DIGITRAFFIC
Digital Data Infrastructure For Traffic System

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Abstract. The problems of traffic and transportation are increasing in terms of congestion, environmental impacts. Also the question of traffic safety needs better solutions than available today. Therefore better tools and systems are needed for traffic management and traffic services. Information and communication technology provides new means for improving the quality of traffic system. This relatively new area called transport telematics suffers from inconsistent and heterogenous architecture and concepts. The lack of a consistent picture of the traffic system is evident. Complete computational picture or model would provide the necessary transparency to the traffic system and basis for various traffic services as well as to intelligent traffic management and control. The goal is to plan a national data model or data infrastructure for traffic system. A solid data model supported by advanced computational methods can be connected to a variety of measurement systems and it can support numerous telematic services for traffic and traveling.

1 The DigiTraffic Concept

The technology of data processing and data communication (ICT) is developing very rapidly and it is more and more applied to traffic and transportation. The generic technologies for performing field measurements and providing telematic services is also growing very rapidly. However, there seem to be gap between the measurement technology and the new services. This gap is caused by the lack of methods for consistently handling the ever growing flows of information. The focus of the DigiTraffic concept is in filling this gap by using comprehensive models of the traffic system and traffic situations. In modeling of traffic system various computational methods can be applied as demonstrated in *figure 1*, which also outlines the full picture of the DigiTraffic concept.

In the DigiTraffic concept the focus is on representing the traffic system and the traffic situations with data structures and data models. The data model is offering a complete state estimation of the traffic system at any given point of time. Various methods and algorithms are needed in order to get accurate state estimations based on the samples from the measurement systems. It is assumed that the most comprehensive results are obtained by combining the measurement data with an accurate data model of the traffic infrastructure and with general knowledge of traffic and driving behaviour.

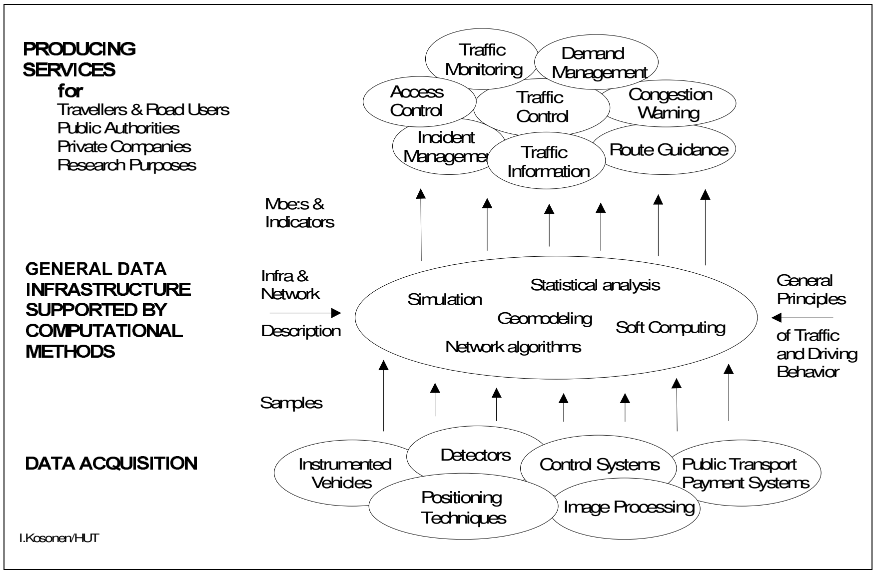

Fig. 1. Producing traffic services through modeling of the traffic system

The implementation of the DigiTraffic concept requires integration between the intelligence and storage i.e. between the software and memory (database systems). The modeling software provides the means for state estimation while the database system is needed for storing and presenting the results as a data model. A geographic information system (GIS) is most suitable in presenting the results and to provide a basis for a variety of telematic services *(figure 2)*.

