ESTIMATING REAL-TIME URBAN TRAFFIC STATES IN VISUM ONLINE

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1 Introduction

If a traffic management centre is set up in a city or a conurbation which is designed to control and guide traffic or to provide merely information for road users, there is one task of vital importance - that is ascertaining the traffic conditions currently prevailing in the road network. Depending on the intended further processing traffic conditions either means the current traffic volumes, resp. the degrees of saturation on all links of the considered network or the travel times on the individual links. Or, a more simple breakdown into few levels of service may be sufficient.

For most control and information purposes it may be helpful to take a look beyond the current traffic states at the future situation, i.e. besides the current traffic conditions the future development of traffic in the near future is to be estimated. Hereby, not only the further development, given unchanged boundary conditions, is of interest, but the objective is to make statements on possible different developments, too, depending on various kinds of control interventions in traffic. In the ideal case the control centre exactly knows about the current traffic state of the whole network. So appropriate control measures may be taken after having calculated the impacts to be expected of alternative measures by means of a forecasting method and selected the best strategy. This process is illustrated by the chart of Fig 1 below.

In a road network there are a variety of detection devices to capture data on the traffic state. For example, each traffic-responsive signal system has been equipped with detectors, which at best may even transmit the acquired data to the control centre. On highways and motorways there are further measurement sites whose data may be used for section control or dynamic route guidance. Moreover, specific detectors can be mounted for traffic management purposes to complete the available equipment. Information which is not gathered automatically but manually, e.g. details on road works or congestion warnings transmitted by road users, constitutes another major data source. In the near future Floating Car Data, i.e. data recorded by moving vehicles and transmitted to the control centre, will gain importance.

All these bits of information contribute to the description of the currently prevailing traffic states at different points of the road network. But they have to be combined in the appropriate way. A traffic model can be the suitable framework of such a data fusion since it allows a source-independent, abstract view of traffic in the road network concerned.

The set of procedures implemented in VISUM Online solves the problem of deriving an estimation of the traffic state in a complete network on the basis of several locally distributed, individual measurement sites and additional information in form of traffic messages and of calculating its further development in a short-term forecast.

