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Work Package leader: arsenal research / Task leader: PRISMA solutions

Contributors:

- arsenal research: Stefan Deix, Roland Spielhofer

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Editors:

Task leader and Main Author

Torsten Schönberg
PRISMA solutions EDV-Dienstleistungen GmbH
Klostergasse 18
A-2340 Mödling

Tel.: +43 (0) 2236 47975 23
Fax.: +43 (0) 2236 47975 90
e-mail: torsten.Schoenberg@prisma-solutions.at
http://www.prisma-solutions.at

Work Package leader and editor/contributor

Stefan Deix
arsenal research
Österreichisches Forschungs- und Prüfzentrum Arsenal Ges.m.b.H.
Giefinggasse 2
A-1210 Wien

Tel.: +43 (0) 50550 6477
Fax: +43 (0) 50550 6666
e-mail: Stefan.deix@arsenal.ac.at
http://www.arsenal.ac.at

Contributors:
Nik Widmann (PRISMA solutions)
Stefan Deix (arsenal research)
Roland Spielhofer (arsenal research)

Reviewed by:
Nicolas Bueche (EFPL)
Michal Karkowski (IBDIM)
Sigvard Tim (VTI)

Final Control:

Released by: Bengt Wälivaara (VTI)
Signature:

Date:

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List of abbreviation

AGORA	EU project
CAN bus	Controller Area Network bus
DSS	Decision Support System
EuroRoadS	EU project
GIS	Geographic Information System
GPRS	General Packet Radio Service (mobile data service)
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HMI	Human Machine Interface
Http	Hypertext Transfer Protocol
MatLab	Numerical computing environment and programming language

NextMAP	EU project
NIRA	Software by NIRA Dynamics
NSDI	National Spatial Data Initiative
OKSTRA	Objektkatalog für das Straßen- und Verkehrswesen (German object catalogue)
PHP	Hypertext Preprocessor, reflective programming language
RoadSTAR	Road Surface Tester of arsenal research
RONCALLI	Austrian Project (Real time information to driver)
SKAT	PRISMA solution's Software for Road and Traffic division
TCP/IP	Internet protocol suite, communication protocol
UMTS	Universal Mobile Telecommunication System
USB	Universal Serial Bus
VISUM	Data model for traffic planning and modeling (PTV)
WFS	Web Feature Service
WMS	Web Map Service
XFCD	Extended Floating Car Data
XML	Extensible Markup Language

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Executive summary

The purpose of Work Package 2 “Surface Safety Monitoring” in the INTRO project is to increase the safety of European roads. With the help of an intelligent combination of sensor technologies and central databases utilizing real-time networking technologies, road safety related to skidding will be improved for the driver. Road Maintenance Authorities will also be able to react more flexible to unfavorable road conditions.

Objectives

The most important aspect of INTRO WP2, Task 2.4 (“Data model, reference network and communication”) was to develop a data model for road safety related data. This model forms the basis for processing static as well as dynamic data containing road safety information. Dynamic data – for example extended floating car data (xFCD) – could include various types of content (in the INTRO project it is current road friction information), whereas static data for example is information about road geometry.

The requirements to the model consist in clearly structured storage and processing of data on the one hand, and on the other hand in high-performance delivery of data to any kind of end user. In the INTRO project two representative types of end users are specified: vehicles with mobile communication to the server and authorities responsible for road maintenance.

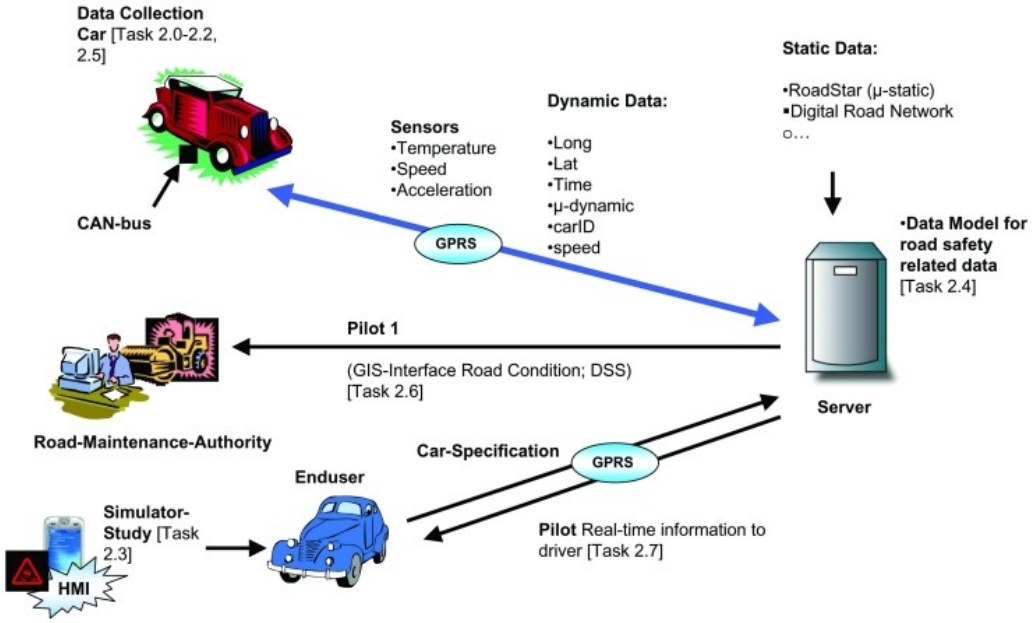


Figure 1: Overview of system architecture

The processed road safety information will eventually play a central role in the “real-time information to driver” (Task 2.7) and “GIS-interface road condition” (Task 2.6) pilot projects.

State of the Art

Several data models in the field of traffic information are in use for very specific fields of application. Data models e.g. from navigation data providers or from the field of Geographic Information Technology (GIS) are especially well known examples.

One objective of the EU project EuroRoadS is to enable easier public access to traffic information. In order to encourage commercialization of this spatial data, EuroRoadS has developed a quality model aimed at ensuring quality from the moment data is collected until its final delivery to the end user.

In 2000-2001, the EU project NextMAP dealt with the issue of edge usage for projected assistance systems. Required data content, geo-objects and

geometric precision, for example street geometry and positional precision, were examined for the benefit of various assistance systems.

Most of the data models are highly specialized (other models are either clandestine or proprietary). From this point of view, there is currently no authoritative or readily acceptable data model that meets the special requirements of INTRO. Special demands are placed on data models when dealing with dynamic data. Specific requirements of users of decision support systems (road maintenance authorities), end users of a road safety information service have to be considered when defining an appropriate data model. Interfaces that ensure a high degree of compatibility have to be developed.

Outcome

During the extensive concept phase, each task partner involved was able to determine all necessary user and data model requirements for an INTRO data model. In addition, previous results from other WP2 tasks (Task 2.0-2.2. and their results concerning Extended Floating Car Data compiled from Data Collection Cars and data from CAN bus) were incorporated in the concept in order to arrive at the most optimal outcome.

Data Model

A data model was developed within the scope of task 2.4 whose goal was to process static (GPS coordinates and road condition parameters) as well as dynamic information (Extended Floating Car Data) on a central server before sending the final results in real-time in the form of Warning Distances and Hot Spots to potential end users or Road Maintenance Authorities.

Static & Dynamic Data

Another element of task 2.4 was the collection of static data (GPS coordinates and road condition parameters). This data formed the basis for constructing a Digital Road Network on the server.

The integration of dynamic Extended Floating Car Data (from Data Collection Cars and data from CAN bus) into the data model was an important consideration while designing databases capable of meeting already defined user and data model requirements.

User Requirements

Especially important for future users of high-quality traffic telematic services is that the data is up to date. This means that for future road condition services, road condition parameters (static) must be collected on a regular basis. Highly accurate information can only be transferred to the end user in real-time (e.g. Task 2.6 and Task 2.7) when current data is available. The acceptance level of such a system drops rapidly if road safety information does not reach the user in time or is completely lost.

Another important user requirements are completely and extensively available databases. High-quality information must be featured at all stages of the digital road network in order to be of benefit to road maintenance authorities as well as end users of telematic services. This applies to high and low level road networks as well as to all necessary attributes (e.g. road condition parameters).

Data Model Requirements

The handling of dynamic data in this context proved to be an especially innovative challenge. Constantly changing dynamic parameters (Extended Floating Car Data) first have to be integrated using appropriate Net-Matching Processes located on the central server. Then they are matched with already integrated static data. Special algorithms for this purpose are executed on the

server. These calculations result in Warning Distances that allow the end user to react in a timely manner to bad road conditions. Another resulting calculation is Hot Spots information which is made available to the Road Maintenance Authority via a GIS-interface. In order to integrate, to export and make available static and dynamic data suitable interfaces were defined.

Implementing the Data Model

One major objective of Task 2.4 was the creation of a Digital Road Network. The Digital Road Network for Traffic Telematic Services is the central content level where the entire static and dynamic contents are located.

In the reference system, the geometric aspect of the traffic network is mapped using the simplest possible structure. This ensures that the basis is modeled using simple lines (edges) as well as the topological correlation to these lines (nodes) [Network topology based on edges and nodes].

In order to model all static and dynamic aspects, four databases were created to manage the entire content:

- Road Network Database
- Street Segment Database
- Attribute Database
- Service Database

These four databases could also be technically implemented into one database in the future.

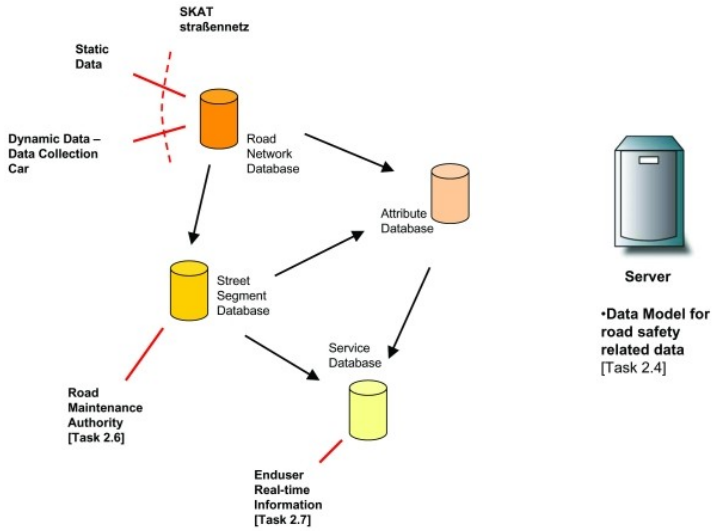


Figure 2: Server: Databases and Interfaces (red lines)

“SKAT straßennetz”, PRISMA solution’s software for road and traffic division, proved to be a very efficient tool and interface to static and dynamic data. The use of this software guaranteed efficient administration of the Digital Road Network at any point of time during the project. Furthermore, both interfaces to the pilot projects (Tasks 2.6 & 2.7) were defined and can be used for planned applications further on in the project.

The requirements for reaching task 2.4’s objectives, as outlined in the project, were successfully implemented. Each stage of Task 2.4 was very carefully monitored, from the collection and evaluation of data and the efficient and flexible construction of databases to the tools used to process static and dynamic data. In addition, quality criteria were put in place to supervise the handling of sensitive information. At the end of this chain of process, it is ultimately the user that stands to receive valuable road safety information. With this information, this project makes a valuable contribution to the safety of all road users as well as a reduction of traffic related fatalities.

Conclusions

The Task-Partner of this project (arsenal & PRISMA) all contributed considerable expertise in the creation of these data model concepts as well as the central server. Already successful tools (e.g. PRISMA solution's software for road and traffic division to process highly sensitive data) were integrated into the workflow in order to simplify the data integration process. Furthermore, the INTRO project was able to greatly benefit from the extensive experience gained from other successful ventures such as the Austrian project RONCALLI (www.roncalli-telematics.com) Real-time information poses a great challenge for all database designers, however in the INTRO project, the consortium now has a model that meets and supports every necessary requirement.

1. Introduction

In the context of INTRO WP2, Task 2.4 builds the foundation for the two planned demonstrators (Task 2.6 and Task 2.7). After the basic evaluation in Task 2.1 and the development of stopping distance models in Task 2.2, Task 2.4 integrates the results of the preceding tasks and develops a framework for managing and transferring road safety related data. This data model is transferred into the software that is necessary to operate the two demonstrators.

Data Model for Road Safety Related Data

In the past, special data models were developed for various applications in the traffic sector. The data models from providers such as TeleAtlas and NavTeq are especially well known and form the network model basis for a number of traffic related applications.

In addition to other commercial data models (e.g. from the GIS manufacturers ESRI), special mention belongs to road authority models such as OKSTRA and to models used for traffic planning and modeling such as VISUM/PTV.