The development of data-model and database system of all the streets and roads is currently under construction in Finland. The DIGIROAD-project is organized under the Finnish national ITS-program (FITS). The DigiTraffic-project is a plausible continuation in the development of DIGIROAD extending the integration of data models, database systems and modeling software into the traffic process, too. The main difference is that the DigiTraffic system is more dynamic, i.e. it changes rapidly during time. Also there is more uncertainty related to traffic than to road infrastructure and therefore more intelligence is required in modeling the traffic.

Compatibility with the national road model is desirable, since the coding of the network is a very big effort. The DigiTraffic database model is planned to use the DIGIROAD model for the basic network structure that is complemented with more detailed modeling of the lane structure and road furniture. The DigiTraffic attaches the dynamic traffic information to the static description of the traffic system. A spatio-temporal database model is needed since not only current traffic situation is presented, but also the history and future scenarios.

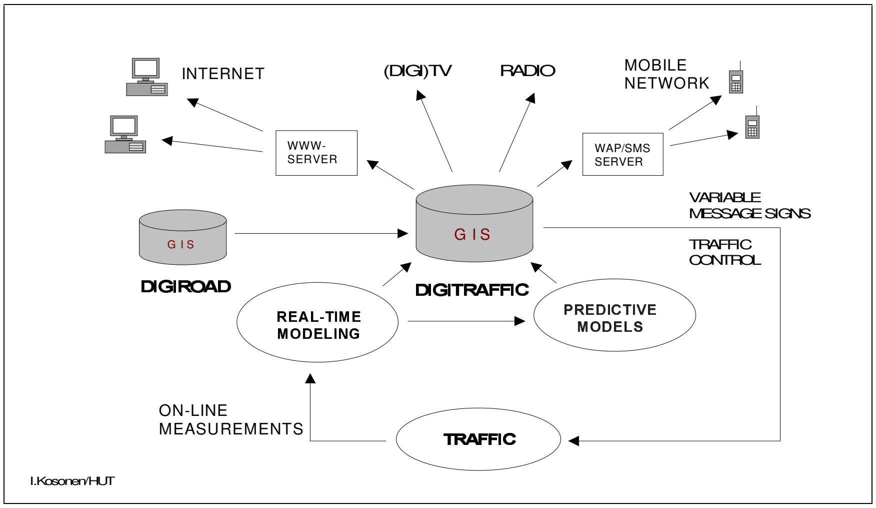

Fig. 2. Integration of GIS and traffic modeling for real-time information services

2 The Data Model

A key concept in the DigiTraffic approach is data model. The concept of data model is already in common use in construction engineering, but not when it comes to more dynamical systems such as traffic. A data model is an abstract construction that defines a given system. A data model defines the types and number of elements that the system is composed of. The features or properties of each element are also described. The structure of the system is also defined in the data model by various types of connections and relations between the elements. The concept of data model is essentially object oriented, while the type of implementation may vary.

Structures like buildings, roads and bridges are commonly handled as data models since they are fairly static systems. These data models are typically three dimensional and associated with CAD-tools, which allow editing of the data model and viewing it from different angles. Recently also four dimensional (4D) data models have appeared, which allow browsing the system through time for example viewing a building in different stages of construction. Similarly a data model of traffic system is essentially a 4D-model, where the traffic situations change according to the time dimension.

A data model as such is only for storing and presenting the system and therefore all the data must be imported. A data model cannot be used for estimating values that are not obtained or measured directly. In a 4D-model the system can be browsed through the time axis, but this does not involve any dynamics of the system.

A data model can be enhanced with functionality and interactions between the objects. This type of data model allows user test the effects of changing some input values. A data model with time dimension and interactions included, is generating new events. The more usual term for event generator data model is a "simulator".

In practical implementation any data model requires both permanent and non-permanent instance. The non-permanent instance allows viewing, browsing and executing the model with appropriate software. The non-permanent instance of data model exist only in the central memory of a computer and it is destroyed by power down.

The permanent instance of the model is not directly usable or executable but it is stored constantly. Permanent instance is usually provided by the computer file system with some physical storage device. There are large number of file formats and script languages for various types of data models. For example text- or CAD-documents can be saved in various formats or using script languages like HTML and its extension XML.