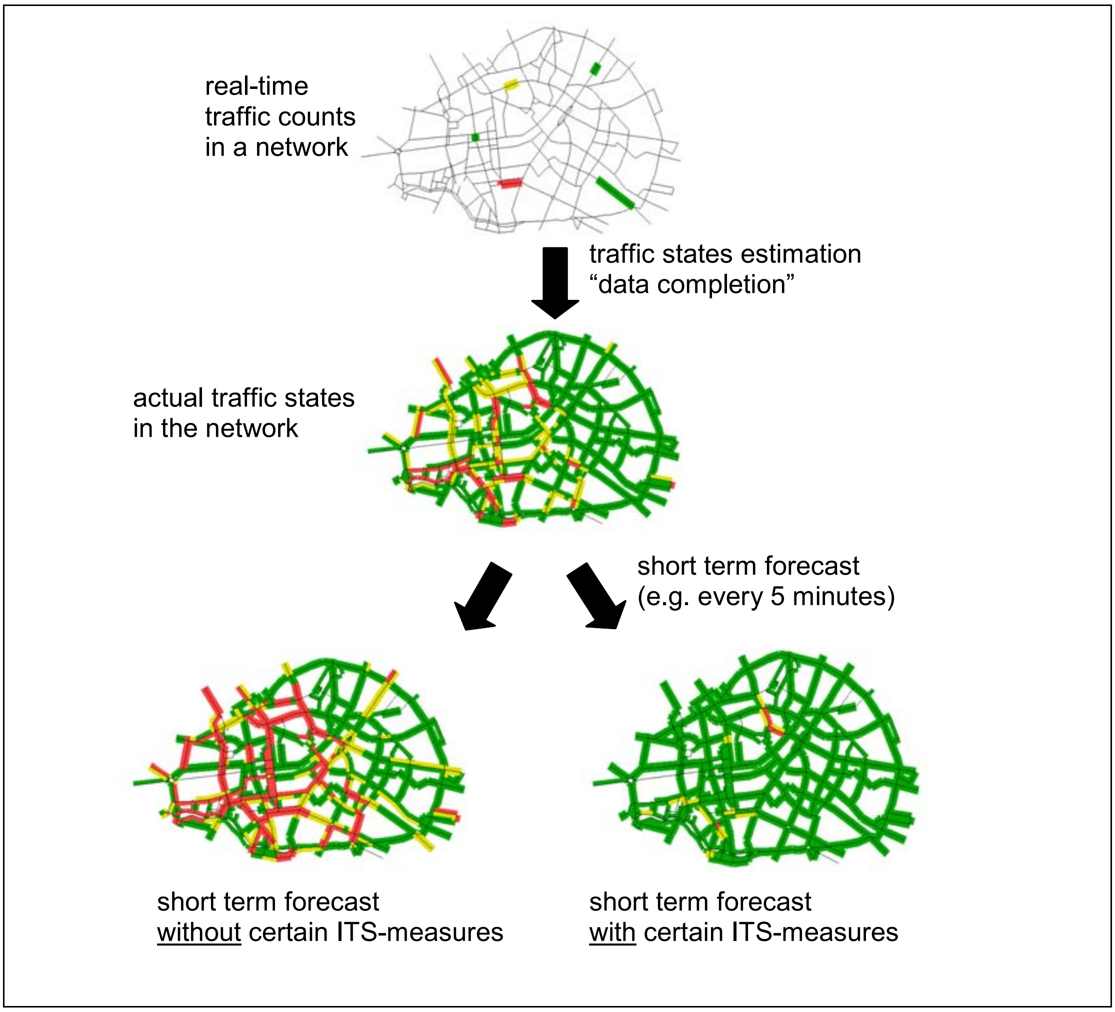

Fig 1: Illustration of the process from currently measured values to forecast traffic conditions, if appropriate measures have been taken

2 Problem Definition

2.1 Traffic state estimation

With the term of traffic state the road user generally associates the information on whether certain links may be travelled on at free-flow speed, i.e. without delay, or whether incidents have occurred. Furthermore, experience has shown that the binary information "congested or not" seems to be the essential one for road users, even if further levels of service are offered. This implies that details on where incidents have occurred or where not are the least information to be provided to inform road users on the current traffic conditions.

However, the situation changes if information on the traffic state does not have to be understood by men only but used by navigation systems for dynamic routing, too. Then

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the description of the traffic conditions has to include the current travel times needed on the individual links of the considered road network.

If such information is not to be used for route optimisation purposes of individual road users but for collective control measures generally aiming at traffic and capacity control, not only travel time as resulting parameter but also traffic volume as underlying, causal parameter has to be known. If in addition to the current traffic state the further development is to be forecast, the same requirement has to be met. Here, too, the current traffic volumes on the links have to be known since the prognosis relies on the forecast movements of these traffic volumes in the road network.

The wish to forecast how the traffic state will develop in future on the basis of the current conditions leads to another requirement to be fulfilled by the information content regarding the „current traffic state". Besides gathering the current traffic volumes on the links („where is how much traffic?") it is equally necessary to know the routes traffic will take („where does traffic go to?).

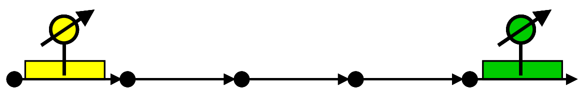
2.2 Short-term forecast

The objective of a short-term forecast is to predict the development of the traffic conditions in the near future. In the context of traffic management systems the time horizon of a short-term forecast is usually 1 hour. In VISUM Online the definition of short-term forecast is not linked solely to the forecast horizon but mainly depends on the current traffic state. With growing forecast horizon the influence of the initial current traffic state decreases and is overridden by the influence of regularly recurring daily traffic flows. In VISUM Online short-term forecast means a prognosis which still is mainly dependent from currently measured values.

If, for example, a forecast based on information about road works calculated traffic impediments in the network for the next day, this would be no short-term forecast in the above-defined sense since today's traffic conditions do not have any influence on the traffic flow tomorrow. A system, however, which updates information about congestion detected on a motorway near road works by estimating how congestion will spread on the basis of the inflowing traffic volume, would produce a short-term forecast, because in that case the forecast situation relies on the current situation.

2.3 Data completion and sensitivity to different measures

Contrary to an information system which can reflect the traffic conditions at the measured sites of the network only, VISUM Online applies a traffic model and generates an added value due to the model-based analysis of measured data. First, the traffic state estimation performs the so-called data completion, i.e. the information on the traffic state is completed for links which are not covered by measurements. The following figure illustrates the general situation of some links which are situated between two measurement sites and which are not covered but whose traffic state will be completed by the system:



Information gained from detectors only

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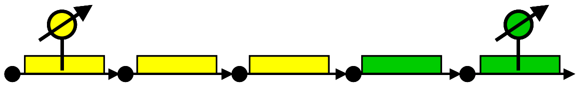
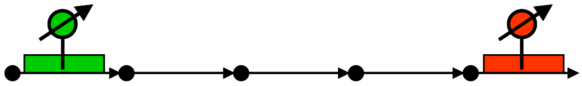
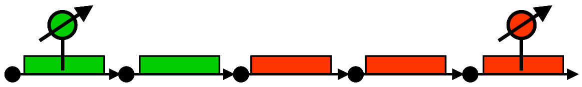


