MONET
Dynamic Network Modeling in Transport Systems

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SUMMARY
MONET is a dynamic road network model focusing on online estimation of present and short-term forecasts of traffic states. Functionality to analyze travel times, queue lengths, traffic states with respect to incident detection and determination of congestion impacts are included. MONET applies models for o-d-matrix estimation and dynamic routing. Within traffic management centers historical and real-time traffic data is provided which is processed by MONET to produce traffic forecasts, needed for various purposes. The system is composed by various models, among them models for statistical evaluation of historical sensor data, traffic demand management, network design, dynamic traffic assignment and mesoscopic traffic simulation. It is designed to use information of various sources such as traffic signal data, historical o-d-matrices, event data, data of road constructions or floating car data (FCD) to predict the current and future traffic situation.

INTRODUCTION
MONET is a crucial part within Intelligent Transportation Systems (ITS). Within our framework especially the Advanced Traveler Information System (ATIS) is of interest, since we intend to provide German metropolitan areas with dynamic traffic information like current travel times or congestion spreading and services like dynamic routing. With respect to this venture we focus on the following:

- **Practicability**, since installation and maintenance of the system must meet certain budget constraints to allow dynamic traffic information at reasonable cost,
- **Accuracy**, since only high-quality information will give the desired (and needed) degree of acceptance of the services,
- **Openness**, since the technologies will continuously be developed within the next years (FCD, vehicle recognition by video, etc.).
As for practical employment, first steps are a field test of MONET in Munich within the German research program “MoTiV” and the ambitious project “BerlinTime”. In Berlin a large-scale content and service providing business is planned based on MONET that is going to start operation here for the first time. Besides of these two applications we investigate further possibilities to apply MONET within existing traffic control systems.

MONET ARCHITECTURE

MONET is an online road network model focusing primarily on estimation of the present traffic condition and short term forecasting. Various existing theoretical models are applied within MONET. Most of the functionality is based on comprehensive dynamic route choice and traffic assignment models. The dynamic network model MONET is an integrated system that is built up of the following components (see fig. 1 also):

1. **Analysis of historical data**
   Historical data comprises sensor data, o-d-matrices and traffic flow patterns. The benefit of analysis of those data is twofold: First the model uses information derived from the data archive to improve traffic forecasting. Secondly historical data is analyzed with respect to traffic demand of large events like sport meetings and exhibitions. For these purposes the data shall be clustered and assigned to appropriate attributes like calendar or event data.

2. **Traffic demand management**
   The task of this component is to generate temporally resolved o-d-matrices on the basis of predefined (static) o-d-matrices, historical data (archived online data) or other statistical traffic demand information. The o-d-matrices are used as initial conditions for the traffic assignment procedure where, in the course of the calculation, they will be corrected permanently.

3. **Data completion, dynamic route choice and traffic assignment**
   The determination of the complete traffic scenario, given the o-d-matrix and sensor data, is carried out by a dynamic traffic assignment algorithm, which is also able to correct the input o-d-matrix. Used time slices for subsequent assignments are 5 – 15 minutes.

   The current MONET prototype uses a modified version of the Path Flow Estimator (PFE) [1]. The Path Flow Estimator essentially iterates an equilibrium assignment procedure to match the volumes on measured links with the volumes computed by the assignment. Besides the estimation of volumes on not measured links the PFE produces an estimation of the used path flow. Data completion and path flows are needed as input for short term forecasting by simulation. The modifications of the PFE algorithm are mainly heuristics to enforce convergence in cases of faulty sensor data. Every measured link forms a constraint of the PFE to assign a volume within a given tolerance interval. If a constraint cannot be satisfied within its given tolerance, the interval will be widened in
a first attempt and then, if it can be fulfilled, it is narrowed again to find the least necessary tolerance interval. If the necessary tolerance exceeds reasonable bounds, the constraint is removed and the corresponding sensor is flagged out. This mechanism points out faulty detectors. Travel demand information in the form of an o-d-matrix can be used as additional constraints or only as weights to give hints to the path building algorithm. The latter kind of incorporation is normally preferred, since for reasonable big road networks the number of o-d-relations would by far exceed the number of measurement sites, so the adaptation to sensor data could be overridden by a mere assignment of the o-d-matrix.