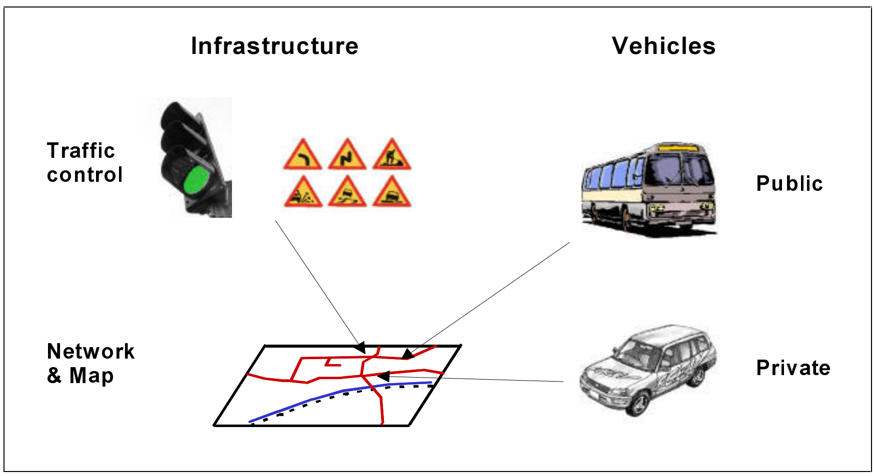

Fig. 3. The main elements of the DigiTraffic - data model

A combination permanent storage system together with executable features can be provided by a database system. In the database system the files are represented by tables, which are managed by a database engine. The database engine provides an executable and fast interface through query language to the permanent file data.

The concept of data model is the key issue regardless of the form of existence. In fact a main problem in the area of infrastructure and transportation is the lack of common data models. Without common data models and script languages, the users and applications cannot communicate and exchange data effectively. This problem is consuming the other benefits the information society in large amounts.

One of the main goals in the DigiTraffic-project is to construct general data models of traffic systems and traffic situations. The DigiTraffic data model consists of description of the network and road furniture, static/dynamic traffic control and public/private vehicles *(figure 3)*. The data model is capturing the complete picture of traffic situations and therefore the basic variables to be maintained are at least speed, position, direction and type of vehicles *(figure 4)*. Supplementary data may be needed for special type of vehicles like trucks, public transport vehicles etc.