Completed information between detectors

Within the framework of data completion there are situations in which the traffic state calculated by the model is of particular importance, i.e. all those situations for which a traffic flow of extraordinary dynamics can be expected based on the available information (measured values and additional data). One situation may be, for example, if a detectors measures congestion. Then data completion in VISUM Online models its spreading onto network parts which are not covered by detection devices:



Congestion detected at detector



Modelled spreading of congestion in the network

The consideration of modified boundary conditions in traffic supply and demand is particularly demanding for a system of estimating and forecasting traffic states. Especially in traffic management systems information about disturbing or controlling interventions into the traffic infrastructure which naturally have impacts on traffic states and their forecasting is often transmitted. The capability of the system to include such additional information into the estimation is defined as its sensitivity to measures. However, not all modifications of the infrastructure are considered as measures in the usual sense, but for the model calculation it is largely irrelevant whether the reduced capacity of the link is due to an accident, road works or a control measure taken.

The figure below illustrates the reaction to traffic impediments even without detection: assumed that on a link which is situated between two detection sites and on which no detection devices have been positioned, one of two lanes will be closed due to road works. A measure-sensitive model is expected to reflect congestion if the link segment is overloaded, even if its impacts have not reached the detector site yet.

Bottleneck without detection

Modelled impacts even without detection

For incidents, be they known from detection or from traffic messages, two different aspects of their impacts on the network can be distinguished. On the one hand, the incident impacts traffic flow directly, which is reflected typically by a queue upstream and reduced traffic volume downstream (due to the limiting effect of the bottleneck). On the other hand, an incident, especially if long-lasting, leads to a deviation of traffic onto other links which are then subject to higher traffic loads and possibly resulting overload effects.

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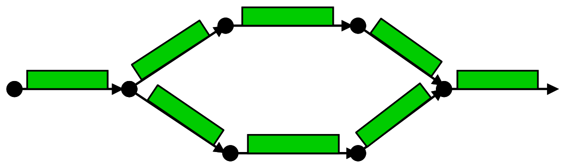
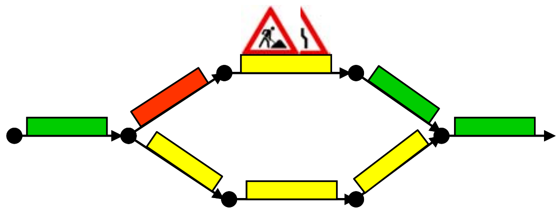
The above schematic figure illustrates the first aspect only. But the system of estimating traffic states equally has to be able to model the diverting effect, i.e. the impacts of an incident on route choice, as shown in the next figure:



Situation without incident



Situation with incident and diverting effect

Short-term forecasting in VISUM Online, too, is measure-sensitive. This means that in addition to the above statements all measures known in advance whose effective period overlaps with the forecast horizon are included into the calculation. This also concerns measures whose impacts cover the complete forecast horizon or measures starting and ending within the forecast horizon.

It is particularly the measure sensitivity which makes up the added value of the model-based estimation and forecast system of traffic states compared to the purely detection-based information system. By intensified, area-wide detection a detection system may be expanded to a practically perfect capturing of the current traffic state, but it cannot provide for the predictive assessment of control measures.

3 Approach

3.1 Data fusion in the traffic model

The estimation of traffic states has to be based on all information describing traffic in the considered area, including current detector data and traffic messages as well as traffic planning expertise and historical data. The appropriate framework for fusing data from all kinds of data sources is a traffic model since a traffic model allows to make the planning information more concrete and to formalize the idea of according to which principles traffic moves.

The solution realized in VISUM Online is based on a planning traffic model in which current measurement data and traffic messages are integrated. It includes the supply side in form of the traffic infrastructure, i.e. the roads and how they are controlled, but also traffic demand. Traffic demand is described by the matrix of the number of trips which are made from one area to the other during a certain time interval. The areas are linked with the road network model by means of connectors. Connectors are those points in the network at which traffic enters the network or leaves the network. The number of areas

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in the traffic model of a city determines the spatial resolution with which demand can be modelled.

So, precondition for the use of VISUM Online is a traffic planning model of the considered area. In many cities such a traffic model is available within the framework of urban traffic planning. It usually can be taken as a basis for further processing. Should none be available, a suitable model has to be produced in a preceding project phase.

3.2 Calculation process

The estimation of the traffic state takes place in two steps: First, a route estimation for a longer time horizon, e.g. one hour, is carried through with aggregated measured values. Then, based on the measured values of the last few minutes a short-term traffic state is calculated by propagating the measured volumes onto the estimated routes through the road network.

The following figure illustrates the estimation process. The major data are highlighted grey, whereby input data are additionally marked by a frame. The individual steps of the process are described in white boxes. They will be explained below.

