ENHANCING USER ACCEPTANCE OF TRAFFIC SERVICES USING IMPERFECT INFORMATION

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Due to the imperfection inherent in real world data, future traffic information services like navigation systems have to deal with missing, uncertain, vague and imprecise information. We argue that revealing the imperfection instead of cleaning data as in today's services will result in higher user acceptance of a service. Such a service can give additional information on how good its returned data will match the real world situation and, therefore, users can better judge how to rank the proposition, e.g., which of the proposed route suggestions to follow. For implementing a service that handles imperfect data, such data has to be collected from the traffic system, stored in a suited database, processed by adapted algorithms and, finally, presented to service users in an appropriate manner.

1 Introduction

The installation of more and more technical car equipment is also a result of advances in communication technologies. Cell phones to communicate with business partners or navigation systems to choose a suitable route are already wide-spread in modern cars. This trend will continue in the near future and lead to the development of even more sophisticated mobile services for vehicles.

All such systems should support a driver and increase the benefit while using a car. A manager can stay on road while contacting his business via an installed phone. Asking a navigation system for the shortest way, should reduce travel time and fuel consumption. Unfortunately, the last assumption may be wrong. Because, over the last decades, more and more people own cars and drive them, traffic jams have become a common problem. If following a route suggestion may lead directly to traffic jam, no time is saved and a user may be disappointed by the service.

One way to overcome this misfortune is to incorporate reports on the current traffic situation in the decision on which way to suggest. Today, radio stations broadcast reports on traffic jams digitally giving their location, their length and, sometimes a rerouting. Receiving such a report, a navigation system can take it into consideration and uses it in its calculation, leading the driver around the congestion. But in many cases, the reports become obsolete or only to some part true by the time they are broadcasted, because the traffic situation has changed in the meantime. Additionally, the assumption, that the given data represents exactly the current situation, may be wrong, too. The position of a traffic jam is not fixed to the given location, but near to the given location. Also, it has not the length of exactly the given number of kilometers, but its length is around this value. Therefore, a service has to deal with imperfect data. First, it does not know if the data is correct and, second, it does not receive exact, but vague values. One way to deal with imperfect data is to pass the decision, which route to choose, to the user and present him/her a list of different alternatives, e.g., giving probability values as additional decision support. One alternative could be route one, but there may be a traffic jam with a probability rate of 80%. Route two may be a few kilometers longer, but shows a lower traffic jam probability.

Today's traffic services cannot deal with imperfect data and, therefore, return results that do not always support sufficiently user interests. Our thesis is, that making the imperfection explicit in the result data and giving users the opportunity to interpret and select a suitable suggestion on their own will increase user acceptance of a service, because a service does not anymore return "wrong" suggestions from a customer's point of view. Moreover, we are not only regarding the services in the vehicles, but also services in the pre-trip usage, and traffic services for traffic managers and traffic scientists, and, imperfection in the user interfaces of the services require managing imperfect data and computing imperfect data within the service realization.

New modern services are mainly driven by improvements in the IT area, but may have an important impact on the whole traffics and therefore also on the economical aspects of the more and more growing volume of traffic. So, it is necessary to push the acceptance of such services, having adequate business models, but also adequate user interfaces and high quality and reliability of the service. Supporting imperfect data on various levels of services will improve the user interfaces and the quality and reliability of services as we will show in this paper. There exist a lot of interesting approaches for new services, though in the most cases without considering imperfect data.

E.g., the CoPark project in Munique [SB02, SU02, coP] introduces services for flexible parking support in a densely populated environment. Big automotive manufacturer are working on sophisticated on-board units for vehicles which take into account sensor data from the vehicle itself and/or provide better services for the drivers like automatic emergency calls in the case of an accident or a breakdown ([Dr.02]). Other approaches are using sensor data and floating car data (FCD) resulting, e.g., in better routing services, that are based on FCDs collected by taxis in Berlin and Vienna ([R.-03]), or in services, that allow a better interpretation of the traffic situation by intelligent evaluation of sensor data in specific critical areas ([H. 02]).