Special requirements were placed on the data model for handling dynamic data (Extended Floating Car Data). Within the scope of the INTRO project, dynamic and static data (e.g. road condition parameters) will be compiled before either being sent to a central server or integrated into specially designed databases via import functions. The goal is to process dynamic and static road safety information so that it can be transferred over defined interfaces to the end user (vehicle driver or Road Maintenance Authority). The added value of this information lies in its contribution to traffic safety as well as safer roads.

This report documents the entire work process: data collection (static and dynamic), data model description and outlook of workflow in WP2.

2. Overview system architecture

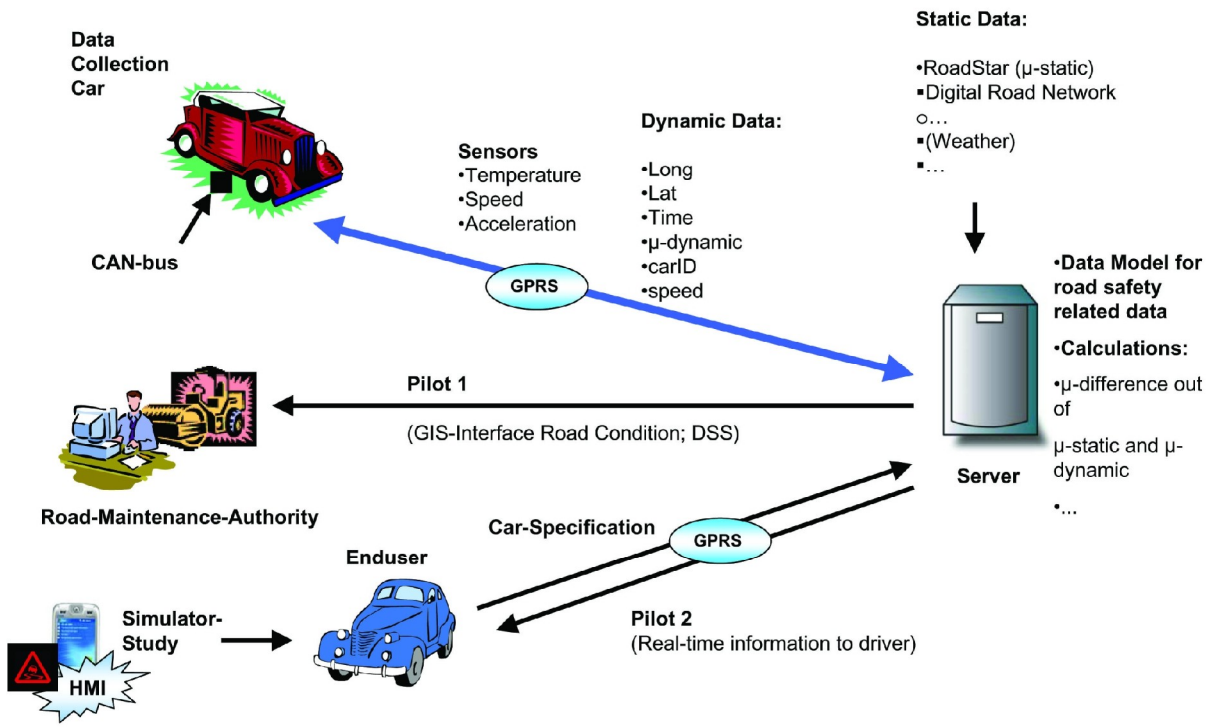


Figure 3: Overview of system architecture

The above schematic overview clearly illustrates how the central topics of Task 2.4 (Data Model for road safety related data) relate to each other and how they connect to other parts of WP2.

The experiences from Task 2.3 (Simulator Study) will be integrated in the pilot program "real-time information to drivers" (Task 2.7) where the HMI results from the Simulator Studies will be finally tested in real-time. The static (e.g. RoadStar-Data, Digital Road Network) and dynamic (e.g. car specification, position, stopping distance) data necessary for the pilot actions are processed

on a central server and transmitted via a mobile communication in real time to the end user (driver, road maintenance authority).

3. Data Collection

Information can either be raw data, as directly delivered by the Data Collection System, or processed data. Each case should be examined individually to determine the information required as well as the format of that information. In the case of INTRO, necessary static data (road parameters & GPS coordinates) was collected with the assistance of RoadSTAR (Road Surface Tester of arsenal research). With the help of in-built sensors of the Data Collection Car, Extended Floating Car Data (dynamic data) is collected and then forwarded via a mobile communication to a central server.

3.1. Methods

The data collection for generating the Digital Road Network as well as for the static skid resistance data (road condition parameters) was done using the RoadSTAR (see Figure 4). The RoadSTAR is a high performance measurement vehicle developed by arsenal research.

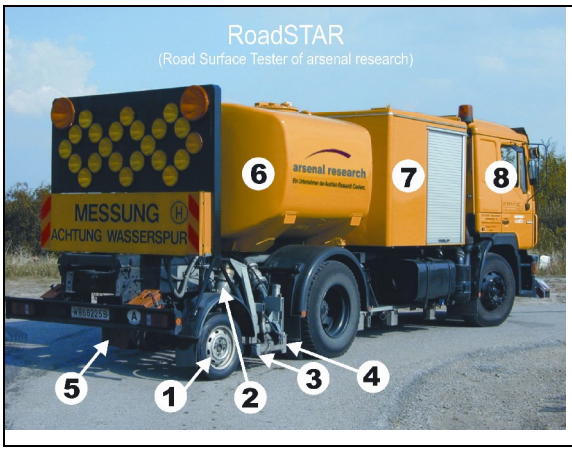
3.2. GPS-Positioning

The GPS data collection was done using an Ashtech G12 GPS receiver. Differential corrections were applied in real time using an OmniSTAR 3200L device that acts as a moving virtual local base station to increase the accuracy of the GPS measurements. The GPS positioning was done with 10 Hz resulting in an average distance of approximately 1.5 m between each

point due to a measurement speed of 50 – 60 km/h. All data was stored using the RoadSTAR specific data collection software in MS Access file format.

3.3. Sensors

Skid resistance measurements were done with RoadSTAR, a modified Stuttgarter skiddometer. Measurements were carried out with 18 % slip and 0.5 mm water film thickness. A ribbed PIARC tyre was used for the measurements. All measured skid resistance values were referenced to a measuring speed of 60 km/h. The measurements were done according to RVS 11.06.65 [1].





① Measuring wheel
② Pneumatic cylinder
③ Wetting unit
④ Pre wetting unit
⑤ Gearbox
⑥ Tank (6000 l)
⑦ device storage
⑧ driver's cab; digital measurement recording

Figure 4: RoadSTAR skid resistance measurement unit

3.4. Test routes

To be able to develop mathematical algorithms to detect road friction parameters from the collected CAN bus data sentences, it is necessary to collect datasets. These datasets have to represent all kinds of different road and pavement conditions. For this purpose two test routes were chosen in the proximity of Vienna.

The first route leads through a more or less alpine region. The road is curvaceous and contains many differences in altitude. Furthermore this track includes a low friction highway section (Highway A2 between the exits 'Wiener Neustadt West' and 'Knoten Seebenstein'). Another reason to use an alpine route is that in wintertime it is more likely to have a wet or slippery pavement on this track. The length of the route is about 120 km in one direction and it takes about two hours to measure it once. A map of the first route is shown in Figure 5.

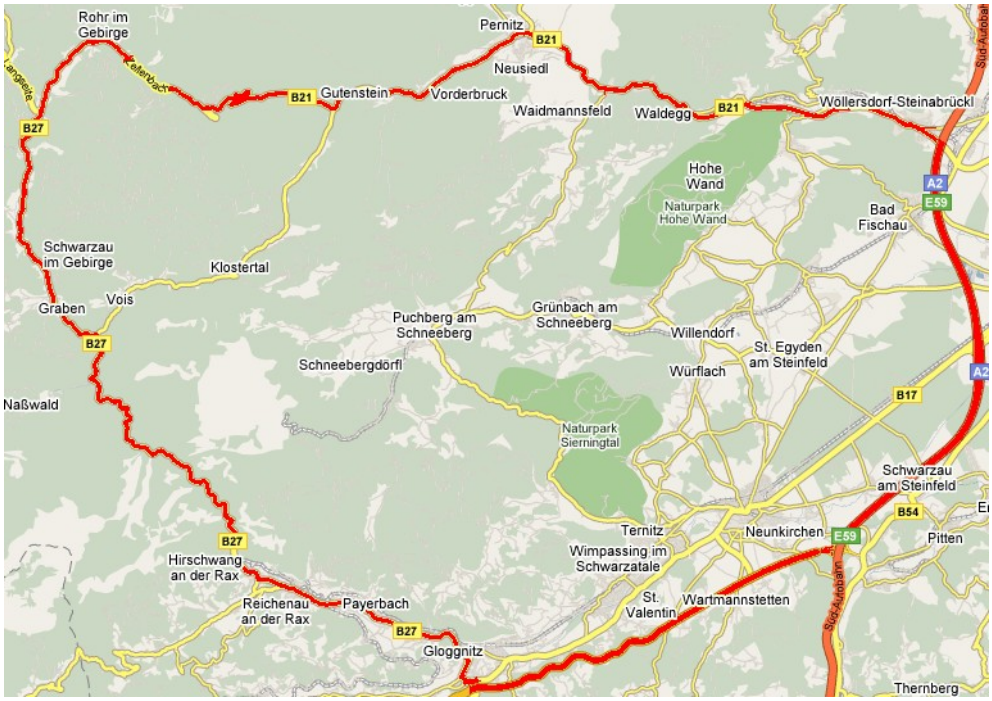


Figure 5: Test route No. 1 (alpine region)

The second route is contrary to the first one. The route leads mainly through plane region. It does not include many curves and the differences in elevations are really small. The route goes from Eisenstadt to Donnerskirchen on a newly built federal road (B 50). From Donnerskirchen back to the highway the way goes over smaller federal roads (B 15, B 60), where the traffic amount is supposed to be less.

The length of the track is about 65 km in one direction and it takes one hour to measure it once. A map of the second route is shown in Figure 6.

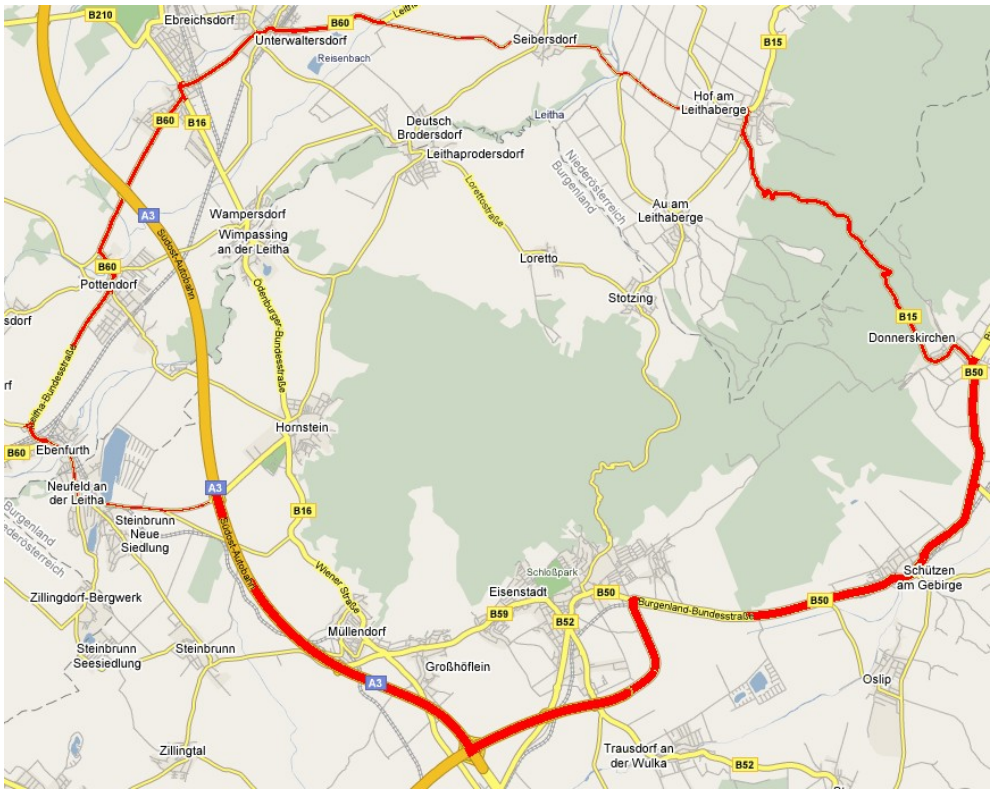
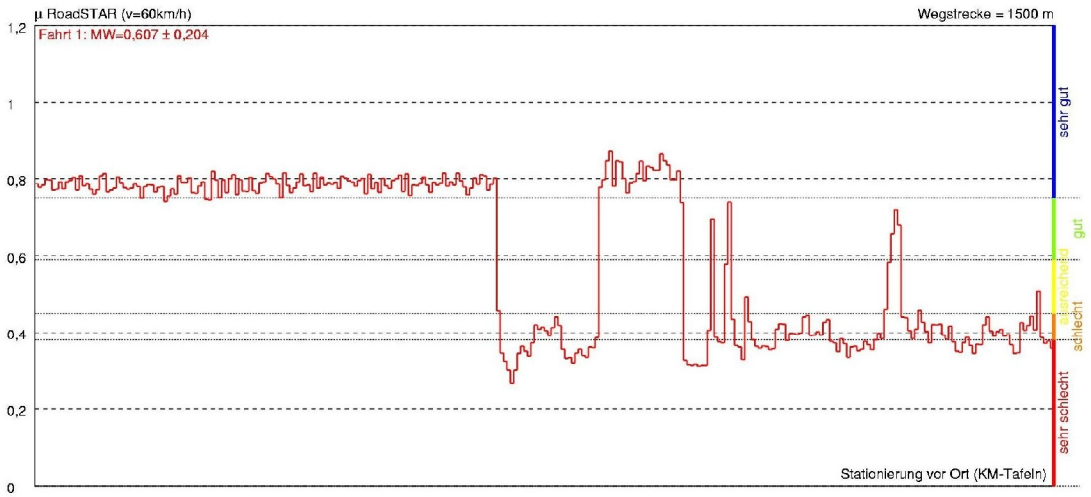