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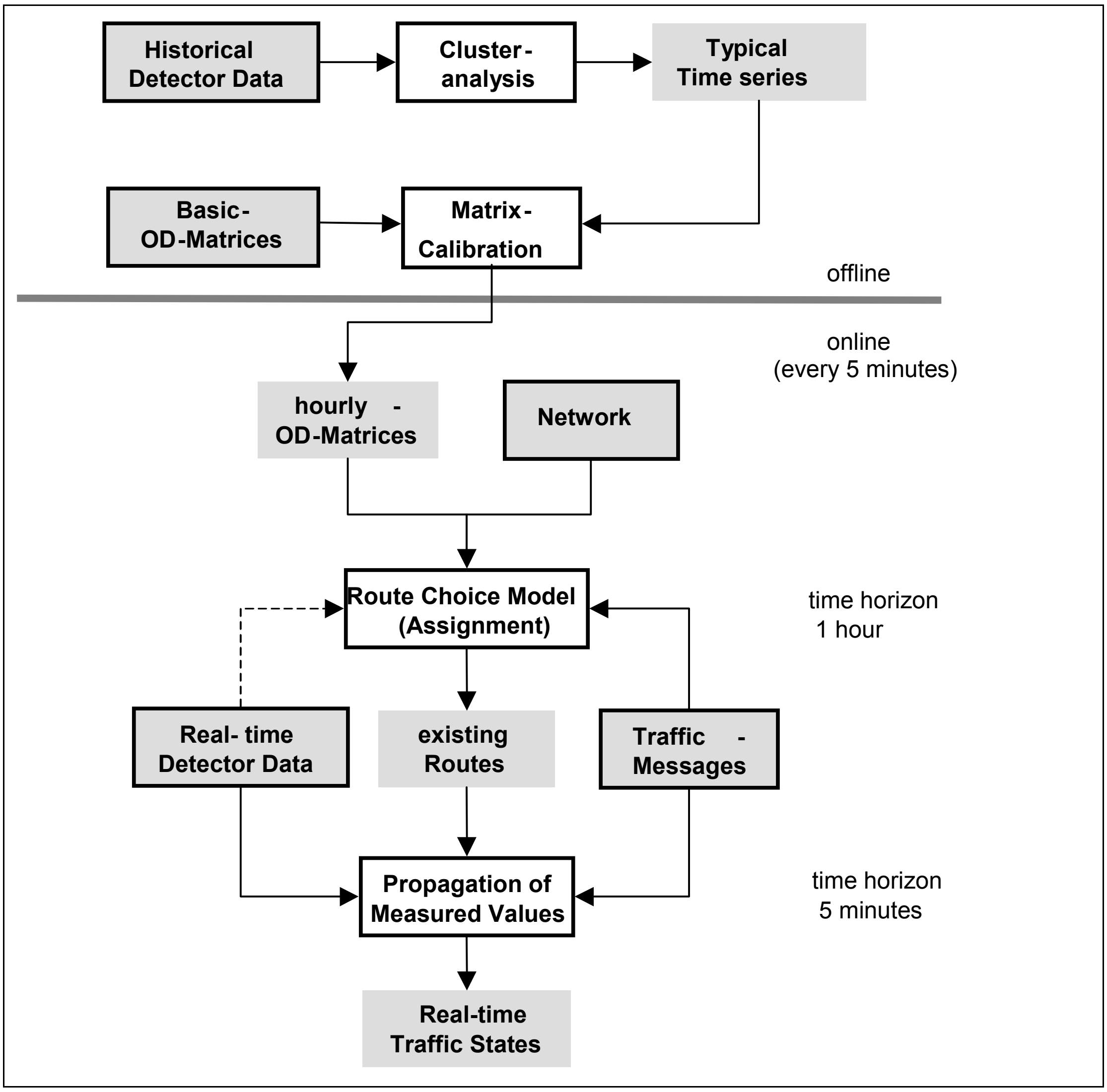

Fig. 2: Process of estimating real-time traffic conditions

The short-term forecast in VISUM Online is based on the application of the method of estimating traffic states in combination with a forecast of locally measured values, i.e. to forecast the traffic state in the complete road network the development of the measured values at the detection sites is forecast and then the same method as previously used for the traffic state estimation is applied to the interpolation onto the whole network.

To forecast the measured values a time series method is applied which from a collection of classified historical daily time series chooses the one matching best and takes its development as forecast. The forecast does not cover the forecast horizon in one step but is calculated in several time slices, on the one hand, in order to allow a more detailed modelling of the spillback and on the other hand, to provide not only the final state but also the development process.

4 Route Estimation

4.1 Route calculation by means of equilibrium assignment

To estimate the routes of the network currently taken an equilibrium assignment is calculated. Prior to the assignment a suitable demand matrix matching the current hour is selected. A network model valid at the time determined is equally chosen and possibly modified to be able to include traffic messages on currently occurring impediments. The route estimation for the current moment then consists of those routes which have been created when assigning the selected matrix onto the current network. The volumes resulting from the assignment are used as estimates for the turning relations at intersections and as substitute values in case of faulty detector data.