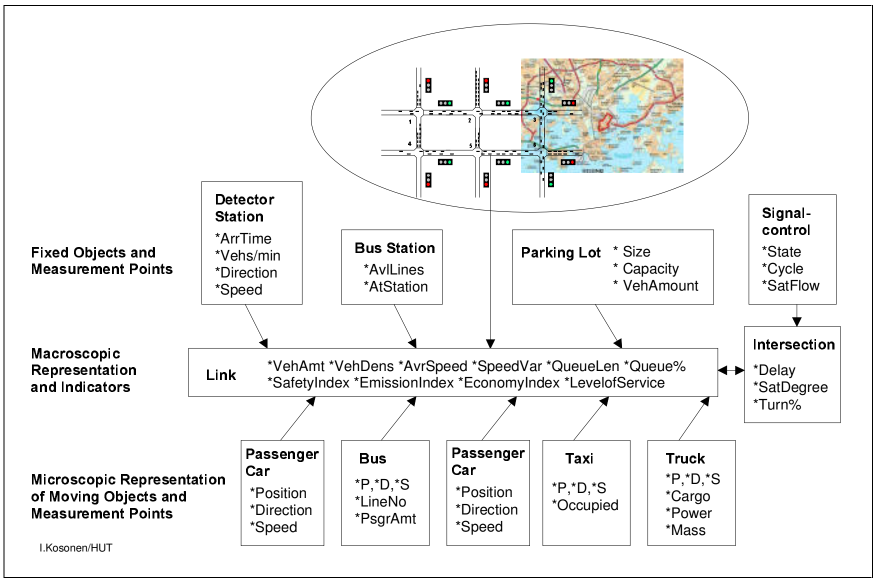

Fig. 4. Outlining the data infrastructure of the DigiTraffic

The microscopic traffic data model serves as basis for deriving higher order traffic indicators of traffic fluency, safety, economy and environmental effects *(figure 4)*. Any new "measurement" operations required, can be directed to the data model only. This way the original (raw) measurement data is no more necessary to store since all essential traffic information is maintained by the data model. The traffic data model can also maintain a macro-scopic view of the traffic situations. The main traffic indicators are computed into link and node level and maintained in appropriate objects of the data model. This will simplify the data search operations. For example a link objects can maintain such traffic data like mean speed, travel time, traffic volume and traffic density while nodes can include data of queues, delays and degree of saturation *(figure 4)*.

In order to obtain traffic information at given time and place, an inquiry is supplied to the data model, which delivers the appropriate data. If the data model is implemented as a database system, a query language is provided to support the search of data. Since the data model of traffic system is essentially a spatio-temporal model, the most plausible implementation seems to be a geographical information system (GIS). GIS is essentially a database system with extensions that support management of spatio-temporal data. The planning and design of a GIS-model for traffic system are discussed by Kosonen [1,2] and Arjamaa [3].

3 Data Acquisition

A raising problem is that traffic data is collected from many different sources with many different methods that are not directly compatible with each other. The measurement systems like detectors, mobile phones, GPS-systems, video cameras provide different type of data that represents one aspect of the traffic system. The traffic data provided by different systems is not compatible with each other as such. Therefore a systematic approach is needed in order to use all the data sources in consistent way to improve the overall quality of the picture from the traffic system.

Since there is only one traffic system in reality, it would be plausible to maintain only one computational picture (model) of it, instead of storing all the different aspects separately. In the data model, only those numbers that are necessary to define a traffic situation, will be maintained. Each measurement system is used to support and improve the accuracy of complete data model of the traffic situations.

In *figure 1* different sources of traffic measurements are outlined. The detectors provide cross-section data with recognition of each vehicle and its arrival time. Also vehicle type, length and speed can be obtained from some detector stations. Traffic flows and time headway distributions can be computed.

Video recording can capture a wide area with single device, but it requires image processing to obtain traffic indicators. However, more useful information can be obtained by detecting queues, platoons, traffic jams and incidents automatically. Travel times can also be measured by automatic recognition of the licence plates at different locations.

Positioning technology is expanding rapidly and it provides a micro-scopic (probe-car) view into the traffic. The probe vehicles basically provide the position, speed and direction of limited number of individual vehicles with certain sample rate and accuracy. Public transport and goods transport are leading the development, but it is likely that larger part of passenger cars will also be probe vehicles in the future.

New vehicles are equipped with information systems and internal data bus to maintain various functions of the vehicle. This information is can also be recorded or transmitted on-line. Trucks are getting digital running recorders, from which the state of the vehicle and engine can be followed. Similar technology is likely to spread into private vehicles later. This type of information can be used to model the driving behaviour and to evaluate emissions and fuel consumption accurately.

Traffic control systems are an important source of traffic data. The control systems are usually attached with number of sensors, but unfortunately they are mostly accessible only by the control system itself. It would be important to create open interfaces for control systems to distribute their traffic sensor data for general traffic modeling and telematic services. Also the status of traffic variable controls like traffic signals and lane/speed limit/route/parking signs are invaluable data in modeling of the status of the traffic system.

In addition to different measurement methods and systems, there are several different organisations that are responsible for collecting traffic data. In many countries the road administration is responsible for main arterials and cities take care of the urban streets. The bus traffic is operated by public transport companies and goods transportation by private companies. All these parties maintain useful information of the traffic system, but the data is not used to build a complete picture of the traffic. An open data format or script language is needed to feed traffic information from different sources owned by various organizations.