Figure 6: Test route No. 2 (plain)

The routes were chosen to represent different levels of skid resistance. Figure 7 shows volatile changes of skid resistance on different sections of the test routes.



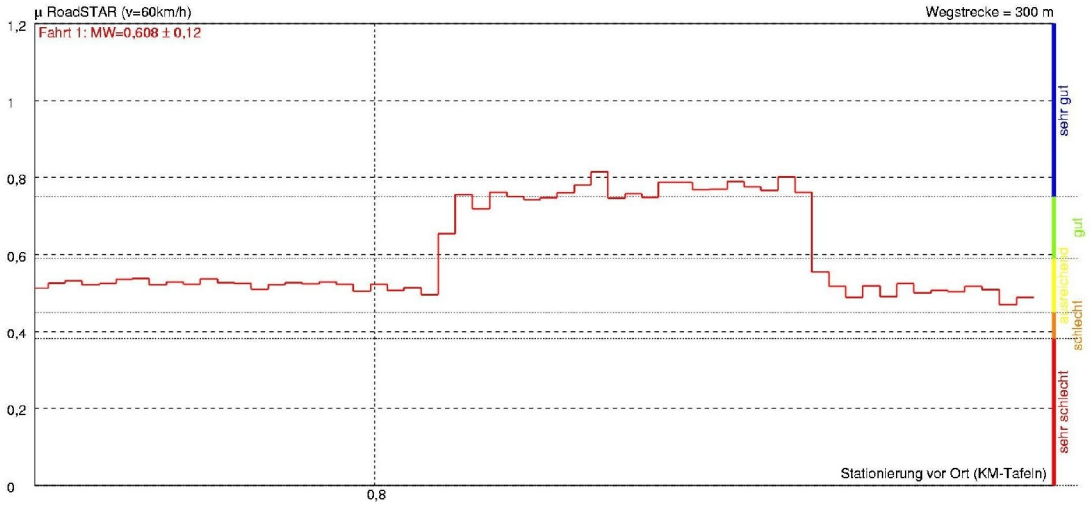


Figure 7: Volatile changes in skid resistance on test routes

3.5. Static Data

Static data was collected from defined test segments using RoadSTAR (see schematic diagram) and integrated server-side. One data-set consisting of GPS coordinates and Road Condition parameters (µ-static) was collected every 5 meters. The Digital Road Network was constructed from the GPS coordinates (generated 25m-segments) and Road Condition parameters were at each 25 meter segment. On the server-side, various databases were created in connection with preparing the road network. These include a Road Network Database, a Street Segment Database, Attribute Database and a Service Database (see Figure 15).

3.5.1. Evaluation Static Data

3.5.1.1. GPS coordinates

The ascertained GPS coordinates gave a first impression of the expected positional discrepancies. This outcome leads to the reasonable conclusion that GPS errors will also occur during pilot testing in Task 2.7 (real time

information to drivers). In due course, effective error correction methods will have to be developed.

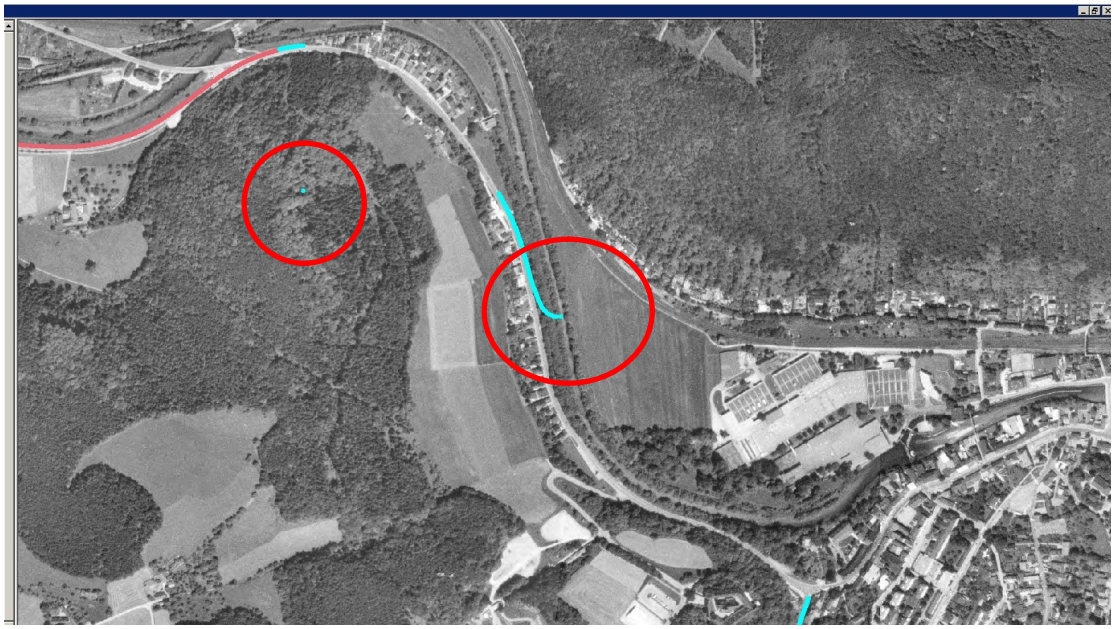


Figure 8: Positional discrepancies; gaps in GPS data

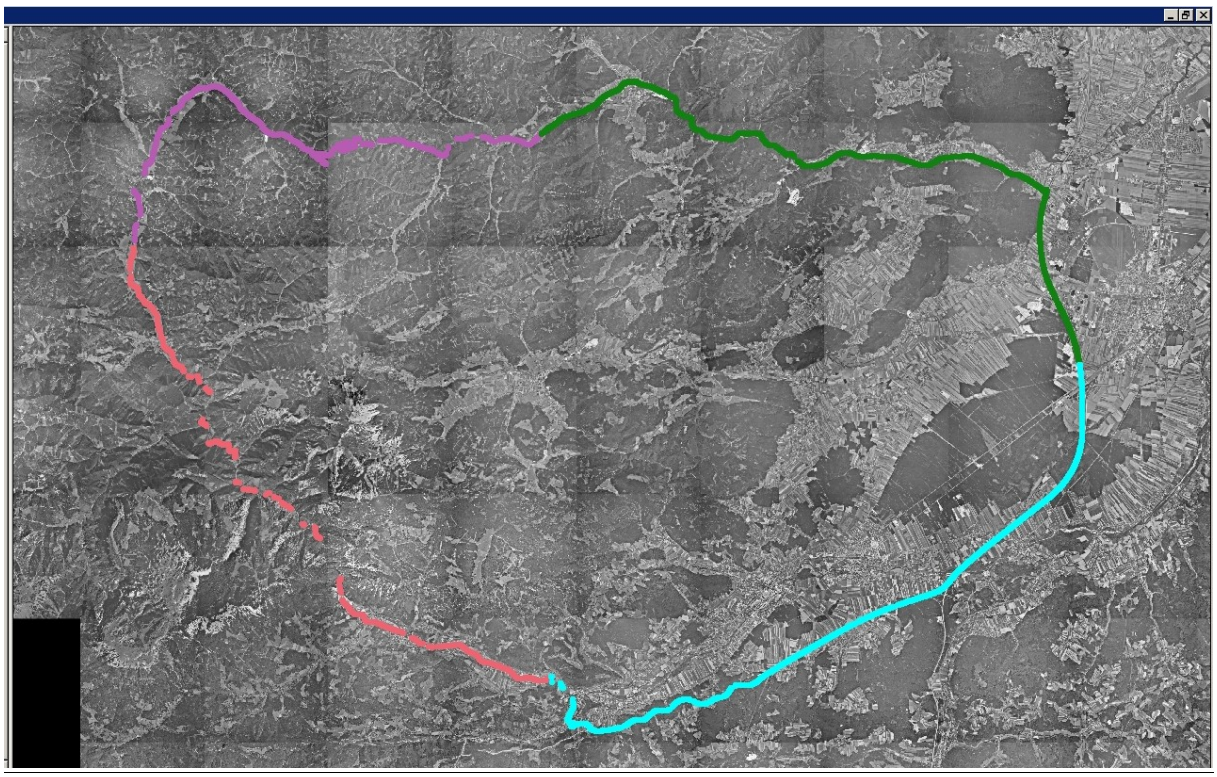


Figure 9: GPS-Track; Test route No. 1 (alpine)

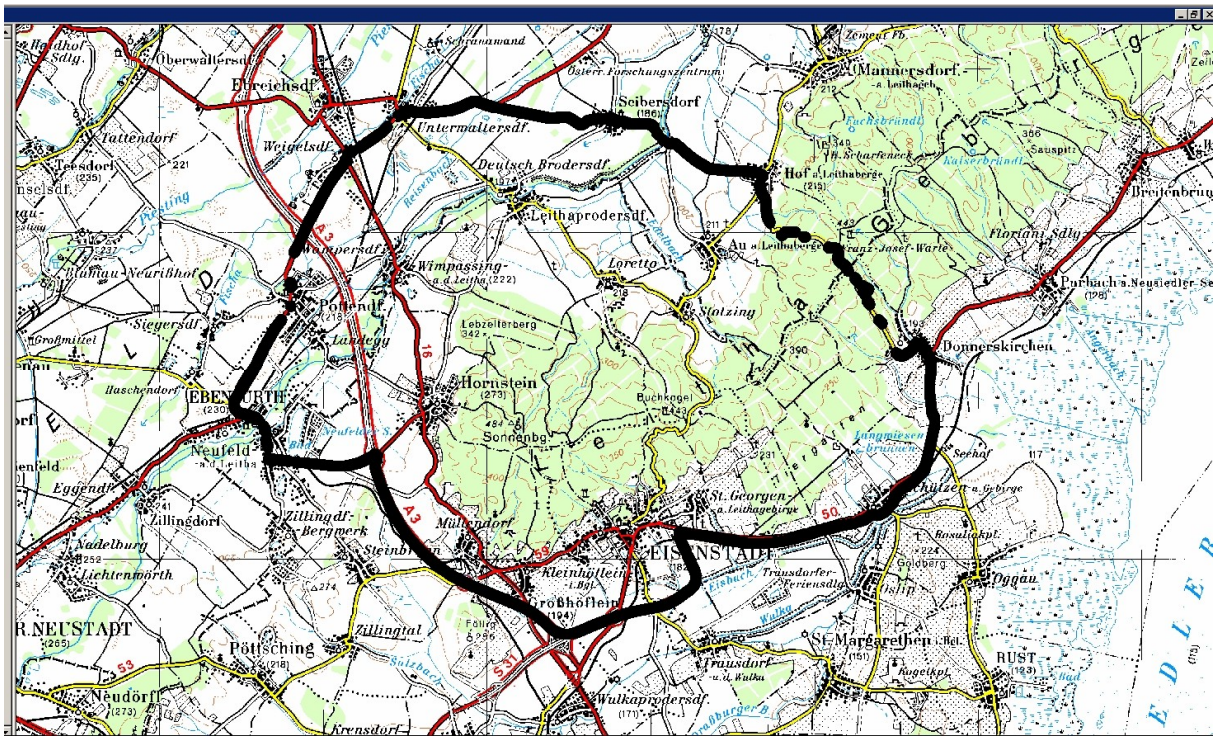


Figure 10: GPS-Track; Test route No. 2 (plain)

3.5.1.2. Road Condition Parameters

In periodical intervals (approximately every 1000 km) the friction device (the torque axle (braking torque), the static and the dynamic wheel load) of the RoadSTAR has to be calibrated. After this calibration a repeated measurement on a reference pavement has to be performed [1]. Before the start of the actual measurements, the RoadSTAR was in a calibrated state.