The paper is organized as follows. In the next chapter traffic services are introduced in more detail: who will use traffic services, what are the components of the traffic services and how will they be presented to the users. We give an overview about various approaches to catch the impact of imperfection on the levels of the service architecture. Then, in order to validate these new services a simulation architecture is presented which will allow to simulate the impact of the services on the traffic and on the user acceptance. Finally, we give an conclusion of the paper and an outlook to future work.

2 Services

Building services, which have to deal with imperfect information, captures several challenges. On one hand, services differ according to the target group, which will use it. On the other hand, imperfection must be supported at all layers of the service architecture. At the user interface it means how to represent the imperfect information to users, in the processing layer algorithms have to handle with imperfect information, and the data layer requires collecting and storing imperfect information. In the following, we give an overview about the target groups of traffic services and then introduce a variety of approaches how to deal with imperfection in each of the layers of a service architecture. We analyzed and developed these approaches in the OVID project [Uni02a, GLGR05].

2.1 Target groups of traffic services

Services are usually designed for a certain target group. In a traffic environment we distinguish between four different target groups [For05]: *pre-trip user*, *on-trip user*, *traffic manager*, *traffic scientist*. If a person plans a trip it uses services before the trip. This use is called pre-trip and the user *pre-trip user*. After that the person starts the trip and uses other services during the ride. This means an on-trip use of services and the person is called *on-trip user*. There are already several traffic management centers which organize traffic in densely populated regions by observing the current traffic and by operating variable traffic signs and sending warning messages. These *traffic managers* also use traffic services. If new roads are to be built or existing roads are to be modified, experts carry out long-term observations in order to determine the necessary properties of a new road or the necessary modifications. These *traffic scientists* are also users of a different kind of traffic services.

These four target groups differ in the kind of information they need and in the kind of presentation they are able to grasp. Unlike traffic managers and traffic scientists pre-trip and on-trip users are no experts in traffic aspects and therefore cannot be provided with data full of technical details. They need to be informed in a clear and compact way. Because an on-trip user has to concentrate on the traffic, he or she should be able to understand the presented messages or graphics within a few seconds. Traffic managers and traffic scientists are able to understand and use data with technical details. They have enough time to analyze this data using data analyzing tools.

2.2 Representation to the user

Not only because we have different target groups but also because bad user interfaces can make a service useless it is important which user interface we present to a certain target groups. The user interface needs to inform the user about the current traffic and about the recommendations of the service. Because this information can include imperfect information the user interface has to be able to present also the imperfection of information.

2.2.1 Using natural language to express imperfect information

As we know from public or private radio stations a traffic report can contain different properties of a traffic jam. We are informed about the kind of the traffic condition (*free*, *dense traffic*, *traffic jam*), the approximate road or highway section where the traffic jam occurs, the expected length of the traffic jam, the time we are expected to loose because of the traffic jam, the reason of the traffic jam and perhaps the expected duration of the traffic jam. All the information mentioned are in some kind imperfect: We do neither know the exact place where the traffic jam occurs nor do we know exactly when a traffic jam begins or ends, nor the exact loss of time.

Therefore a radio station has to select the important traffic reports – in fact a processing of imperfect information (refer to section 2.3) – out of a set of imperfect traffic reports and to present them to the listeners. The acceptance of this traffic report service depends predominantly of the truth of the report. A good traffic service finds the correct trade-off between too exact reports which are therefore incorrect and too vague reports which are always correct but useless. A report which specifies the length of a traffic jam as 2.387km seems too exact and is most probably not true and a report which specifies the length of a traffic jam as somewhere between 0 and 25 kilometers is probably always true but not useful. One method, we already use in spoken language, is fuzzy theory [Zim92], where we describe vague aspects using linguistic variables like the kind of the traffic condition. Such a linguistic variable has got several fuzzy terms like *free*, *dense traffic* or *traffic jam*. We describe a linguistic variable either by using one of the fuzzy terms (see also Figure 1) or by specifying the grade of memberships of a traffic report to all fuzzy terms of a linguistic variable. In the latter case we think of fuzzy terms as fuzzy sets.

