governments or by private road companies. The consequence is that the data is not readily available. The support, up-dating and availability of this data have to be solved.

3.1 Map data

3.1.1 Road and bridge data

The road condition data is data that is collected to be used for monitoring and inventory of road networks through the use of PMS (Pavement Management System). The most commonly collected parameters are:

Wear and deformation data such as:

- ▶ Transverse unevenness (Rut depth)
- ▶ Longitudinal unevenness (IRI =International Roughness Index) or other
- ▶ Skid resistance
- ▶ Surface roughness (Macrotexture)
- ▶ Longitudinal, transversal profile

Geometrical condition data such as:

- ▶ Longitudinal slopes (hilliness)
- ▶ Crossfall (Banking)

The section length that a single parameter represents varies between 10, 20, 50 and 100 m. These represent data that can support the models chosen for HEAVYROUTE. Since some models are used for safety warnings, it is extremely important that they are reliable data.

The results of a study of bridge databases showed, on the one hand that the availability of the bridge parameters is very good, but on the other hand that most of the road and especially traffic information are not included in the bridge databases. This information is most likely available in separate (road traffic) databases which make it essential and useful to link the road and bridge databases.

Uniform interfaces should be set up in order to integrate the road and bridge database information into other more dynamic systems like traffic management systems. This would enable easy, standardised and quick queries concerning the current load of HGV traffic on the bridge to protect the bridge from damage and to increase the life-time of the structure.

The results of the study also showed, that the databases are managed in different ways. These varieties occur because of different national regulations and national management concepts. It can therefore be assumed that information of different national bridge databases is also stored in varying qualities and quantities. Quality here refers to the level of comparability by using the same units, hence a very critical issue for the bridge sensitivity model. Therefore uniform standards for national databases in terms of quality and quantity of data should be introduced.

Finally, a future HEAVYROUTE database should consist of a combined approach of structuring, storing and updating bridge, road and traffic data.

3.1.2 Dynamic data

There is an established information chain available in most countries for two types of applications/services:

1. Traffic management and traffic information for end-users (driver);
2. Weather information for professional as well as private users.

Traffic information

Sources of Raw Data on Traffic Conditions - Data on traffic conditions on the roads can be taken from various sources. They are:

▶ **Local (Stationary) Road Detection**

There are a number of local, stationary detection systems on the road network. These detectors differ in how technically the traffic data is acquired, in the acquired traffic parameters and in the aggregation and report strategy of the data. The following detectors are usually applied in practice:

- (1) Inductive loop detectors near signalised junctions for local vehicle actuated control
- (2) Inductive loop detectors for strategic signal control
- (3) Detectors of intelligent highway systems
- (4) Autonomous detectors for traffic management
- (5) Webcams and other Cameras

The systems from (1-3) are generally owned by public or private road operators. In general, only system (3) is systematically collected centrally to establish road traffic conditions in a traffic management centre, usually for motorways and some important trunk roads. Systems (1) and (2) are installed primarily for local control, and are only collected in some cases; usually some larger urban agglomeration with traffic problems necessitating additional effort for traffic management. Type (4) systems are also installed by private traffic information providers (e.g. DDG on German motorways) if no public raw data is available or accessible.

▶ **Mobile Detection – Floating Car Data**

Floating car data (FCD) are collected from driving vehicles and are then transferred to a control centre. The vehicle must have a tracking function, i.e. it must know where it is, usually with the help of a GPS receiver. On the other hand, a communication channel between the vehicle and the traffic information centre must exist, so that information can be further processed.

The data from an FCD system can be used to gain at least the travelling times of individual vehicles on the routes which they have driven.

▶ **Mobile Detection – Floating ‘Mobile’ data**

‘Floating mobile data’ is a relatively new form of data sourcing from the connection records of mobile telephone network base stations. With sufficient equipment of these base stations, a picture of the traffic situation on major roads can be generated with regards to travel time. The approach is contingent on sufficient traffic on the road and sufficient market penetration of the network provider; otherwise the resulting data quality is not sufficient. If such conditions are met, travel time information on a significant part of the road network can be generated.

▶ **Raw Traffic Reports („Messages“)**

Another important source of information is the traffic reports, which are often not generated automatically, but manually by staff using a report editing tool. The source for the report are people on the ground, either police agents, road side assistance, road maintenance personnel as well as private drivers (as part of a congestion reporter network or not).

▶ **Offline Data**

Offline data are becoming an integral part of quantitative traffic data processing. The data can be derived from statistical aggregation processes of quantitative, historical data (stationary road detectors or FCD). To a limited extent, statistics on traffic reports can also be used to deduct typical patterns (e.g. morning and evening congestion patterns). As a second option, offline data can be derived from transport modelling techniques. As a result, sets of time series are created showing typical patterns for the individual road segments to which the source data refer. Over time, these patterns are usually categorised by different features (weekdays, holiday start, weather etc.). This categorisation and the matching of recent real time data make them useful for forecasting the traffic situation.

▶ **Traffic Information Generation**

Typically, two separate sides can be distinguished:

- The processing of quantitative data from stationary and mobile sensors into a network traffic situation (flow, speed, level of service and its forecasts per link for the network).
- The processing of traffic reports from verbal information items received from staff on the road (police, traffic jam reporter etc.).

Both sides can exchange information with each other. The specific implementation of these two data flows differs a lot between different entities involved in producing traffic information. Not all steps on each side are implemented by the respective actors.

The resulting products are:

- Traffic reports (messages)
- Speed/travel time/LoS situation on the network (current, forecasts)
- Speed/travel time or LoS patterns over time (i.e. per day)

▶ **Service Provider – Client – Service**

Examples of service providers are Traffic management centres, Print editors, TV station-program and videotext, Radio broadcast, voice and data, Call Centres (GSM/ mobile phone), Internet Service Providers. Channels/clients can be for example VMS panels, GSM/Mobile phones, Mobile data services (GSM, GPRS), RDS/TMC radio receivers, Internet. Services provided can be display of events/travel times, traffic information (spoken, written lists, maps), navigation support and dynamic routing, etc.

Weather

▶ **General data chain**

Each country has more or less independently established a national weather service which uses local detection and satellite information to establish a current weather situation and weather forecasts. The national systems have been integrated into data exchange networks, for enabling models with larger coverage than the national borders. Different types of bulletins map representations etc. are generated and transmitted to the professional users or channel & service providers responsible for distribution, via print media, internet, broadcast to end users.

Apart from the general services, a number of specialised systems and services have been developed in each country, e.g. with regards to traffic management operations. Here, additional road side detection units are operated to generate a local picture of weather with regards to road conditions and to generate forecasts and warnings for road conditions in order to improve traffic management operations (winter services). These services on weather data for road conditions are not harmonised as such across countries.

The two major protocols for traffic data DATEX and RDS/TMC include weather conditions as far as relevant to the respective users (e.g. certain warning types). The traffic management and traffic information centres in each country can integrate the information (forecasts, warnings) from national weather information systems as well as from the specialised systems for road condition detection and forecast into the traffic information data chain. In order to provide weather information to final road users, currently, the institutions responsible for traffic information integrate weather information via manual report editing, which are then coded, channelled and distributed jointly with other traffic messages through the data chain.

3.1.3 Truck attributes

An overview of the NAVTEQ truck attributes that are integrated into the Map&Guide 2008 version and used for the HEAVYROUTE routing are show in Table 3-1. The attributes are based on the NT Specification 2.3. The data basis is Q4/2007

Table 3-1 Navteq truck attributes

Main Type	Sub Type	Routing	Symbol
10 - Height	1 - Bridge 2 - Tunnel 4 - Arch Bridge 5 - Arch Tunnel 7 - Other	Yes	Yes
20 - Weight	1 - Bridge 2 - Tunnel 6 - Road	Yes	Yes
21 - Weight per Axle	1 - Bridge 2 - Tunnel 6 - Road	Yes	Yes
30 - Length	1 - Bridge 2 - Tunnel 6 - Road	Yes	Yes
40 - Width	1 - Bridge 2 - Tunnel 6 - Road	Yes	Yes
50 - Legal	21 - All trucks forbidden 22 - All trailers forbidden 23 - All trucks with hazardous goods forbidden 24 - All trucks with explosive and flammable goods forbidden 25 - All trucks with natural goods that can be harmful for the water forbidden 26 - All trucks forbidden except residents and deliveries 27 - All trucks forbidden except residents 28 - All trucks forbidden except deliveries 29 - All trucks forbidden except public	Yes Yes Yes Yes Yes Yes Yes Yes No	Yes Yes Yes Yes Yes Yes Yes Yes No
51, 52, 53 - Legal_RDM_ No Left/Right/U-turn	21 - All trucks forbidden 22 - All trailers forbidden 23 - All trucks with hazardous goods forbidden 24 - All trucks with explosive and flammable goods forbidden 25 - All trucks with natural goods that can be harmful for the water forbidden 26 - All trucks forbidden except residents and deliveries 27 - All trucks forbidden except residents 28 - All trucks forbidden except deliveries 29 - All trucks forbidden except public	No	No
54 - Speed Limit	21 - All trucks forbidden	No	No
60 - Warning Signs	51 - Steep Hill Downwards 52 - Steep Hill Upwards 53 - Risk of Grounding 54 - Sharp Curve(s) 55 - Lateral Wind 56 - Tree Overhang	In POI-Layer p_seu.poi (Signes)	Yes Yes Yes Yes Yes Yes

70 - Preferred Route	61 - Preferred Route for Trucks 64 - Preferred Route for Trucks with Hazardous Goods	Yes Yes	No No
80 - POI	71 - Truck Stops 72 - Petrol Station 73 - Restaurant	Not included	

3.2 Effect Models

HEAVYROUTE has identified and adapted effect models that would be used to calculate the recommended routes. An inventory of available effect models, such as fuel consumption and emissions, ride comfort, noise as well as road and bridge deterioration models, for deriving the “optimum” route and reducing impacts on the infrastructures was done (Sjögren, 2008; Omasits, Reichhold, Mefti, 2008; Imine, 2008). A relevant model that was found to be transnational was prioritized. Several relevant models have actually been developed within recent European projects as for example fuel consumption and emissions model ARTEMIS (Keller, 2007) and the external noise model developed in Imagine/HARMONOISE (de Vos, 2005). In some cases, however, national models had to be chosen, as is the case for the road deterioration and the accident model. For road deterioration it is most certain that different models have to be used in different countries due to the local traffic load, climate and geological conditions. In Figure 3-1 a flow chart with models can be seen.

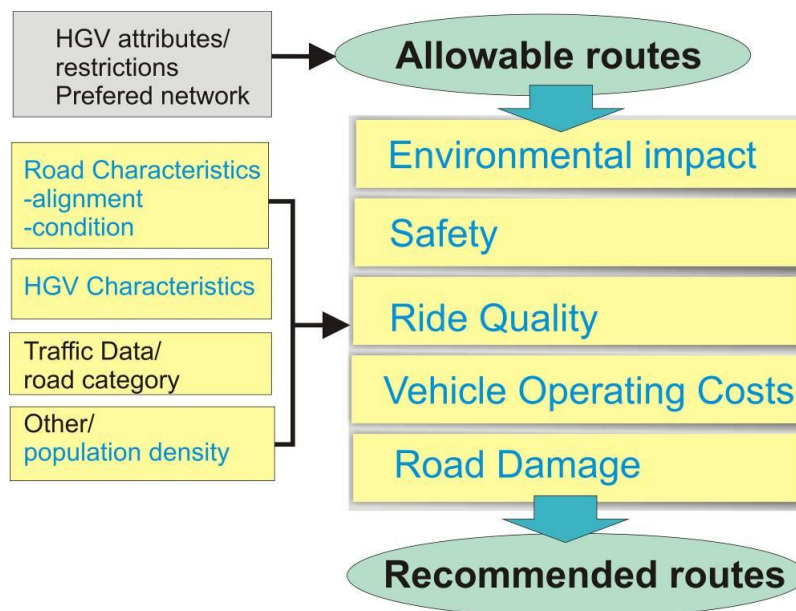


Figure 3-1 Flow chart with models

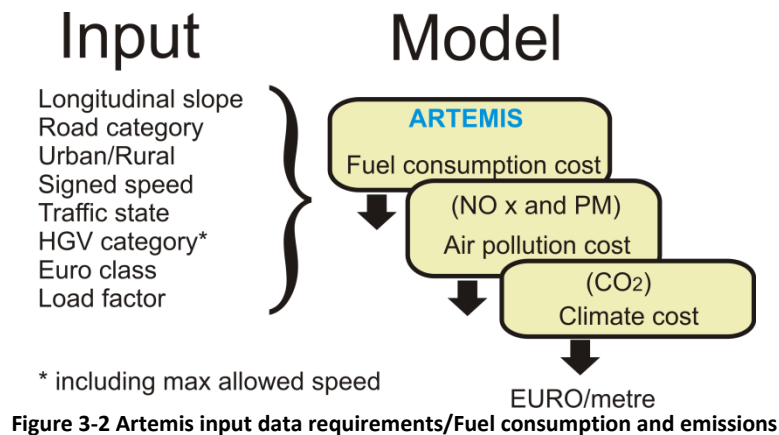
3.2.1 Fuel consumption and emissions

ARTEMIS is a model for estimations of exhaust emissions (CO₂, NO_x, particulate matter, etc.) and energy use for road traffic on a macro level. In principle total mileage per vehicle category and year is split into traffic situations. For each traffic situation and vehicle category there is a fuel consumption factor (fc).

ARTEMIS input demands, see Figure 3-2.

- ▶ Vehicle including trailer
- ▶ Vehicle year model class (emission concept)
- ▶ Load
- ▶ Road: area; road type and speed limit
- ▶ Traffic conditions (level of service).

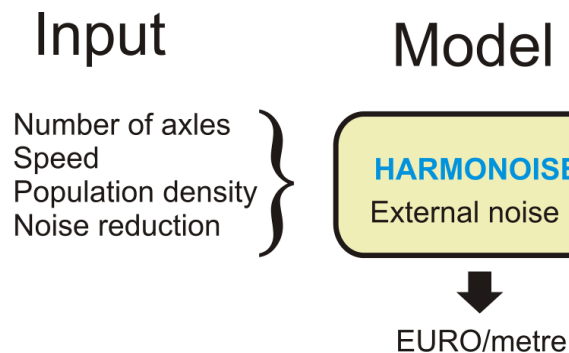
As an output emission values per km can be calculated, and can then be translated into marginal emission cost by cost functions.



3.2.2 External noise

Harmonoise is a model developed in the projects Imagine and Harmonoise, which calculates noise emission strength at the sources (depending on truck type, pavement and speed) and then transforms it into exposure of the population. Monetary valuation functions can be used to derive the marginal cost of noise emissions. This requires data on population density along each link, see Figure 3-3.

The marginal effect is the effect one vehicle has in relation to the traffic already on the link. Therefore the current traffic situation on each link is of importance, and must be added to the input requirements.