During the measurements, the standard test conditions as specified in [1] were kept.

Furthermore, the repeatability of the measurements has to be confirmed. The repeatability has to be proved on a reference pavement with a minimum length of 2 km. The offset of the mean value between two measurements (50 m-values) has to be $\Delta\mu \leq 0{,}03$ and the twice standard deviation (50 m-values) has to be $2\sigma \leq 0{,}05$ according to [1]. These requirements were met

with two reference measurements – before and after the actual measurements.

3.5.2. Interface to Road Network Database

Collected static data was integrated into the Road Network Database (see chapter 5.4.1) using the “SKAT straßennetz” import interface (see chapter 5.4.1.3). Data first has to be in a specific shape-format. Update mechanisms are available should static data need to be modified. Data is exported using the “SKAT straßennetz” for updates that occur during both test segments in WP2. The exported shape is updated and subsequently imported again via the import interface. In the case of high data volume nationwide applications, a separate function would have to be especially designed. Currently available semi-automated update processes will therefore be implemented on a fully automated basis.

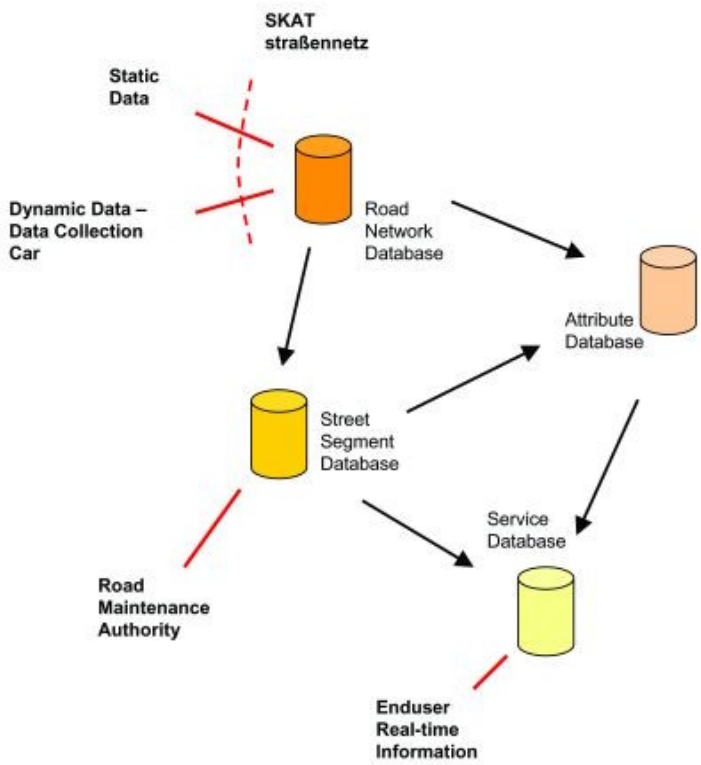


Figure 11: Interfaces (red lines)

3.6. Dynamic Data

Dynamic data (sensor data and data from CAN bus = Extended Floating Car Data [XFCD]) will be collected using a Data Collection Car. Other variables to be collected along with this data include sensor data, latitude/longitude position, time, µ-dynamic, car ID and speed. This information will then be transferred via a mobile communication to a central server. Only data that meet specific conditions will be sent to the server. For this purpose, plausibility checks will be conducted by the collector car as well as by the server (1 vehicle plausibility). Non-plausible data will be discarded before it can be used for algorithm purposes.

The collector car requires RoadSTAR data µ-static as comparative values from the server, which will be made available to the collector car from the server by way of a calibration service (Web Service; see chapter 3.6.2.2). A calibration service will be developed in this context, that can be called up using current GPS coordinates and made available using one or more µ-static values. By way of an additional service, dynamic data will be linked to street segments (Net-Match, Segment-Match). Initial communication tests between collector car and server have already been successfully carried out.

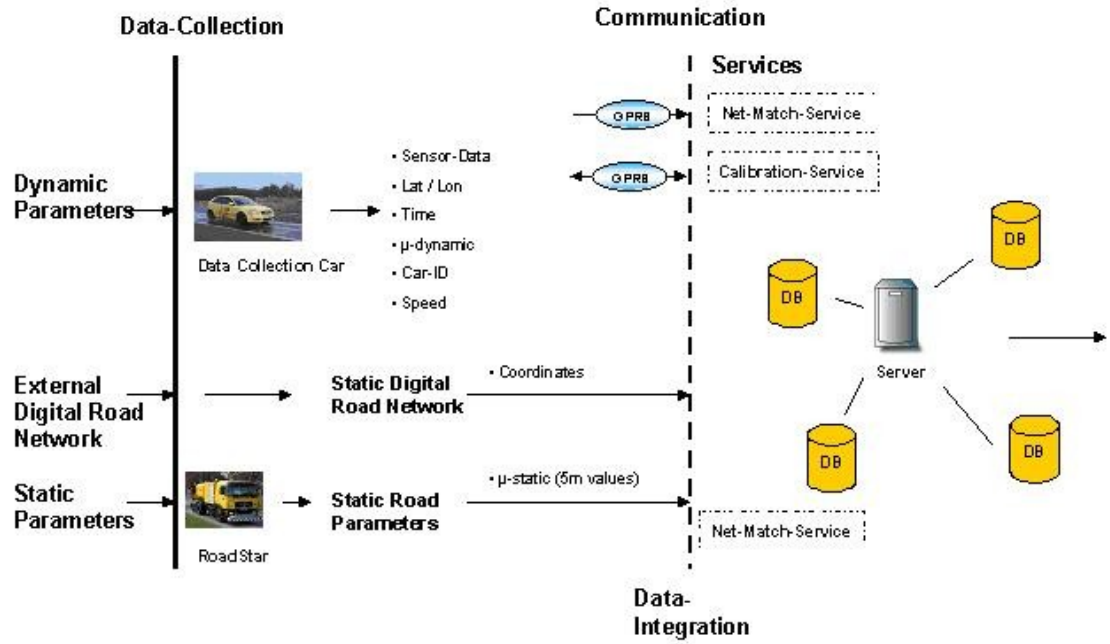


Figure 12: Schematic diagram of data collection and communication with central server

3.6.1. Extended Floating Car Data (XFCD)

The “Extended Floating Car Data” concept describes data collected from vehicles located in flowing traffic. These vehicles compile traffic related data which is then transferred to a central server via various mobile wireless technologies such as GPRS and UMTS. Each message sent to the server contains the time and location of the vehicle at point of measurement. Vehicle position is determined using GPS. In addition to classic vehicle attributes such as position and speed, XFCD (Extended Floating Car Data) features additional sources of information and input functions. This is transmitted together with conventional data and forms an important factor in the generation of added value.

XFCD involves the further steps of auto electrical data being first sent to the server before then being evaluated using situational-specific algorithms.

Dynamic data (road parameters and GPS coordinates, etc) is then checked on plausibility on the server to determine for example if similar data was received from other XFCD participants in the same area. Should this be the case, then a message from the server is sent to other drivers in this location to warn against potentially dangerous conditions such as black ice. For WP2 in the INTRO Project, Extended Floating Car Data is collected and sent to the central server by Data Collection Cars located on two test routes (see chapter 3.4) in Easter-Austria.

3.6.2. Data Collection Car

The Data Collection Car is an Audi A3, which was equipped with the required hardware and software by NIRA Dynamics. The equipment includes a CAN to USB box, which delivers the CAN bus data to a USB Port. Furthermore NIRA Dynamics provided software drivers and a software suite (ND4 Suite), which are needed to connect the CAN bus to a laptop and read its data sentences. To this equipment arsenal research added some additional sensors, namely an external acceleration sensor and a GPS receiver. The external sensor is connected to the laptop via USB and the GPS receiver via an old fashioned serial port.

All those components are linked together by a MatLab Program (MATLAB is a numerical computing environment and programming language). The NIRA ND4 Suite communicates with MatLab program over TCP/IP, for the other sensors, MatLab reads directly the respective ports. A component diagram of the used data collection system is shown in Figure 13 below.

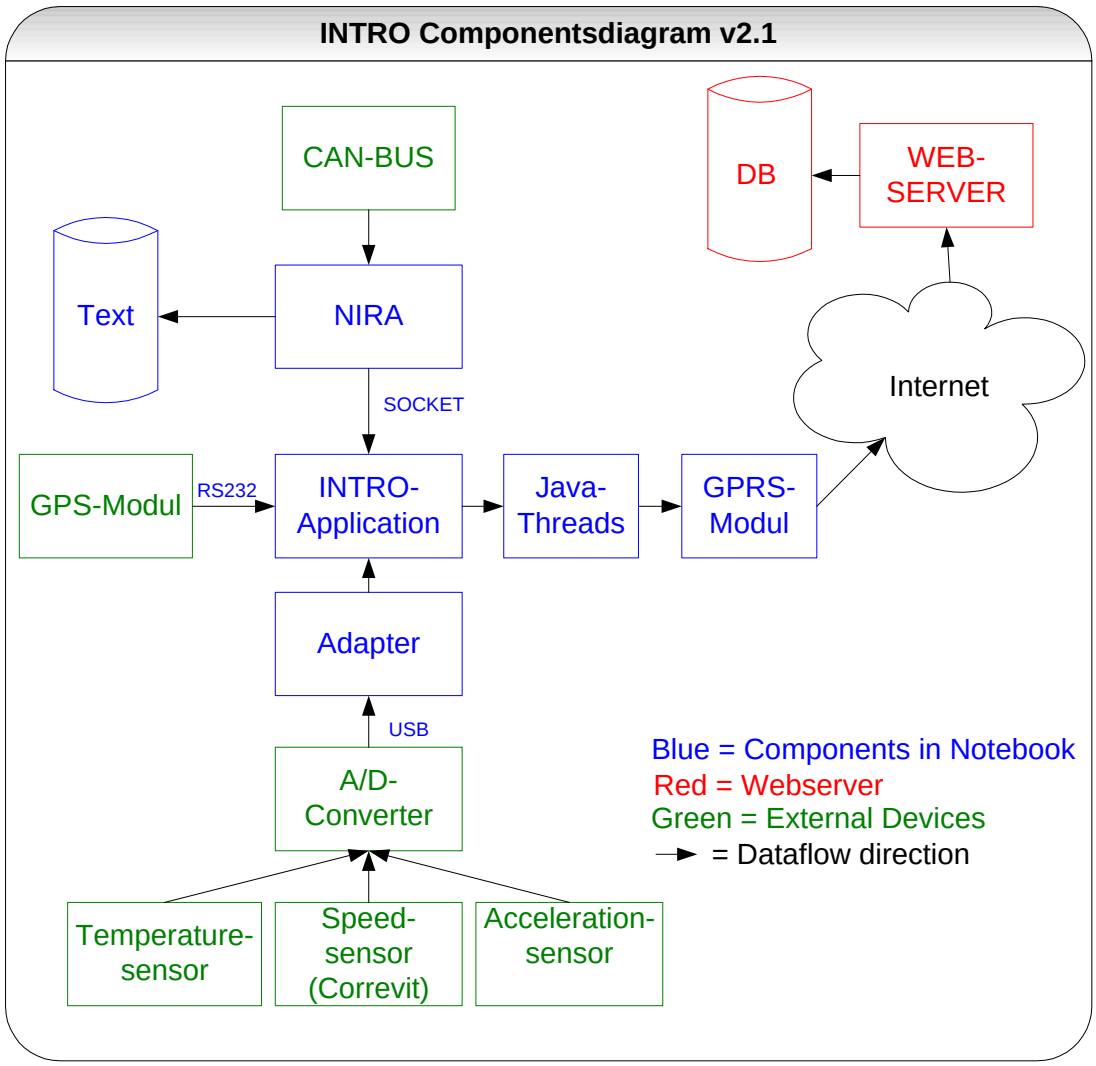


Figure 13: Component diagram for data acquisition software

3.6.2.1. CAN bus OUTPUT

The used hardware can deliver one data sentence every tenth of a second (10 Hz). One CAN bus data sentence consists of 28 single data records which are the following:

Value	Abbreviation	Comment
Time	t	Time in hour:minute:second,millisecond
Speed	v	Speed in m/s

Longitudinal Acceleration	ax	In m/s²
Lateral Acceleration	ay	In m/s²
Angular velocity	w_FL	For front left wheel in rad/s
Angular velocity	w_FR	For front d right wheel in rad/s
Angular velocity	w_RL	For rear left wheel in rad/s
Angular velocity	w_RR	For rear right wheel in rad/s
Engine torque	tau	Torque in Nm
Engine RPM	RPM	
Engine temperature	Te	Temperature in °C
Ambient temperature	Ta	Temperature in °C
Steering wheel angle	Beta	Angle in degrees
Yaw-rate	Psidot	Yaw-rate in degrees/s
Brake	brake	1 if brake is active, 0 otherwise
Clutch	clutch	1 if clutch is active, 0 otherwise
Estimated friction coefficient	myMax	
Normalized traction force	my_FL	Traction force for front left wheel
Normalized traction force	my_FR	Traction force for front right wheel
Normalized traction force	my_RL	Traction force for rear left wheel
Normalized traction force	my_RR	Traction force for rear right wheel
Slip	s_FL	Slip for front left wheel
Slip	s_FR	Slip for front right wheel
Slip	s_RL	Slip for rear left wheel
Slip	s_RR	Slip for rear right wheel
Current pavement mark	mark	
Slip slope	k	
Active/Inactive	off	1 if system is inactive, 0 otherwise

In addition to these 28 values the external sensors provide the following values:

Value	Abbreviation	Comment
Longitude	long	Geographic longitude
Latitude	lat	Geographic latitude
Speed	v	Speed from the GPS Receiver in mph
Acceleration	ax	Longitudinal acceleration from ext. sensor
Acceleration	ay	Lateral acceleration from ext. sensor

Acceleration	az	Acceleration in height from ext. sensor

During a test drive those values are written into a text file. Due to the fact that the GPS receiver works at a frequency of 1 Hz, two files are created. The first contains the 10Hz CAN bus and external sensor data without the GPS values, the second contains only the datasets which can be matched to a GPS position. This means, that the second text file contains all listed values at a frequency of 1 Hz.

3.6.2.2. Calibration Service

The Data Collection Car requires µ-static values, collected by RoadSTAR (Road Surface Tester of arsenal research), from the server as comparison data. Road Condition Parameters (µ-static) will be made available to the Collector Car from the server with the help of a calibration service (Webservice, see Figure 12). An algorithm that will be called up using current GPS coordinates will be developed later in the project that will make one or several µ-static values available to the Collector Car.

3.6.3. Interface to Road Network Database

The data transmission from collector car to the Road Network Database is done via GPRS or UMTS via cellular modem. One dataset is transmitted per second. HTTP-GET is used as transmission protocol.

A PHP script on the web server (see Figure 13) is invoked via HTTP. This PHP script reads the dataset, splits it and prepares and executes an INSERT statement for the database. Furthermore, some plausibility/range checks are performed before the dataset is inserted into the database. During an evaluation the average time for the transmission via GPRS was measured with 1.5 seconds. In case of poor GPRS reception and a failed transmission the dataset is stored in a buffer on the collector car and transmitted as soon as the GPRS reception is available again.

4. Data Integration and Digital Road Network preparation

After evaluating static data, the Digital Road network is semi-automatically created for the test area using GPS coordinates with a standard GIS program and then imported into the Road Network Database (see chapter 5.4.1).

4.1. Net Matching

Net Matching (also known as “Map Matching”) is the process by which the actual position of a vehicle (one coordinate) is matched to the Digital Road Network. The GPS position transferred by the appropriate receiver is then compared with the edges in surrounding areas. Each point (data record) is matched to the street segment corresponding to the minimum orthogonal distance and its approximate alignment with the vehicle’s heading.

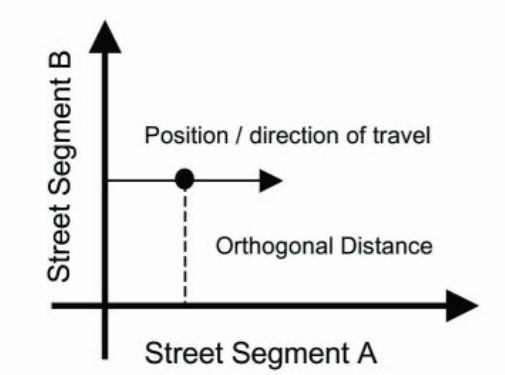


Figure 14: Net Matching

The above diagram depicts the alignment of the current coordinate to street segment A. In this case, the orthogonal distance to street segment B is shorter. Since the vehicle heading does not match the alignment of the street edge, the position will be aligned with street segment A.

In order to guarantee high performance, Net Matching is located in the Street Segment Database (see chapter 5.4.2).

5. Data Model

5.1. State of the Art

There are a multitude of data models in the field of traffic information used for very specific fields of application. Data models from navigation data providers such as TeleAtlas and NavTeq are especially well known examples. Other generally applicably data models come from the field of Geographic Information Technology (GIS), for example the American NSDI (National Spatial Data Initiative) standards or the Transportation Data Model from the ESRI (GIS manufacturers) data model series. These are completed using data models derived primarily from various road authorities. With regard to this, the German object catalog “OKSTRA” (Transport network schema for German road network) is worth mentioning.

There are also data models with noticeably different goals (and with often less demands for consistent data modeling) that serve as the basis for traffic planning and/or traffic modeling. These derive partially from proprietary development and special applications or from commercial software production (e.g. PTV’s VISUM – Germany’s leading traffic planning software company with specialized programs for all phases of traffic planning software).

One objective of the EU’s EuroRoadS project is to enable easier public access to traffic information. In order to encourage commercialization of this spatial data, EuroRoadS has developed a quality model aimed at ensuring quality from the moment data is collected until its final delivery to the end

user. This also involves quantification of card data quality and a description in a form understandable to the user. Fulfilling the quality and content requirements of the user is of particular importance as well.

In 2000-2001, the EU's NextMAP project dealt with the issue of edge usage for projected assistance systems. Required data content, geo-objects and geometric precision, for example street geometry and positional precision, were examined for the benefit of various assistance systems.

These data models are all very highly specialized (other models are either clandestine or proprietary), which leads to the conclusion that there is currently no authoritative or readily acceptable data model that meets the special requirements of INTRO. Special demands are placed on data models when dealing with dynamic data. As users of decision support systems (road maintenance authorities), end users of a road safety information service have specific requirements that must be considered when defining an appropriate data model. The eventual aim will be to develop interfaces that ensure a high degree of compatibility.

5.2. User Requirements

5.2.1. Up-to-dateness

It is especially important for future users of high-quality traffic telematic services that data is up-to-date. This means that for future road condition services, road condition parameters (static) must be regularly collected. Highly accurate information can only be transferred to the end user in real-time whenever current data is available. The acceptance level of such a system drops rapidly if road safety information reaches the user too late or not at all. It has been shown that systems whose advantages are easily recognized (e.g. navigation systems) find ready acceptance within society.

Under ideal circumstances, dynamic data is regularly updated so that more Extended Floating Car Data from data collection cars can be sent to the server.

In order to guarantee the up-to-dateness of a Road Network Database, special editing tools are needed to integrate new data while preventing the loss of existing information. High-quality data can only be made available through flexible data management (see chapter 5.4.1.3 concerning SKAT straßennetz).

5.2.2. Completeness

Another important user requirement are complete and extensively available databases. High-quality information must be featured at all stages of the Digital Road Network in order to be of benefit to road maintenance authorities as well as end users of telematic services. This pertains to high and low ranking road networks as well as to all necessary attributes (e.g. road condition parameters).

Regarding attribute maintenance, companies that offer road information, applications or products (e.g. navigation systems) place the highest priority on the completeness of agglomeration. They tend to focus on what they consider essential main roads or “very important areas”, such as those frequented by tourists. Surveying and updating data will also primarily be concentrated on agglomeration in the future since this is what garners the greatest commercial interest.

Numerous attributes are often achieved when collecting data for navigation systems through semi or fully automated geographical encoding processes that cannot replace on site collection on a qualitative basis. This certainly cannot form the basis of a reliable road safety service (road condition) since

this information has the potential to influence many factors including driver behavior.

5.3. Data Model Requirements

5.3.1. Processing the Digital Road Network

A Digital Road Network changes constantly. New street segments are added or altered and the constant import of Extended Floating Car Data places special demands on the Digital Road Network. Extended Floating Car Data collected in real-time from Data Collection Cars updates Road Condition Parameters linked to the Digital Road Network. Network topology based on edges and nodes and the attributes linked to this are in constant change thereby necessitating a flexible and highly dynamic architecture.

5.3.2. Compatibility

Another important aspect is the compatibility of the Digital Road Network with other reference systems. Special converters are necessary to use the Digital Road Network developed for INTRO in another reference system, for example NavTeq or TeleAtlas. The issue of converting between different reference systems was addressed by EU projects (e.g. AGORA) which concluded that the problem is the transfer of single events from one reference system to another. Various solutions were suggested that differ in reliability, precision of results and their requirements for data attributes and the geometric precision of data input.

In the RONCALL_I2 project (co-financed by the Austrian Ministry of Transport, Innovation and Technology), a special converter was developed for this purpose which converts net references from other reference systems (e.g.

TeleAtlas) into the RONCALLI reference system and vice versa. This component was developed so that content and service providers could easily exchange data on the RONCALLI traffic telematics clearinghouse. This method was employed during development of the INTRO data model for Extended Floating Car Data.

5.3.3. Static data changes

Another important requirement of the data model is the flexible handling of static data. As opposed to time critical data, static data does not undergo constant change. Road Condition Parameters were collected on two test routes in Easter-Austria for the INTRO project using RoadSTAR (Road Surface Tester of arsenal research). This information will be exchanged or updated using either semi-automatic or automatic processes with help from specially developed program functions. Although these functions (semi-automatic and automatic processes) extend beyond the scope of the INTRO project, they will still be theoretically integrated into the project.

5.3.4. Dynamic data changes

Dynamic Extended Floating Car Data requires complicated updating processes. Data Collection Cars constantly collect new data and send them to the central server. They are synchronized with static data and with the help of algorithms, it is then decided whether a warning for this specific area should be sent to the end user. This update process for the database has to be fully automated in order to avoid delays. If bad road conditions are detected on this stretch of the Digital Road Network, then this information should be sent to the related vehicle preferably in real-time.

5.3.5. Historization

Of particular importance is the maintenance of data history, i.e. the administration of and access to the “historical” databases of a traffic information system. This ensures that problem areas such as attribute validity and condition mapping at various intervals (also geometry) are properly addressed. On the database end, selections based on valid time criteria will be made possible. Street segments or attributes that have to be edited because of current data will receive inception or expiry dates. It will also be possible to recreate information at all data levels at any time because of database historization. Edit changes can therefore be reproduced for any point in time. This could also prove to be of importance in legal or statistical matters. The legal safeguard of traffic safety messages sent to potential end users or to a Decision Support System for the Road Maintenance Authority will also pose further questions. These questions must be intensive scrutinized and answered before any entry into the market is undertaken.

5.4. Implementing the Data Model

The INTRO Digital Road Network for traffic telematic information is the central “Content Level” and serves to locate the entire static and dynamic content.

There are many reference systems for traffic telematic information. The mostly commercial providers of this information are permanently confronted with the problem of not being able to guarantee the up-to-dateness and homogenous quality required for traffic telematic services. For applications or traffic telematic services that reach beyond the scope of this project, up-to-dateness and the extensive availability of content are of great significance.

Four separate databases were created in order to administrate the entire content (Digital Road Network and Attributes): the Road Network, Street Segment, Attribute and Service Databases These four databases could also be technically implemented into one database.