2.2.2 Visualization of imperfect information

We can present information to a user not only using natural language but also using graphical representation. We are used to a variety of different visualization methods. Many of these methods can be modified to represent also imperfect information. The following examples are collected and proposed by [For05].

In Figure 1 the traffic condition of a road is visualized including uncertain information using different colors in a map. In Figure 1 the traffic condition is displayed in a road map. For each direction of a road the road section is colored according to its traffic condition. Because the traffic condition is uncertain we have to express the uncertainty of the traffic condition, too. In Figure 1 *left* the uncertainty is modeled adjacent to the colored road sections. The uncertainty reaches from very dark which means very certain to very bright which means very uncertain. The uncertainty can also be represented in a separated map as proposed by [MHvW+93] (see Figure 1 *middle*). Figure 1 *right* includes vague information. The transition between different traffic conditions is modeled using color transitions.

Another possibility is to use a mosaic plot in general used for statistical purposes, e.g., in [You]. In [For05] the mosaic plot is used to represent the normalized grade

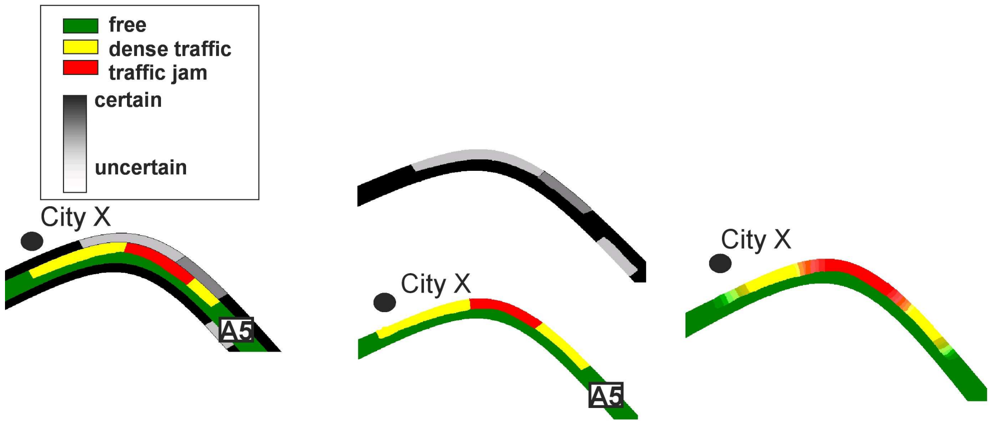

Figure 1: Visualisation of traffic condition with imperfection [For05]

of membership to different terms of a linguistic variable. The name and the thickness of the bar can provide additional information. Figure 2 displays the grade of memberships to traffic condition terms of different road sections. The thickness of a bar is proportional to the length of the road section. The dotted part determines the impreciseness of the attribute represented by the thickness of the bar.