4 Computational Methods

The important link from measurements to useful traffic services is the refining of the raw data with various computational methods. The focus of the DigiTraffic as a research project is on modeling of the traffic, which requires a solid data model as a skeleton that is complemented with various computational methods and algorithms. The DigiTraffic concepts as such is not limited to any particular computing method, but the focus in this article is on integration of the data model with simulation dynamics. The overall goal is to use methods that fulfil the picture of the traffic situations.

The spectrum of potential methods varies from statistical analysis to soft computing and from traffic assignment models to various types of simulation. Statistical analysis is a basic method in many cases for refinement of the raw data to meaningful traffic indicators. The computational methods can be divided into many categories like structured and unstructured models. With structured models, like simulation, the interest is on the internal structure and state of the model. With unstructured models like neural networks the interest is not on what is happening inside the model, but on the inputs and outputs (black box model). It is proposed here that the structured framework (the data model) can be attached with various types of algorithms to provide the required dynamics to the system.

4.1 Microscopic Simulation

In the microscopic level of modeling the focus here is on using simulation models. A simulation model contains the general principles of traffic and driving behaviour. This information can used to complement the measurement data (samples) into a full picture of the traffic situation. The simulation algorithm is used to compose the dynamics and behaviour to the data model.

Simulation is basically used to interpolate the traffic situations between the samples from different measurement systems. For example the simulation model can "drive" a vehicle from one detector to another. Also simulation model can move a probe vehicle while waiting for a new sample from the GPS-system. Other traffic is generated based on the knowledge of average traffic flows and the driving behaviour is adapted in interactions with measured vehicles.

Simulation model can also be used to provide short-term predictions [4] and predict the effects of incidents [5]. Additional copies of the simulation model can be started to run simulation with very fast speed in order to get predicted traffic indicators. Different scenarios can be tested by simulating with different traffic control and management options. The actual control operation can be chosen from various candidates based on which one gave the best simulation results.

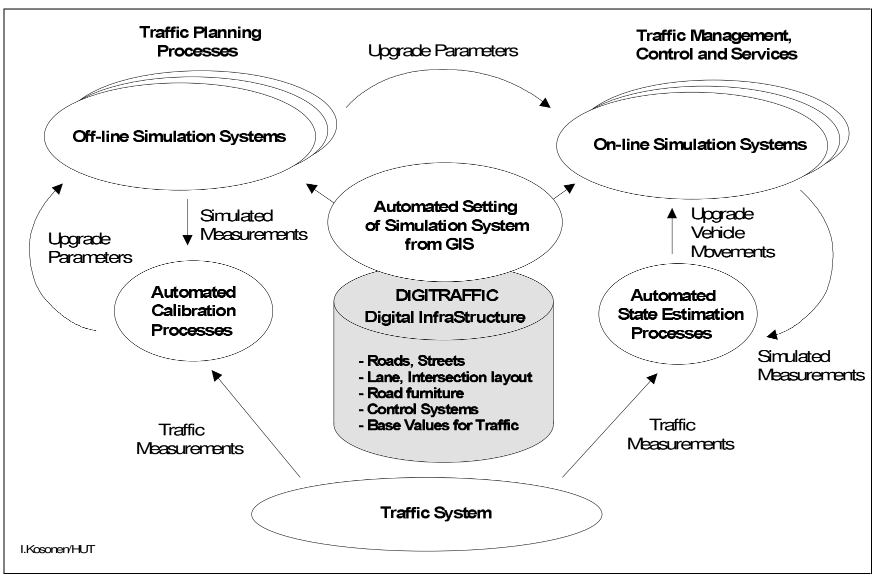

Fig. 5. Automated simulation environment based on the DigiTraffic concept

There are various level of accuracy within microscopic simulation models, too. The simplest mode of micro-simulation is cellular automata (CA). This model provides high speed and few parameters to calibrate on-line. More realistic and detailed model provides more information, but requires more calibration and computing power *(Kosonen 1999)*. The lack of computing power will probably not be a bottleneck in near future as the computers get more and more powerful and cheaper all the time. Therefore it is likely that microscopic traffic modeling will get more and more important in the long run.