Besides of that tests are performed with a new dynamic route choice & assignment model that is based on recurrent neural networks [4] and can run real-time even for large road networks. This adaptive model consists of two cooperating neural networks: one for the identification of the real traffic system and the other one for the adjustment of certain control parameters of the first. Remarkable features of the model are the adaption of the system dynamics by means of a data driven learning algorithm, the simulation of traffic spillback effects with link interactions and the possibility of parallel implementation to increase the performance.

4. Short term traffic forecasting

Starting from the current traffic state the traffic situation will be forecasted for periods between 15 to 30 minutes. This is managed by using the static equilibrium assignment component and a mesoscopic traffic simulation based on appropriate historical data. The traffic simulation part of MONET is performed by the DYNEMO model [2].

DYNEMO is a traffic flow simulator for both urban and interurban road networks. It is able to deal with networks with about 100,000 vehicles moving simultaneously, and has been used to simulate a large part of the German motorway network. Regarding movement of vehicles, DYNEMO is a mesoscopic model in the sense that the unit of traffic flow is the individual vehicle rather than the temporal and spatial aggregates used in static assignment models. Their movement, however, is governed by the average traffic density on the link they traverse rather than the behavior of other driver-vehicle units in the immediate neighborhood as in microscale models. The traffic flow model is based on the well-known formula known from hydrodynamics:

\[ u_i(t + 1) = u_i(t) + (U(k_i(t)) - u_i(t))/\tau + \delta (k_{ri}(t) - k_i(t))/\Delta_i, \]

where

- \( u_i(t) \) = the mean speed traveled on a link segment \( i \) at time interval \( t \),
- \( k_i(t) \) = density [veh/km] on a link segment \( i \) at time interval \( t \),
- \( \Delta_i \) = length of link segment \( i \),
- \( \tau \) = reaction time.
For each junction within a network signal control or priority rules are specified. Decision points are placed anywhere within the road network, where vehicles can alter their calculated routes e.g. in response to dynamic information or guidance. Vehicles will minimize a generalized travel cost function considering travel time, distance and cost. It is evaluated once at the beginning of the simulation, and if it depends on the current traffic situation (e.g. travel time), optimum routes are optionally updated by DYNEMO based on the current traffic volumes. Furthermore, fixed routes are specified if subsets of vehicles will follow guide signs or temporary diversion. Vehicles are classified into up to 100 types and route-choice behavior can be specified for each type separately.

5. Long term traffic forecasting

Another type of traffic forecasting is provided to estimate the traffic volumes for a whole day in the future. MONET uses a demand-based approach, i.e. the forecasting takes place on the level of o-d-matrices. Historical o-d-matrices are classified and typical demand patterns are extracted for different types of day, e.g. normal Monday, holiday etc. For several types of events additional o-d-matrices are generated, e.g. the additional trips generated by a big sporting event could be estimated by taking into account the number of sold tickets and the distribution origins, where the visitors come from. The latter information can be provided by the ticket-selling system, or it can be computed using a simple gravity model approach. The predicted traffic demand for a certain day is then constructed as the sum of the normal matrix for the appropriate type of day and the matrices for all known events. This o-d-matrix is then assigned to the road network using a dynamic assignment procedure based on time-slices of 15 minutes. As a result the traffic volumes for all road stretches are computed as time series for the whole day.