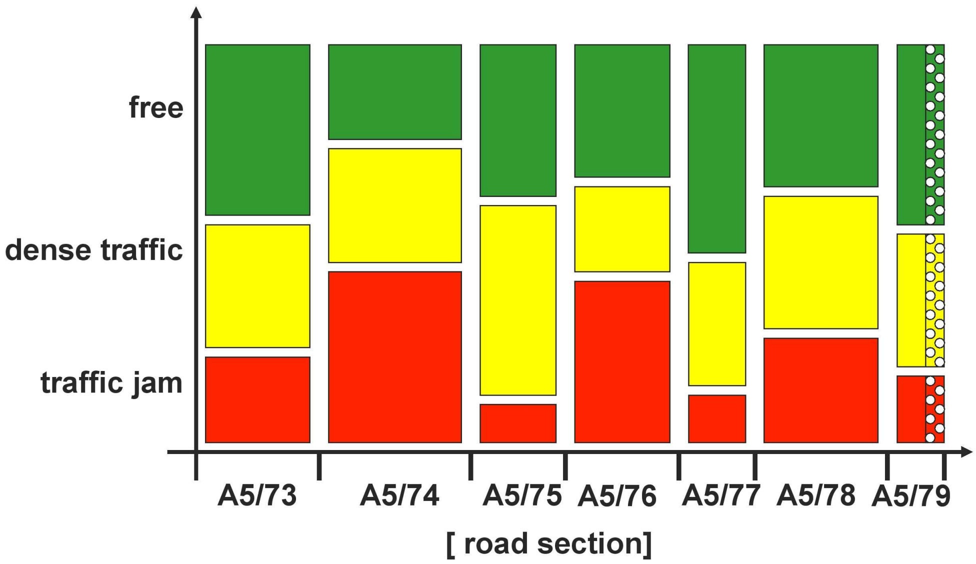

Figure 2: Application of mosaic plot to visualize linguistic variables [For05]

The last example extends the table lens technique [PR04, Inx]. In Figure 3 (left part) the precipitation of several road sections is described. The length of the bar represents the amount of precipitation. The darkness stands for the uncertainty of this weather report. In Figure 3 (middle part) vagueness of a traffic condition is described by using fuzzy terms. The normalized grade of membership to the terms free, dense traffic and traffic jam is shown using different colors. Both uncertainty and impreciseness are used to represent average speed in Figure 3 (right part). The length of the bar represents the speed, the darkness of the bar the uncertainty and the dotted part of the describes the expected speed interval stated in the report.

While the use of colors in a map (Figure 1) is appropriate to all mentioned target

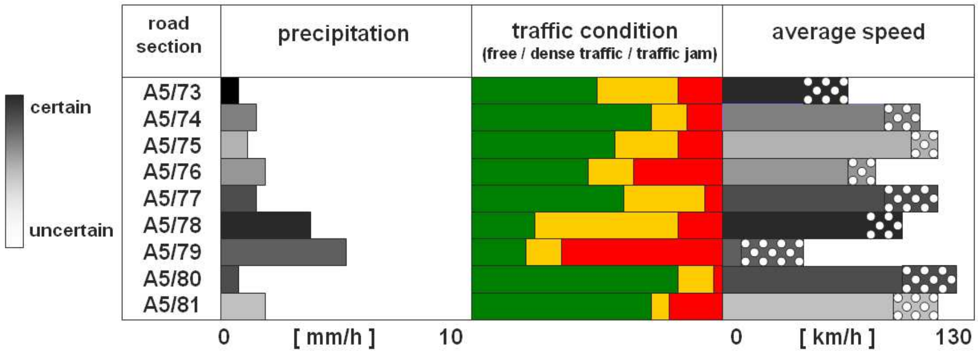

Figure 3: Representation of imperfect information by using table lens technique [For05]

groups, the mosaic plot (Figure 2) and the table lens technique (Figure 3) are only useful for the *pre-trip user*, the *traffic manager*, and the *traffic scientist*.

In order to build good services which can deal with imperfect information we need a good representation of the imperfect information adopted to the needs of the target group.

2.3 Processing

Sensor data are basic data sources in the traffic area, that are input directly or indirectly to services. Some aspects of traffic sensor data are introduced. A service usually consists of several components which are linked together. These components are responsible for the processing of all kinds of information. In the following we show how to adopt a meta model which allows the components to exchange meta data about the imperfection contained in their data. After that we discuss the application of these concepts to components used for traffic forecast.

2.3.1 Sensor Data Networks

Sensor data are an important source of traffic data. Because sensors are widely distributed and handle with basic data, sensor networks help to summarize and aggregate sensor data and get a more sophisticated basis for further processing.

In [Chr04] several technologies managing sensor networks, and querying and aggregating sensor data are analyzed on how to support sensor networks in the traffic area, and how to integrate the handling of sensor data and sensor networks in the OVID simulation platform.

There also exist approaches to handle imperfect sensor data, which is essential, because imperfection is inherent to this type of data, e.g., because of measuring errors or distortion of single sensors or communication failures. Gaussian Abstract Data Types GADT ([FGB02] provides an object relational data type for values obeying a continuous probability function with Gaussian probability. It is shown that Gaussian probability enables an efficient processing of a more precise representation of sensor data as without representing the imprecision at all.