Extensive microscopic traffic simulation models for major cities are being constructed all the time. The construction of such models with detail description of street network and lane organization is a major effort in terms of money and man years. Also for this reason there is a need for common data model or data infrastructure of the traffic system. The common traffic system data infrastructure would be independent of any particular simulation or analysis software. It would allow loading the road network and other traffic system data from national database systems, that are maintained by road authorities *(figure 5).* Also the exchange of traffic data between various systems would be simplified. The same data infrastructure could be used for traffic planning purposes (off-line simulation) and for producing of the on-line traffic services.

4.2 Calibration and State Estimation

One of the basic problems in using micro-simulation is the calibration of many parameters. The manual work needed in doing measurements, running simulations and comparing results easily gets far too much to handle, because of the large number of possible parameter combinations. More automatic calibration processes are needed to solve this problem.

New methods have been developed for automatically running simulations, comparing results against the field measurements and finding new parameter combinations. The next step in this process is to automate the collection and processing of field data as well and integrate it to the automated calibration processes. As the automatic measurement and calibration processes take place in more continuous basis, this will gradually lead to a concept that could be called "learning simulation systems". The future goal would be an "always up to date" simulation systems that would automatically adapt to the changes of traffic and driving patterns *(figure 5).*

The same simulation framework can be used for real-time simulation applications as well. In this mode of operation the calibrated simulation model is attached with state adjustment process. This process is used to generate, remove, reroute, relocate and speed adjust individual vehicle objects on-line, hence correcting the errors between the field data and the simulated traffic situations *(figure 5).*

4.3 Integration with Other Modeling Systems

A micro-scopic simulation provides a full picture of the traffic. It contains at least the speed and position of each vehicle at any time. Therefore a time space diagram can be provided from any vehicle. More detailed simulation models can also provide information of momentary accelerations, braking, time headways, engine states etc.

The simulation model can be integrated with more advanced and detailed modeling systems for evaluating emissions, air quality, noise, fuel economy, time economy, safety risks etc. The simulation output data model opens a common interface for such post-processing modeling systems that can be developed by various parties *(figure 6).*

As an example the detailed modeling of emissions and air quality is outlined here. From simulation it is possible to evaluate the momentary emissions at any point. The speeds and accelerations of individual vehicles are provided by the micro-simulation model. The vehicle state of motion can be converted into emissions by using matrixes for each emission type. In future more detailed estimations will be obtained by modeling the engine state as well (rpm/torque) and by combining this information with so called engine maps.

A simulation model provides the rate of emissions (mg/s) at given source points. This data must be fed into a spreading model in order to estimate the quality of air at any point. The spreading model takes in account the weather conditions, wind direction, temperature etc. The combination of simulation with air quality modeling has been studied by Helsinki University of Technology together with Finnish meteorological institute. The method allows estimation of different emission types accurately [6].

5 Services for Traffic

The traffic information produced by the real-time modeling system can be utilized by variety of services. These services can be provided by any party (commercial or non-commercial) that has access to the common traffic model through database systems. The services owned by different parties can be delivered to road users through various channels including (digital)radio with RDS/TMC messages, (digital)TV, Internet, vehicle terminals, mobile phones/communicators and variable message signs at the road side. It is likely the direct access to the traffic related modeling systems will be limited to authorities and researchers. The end-users will access a separate service database that can be tailored for the convenience of users *(figure 6)*.

Services for drivers may include real-time traffic information, incident/congestion warning and route guidance etc. The important issue is to have common ground (model) for all services, which ensures that no contradictory or inconsistent information or instructions are delivered to the road users.

The real-time modeling of traffic system offers new means for authorities to monitor and supervise the traffic system in detail. Time series of any given traffic indicator can be provided from any place. In future this kind of information can be used in planning and maintenance of the traffic system. Also for pure research purposes such a modeling system would be of great importance.

The DigiTraffic concept can also be used to improve traffic control and management systems. These systems include traffic signal control, variable speed limits, lane usage control, access control, road pricing and incident management. In order to reduce traffic problems more comprehensive and intelligent control schemes are needed.