3.2.3 Road deterioration

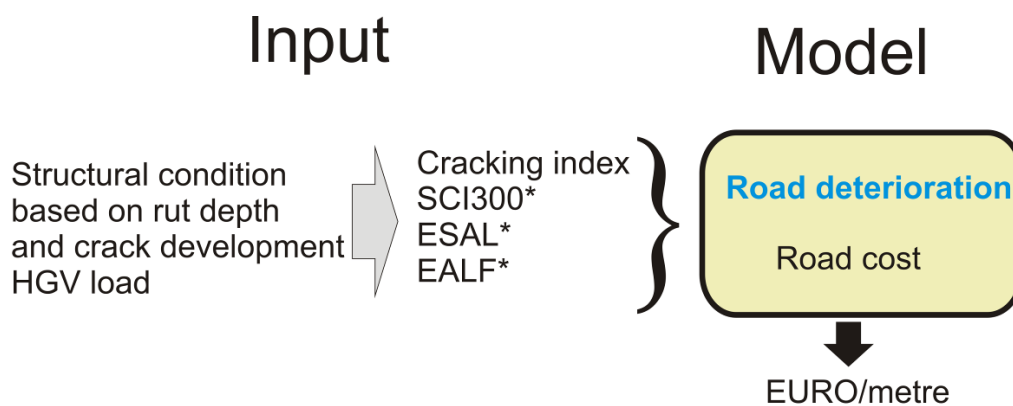
A Swedish model was proposed to make predictions of pavements lifetime. It is based on methods for calculating structural failure. Knowing the predicted lifetime it is possible to calculate the yearly cost, or the cost for each heavy vehicle, for the degradation of the pavement.

The number of standard axles (ESALs, 10t or 100 kN) to failure for a specified pavement segment is evaluated according to two criteria; fatigue cracking (crack initiation and propagation) as well as rutting. The data needed as input for this model is primarily falling weight deflectometer data (SCI300). To calculate the marginal cost the single vehicle Equivalent Axle Load Factor (EALF) has to be estimated from the vehicle axle load and configuration. The SCI300 is estimated from Figure 3-4.

The model's input demands are as shown in Figure 3-5.

ADT _{Heavy}	0-25	26-50	51-75	76-100	101-150	151-200	201-400	401-800	801-1600	1601>
SCI300	300	200	180	165	150	140	125	105	90	70
Road type	Other roads		Secondary roads			Primary roads		Highways		

Figure 3-4 Estimation of sci for different road categories and annual average daily heavy vehicle traffic



*SCI300=Surface curvature Index 300 mm
 ESAL=Equivalent Standard Axle Load
 EALF=Equivalent Axle Load Factor

Figure 3-5 Road deterioration model input data requirements

3.2.4 Ride quality and comfort

Ride quality and comfort models include a number of factors such as riding quality related to lack of evenness on the travelled route but also other factors such as environmental factors, road line design, road width, turning points and availability of resting places etc. Different users/stakeholders however could mean different weighting on the factors. The driver for example, primarily wants a safe and comfortable journey while the road owner/manager wants to minimize the road and bridge deterioration and thereby the maintenance costs.

In HEAVYROUTE the focus for ride quality is related to vibrations induced from unevenness of the road surface. A model developed in Australia has been selected called HATI (Heavy Articulated Truck Index). This model uses the two longitudinal profiles in the wheel trucks as input, Figure 3-6.

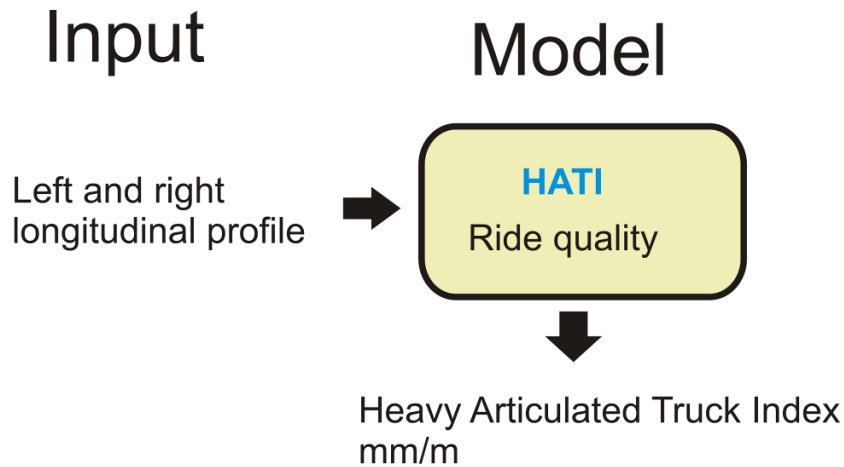


Figure 3-6 HATI input data requirements

3.2.5 Bridge load effects

A model based on traffic micro-simulation is developed in order to estimate HGV impact on bridges. Using measure traffic as input of this model, several traffic configurations are generated with different vehicle speeds and gaps. This model is used to manage the gaps in order to reduce the effect of HVG on bridges.

Several results with different traffics were obtained using Pollux software on different types of bridges to calculate the load effect.

3.2.6 Safety

Traffic accidents are a human tragedy and one of the most important cost components in a welfare economic overview of road and truck traffic. The accident modelling of HEAVYROUTE is of a more general form than the other cost functions. It was chosen to rely on an average risk for HGVs adjusted for the severity of the expected accident and adjusted for the difference in expected risk for different road types. However, in principle the black spot (driver warning) application of HEAVYROUTE could be applied to develop more specific cost functions.

Valuation of accident risk

The valuation of an accident can be divided into *direct economic costs*, *indirect economic costs* and a *value of safety per se*. The direct cost is observable as expenditure today or in the future. This includes medical and rehabilitation cost, legal cost, emergency services and property damage cost. The indirect cost is the lost production capacity to the economy that results from premature death or reduced working capability due to the accident. However, these two components do not reflect the well-being of people. People are willing to pay large amounts to reduce the probability of premature death irrespective of their production capacity. The *willingness-to-pay (WTP)* estimates the amount of money people are willing to forgo to obtain a reduction in the risk of death.

From the WTP a 'value of statistical life' (VSL) can be derived. However, lately serious questions on the reliability of the results have been raised. In principle, it turns out that the responding individuals are not aware of the exact type of safety improvements that they are asked to pay for. One consequence may be that respondents report the same WTP for a larger safety improvement

as for a smaller improvement. If the responses are only weakly dependent on the magnitude of the risk reduction, almost any VSL can be derived from the studies.

Irrespective of this, or depending on this, the HEATCO project makes recommendations on methods to adopt when estimating VSL and basis its recommendations on a limited number of well conducted studies. The project recommends default values per member states in situations where no available up to date value exists.

Model

It is difficult to find evidence that suggests that the accident cost per vehicle kilometre is significantly different between different configurations of HGVs. In fact, data tells us generally that larger trucks are safer. This can be an effect of uncontrolled variables; the largest trucks are driven on the safest route in long distance interregional transport with the best drivers. In HEAVYROUTE one average figure for accident cost (AccidentCostDist) of HGV per vkm¹ is used. This information is based on Swedish accidents with HGVs over five years (Vierth et al, 2008).

The average accident cost will differ between different road types. Due to problems with exposure data observed accident risk for HGV only could not be used. Instead risk and cost information based on all road traffic where passenger cars dominate was used and the deviation from the mean was then used to adjust the AverageCostDis above. This approach assumes that the risk and severity for HGV accidents has the same distribution as all traffic accidents.

3.3 Cost Database

All roads in the road network are divided into “homogeneous” links. The effects and corresponding marginal costs for each specific vehicle (defined by vehicle class, Euro class and load factor) are calculated for each link and are included in a link based cost database for use in the pre-trip routing application. The contents of the database are shown in the table below (Table 3-2).

Table 3-2 Contents of the HEAVYROUTE cost database

Link_ID	The ID number of the current aggregated link (VTI-link)
Vehicle class	The ARTEMIS size class of the vehicle
EuroClass	The emission class of the vehicle
LoadFactor	Percentage of maximum load (cargo)
NoiseReduct	Yes means road surface with noise reduction is being used
EmCost [Euro]	Total emissions cost (NOx+CO2+PMm) for one vehicle to pass the current link
NoiseCost [Euro]	Noise cost for one vehicle to pass the current link
RoadCost [Euro]	Road deterioration cost for one vehicle to pass the current link
AccidentCost [Euro]	Accident risk cost for one vehicle to pass the current link
FuelCons [g]	Fuel consumption for one vehicle to pass the current link
Length_HATI>4mm	The total length [meter] for which the HATI value exceeds 4mm on the current link
QuantityCO2 [g]	Emitted quantity of CO2 caused by one vehicle to pass the current link
QuantityNOx [g]	Emitted quantity of NOx caused by one vehicle to pass the current link
QuantityPM [g]	Emitted quantity of particles caused by one vehicle to pass the current link

The calculations require that all necessary model input data are available on all links.

¹ AccidentCostDist = 0.48 SEK/vkm

Figures 3.7 – 3.9 show the costs per kilometer calculated for the Swedish test area (see section 9.2) using the HEAVYROUTE cost database. The red line marks the middle of the road and the different magnitude of cost on different side of the road mirrors the difference in gradient which affects the fuel consumption model. In urban areas a different driving cycle increases the consumption

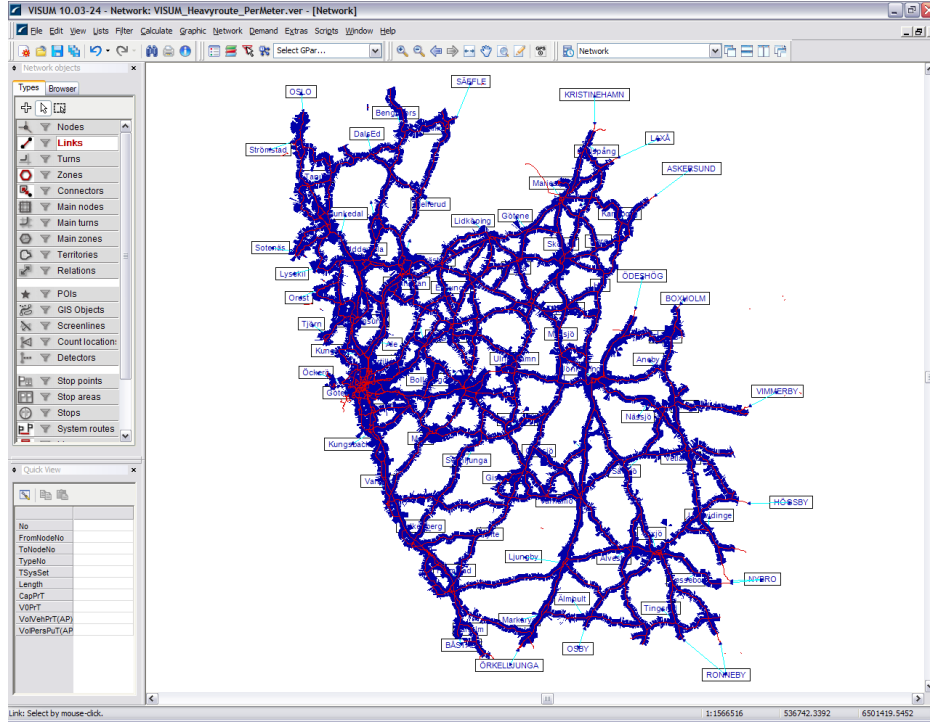


Figure 3-7 Fuel consumption per vehicle kilometer in the Swedish test area (see section 9.2).

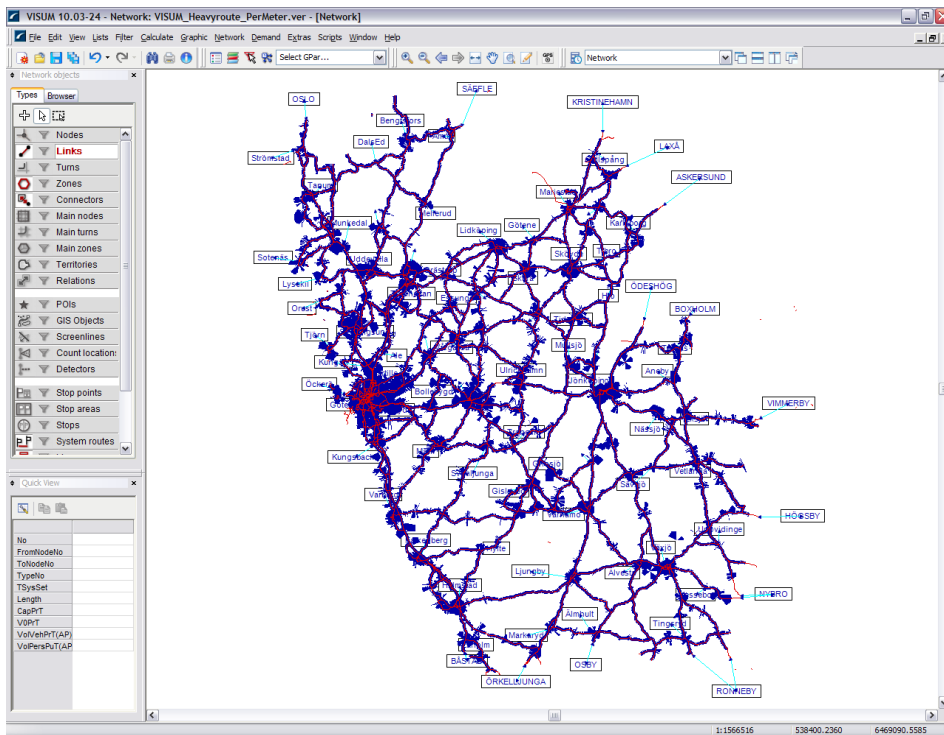


Figure 3-8 Cost of air pollution and CO2 per kilometre for the Swedish test area

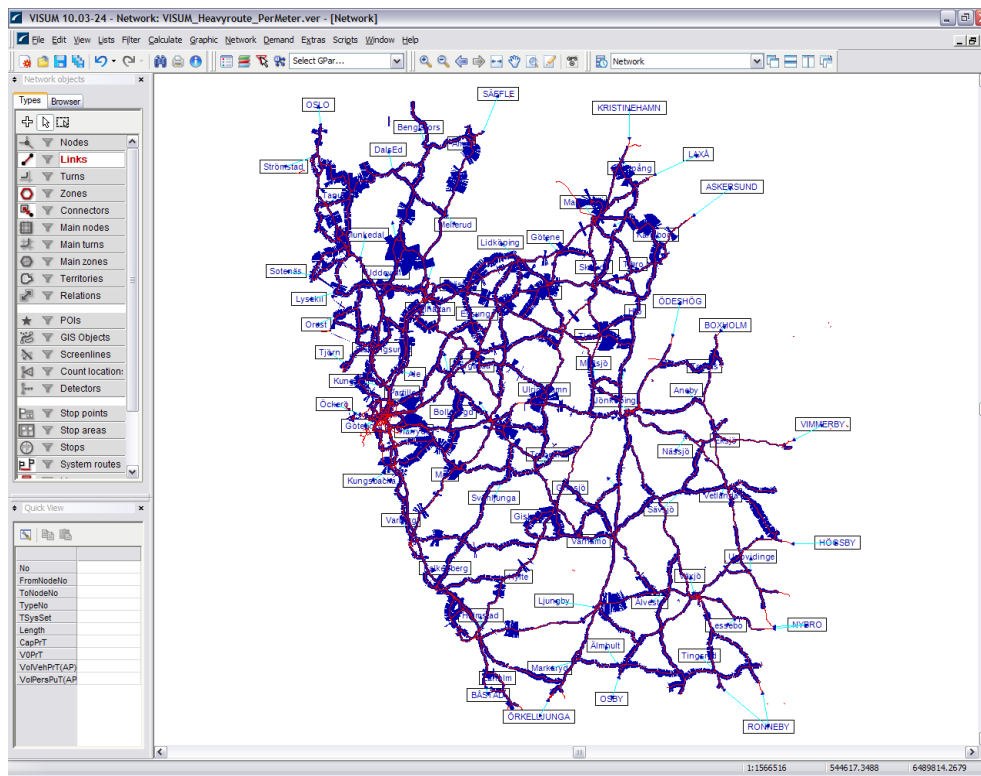


Figure 3-9 Road infrastructure cost in €/km for the Swedish test area

4. Pre Trip Route Planning Application

The purpose of the pre-trip route planning is to find the best alternative route taking into account additional parameters like effects on the infrastructure, the environment, traffic safety and driver comfort, and in addition a preference ranking of these parameters.