In [CP03] another probability model is introduced based on intervals. It allows to model insecure sensor data with three types, point-exact data, insecure data within a certain interval with MUST and MAY semantics, and data obeying a certain probability distribution within this interval.

2.3.2 Common Warehouse Metamodel

Services are build using different components. If these services have to deal with imperfect information also the underlying components need to deal with it. For this reason these components have to inform each other what kind of imperfect information they exchange. A meta model is needed which allows to describe also imperfect information. Many traffic services depend on components for analyzing data. A meta model for analyzing data already exists. The Common Warehouse Metamodel (CWM) [PCTM02, PCTM03] is appropriate to describe meta data of analyzing components especially in the data warehouse environment. This model can be adopted in order to support imperfect information and also be used for a platform of traffic services [SMH04, Hil05].

In the following we suggest one possible modification which supports also the modeling of imperfect meta data. The CWM consists of layers which are formed by several packages. All other packages use the *Core*-package (see Figure 4) which is also the main part of UML [omgb]. Both CWM and UML are specified by the Object Management Group (OMG) [OMGa]. Because all other packages use this package it can be modified to support also imperfect information. Then all packages using the *Core*-package will also support imperfect information.

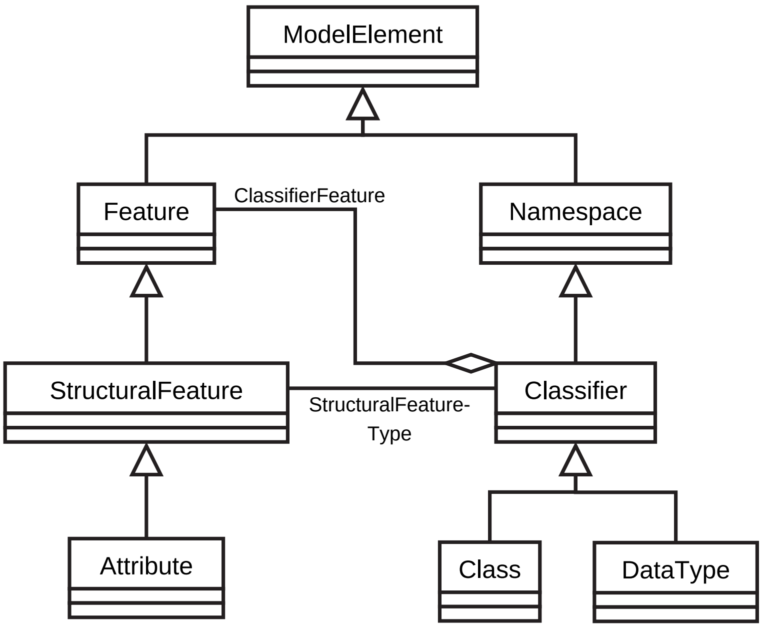

Figure 4: CWM: extract of the *Core*-package [PCTM02]

Known from the UML there are classifiers (e. g. classes) which consist of several features (see Figure 4). A *StructuralFeature* is derived from *Feature* and an *Attribute* is a derivation of a *StructuralFeature*. Each *StructuralFeature* is associated with a *Classifier*, its *StructuralFeatureType*.

Almost all other elements are derived from elements of the *Core*-package. E.g., a relational table is a derivation of a classifier and the relational column is derived from

Attribute. For uncertain information [Hil05] proposes therefore to extend not only *Classifier* but also *Attribute* using the profile mechanism of UML2 [omgb, omgc], which will be soon adopted by the CWM.

Figure 5 describes a UML2 profile for uncertain information. In this profile classifiers can be declared uncertain and are related with attributes which describe the grade of uncertainty. Because there are also approaches using probability intervals the profile allows also lower and upper bounds for probabilities.