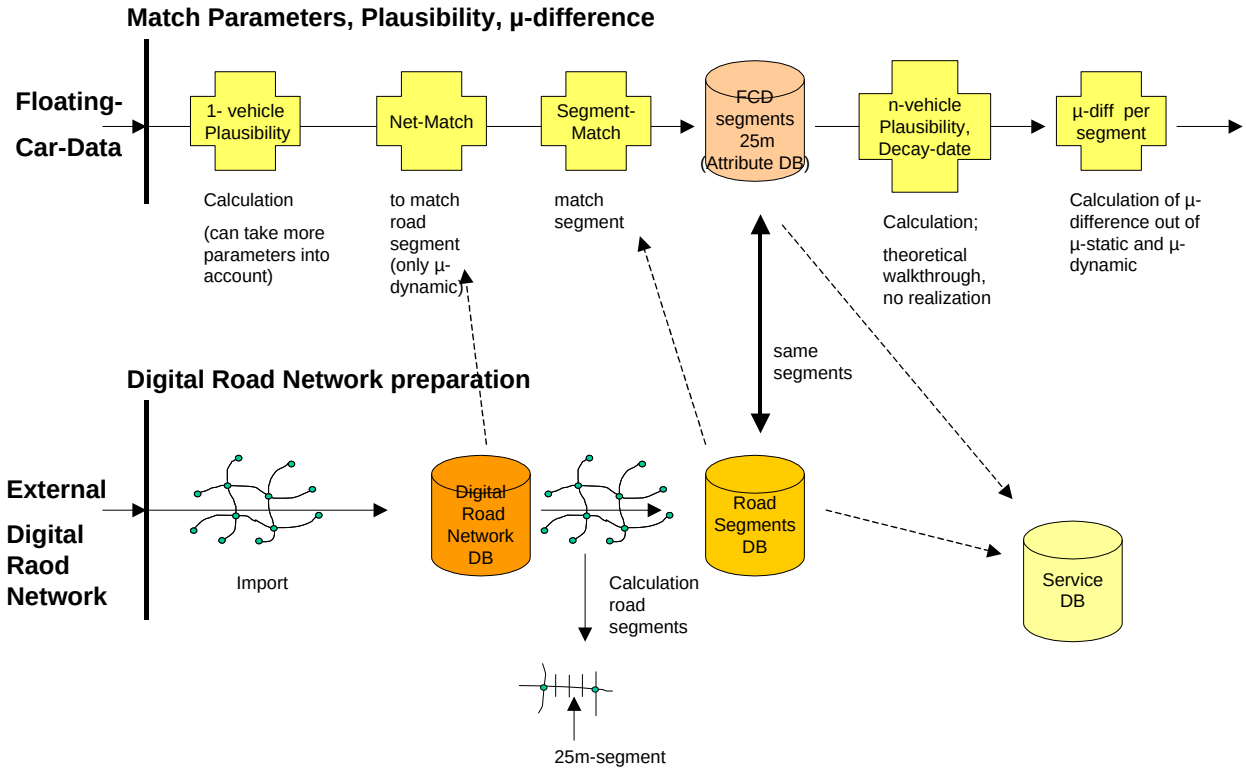


Figure 15:Schematic diagram of server

5.4.1. Road Network Database

5.4.1.1. Network topology based on edges and nodes

In the reference system, the geometric aspect of the traffic network is mapped using the simplest possible structure. This ensures that the basis is modeled using simple lines (edges) as well as the topological correlation to these lines (nodes).

The edge is the central element of the basis geometry. It features a unique code (kanten_id) and a list of at least 2 vertices which are filed with their respective coordinate values (vertex_x / vertex_y).

5.4.1.2. Events

All observable conditions along or on the street will be indicated as events. They are clearly defined spatially (correlated on road center lines), temporally (period of valid time) and content wise. Events are basically displayed either as point or line graphs in each projection on the axis. Data compiled from both test areas are displayed using point graph events (point graph road condition parameters [µ-static]) that are linked to the Digital Road Network using a Matching Process (see chapter 4.1). From these point events, line events can eventually be created through generalizations that correspond to 25 meter segments (each event is a segment). These segments refer to an entire edge or part of an edge.

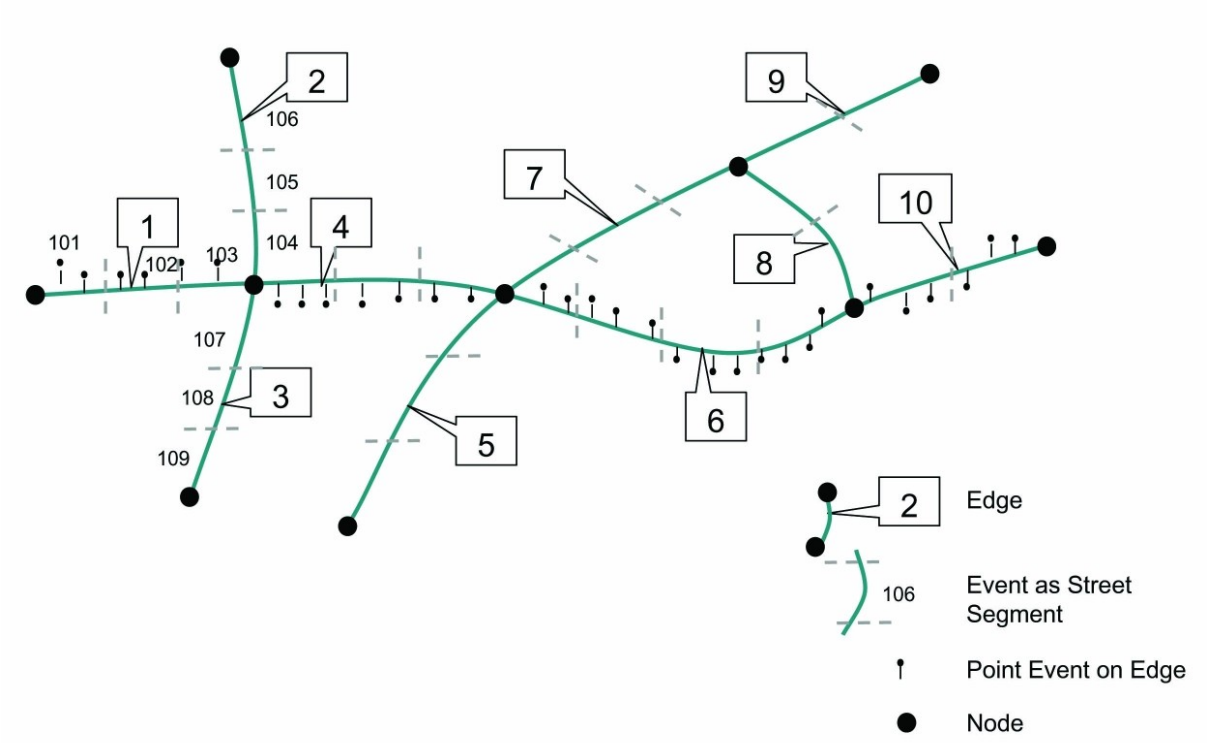


Figure 16: Road Network Database

The Digital Road Network is imported into the Road Network Database after it has been created from GPS coordinates. In contrast to the other three databases (Street Segment, Attribute & Service) changes to the Digital Road Network and Attributes can only be made in the Road Network Database. After each change to the Road Network Database, the Street Segment Database has to be regenerated. Converting the Road Network Database to the Street Segment Database is done by an automated process. Data historization has been planned in order to be able to reproduce each change.

5.4.1.3. Tasks and Functions for editing Road Network Database

The Road Network database is subject to a constant update process which can only be carried out via specific tools. In this project, the “SKAT straßennetz” (PRISMA solution’s Software for Road and Traffic division) is used to process the Digital Road Network. SKAT facilitates the administration of the Digital Road Network. Complete changes in the flow of traffic, changes in street names, changes of responsibility and the like can be implemented. A consequential history log feature ensures that transactions can at any time be fully restored and reconstructed. Processing procedures are saved directly in the Road Network Database.

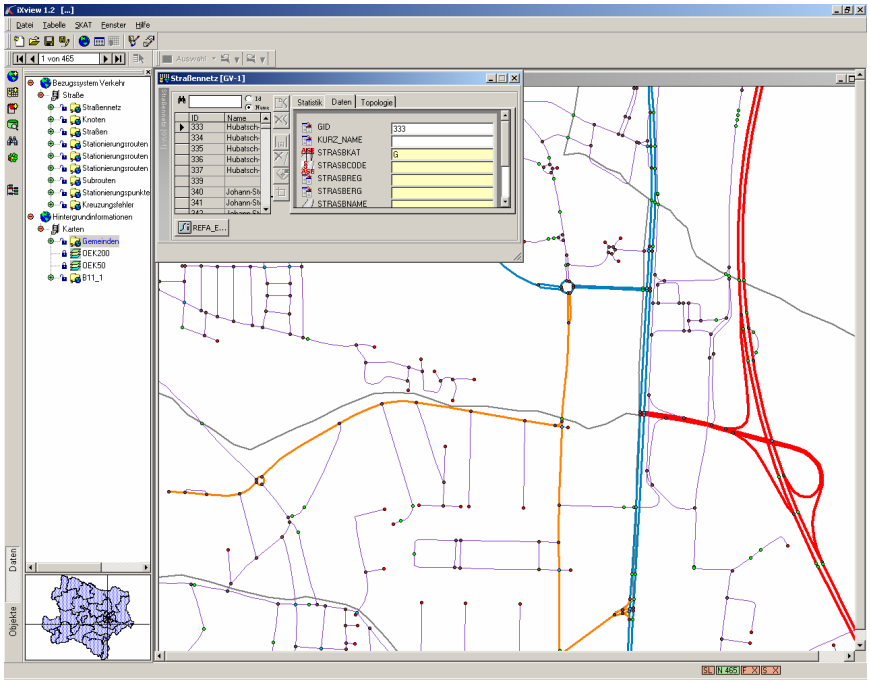


Figure 17: SKAT straßennetz (Software for Administration of Digital Road Network)

The following overview provides an example of potential tasks and functions:

- Edit Digital Road Network
  - Add new edges
  - Edit edges
  - Delete edges

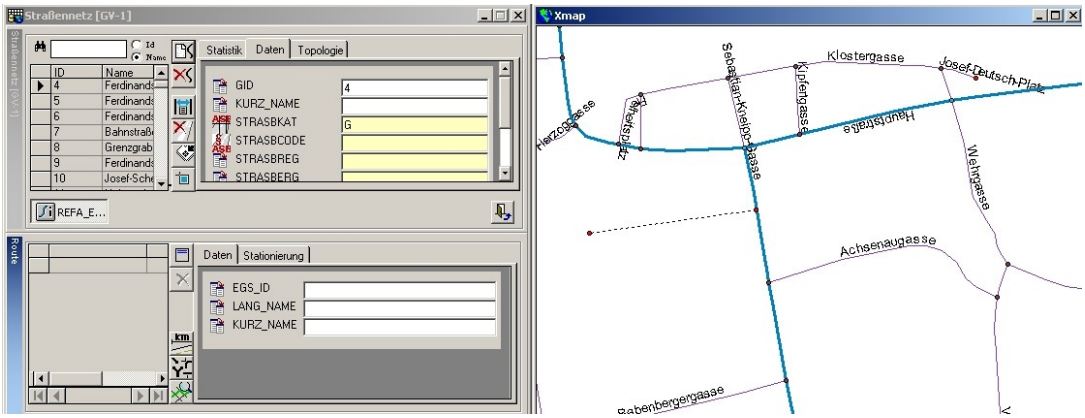


Figure 18: SKAT straßennetz (Changes of edges and nodes)

- Edit Topology
    - Insert nodes (split edges)
    - Delete nodes (merge edges)

- Edit Attributes
    - Change attributes
- Chainage
- Routes
- Administration of Events
- Historization
- Net Matching
- ...

Chainage of Digital Road Network

Another function is the chainage of the Digital Road Network. The term “chainage” refers to the continuous meter/kilometer count along a road center lane. This allows the Road Maintenance Authority to more easily compare kilometer information from the road with information from the GIS as well as process the Digital Road Network.

Routes

Edges are joined to routes according to their designation (street name).

5.4.2. Street Segment Database

Events (25m segments) are created from the edges of the Road Network Database using a program function. A second function converts the Road Network Database to the Street Segment Database.

The Street Segment Database therefore contains only edges that correspond to events. This database features important algorithms that compute warning areas for end users as well as Hot Spots for Road Maintenance Authorities. The following calculations are made in connection with this database:

- Calculation of µ-static per Segment

µ-Static (Road Condition Parameter) is made available at the beginning of the process as a point event and is later converted to a line event per segment (average µ-static value per segment).

- Calculation of µ-dynamic per Segment

µ-Dynamic per segment (average µ-dynamic value per segment) is calculated from point events sent to the server from Data Collection Car at regular distances.

- Calculation of µ-difference per Segment

µ-Difference is calculated from µ-dynamic and µ-static. With the use of further algorithms, “Warning Distance” and “Hot Spots” are derived from µ-difference values.