The first step in the pre-trip planning is to derive allowable routes using characteristics of the specific HGV and considering preferred networks for HGVs. The next step is to calculate outcome from the selected models in order to find the most cost-effective route. This means that the costs to use the route should be as low as possible. For each of the models a marginal cost function was established.

4.1 Overview of the pre-trip routing application

An overview of the pre-trip routing application including the map integration process is given below in Figure 4-1.

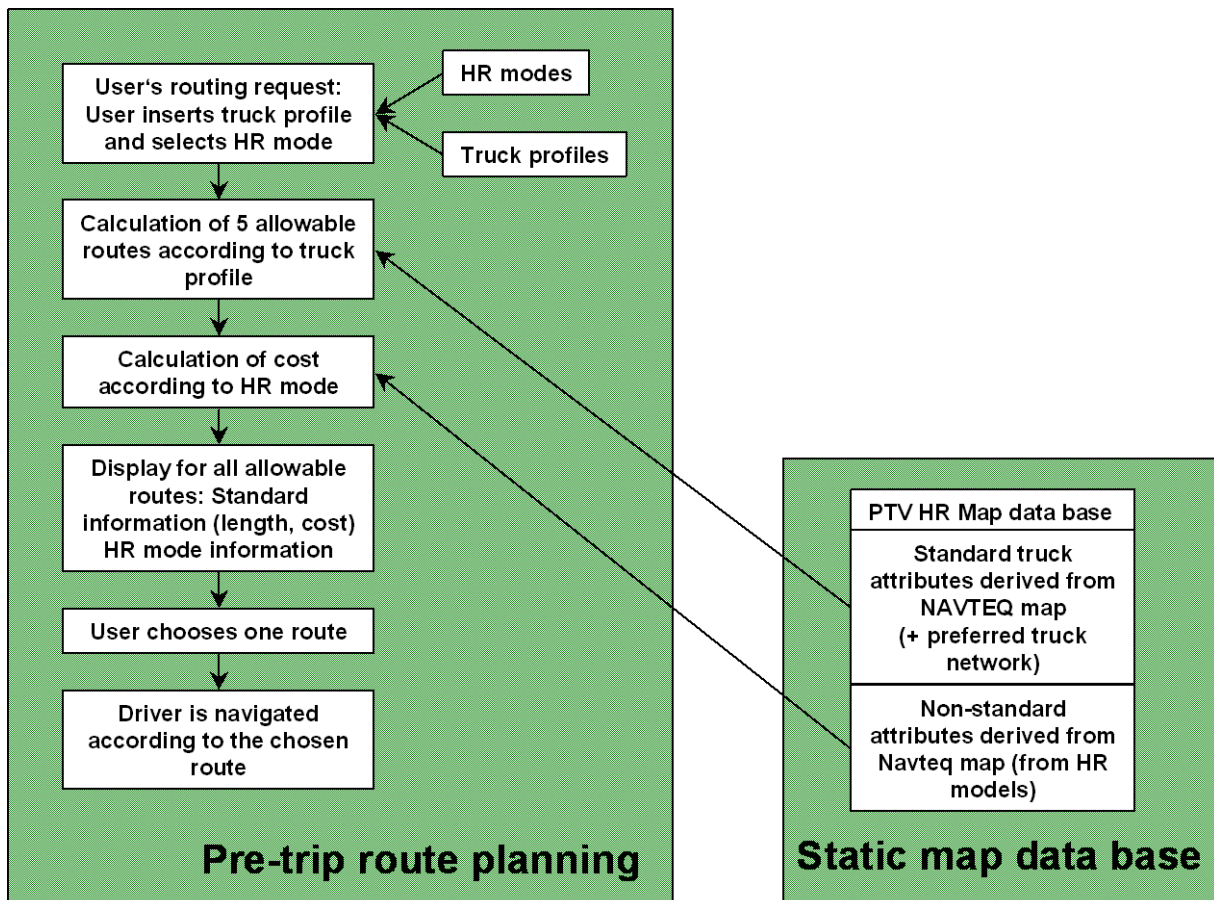


Figure 4-1 Static route planning and navigation overview including map integration

A general overview of the workflow within the application is given in Table 4-1.

Table 4-1: Workflow of the pre-trip application

Step	Description	Data/information used
Step 1	Driver/Dispatcher chooses truck profile (and inserts additional trip specific information)	Predefined truck profiles
Step 2	Driver/Dispatcher can specify in the user settings which HEAVYROUTE calculation mode(s) (e.g. Fuel consumption, Infrastructure costs) he would like to see within the display of results. Predefined he will see the results for ALL modes	List with description of the HEAVYROUTE calculation modes
Step 3	5 allowable routes are calculated by the routing engine	Tuck attributes (NAVTEQ)
Step 4	For the 5 allowable routes the costs and additional information according to all HEAVYROUTE calculation modes are calculated	HEAVYROUTE data base to derive recommended routes (non-standard truck attributes)
Step 5	The 5 allowable routes and the related costs are displayed following the potential pre-selection as done in step 2	
Step 6	Driver/Dispatcher chooses one route	
Step 7	The chosen route is handed over to a mobile device	
Step 8	The driver is guided according to the chosen route	

4.1.1 Driver's/Dispatcher's route request and mode choice

The driver/dispatcher inserts a route planning request including the following information:

- ▶ Starting and end point (From/To);
- ▶ Starting date/time;
- ▶ Vehicle profile;
- ▶ Additional vehicle information;
- ▶ HEAVYROUTE mode for the calculation of recommended routes.

To simplify and minimize the amount of data without jeopardizing the possibilities to demonstrate the capabilities a selection of vehicles was done (see Table 4-2).

Table 4-2 Vehicle profiles in Heavy Route

Vehicle class	Vehicle profile	Type	Type	Gross weight (tons)	No axles
1	Nordic European	TT/AT	Semi trailer or articulated truck	50-60	7
2	Mid European	TT/AT	Semi trailer or articulated truck	34-40	5
3	Rigid truck	RT	Rigid truck	14-20	3

The driver/dispatcher can also choose the following **Additional vehicle information**:

- ▶ Selection of the existing Euro class² of the special truck profile (Euro 1 – Euro 4);
- ▶ Selection of the load class of the vehicle (empty = 0%; partially loaded = 50%; full = 100%);
- ▶ Noise reduction (Yes – No).

In the developed application these selection criteria look like this in Figure 4-2:

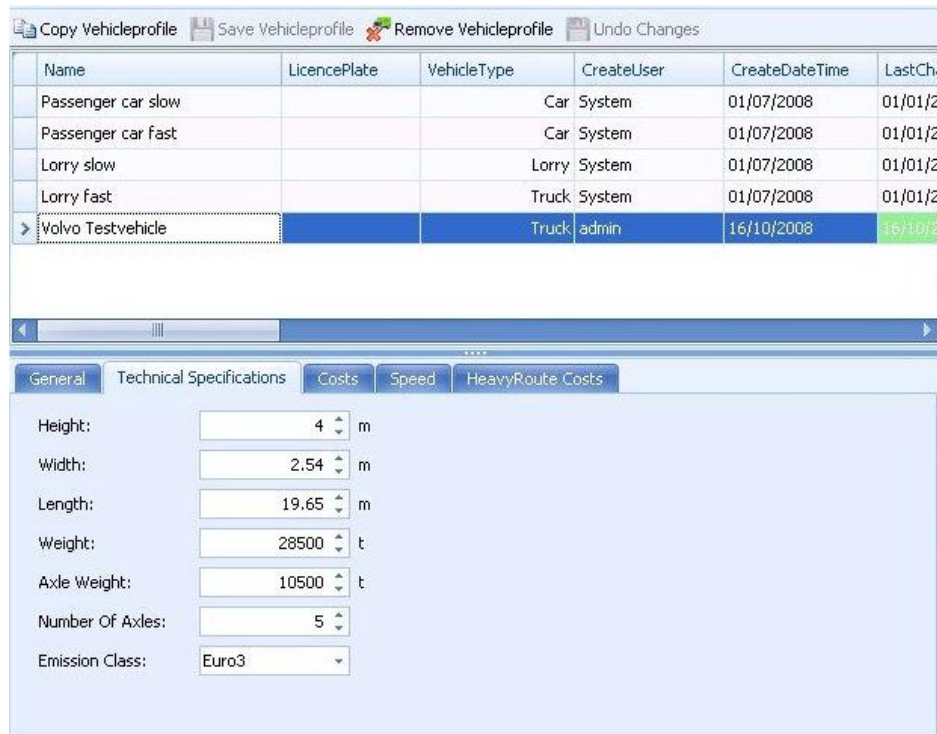


Figure 4-2 Surface of the selection criteria

The dispatcher can specify in the user settings which HEAVYROUTE calculation mode(s) (e.g. Fuel consumption) he would like to see within the display of results. The following **modes** are available within the settings:

- ▶ Standard;
- ▶ Fuel consumption;
- ▶ Noise;
- ▶ Emissions;
- ▶ Environmental effects;
- ▶ Infrastructure costs;
- ▶ Accident costs;
- ▶ Societal costs;
- ▶ Ride quality.

Predefined he will see the results for all modes in Figure 4-3.

² E.g. the age of the vehicle.

Stop Off Points		Itinerary		HeavyRoute Costs									
Route	Tot...	Tot...	Emi...	Noi...	Inf...	Acc...	Fuel	HATI	CO2	NOx	PM		
93.51	01:07...		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
106.78	01:20...		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		

Se...	Description	E...	N...	I...	A...	Fuel	H...	C...	N...	PM
30662...	SegmentId	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31536...		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30662...		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30662...		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30662...	turn left onto Alkalievä...	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31536...		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31536...		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
72369...	turn right onto E45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
72369...		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80510...		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80510...		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30839...		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

COUN...	SU...	SU...	SU...	SU...	SU...	AVR...	SU...	SU...	SU...	
115.32	01:43...		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
151.25	02:04...		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
117.71	01:48...		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 4-3 Results of the HEAVYROUTE modes

4.2 Allowable routes

Based on the NAVTEQ map Q4/2007 and the additional truck attributes, the route planning application calculates 5 different allowable and at the same time optimised (time/km driven) routes. The following screen illustrates the interface of the routing application, Figure 4-4.

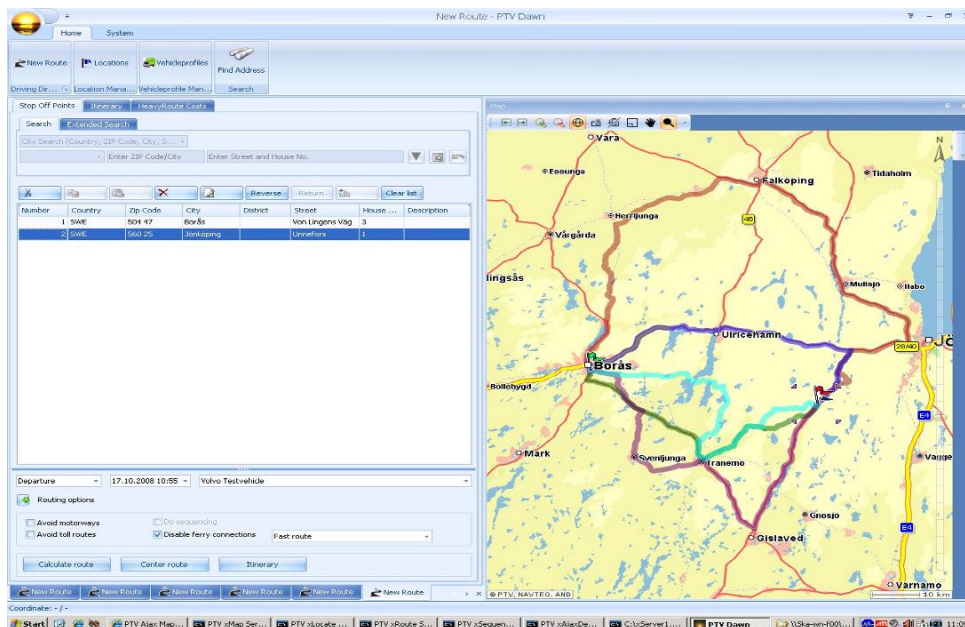


Figure 4-4 Overview of the 5 calculated routes

4.3 Recommended routes

For the 5 allowable routes additional calculation is done by using the costs/units integrated in the HEAVYROUTE data base (delivered by the HEAVYROUTE models). The solution is displayed as follows:

- ▶ The system indicates the solution that is the best according to the selected mode. The user (Driver/Dispatcher) can click on this solution or the others in order to display them in the map. The user chooses one of the routes. This chosen route is transferred to the navigation unit (OBU).

For the five allowable routes the costs and additional information according to all HEAVYROUTE calculation modes are calculated and displayed following the potential pre-selection.

Figure 4-5 shows the results of the costs per calculated route:

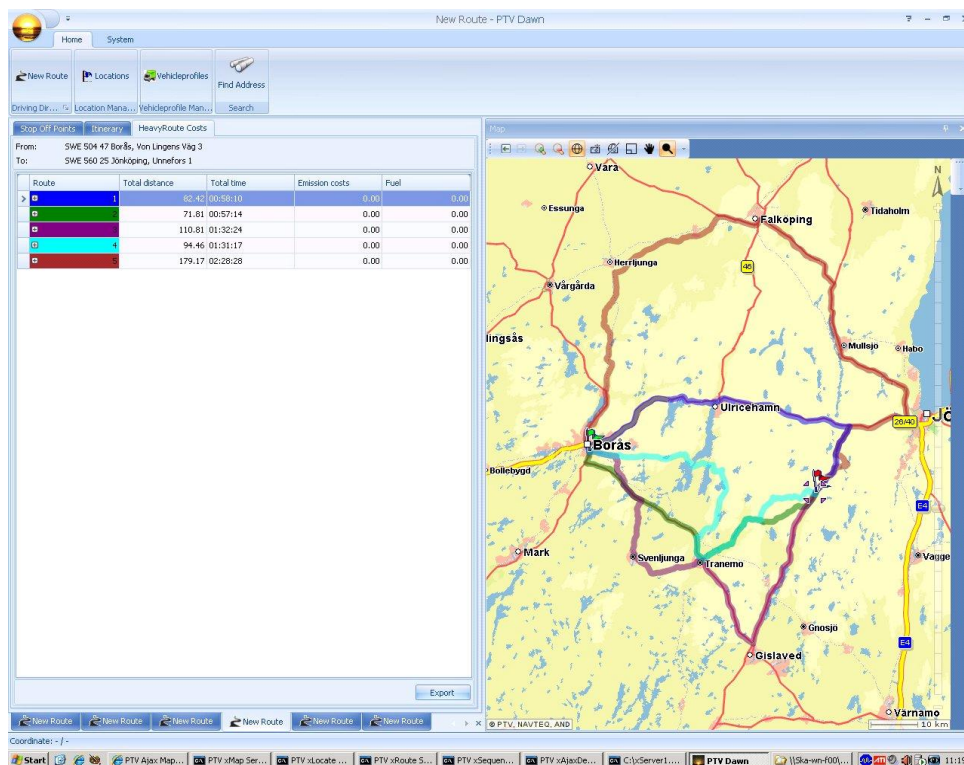


Figure 4-5 Costs results of the calculated routes

4.3.1 Navigate driver according to recommended route chosen

According to the handed over route the on-board navigation unit guides the driver following the chosen route. Alternatively the solution might also be transferred to NAVTEQ's ADAS-research platform.