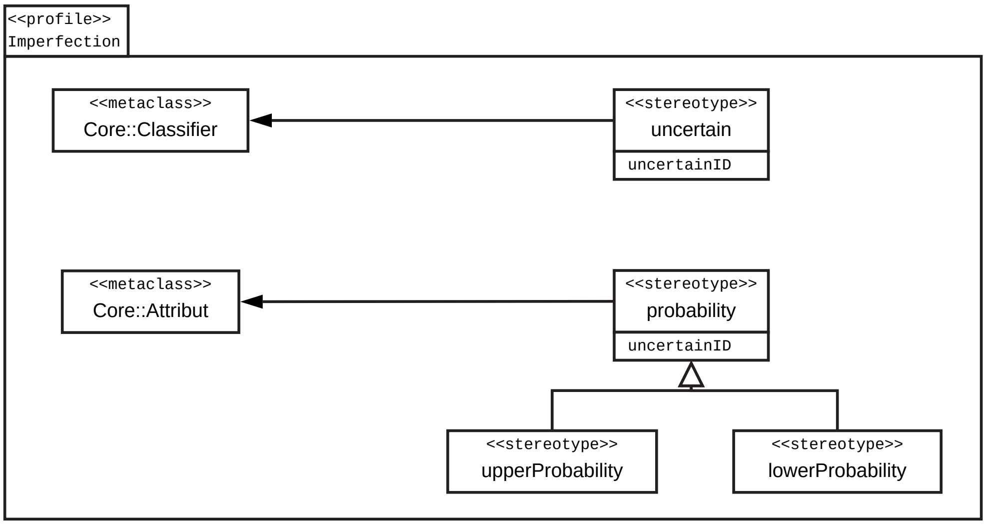

Figure 5: CWM: UML2 profile to support uncertain information [Hil05]

An example of a relational table with uncertain information is given in Figure 6. It is build by using the profile of Figure 5. The relational table is declared uncertain and has got an additional relational attribute which describes the degree of uncertainty. In this case the uncertainty is related to the whole table and not to a single relational attribute.

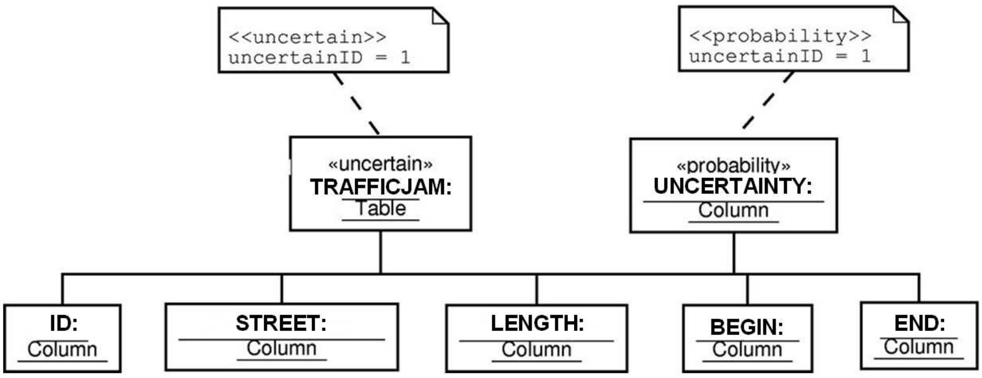

Figure 6: CWM: Relational table with uncertainty [Hil05]

2.3.3 Traffic Forecast

Even if the components of a service are capable to deal with imperfect meta data and therefore to exchange imperfect information these components still have to process this imperfect data internally. The family of traffic forecast services seems to be a promising field for services dealing with imperfect information. These services have to deal with imperfection by nature. The results of traffic forecast services is a forecast and therefore uncertain. We have already shown that the information collected by traffic services is often imperfect. A traffic forecast service receives, processes and delivers imperfect information.

We can build a simple traffic forecast service by measuring the traffic on Mondays and by predicting the traffic on next Monday as the average of the already measured Mondays. Even if this is a very simple strategy it is clear that the quality depends on the number of measured Mondays. If we have only measured one Monday our result is very uncertain. If we have measured all the Mondays of the last decade the measured data of the years before will dominate the forecast result. The forecast service would react to structural changes very slowly and therefore deliver also only very uncertain forecast results.

We suggest to inform the user of a service also about the quality of the service and the amount of the processed measured data. Expert users like traffic managers and scientist can be informed in more detail. Normal users have to be informed in a simpler way perhaps just with one single grade of uncertainty or with a fuzzy term describing the uncertainty of a forecast. We think that services which provide also the imperfection of their results will lead to a better user acceptance and therefore to a competitive advantage.