4.2 Representative days by cluster analysis

In a preparatory processing step the hourly matrices to be selected are derived from historical measured values and matrices. To produce these matrices a clustering method is applied. It has been developed in analogy to similar methods used in the field of time series forecasting. However, individual detectors are not considered separately but all measured values in the network at the same time. The objective is the calculation of representative days from pre-defined categories of days, whereby for a start the categories of days usually comprise the seven week days. However, a more detailed break-down into holidays, weather etc. is possible. A day category may have several representatives, as there may be several typical series for a Monday, for example. At the beginning of the day VISUM Online starts with that cluster in which the majority of days has been incorporated, since without having any further knowledge, that one is the most probable cluster. In the course of the day the cluster may be changed if the measured volumes suggest so.

4.3 Matrix calibration

For each hour of every representative day a demand matrix is calibrated. This is done by combining the maximum entropy approach with fuzzy logic, allowing for a certain inaccuracy of the measured values. To ensure a good quality of the matrices generated so the process has to be based on an initial matrix, whose structure, i.e. the origin-destination relations, has to be reasonably realistic. Such matrices are usually part of the traffic planning models as hour-group matrices.

5 Propagation of Measured Values

5.1 Propagation of measured values along routes

In order to be able to extrapolate the traffic volumes measured at individual sites onto the complete road network, the measured values are propagated through the network, starting from the measurement sites along the routes gained from the route estimation. The propagation method is based on the idea that the traffic volume measured at one detection site is composed of various streams which branch off into the network in front of or behind the measurement site. Knowing which streams the detected value is composed of, their shares can be propagated in the network along their routes. The below figure shows an exemplary route bundle passing a detector which has been generated by an equilibrium assignment.

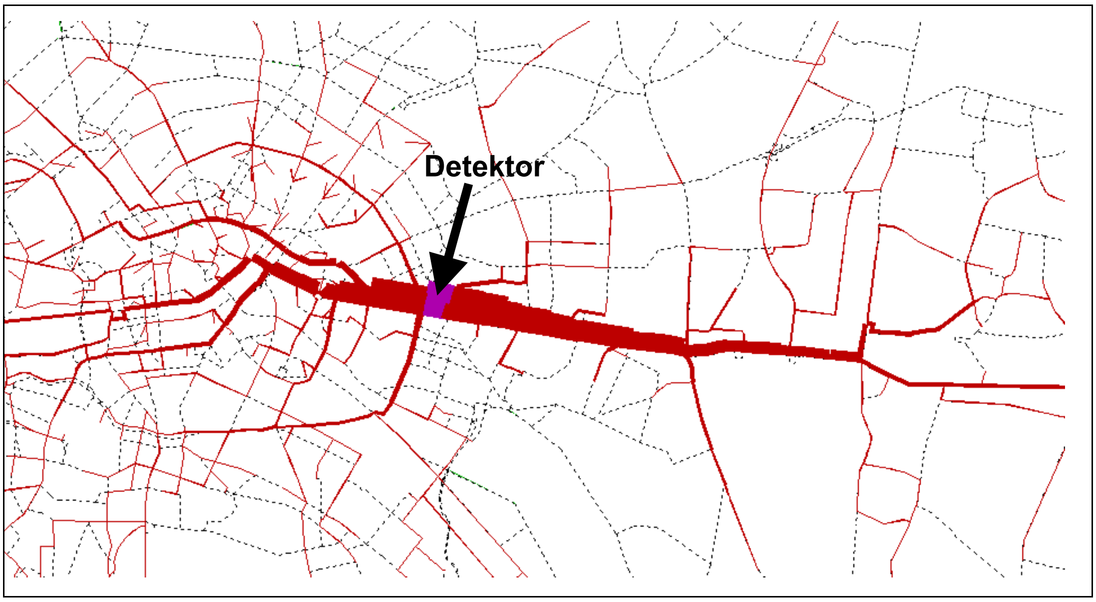

Fig. 3: Depiction of a route bundle passing a detector. The bar width reflects the traffic volume.

5.2 Reliability value

Since such tracing of measured values becomes more and more insecure, the more turning processes are involved, a so-called reliability value is kept during the propagation process. It decreases with growing distance from the measurement site. This reliability value is used to conciliate conflicting information on a link. For example, the traffic volume of the assignment, which has been calculated for the route estimation, is set as additional information of low reliability. In the proximity of detectors these values are overridden, whereas in areas far from each detection the values gained from the assignment are taken as the best estimation of traffic volume. Hereby, transition in between is naturally smooth.

5.3 Queue modelling

If during propagation in the road network a measured traffic volume meets a bottleneck whose capacity is lower than the volume, a queue will occur. In the course of the time the queue may spread onto the upstream links, too. The queue decreases again when the arriving volume falls below the capacity.