Figure 4-6 Mobile device

The dispatcher chooses one route and hands it over to the mobile on-board unit (10). The driver is guided according to the calculated route during his trip.

5. Driver Support and Warning Applications

5.1 Roll-over

Before the trip, the rollover study is done in order to calculate the recommended speed along the specified route. This speed is then compared to the actual speed measured by GPS (or other sensor installed in the vehicle). If the actual speed is greater than the recommended one, the rollover risk can exist. An alarm can be sent to the driver in order to reduce his speed and avoid the rollover.

The vehicle is equipped with different sensors to measure the vehicle dynamics. The following measures are used for this study:

- ▶ *SteeringWheelAngle* – radians
- ▶ *VehicleSpeed* - km/h
- ▶ *YawRate* - rad/s
- ▶ *GPS_Speed* - m/s

The following states are estimated by the developed program:

- ▶ Estimation of impact forces,
- ▶ Estimation of the centre of gravity height,
- ▶ Recommended speed calculation,
- ▶ Lateral acceleration

Simulations are done in order to validate the proposed approach. However in order to improve the robustness of the method, some sensors are needed.

5.2 Black spots

The dimensions of HGV are definitely bigger than those of the passenger cars and their dynamics behaviour is rather different (multi-axles, attachment of the trailer etc). So, heavy vehicles represent a real danger for road users by increasing the risk of fatalities in the event of an accident. A global safety study was performed to detect “black spots” of infrastructure and incorporate them into the HEAVYROUTE system.

Analyses of databases were conducted to detect critical points of infrastructure regarding safety. These led to numerical simulations in order to provide a speed limit depending on the geometrical characteristics of road and skid resistance. In the third step, a “black spot warning” application was developed and implemented in HEAVYROUTE system.

5.2.1 Dangerous configurations regarding safety

European database analysis showed that accidents involving a heavy vehicle alone mainly occurred by rollover, jack-knifing or go off the road. Five situations with a high risk of accidents were detected:

- ▶ Curves with a small radius of curvature and a low skid resistance on primary roads,
- ▶ Curves with a high radius of curvature and a low skid resistance lying on secondary roads and rural highways,
- ▶ Large curves in descent,
- ▶ Roundabouts,
- ▶ Ramps with a longitudinal slope higher than 5% and a length greater than 1500 m.

A sixth situation was added in the application: reverse cross fall in curves, which can result in greater water depth in the area where the cross falls becomes equal to 0. This water accumulation leads to a decrease in skid resistance.

Thus, the HEAVYROUTE system gives two types of information to the driver. For dangerous areas like ramps, the system will give driving restrictions to limit risks of accidents. For other areas where the risk is directly related to the speed of heavy vehicles, a safety limit is proposed.

5.2.2 Experimental results with the “black spot warning” application

Experimentation was realized on Swedish roads in 2008. The infrastructure data were used in the “black spot warning” application. Thus, risky areas were detected and a safety speed profile was calculated in the pre-trip application. Then, the real speed of the vehicle was compared against this safety speed profile during the tests for several drivers.

The application indicated speed changes located in the areas where the driver really modified his speed, but proposed higher safety speed than the real speed. This overestimation is due to the hypothesis used in numerical simulations. First, the skid resistance of the roads is not available in the road databases. Thus, a constant friction value was used in the numerical simulations, whereas previous studies showed that skid resistance has a great influence on the maximum speed in curves. Then secondly, the load of the vehicle plays a role in the maximum speed in curves. The simulations were achieved with two values of load, which are different from the real load of the heavy vehicle. Lastly, the truck model used in the numerical simulations was not of the same parameters as the one used during experimentations.

During the tests, the “black spot warning” application correctly detected the area where the driver should decrease his speed regarding road characteristics. Nevertheless, the recommended speed was always greater than the real speed applied regardless of the driver considered. The gap between the real speed and the proposed speed can be explained by some hypothesis done in the simulations (constant skid resistance, fixed load of the heavy vehicle etc).

In fact, this experimentation showed that the concept works: the “black spot warning” application is able to detect dangerous areas on the infrastructure (ramps, roundabouts, curves). It is therefore possible, to choose one way or another by considering the risk of each itinerary. In the future, the road database should contain skid resistance data to improve the safety speed prediction. Moreover, the application should be implemented in real time considering the location of the heavy vehicle thanks to GPS. The safety speed prediction could be done instantaneously. Lastly, a connection between the rollover system and the black spot warning application could be realized in order to provide a safety speed by taking into consideration the road characteristics and the dynamic behaviour of the truck.

6. Application for HGV Management on Bridges

6.1 Static load

The aim of this application is to avoid bridge overload. This is done by monitoring the effect of vehicles approaching a bridge and influencing the vehicles (e.g. they need to reduce speed, increase the gaps or limit the Heavy Lorries Weight) by use of fixed signs if a critical situation for the bridge is expected.

The information about the vehicles approaching/on a bridge is integrated into the CASTOR/POLLUX model and a prognosis of the fatigue effect on the bridge is calculated. For the load effect prognosis, new probabilistic method called 'Peaks Over Threshold' (POT) (described in the paper of Coles Stuart, 2001) is used in order to identify the extreme load events and estimate the extrapolated return value for the selected data sets, using approximately 2 months of RN4 French national road traffic recordings.

Several studies of fatigue were carried out by using Pollux software with the help of three influence lines of a pre-stressed concrete bridge in Vienna (Austria) (with spans of 60 and 90m). Four traffic recordings were used, of which three were French motorway traffics (A64_2007, A6_1989, A4_2008) and the last relate to a French national road (RN4_2007). The found damage is very weak, in fact, below a certain threshold Pollux software issues that the damage is not representative and thus null, which leads to infinite lifetimes for all the fatigue classes. This does not signify that the bridge have really infinite lifetime, but that they are not very damaged.

6.2 Dynamic load

Dynamic load is created by dynamic effects of the static traffic load. The effect of the static traffic load on the bridge is increased by the resonance of the bridge, pavement unevenness and vehicle movements. The increased effect leads to increased fatigue of the bridge material and thus decreases bridge lifetime. The magnitude of increase of the load effect is described by the dynamic amplification coefficient.

The value of the dynamic amplification coefficient was investigated in HEAVYROUTE project for a variety of situations. The dynamic amplification was calculated using transient analysis with finite-element model of bridge and truck. The calculation method ensured a full interaction between bridge and truck.

The investigated situations included four different bridge construction types, different span lengths (8 -40 m), two different vehicle models, various percentages of vehicle loading and speeds between 40 and 120 km/h. The dynamic amplification varied depending from 1,0 to 1,7. Comparison between different bridge types showed higher amplification on light-weight (steel) bridges. The amplification was in all cases dependent on vehicle mass. Fortunately, heavy vehicles produce lower dynamic amplification values. The influence of vehicle speed was not completely consistent, but larger speed produced larger load effects in majority of the cases.

A test was carried out on a bridge in Vienna. The aim was to test the predictions of the calculated bridge response. The measurements on the bridge revealed lower dynamic amplification than was predicted by the model. It can be concluded that the calculated dynamic amplification is conservative for concrete bridges. It can be deemed that damping of the bridge is larger than assumed in the model.

7. Driving Simulator Tests

7.1 Roll-over, timing and HMI

The aim of this specific study was to investigate how a roll-over warning system in HGV's would influence driver behaviour, and to identify the HMI that has the highest potential to lead to safe driving in critical situations. Different interfaces were tested and the system acceptance of the end user, i.e. the driver, was also investigated.

There are a number of issues to consider when implementing any advanced driver assistance system (ADAS). These issues are connected to what the system should look like, under which circumstances a warning should be given, what kind of warning, at what timing the warning should be given, etc. Not all of these issues can be studied within one simulator study; neither can any conclusions be drawn about long-term and adaptation effects.

For this simulator study the intention was to investigate three different HMI's for providing the driver with a visual warning as well as two different timings. Apart from data on driver behaviour from the simulator driving in itself, questionnaires were given to the drivers to yield data for conclusions on drivers' expectations, acceptance of the system and possible concerns.

The drivers

The experimental group consisted of 24 persons, both experienced and inexperienced truck drivers. Due to difficulties recruiting female drivers, only two of these were women. Inclusion criteria used were annual mileage, possession of driving license for a minimum of years and the driver's age.

The vehicle

In order to create realistic situations with roll-over risk the simulated vehicle had to be a rather large truck with a high centre of gravity to cause instability. A large truck is also necessary to attain a large effect of strong side winds.

The vehicle model used is based on data corresponding to a Volvo truck and semitrailer with 3 axles (front, driving and boggie axle, respectively). The total weight of the simulated truck was about 26000 kg.

The experimental route

The experimental route was also a normal rural road, approximately 60 km long, with a speed limit of 70 km/h. It took about 60 minutes to drive in total. The driver passes a number of other vehicles, both private cars and busses along the route. These occurred at exactly the same spots for each driver.

The experimental route was divided into three equally long sections. On each section the driver encountered four "critical situations". Two of the situations were sharp curves toward left (Cl) and towards right (Cr) respectively, one a steep downhill slope (S) and the other - a situation with strong wind (W) from left road side. Before the sharp curves there was a rather long and more or less straight road section to allow the driver to attain a sufficiently high speed. The road geometry and environment were such that the curves are concealed for the driver as long as possible.

On two of the sections there was a driving support system giving the driver a warning when he approached the four critical situations. On one section, the driver had to handle the critical situations without the driving support system.

The Human Machine Interface (HMI)

The following HMI's presented in Figure 7-1, a-d were used in the simulator study. The HMI's were presented to the driver on a separate LCD screen placed on the dashboard. Each time a warning is switched on the driver is notified by a beep.

A critical speed limit for roll-over risk was set for the sharp curves. If the driver approaches the curves at a speed that is higher than the recommended speed a warning is given. The design of the experiment (including the route) was such that it almost guaranteed that the driver would approach the curves at too high speed.

The roll-over warning was presented either only as a symbol (Figure 7.1 a) or as a symbol together with a speed indicator showing actual speed in relation to the recommended (critical) speed (Figure 7.1 b). The symbol was displayed disregarding the direction of the curve.

Apart from the roll-over warning, the driver also received a warning when approaching a steep slope or a section of the road with strong side wind. In this case the warning was only given as a symbol, i.e. without the recommended speed.

Furthermore, two different pre-warning times were studied. Half of the participant group received an early warning and the other half a later warning. The participants in the "late warning" group received a warning when they had a time headway of 5 seconds left until they reached the critical point. The "early warning" group received a warning when they had a time headway of 8 seconds left.

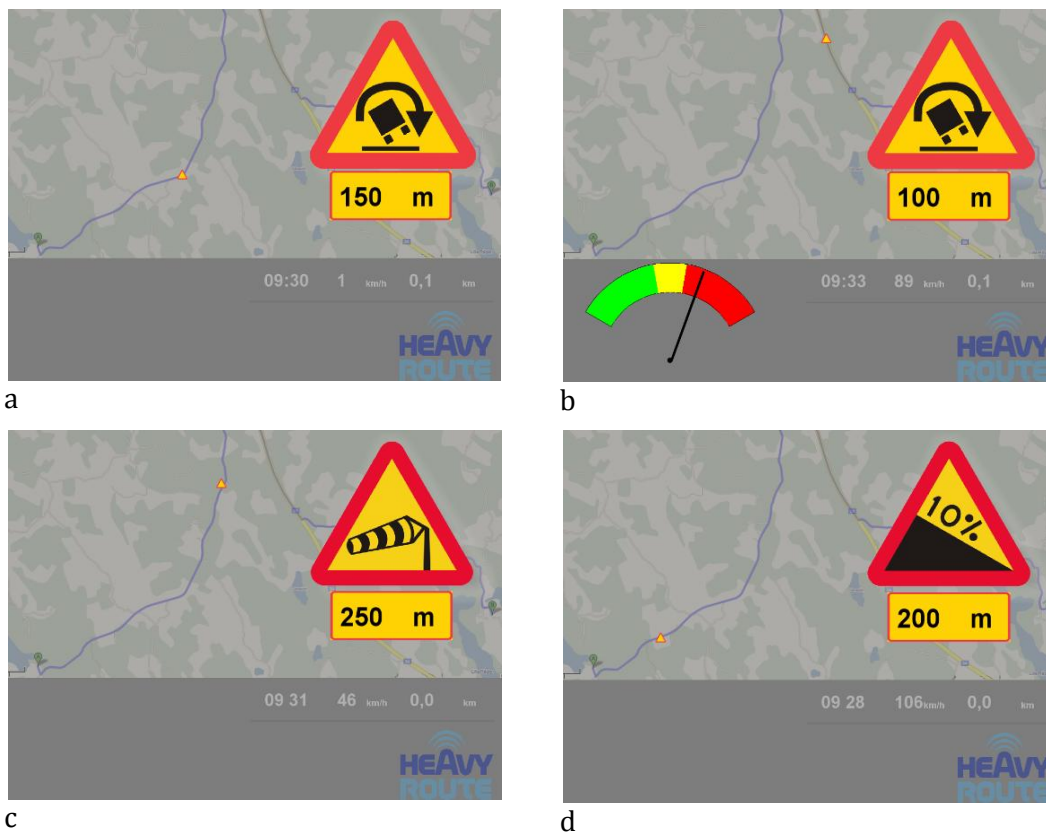


Figure 7-1 The different HMI's in the simulator study: a) Roll-over warning with symbol only, b) roll-over warning with symbol and recommended speed, c) strong wind warning and d) steep slope warning.

Collected data

During the simulator test data on driver behaviour, such as speed, acceleration/ deceleration and lateral position, was collected. The drivers were also given a questionnaire with questions on their attitude to warning systems as well as their opinion on the consequences of warning systems on safety, comfort, travel time etc. These were to be answered before and after driving in the simulator.

7.2 Results and conclusions

The warning systems were found to have a significant effect on driver's behaviour. The experienced drivers performed generally somewhat better than the inexperienced. There were no significant effects from the pre-warning time's lengths. However, rationally the pre-warning time can be too short so that the driver does not have time to adapt her or his behaviour. Likewise the warning might be given too early so that the driver is unable to foresee when the obstacle will occur. Presumably the interval 5-8 seconds contains admissible pre-warning times.

When approaching the obstacles the warning systems have the overall effect that the drivers come to lower speeds at the obstacle than without the warning system.

When approaching a curve inexperienced drivers gain more from the warning systems than the experienced. Corresponding differences between inexperienced and experienced drivers were not found at the other kind of obstacles (strong wind and steep slope).

Both experienced and inexperienced drivers have a positive attitude towards having the support from a system that gives a warning for critical situations.

The inexperienced drivers expected a somewhat greater influence of a warning system on traffic safety than the experienced drivers.

Almost all inexperienced drivers and about two thirds of the experienced drivers preferred the warning system with indicator for recommended speed.

Concerning the pre-warning time (5 and 8 seconds, respectively), the result was actually that it was too short in both cases, with no significant difference between experienced and inexperienced drivers. Nor was there any significant difference in how the drivers experienced the timing for the two different warning systems for roll-over risk (without and with indicator for recommended speed, respectively).

8. Field Tests

8.1 Pre-trip route planning and navigation

A field test was conducted in Sweden to test and demonstrate the functionality of the pre trip planning, the navigation and the on board driver support system developed in HEAVYROUTE. Another aim with the field tests is to validate some of the effect models. Since fuel consumption is easy to measure, the focus is on this. As there is no cost function available for ride quality it cannot be considered in route optimization, but it was anyway tested in the field test. Ride quality can be an important factor in the route choice for heavy vehicles e.g. if the effect of vibrations on drivers (EU directive) and goods is considered.