2.4 Collection and storage of imperfect information

If services are able to process imperfect information they also have to be able to store this imperfect information persistently. There exist several data models which can deal with imperfect information. These data models include not only relational approaches [BGMP90, RB91, DS96, LLRS97] but also object-oriented approaches, e.g., [Wit02].

In [BGMP90] a probabilistic relational model, which allows also missing probabilities, is introduced. It can be used for storage of uncertain information. The approach of [BGMP90] has been extended by [LLRS97] so that not only single probabilistic values but also intervals of probabilistic values are supported. While [BGMP90, LLRS97] attach probabilistic values to relational attributes they violate the rules of relational normal forms. The approach of [DS96] avoids these problems with normalization by attaching probabilistic values only to whole relational tuples. [RB91] is an example of an approach which does not use probabilistic theory but possibilistic theory which is more adequate for fuzzy information.

In the approach of [LLRS97] every attribute can consist of a set of values. For each element of the set there exists a probability function $h_{attribute}$ which returns the probability interval of the element. Table 1 gives an example of such a probabilistic relation with intervals. The first column denotes the observation point. The observation point is always certain therefore the set of values consists always of one element and the probability functions $h_1(1), h_4(2), h_7(3)$ return always the interval $[1, 1]$ which means that the elements occur definitely. The second column denotes the number of cars per minute and the third column the average speed measured at an observation point. In these columns some attributes are uncertain. For example at observation point to the average speed is 120 or 130. The probability interval of

OBSERVATION POINT	CARS/MIN	AVG-SPEED
$[1]$ $h_1(1) = [1, 1]$	$[20, 40]$ $h_2(20) = [0.4, 0.7]$ $h_2(40) = [0.5, 0.9]$	$[120]$ $h_3(120) = [1, 1]$
$[2]$ $h_4(2) = [1, 1]$	$[30]$ $h_5(30) = [1, 1]$	$[120, 130]$ $h_6(120) = [0.8, 0.9]$ $h_6(130) = [0.1, 0.3]$
$[3]$ $h_7(3) = [1, 1]$	$[30, 50]$ $h_8(30) = [0.4, 0.7]$ $h_8(50) = [0.5, 0.6]$	$[100, 120]$ $h_9(100) = [0.6, 0.9]$ $h_9(120) = [0.0, 0.4]$

Table 1: Example of a probabilistic relation with intervals [Här05]

120 is $h_6(120) = [0.8, 0.9]$ and for 130 $h_6(130) = [0.1, 0.3]$.

Another challenge is to process the data stored as described before. The aggregation of imperfect information is a hard task due to the problem to achieve results which are still useful for the human user. A description of aggregation operators for imperfect data goes beyond the scope of this paper (see [Här05]).

3 Evaluation

Because implementing traffic information services in real world is always connected with high investment costs, we investigate the impact on traffic flow by simulating both, the traffic system and the traffic information services. In the OVID [Uni02a, Uni02b, GLGR05] project, we follow a micro-based simulation approach to achieve transferable results and model private transport and freight traffic by representing each single road user separately within our software system.

The two components mobiTopp and VISSIM together form the simulation traffic system. The microscopic model mobiTopp generates the traffic demand by modeling inhabitants of the before specified investigation area and their individual travel behavior. Based on statistical data, each actor follows a sequence of daily activities like driving to work in the morning or enjoying leisure activities in the evening. At least, these activities result in a list of rides describing at which time a person plans to travel from location A to location B. These information are transferred to the traffic flow simulation tool VISSIM, which executes the trips by simulating the specified rides on a micro-model of the traffic network.

The actual implementation of the simulation platform includes routing services that provide route suggestions for pre- and on-trip situations. So, both a person at home planning a trip and a person on tour who wants to change the pre-planned route can ask a service for route recommendations. A network of software agents handles such requests and sends replies based on both information of the actual traffic situation and a near-future forecast of expected traffic flow. The analyzed data includes output from the VISSIM traffic flow simulation, that is stored in a database. With the OVID simulation platform, a set of different scenarios will be performed to investigate the impact of information providers with various capabilities and different economical figures on traffic flow.