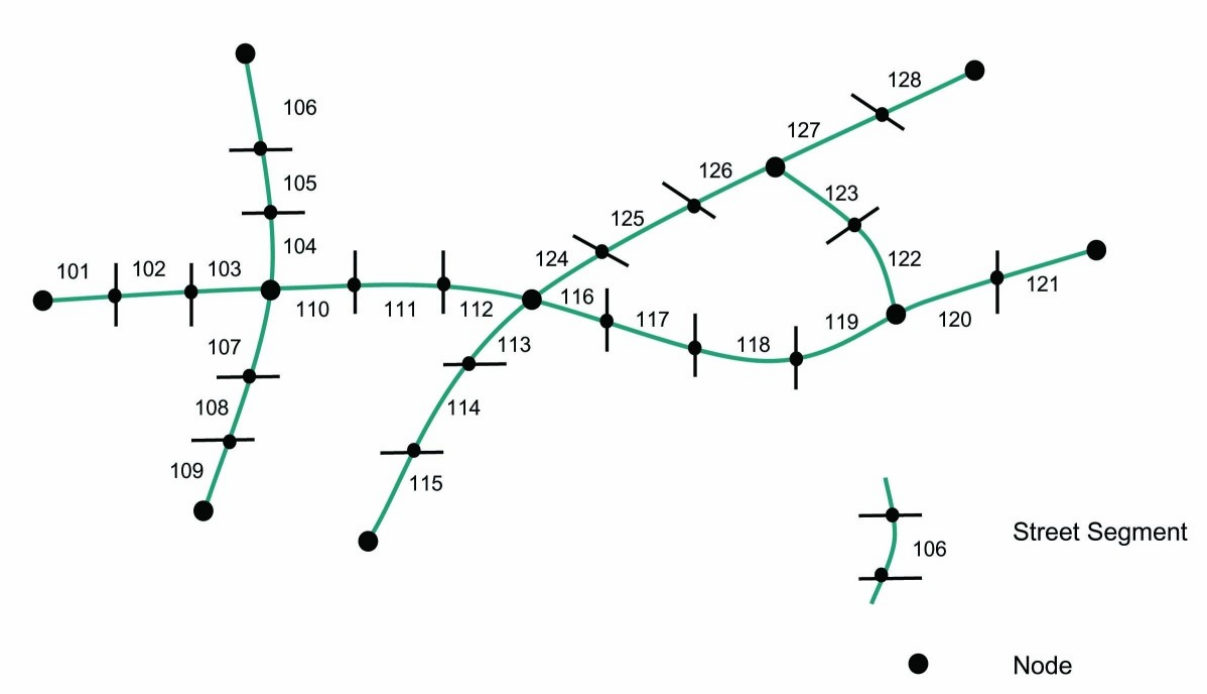


Figure 19: Street Segment Database

Edits are not made in the Street Segment Database. These functions are limited to just the Road Network Database. High performance from the Street Segment Database is especially important for handling Extended Floating Car Data. This is guaranteed by limiting edit processes to just the Road Network Database.

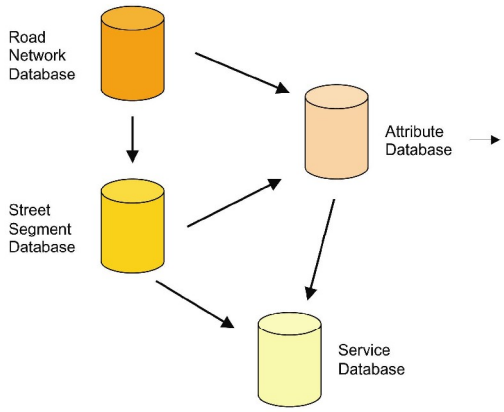
In contrast to the Road Network Database, the Street Network Database will not be historicized since it can be generated at anytime from the Road Network Database. The lack of historizational functions greatly increases performance.

5.4.3. Attribute Database

The Attribute Database contains all important attributes (e.g. µ-static [Road Condition Parameters], µ-difference and Street Segment ID). Attributes are assigned to edges and events.

The following example explains the connection between generated databases [Road Network, Street Segment & Attribute databases] (see Figure 20).

- Edge ID 2 has the street segments 104, 105 and 106 in the Road Network Database. The corresponding edges in the Street Segment Database are ID 104, 105 and 106. In the Attribute Database for example, attributes are assigned to ID 104 (e.g. 0.9 µ-static; 0.1 µ-difference).



Street Segment	µ-static (average of point events per link)	µ-difference (Calculation out of µ-static and µ-dynamic)	Validation (Warning, not Warning)
101	0,7	0,2	
102	0,8	0,3	
103	0,8	0,2	
104	0,9	0,1	
105	0,2	0,5	
106	0,3	0,3	
107	0,5	0,1	
108	0,7	0,2	
...	...	...	

Figure 20: Attribute Database

The Attribute Database, like the Street Segment Database, will also not be historicized.

5.4.4. Service Database

For the Pilot II project (real-time information to driver, Task 2.7 of WP2), an additional database will be created. The Service Database consists of edges, the Digital Road Network and attributes. It processes positional data sent from the client (end user; e.g. mobile device) and compiles updates based on this information (see Figure 24). These updates will then be sent in compressed format via a mobile communication to the client.

The requirements of the Service Database (high performance, simple data access, limited number of conversions) will be ensured by a database scheme. The XML data type is the format for the database fields which will be sent to the client via the interface. Data content will be spatially classified (tiling) as a structural criteria for the database. This “tiling” will be created from the interface between the Street Network Database and Service Database.

5.4.5. Interface Street Segment Database – Service Database

The Street Segment Database is connected with the Service Database via an interface. This interface comprises the following steps:

- Creation of tiles (dependent on the respective amount of data)
- Coordinating the geometry of the Digital Road Network with tiles, so that each street section can be uniquely assigned to a tile
- Transformation of coordinated geometric data into the spatial reference system
- Preparation of raw data and creation of XML data for mapping street geometry and attribute categories
- XML data is then imported into the Service Database
- A Data Access Service processes client requests and distributes responses that are generated directly from the Service Database (see chapter 6.3.1)

5.5. Data Quality

Decisions made using spatial data are only as good as the data itself. Quality assurance therefore plays an especially important role in this regard. It is not enough to simply collect and integrate data into systems, rather additional measures such as quality control must be implemented before high-quality services can be reliably offered in the telematic sector.

Only with quality control measures can services such as an early warning system for bad road conditions function at a reliable and acceptable level. Customer approval is therefore highly dependent on the quality of data at hand. Finally, the main attraction of services lies in their dependability and the quality of their basic content.

Spatial data features at the heart of each geographical information system (GIS) and can be used for a variety of different purposes. This is then interlinked, blended and overlaid with other types of data in order to produce new details.

In addition, spatial data represents enormous value. One of the main goals of GIS projects therefore should be to maintain and safeguard this value while acquiring, collecting and administrating spatial data. These should represent the minimum requirements for employing an efficient GIS system.

5.5.1. Aspects of Data Quality

To more precisely define the quality of spatial data (static and dynamic) more detailed definitions are needed for general data quality terms.

For this purpose, the following categories are currently in use:

- Up-to-dateness
- Precision
- Accuracy
- Completeness
- Consistency

Up-to-dateness

This term describes the length of time available data remains valid. Static data derived from the Austrian INTRO test routes (GPS coordinates and road parameters) were taken from a current RoadSTAR (Road Surface Tester of arsenal research) trial. Measurements compiled from road conditions serve as the basis for calculating “Warning Distance” (real-time information to driver) and “Hot Spots” (GIS interface for Road Maintenance Authority). The validity period of this information is of great importance to high quality telematic services. This will be examined in further detail in the section entitled “Decay Date” (see chapter 5.5.3).

Precision

Precision describes the deviation of data from their true value (or from their expected value in case this is not known). For this project, data precision will be determined using plausibility calculations (“1” or “n” vehicle plausibility).

Accuracy

This is the opposite of incorrectness. Accurate data should therefore be spatially, temporally and thematically correct. Errors can occur, for example, on account of compilation mistakes (spatially or thematically) or because of incorrect geographic referencing of data records.

Completeness

Required data must be made completely available in the necessary quality. Incomplete measurements can occur on some segments while collecting static as well as dynamic data. Gaps and improbable data records should therefore be methodically handled and scrutinized, especially when compiling

static data (GPS coordinates and road parameters). Completeness and extensive availability of static data is an especially important requirement for offering future attractive services to the end user. Further information on this topic can be found in chapter 3.5.1.

Consistency

Consistency describes the logical validity of available data. This is especially true for the Digital Road Network. Maintaining consistency is however essential for other databases as well. One basic requirement for maintaining consistency across the board is a clearly structured modeling of data.

5.5.2. Dynamic parameters: Which components can fail?

During this project it was made clear that when dealing with dynamic parameters, components can fail which could then have negative consequences when calculating “Warning Distance“ or “Hot Spots” in Pilots I and II (Task 2.6 and 2.7). In this regard, the following components will be addressed in more detail:

- Data communication
- Sensors
- GPS

In the course of this project, solutions to these problems will be examined. At first glance, the following results became clear:

5.5.2.1. Data communication

Mobile Communication between the Data Collection Car and server has already been successfully tested. Because of gaps in network coverage however, communication disruptions can sometimes occur. Under such

scenarios, dynamic parameters cannot be immediately transferred to the server. The transfer of data packages can then only resume once a network connection has been reestablished.

5.5.2.2. Sensors

Sensors function similarly to data communications in this project. The “Data Collection Car” constantly transfers dynamic data via built-in sensors in regular intervals to the central server. Should sensors fail, then dynamic road parameters would not be transmitted. Calculations of µ-difference per street segment would also not be possible. µ-difference would then be calculated from µ-static and µ-dynamic. Because of the unavailability of µ-difference values, “Warning Distance” and “Hot Spots” information would also not be possible. It is then possible that “no data” error messages are sent to the end user, whether road maintenance authority or private customer of “Road Condition” services, because of missing dynamic information. Despite this, information could still be made available to the end user using an interpolation function or using µ-static.

5.5.2.3. GPS

In the case of a GPS outage, it would not be possible to transfer GPS coordinates to the central server. This would see collected road parameters having no referential relationship or connection to the Digital Road Network via the Net Matching Process. End users could also possibly receive “no data” messages under this scenario. One possible solution to this would be the use of an interpolation function.

Further calculations are necessary on the server because of the integration of dynamic Extended Floating Car Data. Plausibility tests and calculations on the decay dates of dynamic information are examples of this.

5.5.3. n-vehicle plausibility & decay date

Apart from the 1-vehicle plausibility and Net-Match algorithms already mentioned, it is also important to consider a n-vehicle plausibility within the scope of this project. Should several vehicles from the same street segment provide conflicting data, then a further plausibility test would be prudent. The decay date of µ-dynamic is an especially important value in this regard as well. N-vehicle plausibility and decay date will not be implemented in this project however, rather they remain well thought out, theoretical ideas for future development.

In future implementation strategies several plausibility checks have to be incorporated to guarantee full functionality. The task of reassessing the data plausibility after each data set delivery or data integration in the system is mandatory. Different confidence intervals in location and value have to be set. A special statistic evaluation has to be conducted to choose a certain number of cars or certain number of measurements to reassure the data values (n-vehicles). The time frame for data plausibility checks has to be verified and is dependent on the so called “decay date” for data sets. As the data up-to-dateness on a given spot is heavily dependent on passing by cars, the decay rate for idle periods needs to be defined and set in a common sense.

For this task a full survey on time for surface condition changes in relation to traffic statistics needs to be conducted. Special strategies for different road types and network levels, or in an even more detailed traffic condition considering manner could be developed and applied.

6. Outlook

In the first Pilot test, the goal of WP2 is to quickly and efficiently give the Road Maintenance Authority the ability to promptly react to bad road conditions by way of Hot Spot calculations located on a server. To this end, tests are carried out which allow the Road Maintenance Authority easy access to information with help from a Decision Support System via a GIS-Surface.

In a second Pilot test, it will be investigated how Warning Distance to be calculated can be sent to the end user with help of a “Road Condition” road safety service. The goal here is to warn the user of bad road conditions. Since road traction cannot be reliably judged by the naked eye, the “Road Condition” service represents a helpful tool for the driver.