Sweden was chosen as test site because of the availability of necessary road network data to support the HR models. The necessary road data had to be acquired from the NVDB (the national road database). The road data from the NVDB was then used to calculate the link based cost database for all routes in the test area.

The original Navteq map data was already updated with truck attributes as an ordinary improvement. Unfortunately, this update only covered functional road classes 1 and 2 (FC1 and 2), where FC1 represent motorway standards. This map data was however used to calculate 5 alternative allowable routes between a selected start and an end point in the test area. Two of these were then chosen for the field tests.



Figure 8-1 The field test truck from Volvo

Four skilled test drivers drove the same test truck (a Volvo FH12 with trailer) along the two test routes in both directions. During the runs, data was logged through two separate CAN buses in the test truck:

- ▶ Brake pedal position
- ▶ Current gear
- ▶ Steering wheel angle, turn counter
- ▶ Vehicle speed

- ▶ Yaw rate
- ▶ Fuel rate
- ▶ GPS: latitude, longitude, altitude, speed and time

Furthermore an acquisition system was installed to collect vibrations in the chair and the chassis of the truck.

To secure a high and well known quality in the comparison, between calculated and measured fuel consumption, the condition of the routes were measured in both directions with VTIs Road Surface Tester equipment.

8.1.1 Results of fuel consumption validation

The evaluation was done by comparing estimated fuel consumption, from the ARTEMIS model with measured (logged) consumption on the test routes. To be able to calculate estimated fuel consumption, specific facts about the used truck is needed such as size class and load factor. Artemis also needed longitudinal slope as input. The comparison between calculated and measured consumption was performed per route. The routes were also divided into a number of shorter sections (approx. 9 per route) to support more detailed analysis.

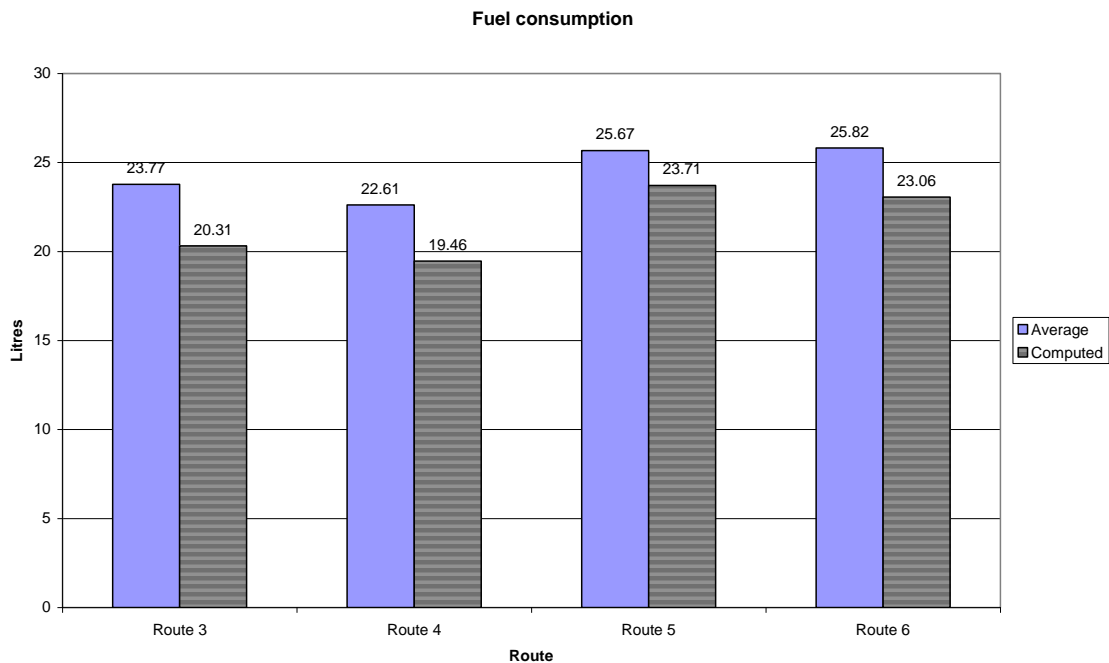


Figure 8-2 Fuel consumption per route, estimated from model and logged average.

The blue bar represents the average consumption logged from the four drivers individual runs per route. The black/white bar is the calculated consumption from the emission model using the truck specific data and longitudinal slope.

There is systematic discrepancy between logged fuel consumption and estimates from model. The logged values were in the order of 15% larger than model values. A possible explanation for this is that model calculations are based on averages over vehicle weight classes, emission classes, traffic situations etc. For the actual measurements the corresponding quantities deviate more or less from their averages. In particular, the total weight of the test vehicle ($\approx 40t$) is close to the upper limit of the ARTEMIS size class (TT/AT>34-40t) that has been used in the model calculations, rather

than close to its mean value (37t). Therefore, one may expect model computations for the field tests to underestimate the true fuel consumption. In fact, if the heavier size class, TT/AT>40-50t, had been chosen then an increase in fuel consumption in the order of 12% could have been expected.

In future implementation of a HEAVYROUTE system it might be appropriate to do a calibration of fuel consumption with respect to these systematic errors for each individual vehicle. On the other hand, it should be kept in mind that the important matter here is to obtain a correct priority ordering of the different routes with respect to costs. Probably, systematic errors tend to preserve the correct ordering while random errors are a bigger threat in this respect.

8.1.2 Ride quality

In Figure 8-3 the driver's opinion compared to the HATI value on the sections can be seen. The drivers were asked during the run just after passing the section on their opinion assessed on a 1 to 5 scale. In general the HATI value and the opinions are quite similar. The driver opinions in the figure are the average value from all four drivers.

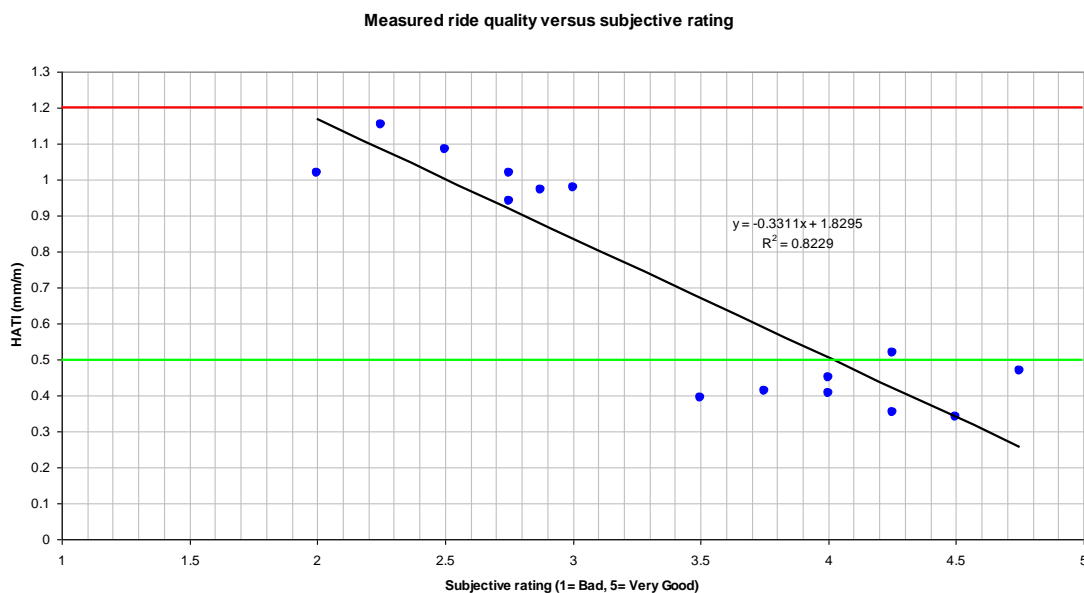


Figure 8-3 Opinions on ride quality against the HATI value

The red and green lines in the figure represent a perception scale established on Australian road conditions. Between the red and green line the road is assessed as good, above the red as fair and below the green as very good.

8.2 Bridge management

The experimentation aims to analyze the HGV driver's responses according to a particular gap regulation between HVG. This experimentation was carried out on the instrumented SAROT site located on Northern A87, in the direction: Angers-PARIS. The selected section is 2x2 lanes in Angers-PARIS direction. This road is reserved for motor vehicle traffic. Speed on the concerned section was limited to 90 km/h especially for the experimentation. In order to have sufficient data, it was decided to carry this experimentation on all the heavy vehicles with more than 3,5tonnes and which represent the majority of HGV traffic. The first analysis was carried out on the raw

recorded data during the first four weeks of September 2008 (from 1/09 to 28/09), but only working days were treated. This is due to the fact that during weekends, the traffic is not dense.

Traffic recorded during this period is around 18 800 vehicles/day. The number of vehicles correctly recorded by the loops (known as "without error") is 439236 over 19 working days. HGV vehicles represent approximately 11.35 % of this traffic.

Between 12 and 30 January 2009, a second analysis was carried out after posting the modified B17 gap panels. The number of HGV correctly recorded by the loops (known as "without error") is 467099 over 15 working days.

Over 15 days, and after posting the new panel "70m between HGV", the HGV should thus have modified their control behaviour to comply with the new regulation.

However, it should be noted that in a general way, 1466 of the 36401 HGV recorded correctly between the 1/09 and the 26/09 (4,02%), did not comply with the regulations of the highway code in term of inter-distance, since the measured distances between the vehicles were lower than 50 m.

Thus knowing that the large majority of the HGV drivers comply with the regulations, it is possible to consider that a significant number of them would have changed behaviour in the presence of the instruction's panels of "Gap 70m ". It was also noticed that among 64753 recordings vehicles (after posting the gap panels), 4889 of them which represent 7.55% did not respect the lawful gap of 50 m and 8059 (12.44%) of them did not respect the advised gap of 70 m.

So, although the sample of heavy truck is relatively weak, it seems sufficient to apprehend the behaviours tendencies evolution of the drivers. It is clear that the behaviour of the drivers was unfortunately not influenced by the panel. This can be explained by the fact that the two measurements series were not successive in time (flow of HGV). The traffic flow was not the same. The other reason is the diversity of the driver's population across the road section.

In the analysis and taking into account the daily weather conditions, the results confirm that the HGV drivers drive more prudently when it rains. If we take the example of the January 13th where it rained from 02h to 12h, the minimum calculated gap for this period was about 158.76m which is greater than the lawful gap (50m) and the advised gap (70m). On the other hand, the 50 m gap was not respected when it stopped raining. This proves the influence that the weather has on the driver's behaviour.

Against the significant number of heavy trucks in infringement, it is necessary to reinforce control by deploying new technologies of road information and traffic management. The installation of traffic management and control system to regulate speeds and inter-distances need the deployment of high technology information services:

- ▶ In the immediate future, the reinforcement of controls can be done only in "handbook". The intensification of controls must be accompanied by indicators of effectiveness and follow-up communicated by the police force;
- ▶ The lawful framework must be simplified, making it more comprehensible and thus better applied and controlled and supporting the emergence of automated solutions;
- ▶ The co-operation with the foreign administrations should be reinforced.

9. Traffic Simulations and Cost Benefit Analysis

9.1 The Bremen case study: Traffic effects of a preferred truck network

Some communities in Germany are currently discussing setting up a preferred truck network in order to cope with the increasing truck traffic demand and the inhabitants' sensitivity. The goal is to concentrate truck traffic in the city area on major arteries that are able to accommodate the demand without interfering with living areas.

A city that already has established and published such a preferred truck network in Bremen. The city authority has classified the city streets into different categories: major through-routes, access-only streets and an area in the city centre that should be avoided.

In a first attempt, the city authorities were contacted to obtain a traffic model consisting of the street network and the traffic demand. The authorities provided access to their model. However, this proved to be more difficult than expected – especially the retrieval of the traffic demand and the transfer to VISUM for further processing seemed to provoke major manual adaptations. It was therefore decided to create a sub model from an available large-scale traffic model (VALIDATE). The Bremen network was cut from this larger model and checked with the available “official” model. No differences could be observed. The advantage of this procedure was the readily available model in VISUM format that was much easier to handle.

Figure 9.1 shows the Bremen network with the daily traffic volumes.

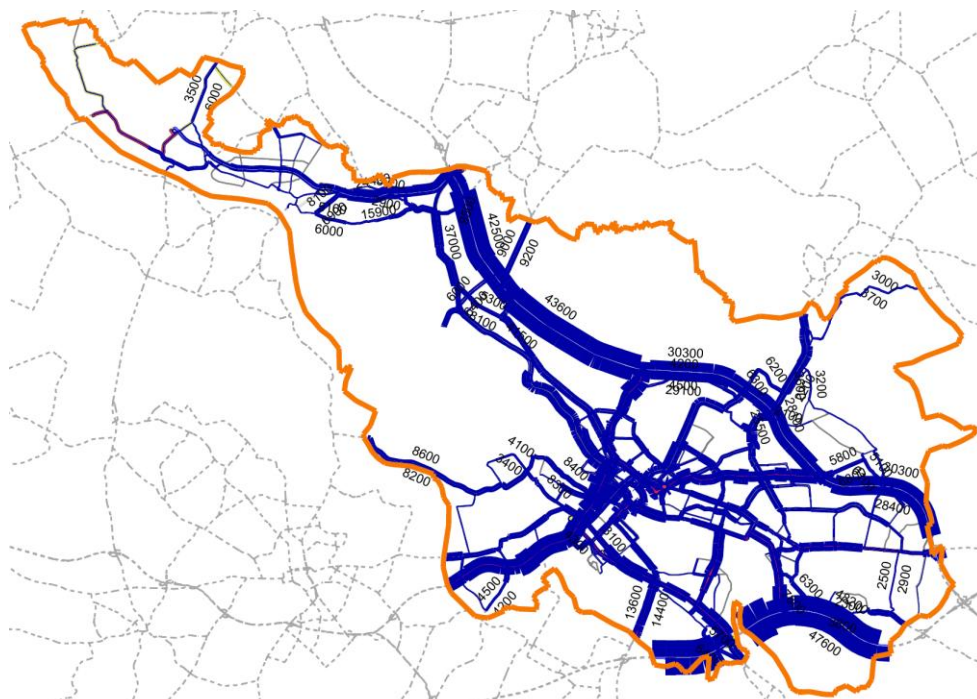


Figure 9-1 Bremen network with daily traffic volumes (vehicles per day)

The implementation of the preferred truck network was meant to change the attributes of each link in a way that the routing/assignment are able to reflect the preferred truck network. Of course, this must only affect truck traffic – passenger cars, however, may then react to the changes of truck volume on the network links. Figure 9-2 shows the differentiation of the network links by truck attributes.