There are several hooks to incorporate imperfection in the system and evaluate its

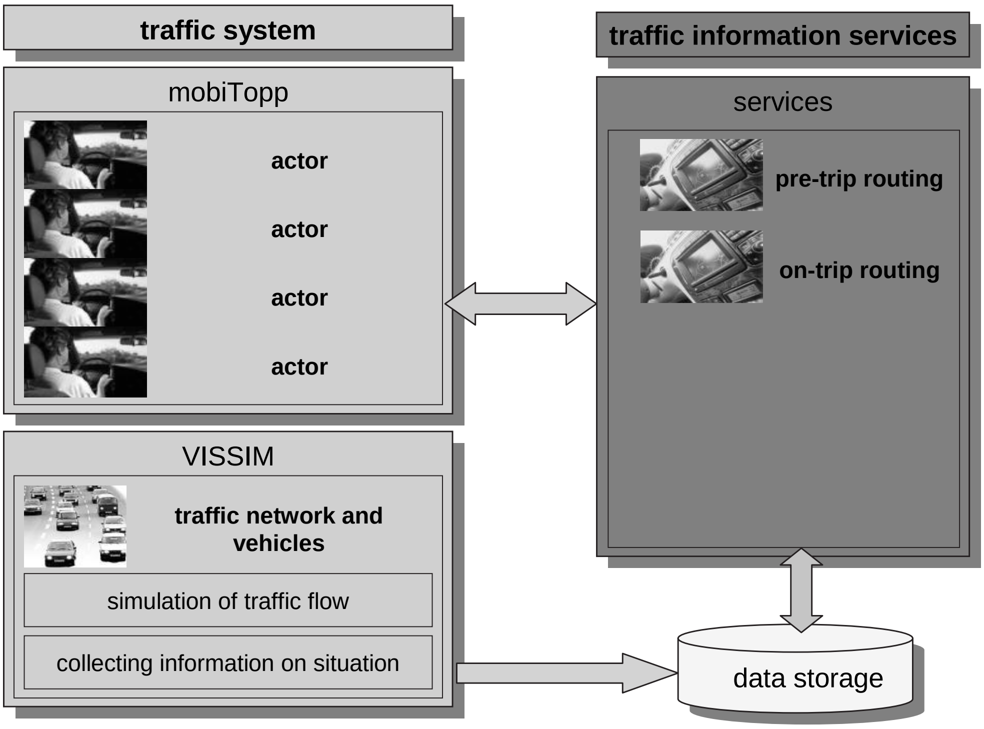

Figure 7: Architecture of the OVID simulation platform

influence on actor's behavior and the traffic flow. The deployed personal behavior model includes a component modeling the experiences made by an actor so far. Based on the strength of past experiences, a person decides whether to follow a route suggestion or to reject it. If a person consults a service several times and receives routes that reduce his/her overall travel time, his/her personal benefit will increase and he/she will tend to access a service more often.

We adjust the behavior model to handle imperfect result data returned by a routing service. For example, a user gets two route suggestions from city A to city B and each of them includes estimated travel time and distance. If for the first recommendation the estimated travel time is shorter than for the second one but less reliable, the user has to decide which one he/she will choose. In this case, different user profiles model the various types of user behavior. Some actors may take no risk and follow the more trustworthy suggestion and others choose the more uncertain but in the case of success shorter one. Additionally, we allow services to calculate with imperfect data trying to increase the reliability of returned suggestions.

4 Conclusion

Imperfection will play an important role for future mobile services because they have to deal with imperfect information from the real world. Revealing the imperfection to the user will increase trust and acceptance of these services. Moreover, imperfection must be handled on all levels of the service realization, i.e., on the basic level of data representation, on the processing level, and on the representation level. Instead of evaluating the impact of future services in real life, our simulation platform provides the opportunity to examine the effect of an arbitrary number of service design alternatives on the traffic system, in combination with other services, and on their acceptance by service users.

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