6. Incident detection

Various algorithms permanently analyze the historical, current and predicted data to determine location and size of traffic congestion and to recognize other incidents. Another task of this component is the generation of trend statements. Incidents can be indicated in different ways. The general idea is to compare the actual measurements to some kind of “normal” situation. The simplest approach therefore is the comparison with averaged historical data for the same measurement site and flagging a problem if the differences exceed predefined thresholds. The more sophisticated algorithm takes into account the overall level of traffic volume, so a congestion can be stated if few or no vehicles are counted on one stretch while other detectors count typical peak-hour volumes. A third kind of comparison is made to the results of a static assignment of the expected traffic demand. Here the volumes from the assignment are scaled to estimate volumes from the PFE and the distribution within the network are compared.
7. **Determination of optimal detector locations**

An essential point with the implementation of MONET-like models is the detector infrastructure of the road network, which, in the very end, plays a decisive role for the quality of the results. For this reason MONET offers an additional planning component to determine the optimal number and the locations of the detectors for a given quality demand. The component is based on a Greedy-like algorithm [5] that tries to maximize the information benefit (with respect to typical flow patterns) by adding gradually further detectors. The goal of this procedure is to satisfy the following criteria: (1) observe as many paths as possible, (2) hit as much traffic as possible and (3) avoid linear dependencies.

![Figure 1: Structure of the dynamic network model MONET.](image-url)

With respect to the software architecture of MONET, four essential parts can be identified, which all communicate via an underlying database:
1. For the management of all the input data, a comfortable user interface is provided. The management of the road network can be done via the graphical network editor of the transportation planning tool VISUM or any other system that is capable to export data to the MONET database format. Integration into the Siemens traffic management system CONCERT is planned, so that network editing can be handled by this system.

2. The integration of MONET in the technical environment of a traffic management center requires interfaces to the systems providing online data. For each source of online data a dedicated subsystem-converter has to be developed that accepts incoming data and delivers it into the MONET database in a standard format. Typically, these subsystems will be the most project-specific parts in a MONET installation.

3. The algorithms described above representing the traffic engineering capabilities of the system, i.e. path flow estimation, incident detection, short- and long-term forecasting etc., are bundled in the so-called MONET kernel.

4. For output of results, any installation requires at least a visualization of the estimated and forecasted traffic states. MONET offers this capability through the graphical interface of VISUM, which can be very freely configured to meet the requirements of the specific environment. Besides this, all computed data is available in the MONET database for visualization by other tools or further use in other information systems. Some installations may require an interface directly back to the traffic control systems; therefore subsystem-converter must be implemented in analogy to the handling of online input data.

The database of MONET can be classified in long-term, medium-term and short-term (dynamic) data:

- **Long-term**: network’s topology and attributes, calendar information, statistical o-d-information (matrices)
- **Medium-term**: roadwork information, event information (possible with o-d-information), link capacities (traffic signals: fixed time control)
- **Short-term**: sensor data, manually reported incidents, capacities (traffic signals: traffic actuated control), FCD, traffic states

MONET produces the following output, which can be used of other exterior subsystems and moreover is stored in an archive database for further evaluation:

- Actual and near future (< 30 minutes) traffic state in the form of: Link and route flows, link travel times, link occupancy rates, link mean velocities, level of service (Fluid, Dense, Saturation, Jam)
- Estimated or corrected o-d-matrices, intersection splitting rates
- Location and size of congestion, incidents
As part of the German “MoTiV” project a prototype of MONET has been applied for the core street network of Munich to estimate the current traffic conditions using historical transport planning data supplemented by online traffic data produced by loop detectors. The following figure shows a part of the road network together with the volumes counted at measurement sites (left) and the completed data from the PFE estimation (right).

![Figure 2: Left: Part of the Munich network with volume counts on selected links. Right: Traffic volumes estimated by the PFE.](image)

To model the road network, a digital roadmap (GDF format) was used as a basis, from which a MONET-compatible road network was automatically generated. This network was then simplified manually to reflect only the major roads. The traffic engineering attributes such as capacity and free flow speed were also added manually, supported by the functional road-class information provided in the digital roadmap.