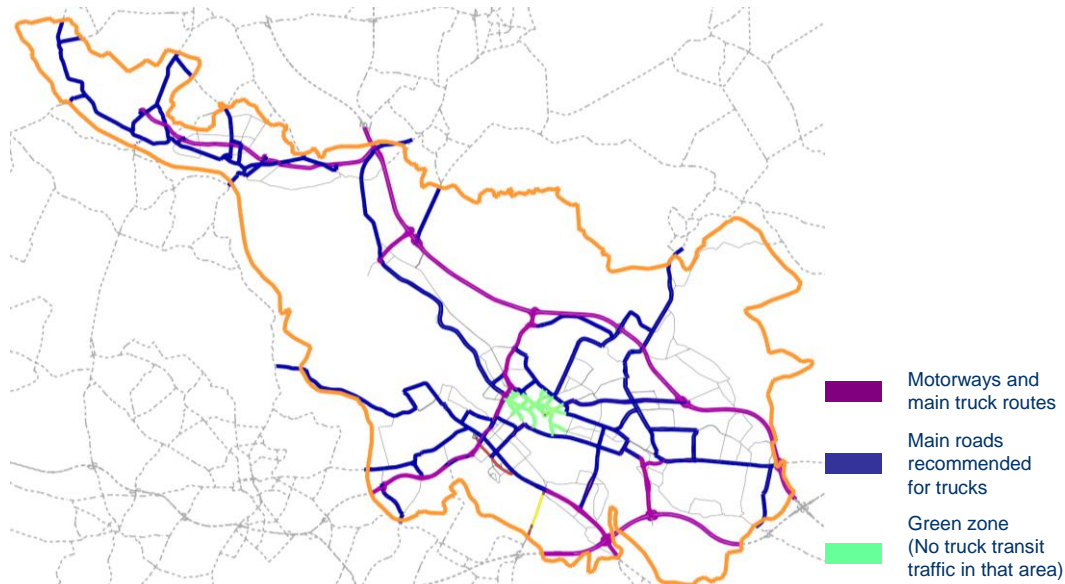


Figure 9-2 Bremen preferred truck network

The assignment with the changed attributes yields only marginal differences compared to the standard assignment. Some sections of the network, however, are considerably affected. This is most evident for the “Green Zone”, the area in the centre (Figure 9-3), which is closed to through truck traffic. Trucks on a typical through link are shifted to routes around this area. These links show an increase in truck traffic. The complete picture in the form of a difference plot is shown below. The link marked red carry more traffic, those in green carry less traffic compared to the base case.

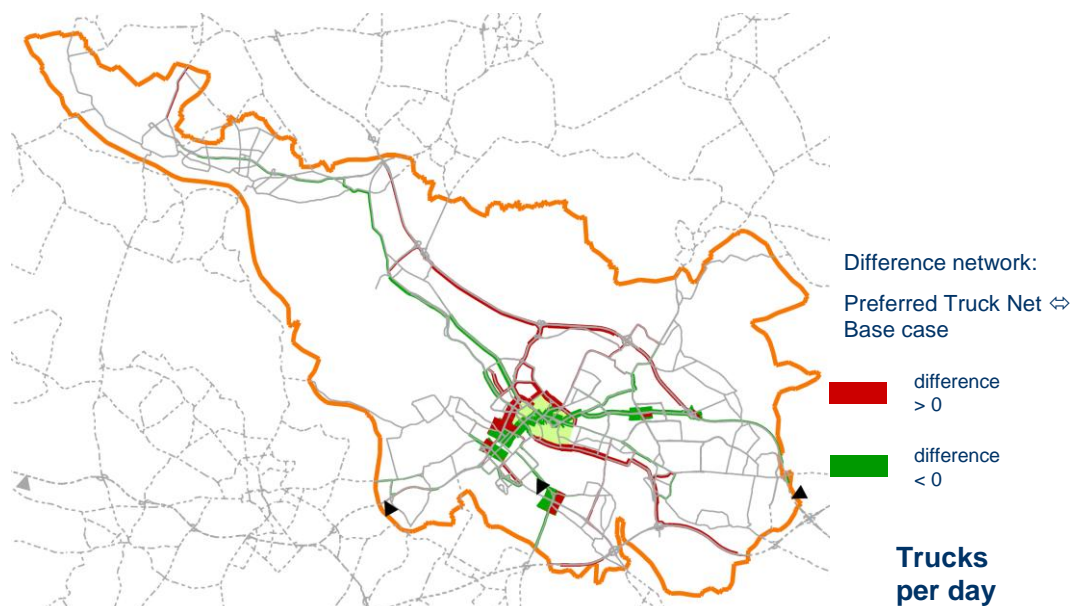


Figure 9-3 Effects of the Bremen preferred truck network

Table 9-1 Effects of preferred truck network on vehicle mileage

	All vehicles [veh-km]	Passenger cars [veh-km]	Trucks [veh-km]
Base Case	7.282.884	6.696.940	585.919
Preferred Truck Network	7.262.103	6.673.335	588.757
Difference %	-20.781 (-0.3%)	-23.604 (-0.4%)	2.838 (+0.5%)

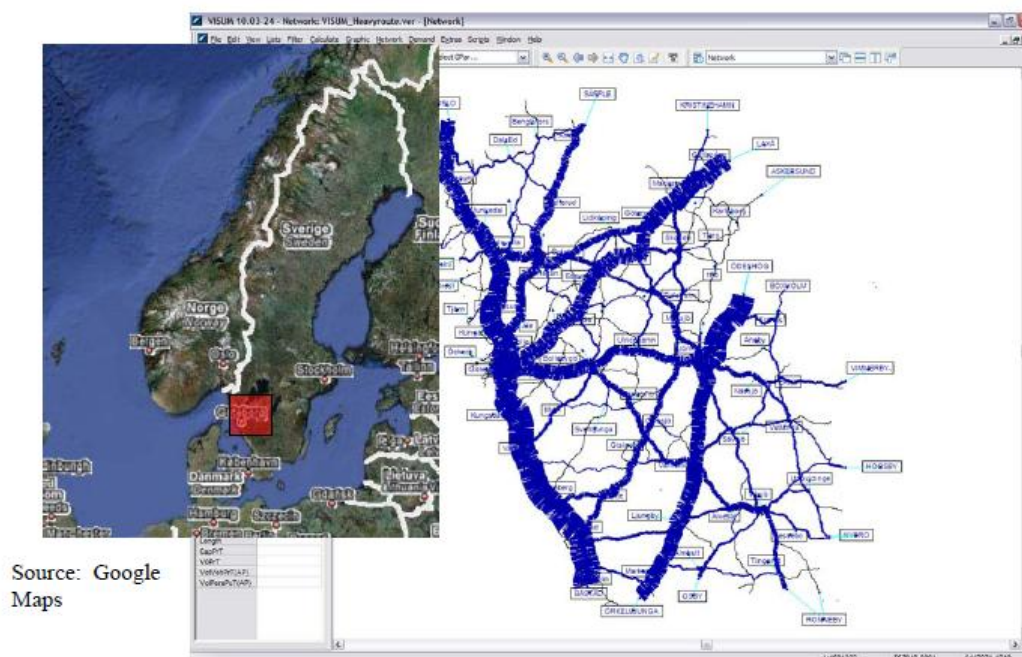
The total net effect for all vehicles is a reduction of vehicle miles. This is surprising at first glance. Due to the fact, that truck traffic is far below 10% of the total vehicle miles, the effect of rerouting trucks has a prominent effect on passenger cars traffic. The reduction of their mileage is higher than the increase in truck-miles, so that a net reduction of vehicle miles is the overall result.

While the reduction of total vehicle-miles is a positive result from a socio-economic point of view, the local effect may look different. The resulting increase in passenger cars in the Green Zone as a consequence in the reduction of trucks might not be a politically acceptable result.

9.2 The Swedish case study: Simulation of different HEAVYROUTE scenarios/modes

The Swedish case was carried out on a network in south-west Sweden. Figure 9-4 below depicts the location of the area within Sweden as well as the daily traffic volume on the roads. The total network consists of around 14.000 km roads.

The OD-matrix originates from the Swedish freight demand model covering the whole of Sweden (and the whole of Europe as well in less detail). The interior of our geographical evaluation region contains 76 municipalities, each corresponding to a zone (or centroid).

**Figure 9-4 Evaluation area in south-west Sweden**

The aim of the Swedish Case Study is to simulate different configurations of the HEAVYROUTE Route Guidance and Driving support (see section 4). The dispatcher can specify different modes in

the application which will guide him during the trip. In this Case Study the following scenarios were simulated:

- ▶ Scenario 1: More advanced VOC function based on Heavy Route; exact fuel consumption based on ARTEMIS data
- ▶ Scenario 2: Air pollution and Climate change optimization
- ▶ Scenario 3: Infrastructure cost optimization
- ▶ Scenario 4: Noise cost optimization
- ▶ Scenario 5: Safety cost optimization
- ▶ Scenario 6: Full HEAVYROUTE optimization

In the case study three different types of vehicles were tested with two different engine-classes, different load factors and noise reduction assumptions.

For the network depicted above the cost functions described in section 3.2 has been applied on a detailed network level with 66000 links. The cost functions includes road wear and tear based on pavement quality and axle load, air pollution emissions depending on speed, slope as well as engine class, user cost, time and fuel consumption, carbon dioxide emissions, accident risks depending on road standard and noise cost imposed on people living nearby the road. All effects are valued in monetary values using latest European Union research (such as the HEACTO, GRACE and CATRIN-projects). However, in contrast to other projects the cost functions are more detailed to mirror the difference in the network.

The primary purpose of the simulations is to estimate the potential benefits of a real HEAVYROUTE system. When it comes to the details, such a system could be designed in different ways. In particular, this is true regarding the selection of “best” routes. One way is, for each origin and destination, restrict the huge quantity of theoretical routes to a few “allowable” and reasonably short routes and, among these, the cheapest route is computed with respect to a given cost function (or mode). This method is called the *allowable route method (ARM)*. An alternative, and equally reasonable, approach would be to, for each origin and destination, directly compute the cheapest route with respect to the given cost. This is referred to as the *optimal route method (ORM)*. The HEAVYROUTE system has been evaluated using both these methods but the results presented are focused on ORM.

Figure 9-5 below shows the distribution of the transportation cost on the evaluation network for a Mid European truck with the ORM approach (the restricted approach gives the same result). The operators own cost is dominant with 44% time cost, 15% distance related vehicle costs and 27% fuel cost. An important consequence of this observation is that the operators own choice of route will carry a heavy weight in the route choice algorithm even when the different cost functions are included. This gives support for the approach which chooses five allowable routes in the HEAVYROUTE application as well as the ARM restriction made in the alternative simulation. It also suggests that the ORM optimization used in the simulation will not redirect truck operators to routes which are too long or time consuming compared to their private optimal path.

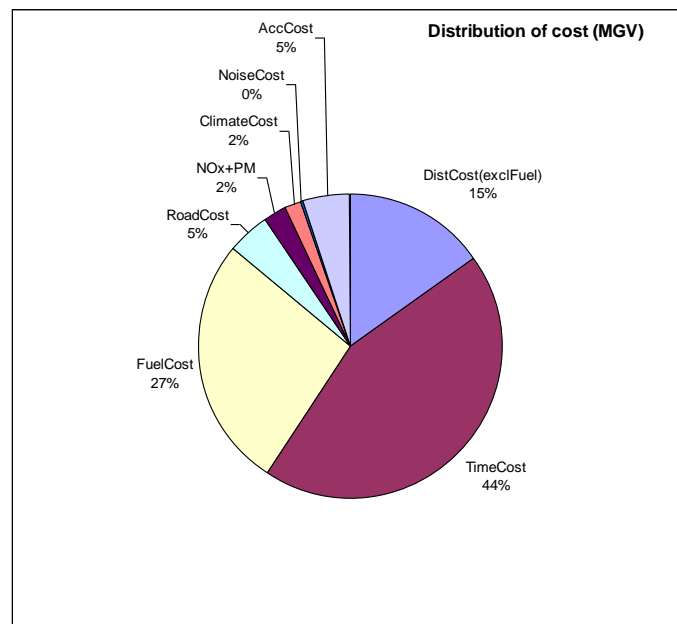


Figure 9-5 Distribution of costs in Base Case, MGV

A second observation is that the sum of the external costs is approximately 14%. This amount is not too far away from the expected fuel tax that is hidden in the fuel cost in the figure above. However, it should be noted that the HEAVYROUTE external cost does not include any congestion costs. The third observation is that when the costs from different scenarios are added they will constitute a small part of the operators own costs. Any changes in the traffic pattern and costs will be marginal.

All results are expressed as changes compared to the Base Case which are route guidance on standard vehicle operating cost and value of time functions ignoring the more detailed fuel consumption modelling of HEAVYROUTE. The “base vehicle” is the Mid European Truck with Euro-3 engine, half loaded and without noise reductions. The focus of the reporting is on the structure of the results and less on the absolute numbers due to the uncertainty.

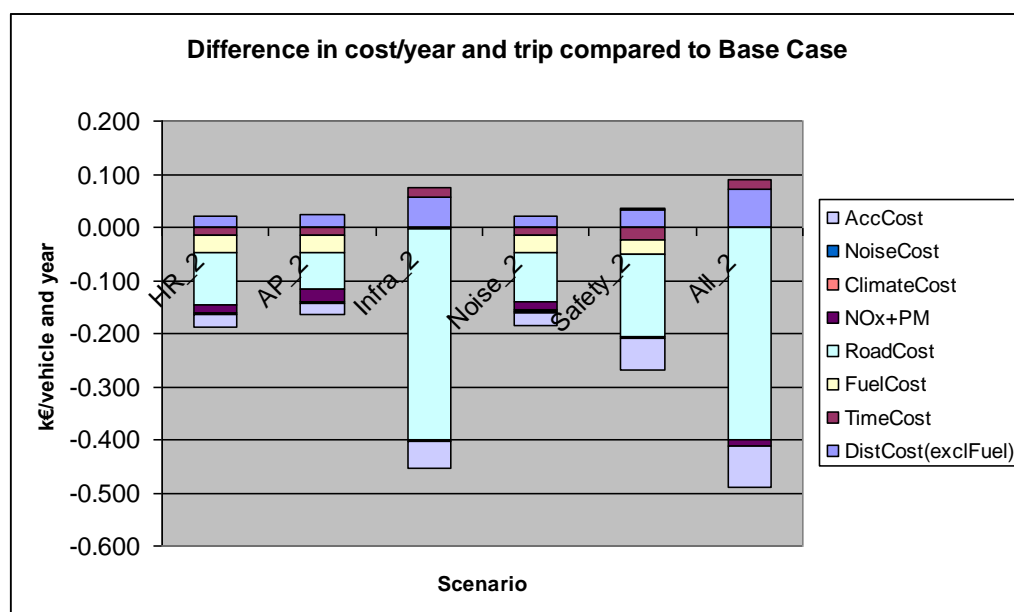


Figure 9-6 Cost changes for the Mid European Truck with different scenarios.

When the application is optimized for air pollution (AP), for example, the highest reduction is in NO_x +PM and Climate Cost of all scenarios as could be expected. The same is true also for optimization towards the other cost functions. The infrastructure cost optimization (Infra) gives the highest cost savings after the full HEAVYROUTE optimization (All). We also observe some conflicts. In the simulation, a redirection of HGVs towards less air pollution (including climate cost) reduces the saving for the road authority for example. An optimization done to reduce the infrastructure cost comes at the cost of less fuel savings, increased time cost and higher vehicle operating cost but an improved accident record. The latter effect is probably due to the high correlation between high road standard, low cost of wear and tear and high safety standard. The biggest total cost saving can be found for the infrastructure cost optimization mode. The second most important component is the safety mode while air pollution and noise have less impact compared to a application with only improved VOC. The full HEAVYROUTE has the highest cost reduction.

The conflict between private cost savings (fuel including tax, time and other distance cost) compared to the total savings for society is depicted in Figure 9-6. Based on simulations it would be expected that hauliers may purchase and use a HEAVYROUTE device for improved VOC functions, air pollution, noise and safety modes. However, they will not add infrastructure cost savings or a full HEAVYROUTE device as their preferred option.