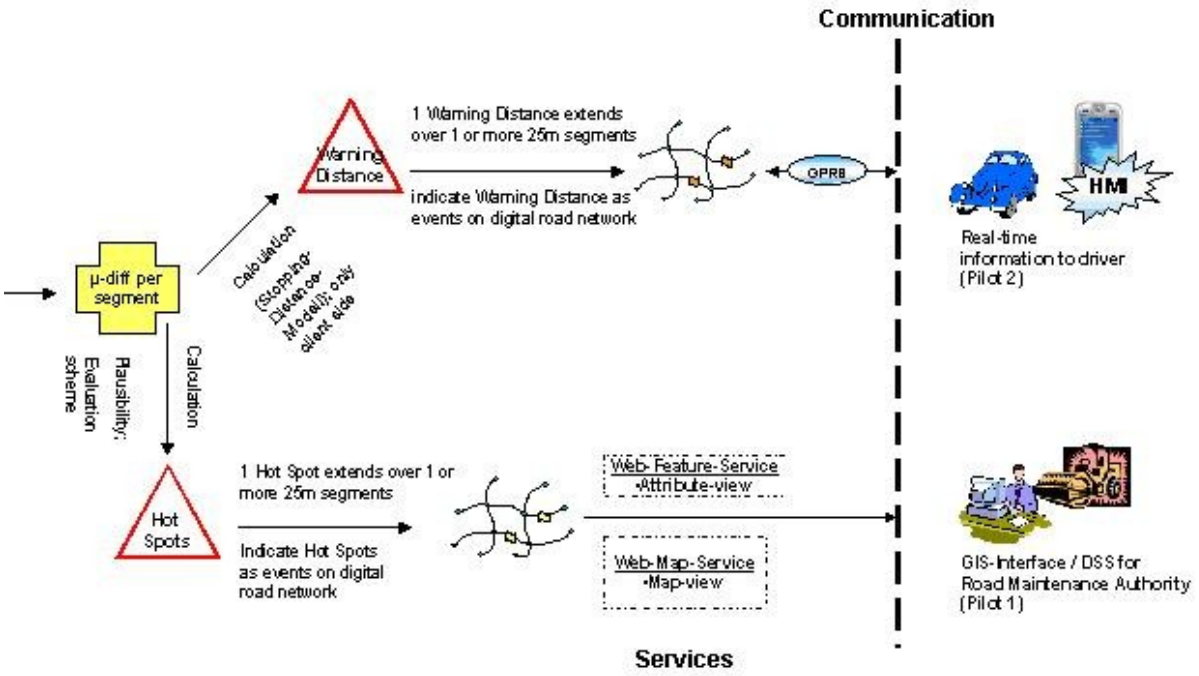


Figure 21: Schematic diagram of server and communication with Pilot I and Pilot II

6.1. Warning Distance & Hot Spots

µ-Difference results represent an additional central algorithm. µ-difference is calculated using µ-stat (static, 1 value per 25 meter segment) and µ-dyn (dynamic, several values per segment).

In order to provide advance notice during unsafe situations, the driver has to be alerted within a predefined distance according to a set of critical parameters.

Warning Distance (the point ahead of the vehicle where the driver is actually looking and presumably wants to go) is ascertained using vehicle speed. The precise and final definition of Warning Distance will be released after further research in WP2.
Hot Spots form the basis of early danger detection by the Road Maintenance Authority so that preventive measures can be taken.

In order to receive Warning Distance and Hot Spots information, additional calculations are necessary. Warning Distance is calculated similar to the Stopping Distance model (One Warning Distance extends over one or more 25 meter segments).

In order to calculate Hot Spots, further plausibility algorithms and determination of evaluation scheme are necessary (One Hot Spot extends over one or more 25 meter segments).

Task 2.3 (WP2) of the INTRO project deals with the question of which format (Human Machine Interface [HMI]; Deliverable D2.3) should be used to warn the traffic participant about unfavorable road conditions. In this task, suitable Human Machine Interfaces will be developed with the aid of simulator studies

and made available to the pilot driver (Task 2.7: real-time information to driver) as an important tool for input at the end of the project.

6.2. Pilot I (GIS-Interface for Road Maintenance Autority)

Further pilot tests will lead to the development of an easy to use GIS-User-Interface for the Road Maintenance Authority. Furthermore, Decision Support System concepts that reach beyond the simple user interface will be determined.

6.2.1. Decision Support System (DSS)

Definition DSS

“A decision support system is a system under the control of one or more decision makers that assists in the activity of decision making by providing an organized set of tools intended to impart structure to portions of the decision-making situation and to improve the ultimate effectiveness of the decision outcome.” [2]

Example of DSS-Structure

A DSS has the following main objectives:

- Improvement of efficiency (information and knowledge access)
- Improvement of communication
- Spread of knowledge
- Transparency of decisions
- Documentation of decisions and decisions context

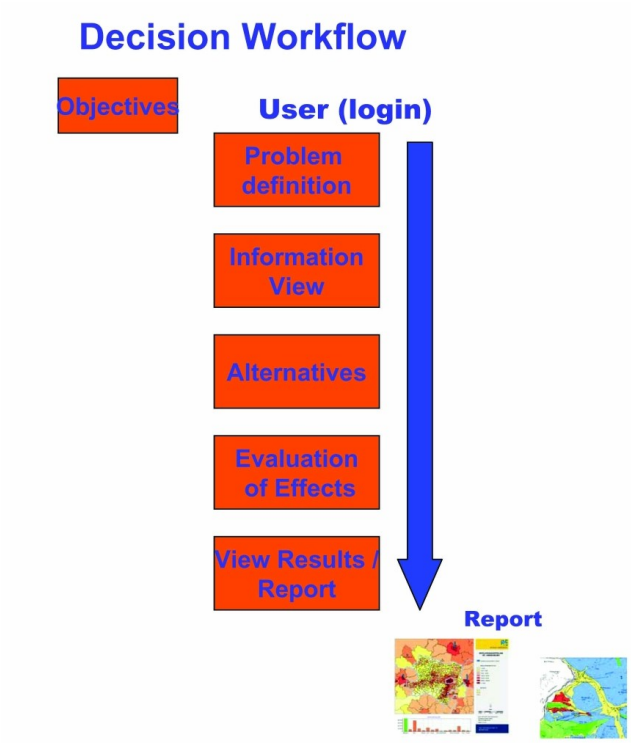


Figure 22: Decision-Workflow of Decision-Support-System

A Decision-Workflow could take the following structure:

Problem definition

The Road Maintenance Authority is confronted with the threat of bad road conditions on a specific street segment. Then it has to be decided if a credible threat exists in this region or not. Furthermore, the problem has to be defined precisely.

Information-View

Here one sees the problem along with potential solutions. In addition, the user is shown background information (what Road Condition means), related facts as well as maps.

Alternatives

All possible solutions and measures are shown that allow the Road Maintenance Authority to try out various scenarios.

Evaluation of effects

In this area the various solutions are evaluated. Which solution should be chosen and what is its potential effect on the budget, political reality or decision process (determining factors)? Each aspect that needs to be taken into consideration will be contrasted, for example reaching the goal as opposed to the necessary financing.

View results / Report

With the help of clearly displayed results, the Road Maintenance Authority has the opportunity to document the entire decision making process. Reports can consist of tables, graphics, text and maps. Output can take the form of a status report or recommendation.

6.2.2. User Interface

For Pilot I, Hot Spots will be made available via web services. A Web Feature Service (Attribute View) and Web Map Service (Map View) are planned for this.

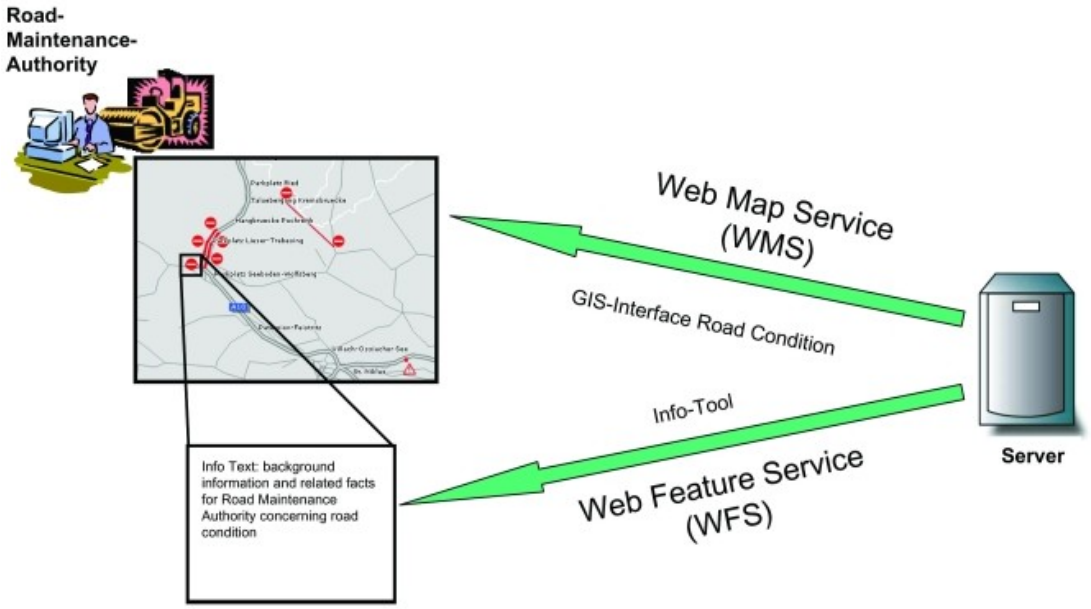


Figure 23: Web Map Service (WMS); Web Feature Service (WFS)

6.2.2.1. Web Feature Service (WFS)

This service refers to a standard from the Open Geospatial Consortium for Vector Data in the GML (Geography Markup Language) format. A WFS is a modern and standardized basis for the use of client server structured GIS and will be made available via the Street Segment Database on the server side of INTRO as long as data is not edited by the Road Maintenance Authority (see chapter 5.4.2). Should the Road Maintenance Authority need to edit data, then all information from the Road Network Database will be made available. The data source for both the Web Feature Service (WFS) and Web Map Service (WMS) is identical, whether or not edit functions are needed (Street Segment or Road Network Databases).

6.2.2.2. Web Map Service (WMS)

The OpenGIS® Web Map Service (WMS) Implementation Specification provides three operations (GetCapabilities, GetMap, and GetFeatureInfo) in support of the creation and display of registered and superimposed map-like views of information that come simultaneously from multiple remote and heterogeneous sources. (www.opengeospatial.org)

6.3. Pilot II (Real-time information to driver)

For Pilot II (Real-time information to driver), the Warning Distance will be made available to the client via a mobile communication connection.

6.3.1. Interface

Server-Client communication (RONCALLI-Interface)

Regarding the server to client interface, existing technology from the RONCALLI Project (www.roncalli-telematics.com) was employed for this purpose.

An interface (Data-Access-Service) between client and server processes client requests and distributes responses that are directly generated from the Service Database.

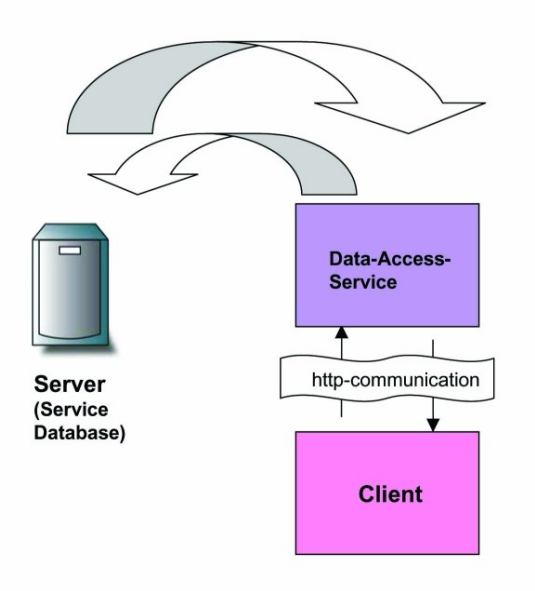


Figure 24: RONCALLI-Interface; Server-Client communication

7. Conclusions

The creation of a data model for road safety related data posed an innovative challenge for all parties concerned. A data model was developed within the scope of task 2.4 whose goal was to process static as well as dynamic information on a central server before making it available to end users. The integration of dynamic Extended Floating Car Data into the data model was an important consideration while designing databases capable of meeting already defined user and data model requirements. It is important that this logic is implied while designing such a model, otherwise databases created from this model will fail to meet expectations and data saved in such databases will not be convertible to useful information. For this reason, each stage of task 2.4 was very carefully monitored, from the collection and evaluation of data and the efficient and flexible construction of databases to the tools used to process static and dynamic data. In addition, quality criteria were put in place to supervise the handling of sensitive information. At the end of this chain of process, it is ultimately the user that stands to receive valuable

road safety information. With this information, this project makes a valuable contribution to the safety of all road users as well as a reduction of traffic related fatalities.

The various partners of this project all contributed considerable expertise in the creation of these data model concepts as well as the central server. Already successful tools (e.g. the processing of highly sensitive data) were integrated into the workflow in order to simplify the data integration process. Furthermore, the INTRO concept was able to greatly benefit from the extensive experience gained from other successful ventures such as the Austrian project RONCALLI (www.roncalli-telematics.com) Real-time information poses a great challenge for all database designers, however in the INTRO project, the consortium now has a model that meets and supports every necessary requirement.

8. References / Further Reading

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