At the moment, sensor data for about 300 links are provided by the signal control central processing unit and several measurement sites on the freeways. They are available in the DEFFORT-telegram format used by the traffic control systems of Siemens. It is planned to broadcast the estimated traffic status via a DAB (Digital Audio Broadcast) system, so that it can be received in equipped vehicles during their trips.

For planning installations of MONET and for the development and refining of the algorithms, a simulation laboratory has been developed. As a replacement for real world sensor data, measurement data from the microscopic traffic flow simulation tool VISSIM [3] were used. They are provided to the MONET database through a subsystem-converter as if they came from a traffic control center. Within the microscopic simulation, the traffic situation in the whole network is totally known, what allows an assessment of the accuracy of the estimation algorithms. It is also possible to test the incident detection algorithms by defining simulation scenarios with temporarily blocked lanes. Of course, the modeling of a
large network at the level of detail of a microscopic simulation requires much effort, but valuable information about placement of detectors and the behavior of the used algorithms in specific traffic situations can be gathered.

**REDUCTION OF NETWORK SIZE**

Due to increasing computing power and data availability the networks for transport planning purposes have increased over time. Currently it is quite common to have about 1 zone per 1000 inhabitants. Typical network sizes for a city of 1 million inhabitants include about 1000 zones and 10,000 – 50,000 links. For data completion this network size is too large to handle computationally. Furthermore this level of detail is senseless since the volumes have only to be estimated for major roads and roads which are running close or above capacity.

Let us call the network suited for transport planning purposes *planning network* $N_p$ and the less detailed network for data completion and forecasting purposes *core network* $N_c$ ($N_c \subseteq N_p$). The following algorithm shows a method to extract the core network from the planning network assuming that the paths flow information is available at any time.

1. **Run an equilibrium assignment,**
2. **Generate all paths for all o-d-pairs and store routes and its associated flows**
3. **For each link of the core network:**
   - Search for all non-core o-d-pairs, whether a path is using the particular link
   - Add the initial flow for the particular link
   - Shift the capacity-restraint function by the initial flow
4. **Run the Path Flow Estimator on the core network using the travel times of the initial flows**

In the following example the zones 1 and 2 belong to the computational network, while zone 3 is only part of the planning network. Links 12, 23, 36 and 69 represent the major road network. Three o-d-pairs are given; only the demand of 100 trips from zone 1 to 2 is fully part of the core network. In order to estimate travel times on links 12 and 69 correctly, the flows with origin or destination outside of the core network have to be set as initial flows on each link of the core network. Therefore the capacity-restraint function on link 12 will be shifted by 70 vehicles.
CONCLUSIONS AND FUTURE ACTIVITIES

In this paper we presented a new dynamic network model that consists of several interacting components. Its main purpose is the online estimation of present and future (short-term) traffic states. A basis version of the MONET system has been realized and tested within the scope of the German “MoTiV” project. So far, the experiences of this and other MONET applications with respect to the estimation of traffic state classes are encouraging. However, considering dynamic routing, an accurate determination of travel times is important, which is a hard task especially for urban networks because of the rapidly increasing travel time functions. On the other side subsequent processes like dynamic routing probably have requirements on the accuracy of link travel times that as yet cannot fully be achieved in all cases (especially for heavy loaded networks). This is why we intent to further extend and improve the MONET model in various ways. For this we are going to concentrate on three items:
1. Online & offline adjustments of the model’s relevant parameters. Meant are in particular parameter that refer to the traffic propagation (e.g. travel time or velocity functions), dynamic route choice (e.g. path distribution parameters) and the determination of time dependent o-d-demands.

2. With respect to the dynamic modeling of large and very large road networks the performance of the procedures is clearly in the focus of consideration. The neural network model allows (massively) parallel implementation of the time consuming parts of the program.

3. Incorporating further information sources (like FCD that probably will be available in the near future) is expected to improve the results significantly.

Moreover advancement are required to reduce the installation and maintenance costs of our MONET system. This will be achieved mainly by providing the system with intelligent components and configurable interfaces for data export, import or update purposes.

REFERENCES