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5.4 Influence of traffic signal control

If for the area to be modelled information on traffic signal control is available, exact traffic engineering capacities can be determined for the different traffic streams at the intersections. In case of fixed-time signal programs the outflow capacity of a traffic stream per lane is the saturation flow multiplied by the green time per cycle. In case of traffic-dependent signal control estimation is possible if the green times are provided online or if the extent of traffic dependence is determined by given overall framework.

5.5 Level of service

Various parameters are available to calculate the level of service. At measurement sites detecting traffic volume and speed both parameters are used to determine the level of service according to a given classification in the volume-speed diagram. At other sites of the network where traffic volume is the only available parameter, be it measured or calculated, the level of service is derived from the degree of saturation, as long as there is no queue. On links with queues the level of service results from the queue length and the remaining traffic volume.

6 Short-term Forecast

6.1 Cluster analysis of historical time series

For a prognosis of the traffic state in the whole road network the measured values at the detectors are forecast and then updated for the whole network by the propagation method used for estimating traffic states. For that purpose again a clustering method is used to determine typical developments. Contrary to clustering daily representatives here each detector is considered locally separated and with a higher temporal resolution.

The detected values of traffic volume and speed are aggregated over the day in shorter time slices (e.g. 15 minutes). Thus, one time series per day is produced for each measurement site first. To obtain representative time series for certain categories of days, the already input time series are clustered in a pre-processing step, i.e. each new time series is allocated to an existing cluster or, if distinctly different from the representatives of all existing clusters, it becomes the first representative of a new cluster. If a new time series has been allocated to a cluster, a new representative will be calculated on the basis of that new time series and the previous representative of the cluster.

6.2 Selection of a representative for forecasting

During operation the values measured at the detectors are continuously compared with the stored cluster representatives so that for each detector the representative so far matching best is known. After some adaptations it is used to forecast the further development of the values measured at this detector. If none of the representatives shows sufficient similarity with the development so far, or if a detector records congestion, the current representative will be dropped and a trend forecast made instead.

7 Consideration of Traffic Messages

7.1 Types and sources of traffic messages

Traffic messages are information on traffic-relevant incidents (e.g. road works) or traffic states (e.g. 2 km of congestion) on certain sites of the network at certain times. Some traffic messages may be included for the estimation of the traffic states as additional source of information on road network, demand or traffic state.

7.2 Consolidation of traffic messages

To be included into route estimation and propagation the information contained in the message has to be firmed up, or respectively quantified. For each message the following details must be known:

1. The *location* of the message, i.e. the set of links in the road network model affected by the message. Messages which cannot be located cannot be used for traffic state estimation.
2. The *period* for which the message has traffic-related impacts.
3. The *traffic-related impacts* of the message. These are determined by the influence of the message on capacity and free-flow travel speed on the affected links.

7.3 Consideration of messages for route estimation and traffic states

The consideration of traffic messages is based on a consolidated stock of messages with clearly defined spatial and temporal impact areas as well as clearly defined traffic-related impacts in form of capacity and speed modifications. The messages are taken into account in both steps (route estimation and measured value propagation).

To include messages in route choice, their impacts are transferred to the road network prior to the assignment. During the assignment process both the reduction of the capacity and the free-flow travel speed take effect since both values are reflected by the resistance function of the links. Prior to the propagation of measured values the capacity reduction described as traffic-related impact is equally transferred to those links of the road network model which have been listed up when locating the message. The recorded speed modifications are allocated to the links, too, but do not play any role during the actual propagation. They only become relevant when the result of the propagation is interpreted as level of service. Due to the capacity reductions the degree of saturation of the links concerned is increased, and during propagation queues may occur.

There is, however, an important difference as regards the impacts of messages on route choice and propagation. During propagation all capacity reductions which are currently

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valid have the same impacts. Supposing the same for route choice would mean that the road users are informed immediately and completely about each incident and take that into account when deciding on the best route.

If, for example, a link gets closed due to an accident, the closure will have direct impacts on the propagation and the arriving traffic streams will queue up. Would the closure equally have direct impacts on route choice, the preceding assignment would already have diverted all vehicles onto other routes and no queue would arise in front of the accident site. It is obvious that for a realistic modelling of the traffic state the closure must not be considered in the assignment immediately when the impacts come up. On the other hand, a link closure due to road works, which is signposted and which has existed for days, will not produce a permanent queue because the road users have learnt to by-pass it. In that case the impacts of the closure definitely have to be taken into account in route choice.

In order to be able to model that situation and similar ones realistically, temporal developments for including messages in route choice have been defined in VISUM Online. Starting from the beginning of their validity they let the traffic-related impacts grow gradually. Each category of messages (accidents, road works etc.) has been allocated individual developments. In the same way developments of abating impacts have been defined after the expiry of the validity.