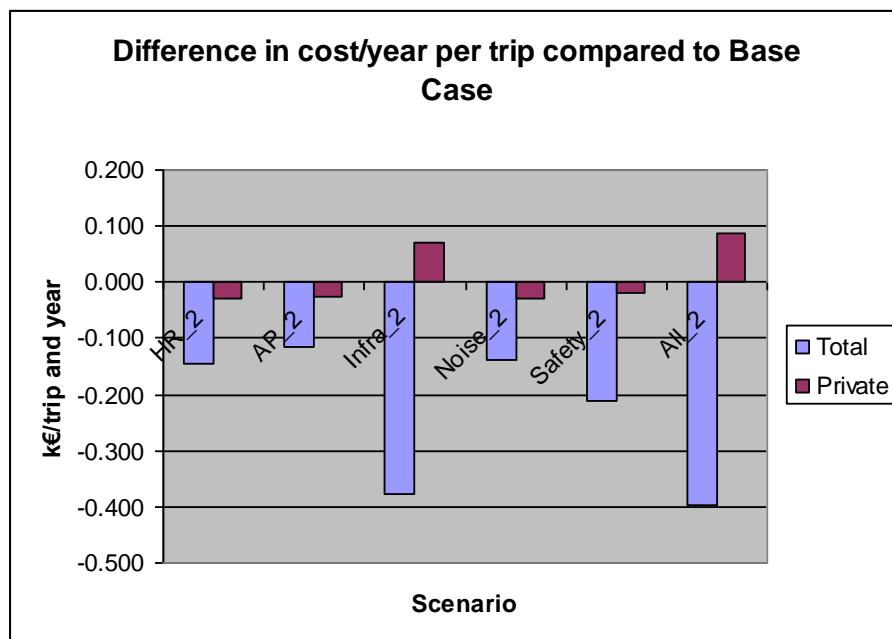


Figure 9-7 Total cost changes for the Mid European Truck; private and total cost.

A simulation with a heavier Nordic European Truck and a smaller Rigid Truck was also made (figure 9-7). The cost reduction with HEAVYROUTE is higher for the heavier vehicle. The cost savings is approximately 1/3 higher for the bigger truck and much smaller, about 1/3 only, for the light truck. The cost savings varies, however, between the different scenarios.

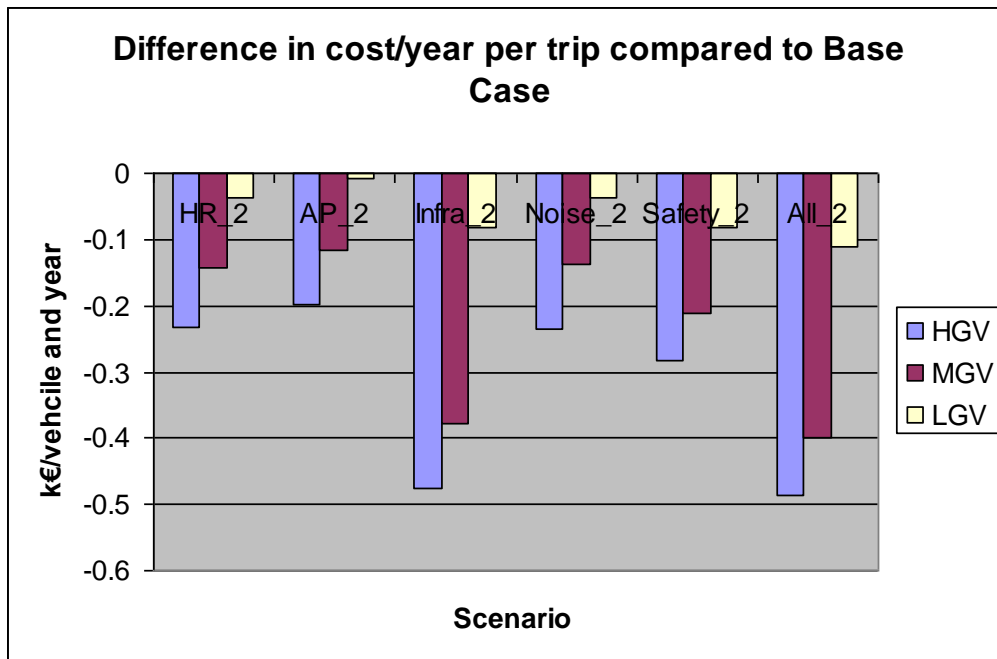


Figure 9-8 Total cost changes for the Nordic European Truck (HGV), Mid European Truck (MGV) and Rigid Truck (LGV)

Route planning and guiding systems are already available today on the market based on GPS technology and digital road maps with algorithms that support the haulier with the optimization of his logistic decision. The benefits to the haulier's have obviously outweighed the system cost and a market product has emerged. The HEAVYROUTE concept has features that have a market potential but it has also characteristics that are more difficult to see a private interest in. Based on traditional economic theory the market will not provide the optimal quantity of a good or service which displays non-excludability, non-rivalry or externalities. Some of these characteristics may fit into the description of the HEAVYROUTE system. For example, it could be argued that a user that follows the advice of the system on the welfare optimal path creates a positive externality towards other fellow road users (due to less congestion and risks) and the society at large (due to less environmental burden). However, the question is why the hauliers should choose this non-selfish solution. The Case Study examines a number of different alternative ways to make this happen;

- ▶ Change the preferences of the private operator – “go green”
- ▶ Tax the polluter (Pigouvian taxes) or subsidies to the cleaner producer
- ▶ Use restrictions

Of moral or market reason the private company may wish to behave more in line with the social objective – e.g. to behave green. Research on private individual's show that a significant proportion behaves with reciprocity or have some sort of altruism in their behaviour. Environmental lobbyist and individual preferences may create an environment where the market rewards firms that behave green. Following the advice on air pollution and accidents in HEAVYROUTE may thus be a prerequisite for better customer relations. The HEAVYROUTE system could be used to monitor this behaviour and used to issue a “Green Heavy Route” certificate. The market for Heavy Route would be limited to the number of operators that chooses to acquire a “Green HEAVYROUTE” certificate.

A system could also be envisaged where users of a monitoring scheme of the Heavy Route type could be allowed to pay the tax according to the monitored external cost in Heavy Route (or other system). Other users, which do not have a HEAVYROUTE system, can still pay the tax according to

the current blunt average taxation system. Obviously, only users with 'well behaved' costs functions will follow the advice of the HEAVYROUTE system. However, this will nevertheless increase the average cost for the users outside the system as the 'well behaved' operators will join the HEAVYROUTE system. A cycle will be created that moves users voluntary into a HEAVYROUTE system with tax differentiation. This will of course have consequences for Governments tax collection which have to be solved. The initial market share of HEAVYROUTE will in this case be limited to operators which today have a higher road tax than their actual social marginal cost.

And finally, a system could be foreseen that allows heavier and longer vehicles on a (limited) road network if their trips are informed by a HEAVYROUTE system. An increase in the length or weight may create an externality per vehicle (road damage, accidents etc). On the other hand, the transportation and logistics costs will be reduced as the number of vehicles will be reduced (and probably outweigh the external costs). The legal requirement to allow these longer vehicles could be that they have to follow the advice of the system. In return they will reap the benefit of longer and heavier vehicles.

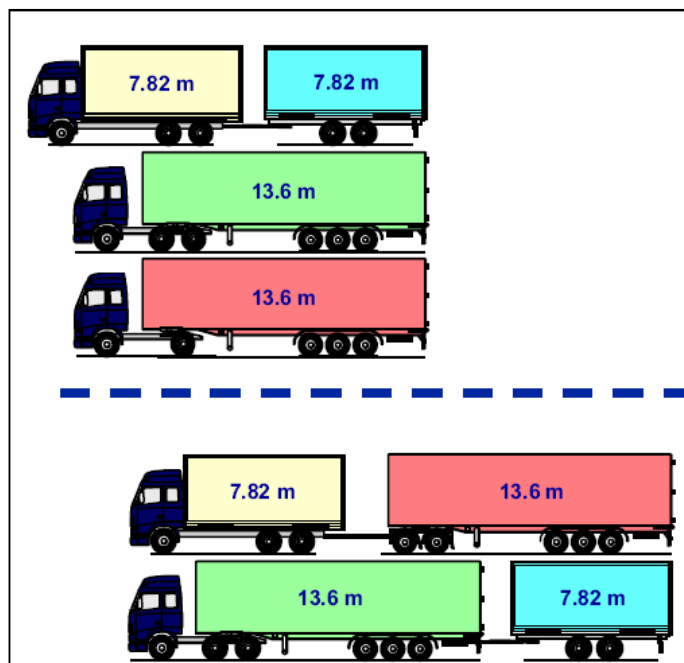


Figure 9-9 New LHV concepts can be allowed if they accept HEAVYROUTE routing advice. Source: Volvo Trucks

10. Conclusions

10.1 Pre-trip route planning application

10.1.1 Effect models and data

The pre-trip route planning is done in two steps. The first step is to derive **allowable (accessible) routes** based on the characteristics of the specific HGV and considering preferred networks for HGVs. This requires that all relevant truck attributes are integrated in the digital map. In the Navteq navigable map database for Sweden, truck attributes are available only for Functional Classes 1 and 2 - that means coverage of the road-network for motorways (FC1) and trunk roads (FC2).

The Navteq product covers the following types of attributes:

- ▶ physical restrictions such as height, weight, width, length;
- ▶ legal restrictions including truck-specific turn restrictions and hazardous material restrictions;
- ▶ warning information for hills (steep gradients), sharp curves and sections with risk for lateral wind gusts;
- ▶ transport-specific POIs (points of interest, e.g. suitable rest places).
- ▶ The second step is then to derive **recommended routes** considering the effects on fuel consumption, safety, environment (noise and emissions), road deterioration, etc. or rather the associated marginal costs that were established.

An important part of the project was to identify and adapt the effect models that would be used to calculate the recommended routes as well as identifying the data needed as input to the models. A criterion when selecting effect models was that they should be valid in most European countries. Several relevant models have actually been developed within recent European projects as for example ARTEMIS and HARMONOISE. In some cases, however, national models had to be chosen, as is the case for the road deterioration and the accident model.

These effect models have to be supported by new data that are not currently used for routing applications. Data can be defined as static, periodic and dynamic based on the update frequency. Using this definition traditional navigation mainly uses static data.

Periodic data is data that represents features that might change dynamically but is measured and presented in time intervals of around one to three years.

For the pre-trip routing application data on road (surface) conditions which is periodically captured by road authorities is particularly relevant.

The basic digital network is provided by companies like Navteq, Tele Atlas and AND. The new information needed by HR is however collected and managed by national governments, by regional governments or by private road companies. The consequence is that the data is not readily available. The support, up-dating and availability of this data have to be solved. Data formats have to be standardised and harmonized and data quality has to be ensured.

10.1.2 Conclusions from macro simulations

In the Bremen case study (see chapter 9.1) for the route planning system it was found that the total net effect for all vehicles is a reduction of vehicle miles. This is surprising at first glance. Due to the fact, that truck traffic is far below 10% of the total vehicle miles, the effect of rerouting trucks is much more prominent for passenger cars. The reduction of their mileage is higher than the increase in truck-miles, so that a net reduction of vehicle miles is the overall result. While the reduction of total vehicle-miles is a positive result from a socio-economic point of view, the local effect may look different. The resulting increase in passenger cars in the Green Zone resulting from the reduction of trucks there might be a politically unwanted result.

In the Swedish case studies (see chapter 9.2), it was demonstrated that different cost functions would change routing and save costs both for users and for society. It was also demonstrated that, as we know, user cost is an important part of the transport cost and will thus strongly affect the routing. This also means that the approach with a number of allowable routes will not limit the efficient routing. It was also shown that HEAVYROUTE will generate a substantial willingness-to-pay for public information infrastructure. However, although uncertain, it was concluded that road authorities are the biggest savers with reductions up to 18% of renewal costs. In the simulation this saving comes in the simulation at an expense of the operators. The conflict means that the market will not develop the most beneficial part of the HEAVYROUTE system. Some alternative policy scenarios that could be developed to bridge the gap were proposed.

One of the observations from these policy scenarios is the unique level of details in the HEAVYROUTE system. A conclusion from a developed HEAVYROUTE system is that it can be used to monitor a change from general regulations to specific regulation. It is possible that in the future longer and heavier vehicles can be allowed on specific parts of the infrastructure. A prerequisite for such vehicles is that their routing is decided in a system, like HEAVYROUTE, that takes societies costs into account.

10.2 Driver support and warning Application

The rollover warning application was done in two stages. First, all the dynamic and non measured states of the vehicle were estimated off line using the developed method. The recommended speed was then calculated along the specified route. In the second step, this speed was integrated into the map and then compared in real time to the actual speed measured by GPS (or other sensor installed in the vehicle). If the actual speed is greater than the recommended one, the rollover risk can exist. An alarm can be sent to the driver in order to reduce his speed and avoid the rollover.

It was seen that the states are well estimated and the speed is sent to the driver in real time. However some false alarms occurred during the tests. This was due to the fact that the calculation was done off-line and not in real time which can be problematic since the vehicle dynamics can be changed during the trip. The road data base was also incomplete (SFC value for example was not measured before the trip). The last reason could be the fact that the vehicle parameters such as masses or stiffness were unknown. To have better result and reduce false alarms it is recommended to add some sensors such as accelerometers to measure the vertical acceleration of the wheels, LVDT sensors to measure the suspension deflection etc.

10.3 Bridge management application

Field tests were carried out in Austria in order to validate the method for calculating dynamic effects of rolling HGVs over the bridges. The dynamic systems of the bridge and the vehicles interact with each other during passage of the vehicles over the bridge. The dynamic factor is the most important parameter, which describes amplification of vehicle's load due to dynamic effects. The dynamic factor (as well as other parameters) was measured on a bridge and compared to the values predicted by numerical simulations.

The comparison between measured and calculated results showed that the dynamic amplification is lower than predicted. Nevertheless, the influence of dynamic amplification on fatigue lifetime is not to be neglected. It was shown, that even at low levels of dynamic amplification, the estimated fatigue lifetime reduction is considerable. For example, a 5% dynamic amplification produces 16% of reduction in fatigue lifetime.

10.3.1 Conclusions from field tests

The tests were done in two steps. The first test was done at the end of 2008, on SAROT experimental site in Angers without panels. It was used as a reference, in order to better estimate the evolution of the HGV driver's behaviours. The second series extended over the two last weeks of January 2009 and after installing the modified panels relating to the instruction of specified gap (70m).

The data analysis showed that some of the drivers did not respect the inter-vehicular time of 2 seconds (between 2 light vehicles) and the 50 m between heavy trucks imposed by Highway Code. A significant number of drivers changed their driving behaviour in the presence of the panels of "Gap 70m".

It was noticed that before the indication of the panel " Gap 70m", 4.02% of heavy trucks did not respect the gap 50 m. After the indication of the panel, 7.55% of heavy trucks did not respect the gap of 50 m and 12.44% of them did not respect the gap of 70 m.

The installation of traffic management and control system to regulate speeds and inter-distances need the deployment of high technology information services. The lawful framework must be simplified in order to be more comprehensible and thus better applied and controlled and supporting the emergence of automated solutions. The co-operation with foreign (European) administrations must be reinforced. I

10.3.2 Conclusions from micro simulations

In the micro simulation of the Bridge management application it was clear that a general simple advice or even regulation to reduce the speed does not lead to a change in the headway distribution. It is obvious that the distances between vehicles changes due to the speed; however, these distances change relatively. The aim to break up platoons cannot be fulfilled by such an advice. This result, that a speed limit is unsuitable for bridge management if platoons are to be re-arranged, is important for the implementation in reality. Such a system could rather easily be put into practice by available technical solutions like WIM and VMS. However, the micro-simulations indicated this solution as not appropriate. Only with a more advanced system that is able to address individual vehicles, like a cooperative V2X implementation, could such an approach be feasible. All in all, the results found in micro-simulation and the experiences can be summarised as follows:

- ▶ An advice given globally to all trucks of “decrease speed” does not result in the desired effect of a break-up of platoons. Vehicles travel slower, but the load pattern (load and gaps over time) is not changed. Although such an implementation is easy to realize with conventional technology, an effect of changing platoons is not realistic.
- ▶ An advice of “increase distance”, also given globally to all trucks will result in changes in the desired direction (breaking up of platoons, increased spacing between trucks). However, major negative effects on traffic flow in general with potential safety hazards could arise. This holds especially at higher traffic volumes when such a system becomes more important.
- ▶ The best solution appears to be a system which addresses individual vehicles. Such cooperative systems are currently under development. They involve communication between vehicles and infrastructure; this means that more information, e.g. exact load status of trucks, can be included in the system. Furthermore, it can be expected that the acceptance of such systems by drivers is higher due to the individuality they display. Because they can target the “right” vehicles, their effect will be greater – the amount remains to be investigated.