However, intelligent and multi-objective control systems require a very detail and accurate picture of the traffic situation as their input, that can be provided by the microscopic traffic data model. Only with this type of detailed input, an intelligent control system is able to optimize the control operations based on multiple aspects like fluency, emissions and safety.

Various traffic control systems need to co-operate with each other in order to make decisions that support each other and are not contradictory. If each system has their own model of the traffic situation, then inconsistent operation may occur. When different traffic control systems can access the same traffic model, they can coordinate and optimize their mutual operations in a consistent way.

Comprehensive traffic model also offers a tool for following the effects of various traffic control and management measures. The traffic model can provide statistics and time series for following the long time changes of the traffic system. This information can be used for various planning and research purposes.

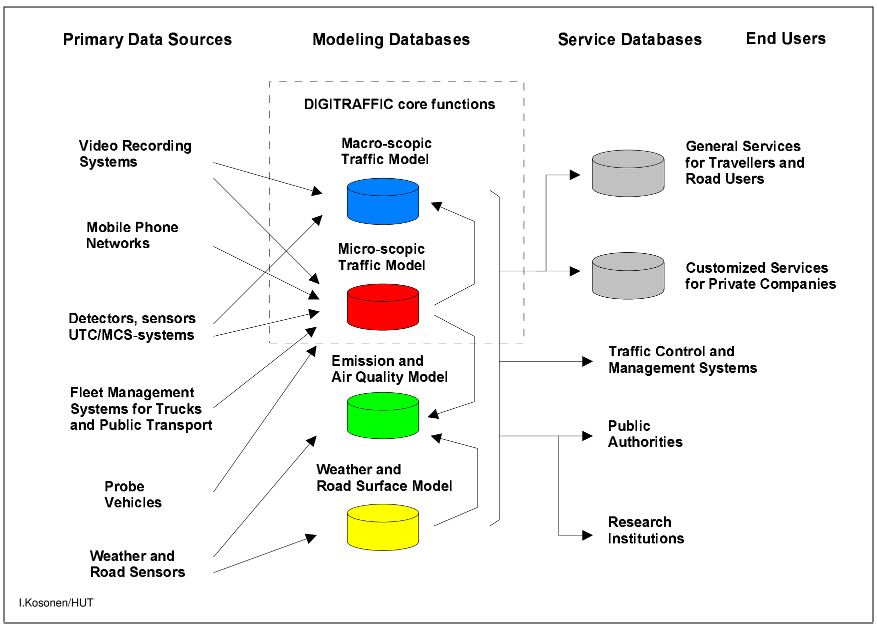

Fig. 6. Integration of the DigiTraffic with other systems and models

6 Conclusions

The DigiTraffic system and concept that is outlined in this paper is part of the Finnish national ITS-programme (FITS) [7]. The ongoing part is a feasibility study that involves defining the basic concepts and principles, outlining the actual system and developing co-operation with interested parties. A second phase of the DigiTraffic-project is laboratory research that is also going on and the available results are mainly based on these laboratory studies.

The laboratory research has shown that it is possible to develop a detailed data-model of the traffic system and implement it as a geographic information system. Also the integration of microscopic simulation with the data model in GIS was done successfully. The use of simulation for real-time modeling of traffic situations was tested with cellular automata simulations. The results of laboratory tests have been sufficiently good. The use of the DigiTraffic concept in improving the traffic signal control with fuzzy logic is also in simulation stage. At the moment better results are expected before actual field studies. The automatic calibration processes with HUTSIM micro-simulation and genetic algorithms have also been tried out with reasonably good results, which indicates that the method is working.

The third step of the DigiTraffic is a pilot study where all the main elements of the concept will be tested in the field. A pilot system is planned to be implemented at the city of Tampere during the summer 2003. The areal signal control system will be installed first. The signal control system provides the detector and signal data to the real-time traffic modeling. The results of the traffic model are stored into a database system (GIS). Finally some traffic information services will be set up to demonstrate the benefits of the system to the road users.

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