8 Practical experiences in the project VMZ Berlin

8.1 The network model of the VMZ Berlin

In 1999 the development of the traffic management center for the city of Berlin started. The basic idea was to collect traffic data from a number of detection devices and use that information to provide a set of services such as dynamic routing in the internet. The senate of Berlin contracted a private consortium to build and operate the traffic management center. A system architecture was chosen that divided the whole system in the so called content platform providing information about the current and future traffic situation and the service platform that provided the services based on the content information to the users.

To measure current traffic flows, about 200 dedicated above-ground detectors were installed. These detectors measure volumes and speeds and report them to the center via a GSM cell phone connection. Since power is supplied by solar panels and thus naturally limited, a maximum number of about 100 transmissions per day is possible. Therefore, an event-driven transmission algorithm is used, i.e. the detector transmits new data if it detects a significant change in the measured values. In addition, a number of loop detectors on the motorways around and in Berlin can be accessed.

The network model used in the algorithms consists of about 10,000 links representing the major road network in Berlin. Travel demand is known from planning applications as origin-demand matrices referring to 500 zones. Demand information was given for separately for the morning and afternoon peek period and for the rest of the day for weekdays. Network and demand were available in the form of a validated model in the VISUM transport modeling software. Fig 4 shows the network model and the positions of the detectors. The solid lines represent the roads for which level of service shall be delivered. The dotted lines are roads that are in the model and used in the computation, but where no level of service estimation is required.

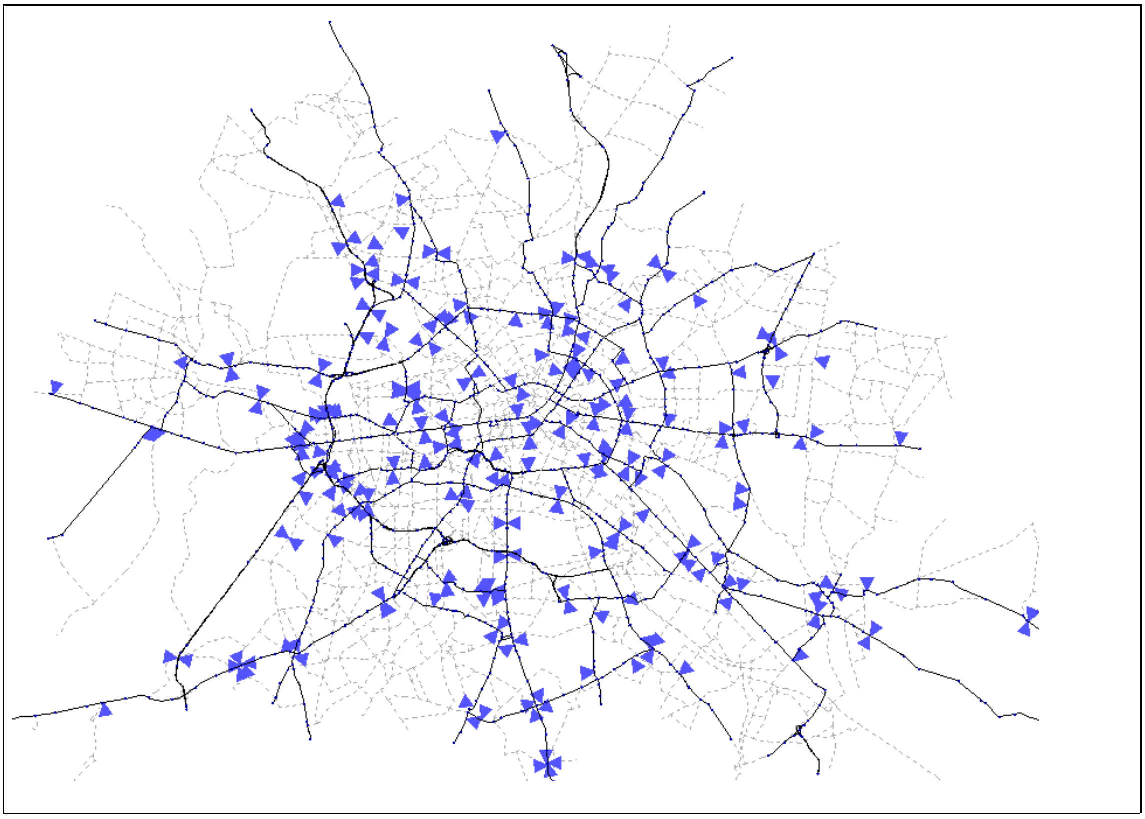

Fig. 4: Network model of Berlin and detector positions.