11. Dissemination and Use

11.1 Dissemination activities

The HEAVYROUTE project has been disseminated using different tools and at various international conferences and workshops. Some of the dissemination activities include:

- ▶ Development of the website to inform a wide audience about the project results and to support internal communication within the consortium through the use of the FEHRL Knowledge Centre (<http://HEAVYROUTE.fehrl.org/index.php?m=32>, “Documents”)
- ▶ Publication of the HEAVYROUTE logo, leaflet, poster
- ▶ Presentation at the INTRO/Intelligent Highways “Greener” FEHRL seminar by Margit Noll (arsenal) on energy efficiency, Brussels, Oct. 25th, 2007
- ▶ Presentation of the HEAVYROUTE project by Stefan Deix (arsenal) during the CERTAIN / NR2C Seminar “Innovation on Road Infrastructure” in Brussels on November 15th, 2007
- ▶ Presentation of the HEAVYROUTE project to EUCAR on January 8th, 2008
- ▶ Contribution of the HEAVYROUTE project to the ERTRAC Research framework on long distance freight in January 2008
- ▶ Presentation of the HEAVYROUTE project at the 6th Symposium of Pavement Surface Characteristics SURF 2008, Portoroz, Slovenia, 20 – 22 October 2008

The 6th symposium on pavement surface characteristics – SURF 2008, organised by PIARC, took place in Portoroz, Slovenia. The FEHRL stand provided a focal point for dissemination (e.g. HEAVYROUTE project) and networking in the research field for the multinational delegates.



Figure 11-1 HEAVYROUTE at SURF 2008

- ▶ Presentation of the HEAVYROUTE project during the TRA2008 Conference in Ljubljana, Slovenia from April 21-24, 2008. A press conference organized by the EC was given by the HEAVYROUTE Project Coordinator, Anita Ihs.
- ▶ Presentation of the HEAVYROUTE project at the European Cities of Science event in Paris (November 2008).

The European Cities of Science was an event under the French Presidency of the European Union. It was a major science exhibition in Europe in 2008. As the theme suggests, “science in the service of society”, the idea behind the event was to establish ties between science and the society at large. The event was opened to all and welcomed youth, families, science lovers, seekers of innovation etc. The HEAVYROUTE project was disseminated in the event as part of FEHRL’s EC projects.



Figure 11-2 HEAVYROUTE at European Cities of Science

- ▶ Presentation of the HEAVYROUTE project at the International Conference on Heavy Vehicles, Paris, France from May 19-22, 2008. Leaflets were handed out at the LCPC booth. A. Ihs gave a press conference on HEAVYROUTE.
- ▶ Presentation of the HEAVYROUTE project at Research Connection 2009, Prague, 7 – 8 May 2009.

Research Connection 2009 (conference and exhibition) was organised in conjunction with the Czech Presidency of the European Union. It was a major event on EU research initiatives.



Figure 11-3 HEAVYROUTE at Research Connection



Figure 11-4 HEAVYROUTE Final Seminar

- ▶ Consultation and communication with reference end-user group. Strengthening of working relations with other projects within the FEHRL Strategic European Road Research Programme (SERRP) cluster and other networks, in particular ARCHES, SPENS and CERTAIN

An overview of the dissemination activities is shown in Table 11-1.

Table 11-1 Dissemination activities of the HEAVYROUTE project

Planned/ actual dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible
Oct 25th 2007	Workshop INTRO/ intelligent highways	Stakeholders / researchers / industry	All EU	75	FEHRL & AIT
Nov 15 th 2007	CERTAIN/NR2C Seminar "Innovation on Road Infrastructure"	Stakeholders, Endusers, Researchers, EC members.	Global	70	FEHRL
Jan 8 th , 2008	EUCAR	Stakeholders / researchers / industry	EU	8	FEHRL, AIT, LCPC
Jan 2008	ERTRAC "long distance Freight"	Stakeholders / researchers / industry	EU	8	LCPC
Feb 2008	Conference (safe highways)	Stakeholders and researchers	EU	150	FEHRL & VTI
April 21- 24 th , 2008	TRA2008 conference, Ljubljana	Stakeholders, End users, industry, Researchers, EC members, road authorities and -owners etc	EU	18.000	EU/FEHRL
April 21- 24 th , 2008	Press release	EC press conference at TRA	EU	1000	EC
May 19-22 2008	Int. Conference on Heavy Vehicles, Paris	Researchers, Industry	EU		LCPC / VTI
Oct 20-22 2008	SURF conference and exhibition,	Stakeholders, Researchers, Industry	EU	300	FEHRL

	Slovenia				
Nov 14-16 2008	European City of Science Exhibition, Paris	Large audience	EU	Over 10.000	FEHRL
Jan 2009	ERTRAC press event	Stakeholders, End users, industry, Researchers, EC members, road authorities and -owners etc	EU	100	FEHRL
Jan 2009	Conference TRB, Washington	Stakeholders, End users, industry, Researchers, EC members, road authorities and -owners etc	Global	11.000	FEHRL
June 9 -10 2009	HEAVYROUTE Final Seminar, Brussels	Stakeholders, End users, industry, Researchers, EC members, road authorities and -owners etc	EU	40	All
Sept. 21-25, 2009	ITS Congress, Stockholm	Stakeholders, End users, industry, Researchers, EC members, road authorities and -owners etc	Global	8000	EU/VTI

11.2 Exploitation of the results

11.2.1 Classification of critical bridges and bridge types

The main exploitation strategy for classification of bridge types is the integration of gathered knowledge and conducted research in common national bridge management and maintenance strategies. The purpose is to reduce lifecycle-costs and increase reliability of the civil engineered transportation infrastructure. Therefore, this specific exploitable result may be valuable through standardization and legal policies especially for authorities. The dissemination of knowledge, common understanding, harmonization efforts and cost benefit analysis are required to stimulate the market. Authorities tend to underestimate the consequences or undervalue positive effects through novel technology developments. As the main “profiteer” in this case is the public body and society as a whole, the accomplished research development is not protected through IPR’s. Contacts to the national road authorities should facilitate wide acceptance and integration in daily business. The main partner involved in the exploitation of results is LCPC due to the conducted research on bridge management systems and fatigue effects from static loading.

11.2.2 Matching process

Experience gained with matching process and use of advanced attributes for future routing applications, provides valuable inputs for further developments of the map database specification, map database technology and location referencing. The matching process results provide direct valuable knowledge for the EU-funded ROSATTE project, which is studying future regular transfer of incremental updates of road safety attributes, especially speed limits and traffic signs, from public authorities, who make the changes, to the providers of map databases for in-vehicle applications.

11.2.3 Generic information on exploitable knowledge

HEAVYROUTE is primarily a research project. It can be seen, however, that there is good market potential for route guidance systems all over the world; therefore it is possible that HEAVYROUTE will be widely implemented providing that there are necessary incentives available.

If the private operators' interests, the external costs and the HEAVYROUTE modules are taken into account, it can be assumed that the HEAVYROUTE system will emerge as a private product first limited to transportation and logistics and that road authorities will be interested in applying the system at a later stage. Environmental costs are expected to be considered even later.

A detailed analysis of the possible implementation of the HEAVYROUTE system can be found in deliverable D4.2 'Development path of HEAVYROUTE systems – impact and socio-economic consequences'.

11.2.4 Exploitation plan of the consortium partners

AIT

The work of AIT in HEAVYROUTE is mainly related to the classification of critical bridges and bridge types regarding heavy vehicle traffic. The results obtained in the project will be used in several ways.

First of all, they are going to be exploited at the national level by integrating the gathered knowledge into national maintenance strategies as well as in ongoing research projects, focusing on the interaction of infrastructure and the vehicle. Secondly, at the European level, the results will be made available to the bridge and navigation industry via scientific publications in order to enable them to base upcoming developments on the results.

ERTICO

The results of the HEAVYROUTE project can potentially benefit most ERTICO partners, especially those dealing with traffic management and route planning or the ones that specialize in Heavy Goods Vehicles.

With its large network of ITS stakeholders, ERTICO will be able to liaise with interested parties and to move forward the project results towards deployment. It is also interesting to examine the possibility of linking the HEAVYROUTE results with other HGV-related projects with the aim to integrate the results into projects currently being developed. If standardization needs should arise, ERTICO will be ready to exploit its already existing relations with standards organizations in order to help in making progress with future standards.

FEHRL

FEHRL will be looking beyond generating publicity to essentially encouraging general public knowledge and stakeholders to use, or further develop the project results. In order to achieve this objective, a cluster of activities are dedicated to endorsing an effective exploitation platform, to draw attention to the potential value of the project and spread awareness to other interested parties throughout Europe.

This dissemination platform is generated by communicating the project results through:

- ▶ The HEAVYROUTE website, dedicated directly to exploiting the project developments, results and achievements.

- ▶ The project database. Use of results in future projects
- ▶ The FEHRLopedia. An online portal designed for road infrastructure knowledge, linking relevant content from various reputable sites on the internet related to the HEAVYROUTE project.
- ▶ Further representation at FEHRL stands during Conferences, Exhibitions, and Seminars.
- ▶ Various future publications committed to raising awareness through press releases, posters, flyers, and film/video.
- ▶ Direct e-mailing, informing our 32 members of the outcome of the project and various aspects of potential interest.

Through these different portals, project-specific exploitation on a national level can be achieved for the process and treatment of the HEAVYROUTE project.

LCPC

LCPC's involvement in HEAVYROUTE deals with two main subjects: driver support (warning systems) and the static load effect of heavy vehicles on bridges.

The black spot warning application and the rollover warning system proved to be efficient and could be implemented in real trucks.

The tests conducted on real site in Angers, in France, can be applied on other sites in order to develop traffic management rules in France. The LCPC is involved in French workgroups and will use the knowledge obtained in HEAVYROUTE project for improving infrastructure management policy.

NAVTEQ

A major task of NAVTEQ, apart from providing map database know how, was the map integration, for the selected test site in Sweden, the outcomes of the specialised models for translating safety effects, environmental impact, effects on the road infrastructure and impact on driver comfort to a map database link cost. The resulting costs per link can be used in the process of selecting an optimal route from various alternative allowable and feasible routes from an origin to a destination. The model outcomes were prepared in relation to the National Road Database (NVDB) of the Swedish Road Administration, as the underlying attribute information was available from various management databases in relation to this map database. The results then had to be transferred from the NVDB network to the NAVTEQ network, which was the network to be used in the field trial and the simulations.

The basis for this transfer is a matching of the aggregated NVDB database segments that were defined by VTI, to the links in the NAVTEQ database. This process is similar to location referencing. It is difficult due to dissimilarities in both geometry and attributes between the two databases. Both the experience gained with the matching process and the insight gained in the use of these advanced attributes for future routeing applications, provide valuable inputs for further developments of the map database specification, map database technology and location referencing. In this way, the results concerning the matching are also valuable for the ROSATTE project, which is studying future regular transfer of incremental updates of road safety attributes, especially speed limits and traffic signs, from public authorities, who make the changes, to the providers of map databases for in-vehicle applications. In addition, NAVTEQ implemented a driver warning plug-in in its ADAS Research Platform, a rapid prototyping and development tool that is widely used in the automotive industry. The development contributes to improving the usability and versatility of the platform.

PTV

PTV plans to use the results for the elaboration of their components and models due to intensive examination of routing algorithm for truck guidance. Furthermore the implemented surface and interfaces can be utilised in upcoming research projects and truck related applications.

As a supplier of software and consulting in the fields of traffic planning, navigation and routing, PTV can pass the enhanced experience down to its customers and stakeholders. The following issues will be addresses:

Enhanced truck route guidance

The target-groups, which can profit from the improved routing, are:

- ▶ Transport operators for HGV (fleet manager and forwarder)
- ▶ Truck drivers (HATI – ride comfort)
- ▶ Authorities (HATI-index, CO₂-emissions)
- ▶ Enhanced truck pre-trip planning and navigation systems

Because of the additional truck attributes and the possibility to choose from different truck profiles PTV can offer an improved truck routing and guidance to truck operators. The benefit for the truck drivers and operators is a more efficient reaction to traffic changes.

Routing results related to infrastructure and emission costs

The results of the HEAVYROUTE project give the possibility to connect real and effective costs to specific route links. This facilitates decisions related to infrastructure improvements and emissions restrictions. The positive effect is that the costs can be calculated for the chosen tour already at the planning state. That is, different tour choices can be evaluated under different aspects of cost parameters and can then be selected (if possible, according to cost parameters).

The relation between routing functionalities and infrastructure and emission costs is useful for authorities and city stakeholders. If these facts are considered from authorities and transport operators a positive side effect might be, for example, the reduction of CO₂ and noise emissions as well as the reduction of infrastructure costs and fuel consumption.

VOLVO

Volvo recognizes the potential of the HEAVYROUTE system and also that many of Volvo's customers could benefit from such a system. Ongoing and future projects at Volvo, internal as well as external, could make use of the knowledge gained from the Heavy Route project. The possibility to combine features from the HEAVYROUTE system with other existing or future systems should be analyzed to investigate possible synergy effects.

VTI

A major task of VTI has been the work with identifying relevant effect models and required input data and develop cost functions for the pre-trip route application. Another major task has been to carry out macro simulations on a real road network to evaluate the HEAVYROUTE cost functions and to estimate the potential benefits of the system as well as manage the field test of HEAVYROUTE.

The very valuable experience and knowledge gained from this work will be, and already is, used by VTI in both national and European research projects concerning road freight transport. Important feedback will be given to the sources responsible for models e.g. ARTEMIS, Harmonoise and HATI

as well as the own developed models. The possibility to establish an economic value to the selected function will be further explored and a process of quality assurance for this novel type of detailed cost functions will be performed. It is possible that further research could be geared towards economic valuation of ride quality where a function is developed but no economic values could be used in the project.

In the macro simulation the detailed cost functions were applied on a large real case network. This is an essential experience and can be exploited in supplying detailed networks with cost functions, including quality assurance system, for external customers. In the project different responsibility areas in the road administration had to be linked; the road planning department, the national road data base division and the maintenance and operations department. This helpful experience will be used by VTI to improve cooperation and formulate ideas on coming projects

The conduction of the field experiment to validate the fuel consumption model was unique in the sense that the route conditions was extremely well inventoried and compared with real life driving of heavy trucks. This gave new and valuable information to the fuel consumption research.

VTI will further explore the possibility to use larger trucks in Sweden (i.e. >60t, 25,25m) in an ongoing project. One of the prerequisite for allowing these bigger vehicles may be the use of a HEAVYROUTE system. In addition, the use of the HR concept for private cars is a challenge that will be further discussed.

The results of HR cover almost all areas of road transport and the result will be spread within VTI to responsible researchers of each area to ensure that the experiences will be used. One excellent arena for this is the annual transport research conference arranged by VTI. All results and experiences of the project are furthermore transferred to the Swedish Road administration.

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