8.2 Quality assessment of the traffic state estimation

The most appropriate method to assess the quality of any traffic state estimation procedure is, of course, to compare its results to the actual real-world traffic state. This, however, requires additional observation. For example, it was planned to compare estimated level of service in Berlin with level of service recorded by human observers. This method is not always practicable for assessments during development and calibration of the algorithms, a more automatic procedure is needed. Therefore the common approach was adopted to systematically omit some of the installed detectors in the estimation process and compare their measured values to the estimated values at the positions of the omitted detectors. It should be kept in mind that this is in a way a worst case scenario, because if the detector positions have been chosen optimally so that they provide maximum information, these positions are inversely the most hard to estimate without a detector.

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To get an overall quality index, each single detector in turn was omitted once and the estimation procedure was applied for time slices of one hour. Then the correlation was computed of all the measured values and the estimated values as explained in the chapter about the offline calibration of the assignment. Since level of service is the final objective, not only the volumes on the links are used but also the degree of saturation of the links defined as the volume to capacity ratio. The capacity values are taken from the transport planning model and thus do not reflect the maximum volume that a link can carry at all but the maximum volume a link can carry while still providing satisfactory level of service.

For a randomly chosen normal Tuesday, the results are shown in the following diagram. The correlation for the hour from 7 am to 8 am is .93 for the volumes and .78 for saturation. The traffic state information is published in the service platform using 3 levels of service. If the following simple saturation based definition of level of service is assumed: LOS 1 below 80 % saturation, LOS 2 between 80 and 100 % saturation and LOS 3 above 100 % saturation, then for 70% of the detection positions the correct level of service is estimated, 26 % are off by 1 and 4 % are off by two in the example, what would be an acceptable result.

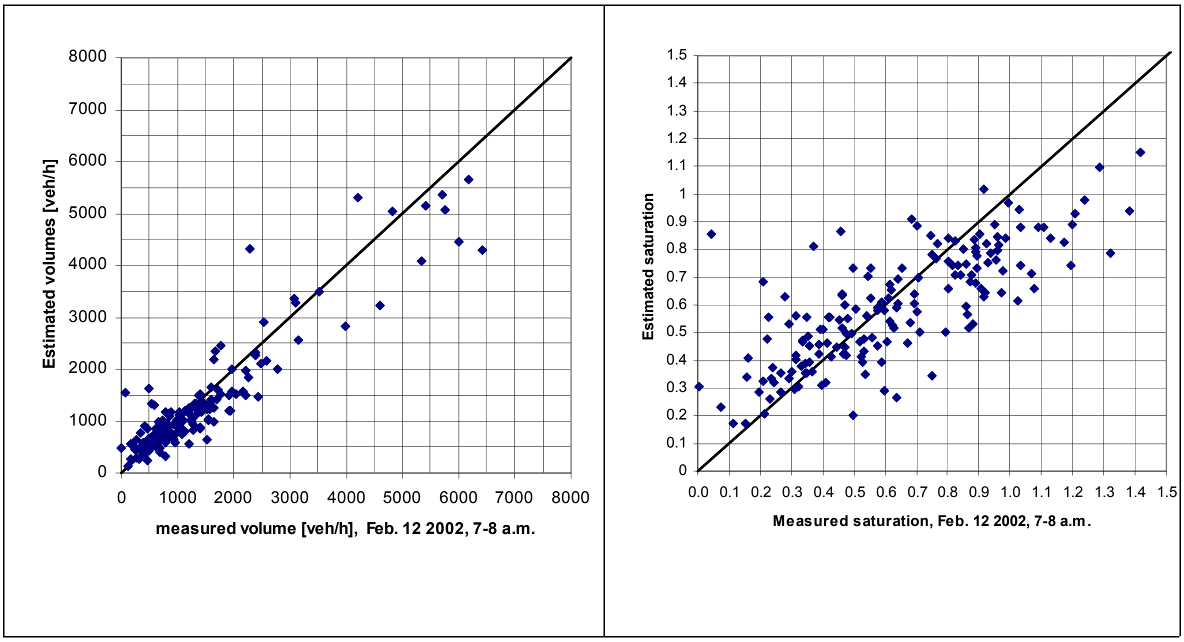

Fig. 5:Measured vs estimated volumes and degree of saturation for all detection points

9 Conclusions

Operating traffic management systems is based on extensive knowledge of the current traffic conditions. Detectors and probe vehicles are the more common means of providing this data. These sources, however, only provide a partial picture of what is happening either at a point in the transportation network or for a sample of trips over a section of roadway.

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VISUM Online offers proven methods to expand these point and sample measurements to accurately describe current traffic conditions where detection is and is not deployed. The model also applies these same methodologies to provide forecasts of traffic conditions.

VISUM Online's modular and open system architecture offers the ideal tools for a truly integrated and intelligent traffic management solution. The different modules have been used for numerous traffic management and telematics projects, either as stand-alone system solutions or embedded in customer- and project-specific system environments. It is designed for freeways and arterial streets as well as for applications in the field of integrated traffic control. It is also the core component for sophisticated traveler information systems where information from VISUM Online can be provided either before or during a trip.

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