Strategic Control in Metropolitan Areas

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Abstract

Traffic adaptive control systems proved to perform better compared to fixed time or traffic actuated control systems. In particular adaptive network control can take into account more global objectives, e.g. minimisation of delay or of travel time within the considered system. For this reason more and more adaptive control methods are being implemented in metropolitan areas. Apart from traffic signal control i.e. variable direction signs, ramp control, dynamic lane assignment or parking guidance. The methods are operating responsively to stochastic variations and to the change of traffic demand over time according to a given objective function.

However, the different systems within a city are in many cases not integrated by a higher level and thus may aim to different objectives. Moreover, there may be the need for common policies which contradict the once given objectives of the respective control systems.

This paper introduces the idea of a distributed but hierarchically structured system architecture that provides a strategic level by which various different systems can be integrated. The paper further focuses on the methodology in which way traffic policies may be translated into the objective functions of single control systems. To show the relevance of strategic control for the day to day operation scenarios for real applications are given for the example of Munich.

1. Context

To provide and to preserve sustainable mobility in metropolitan areas strategic policies need to be realised by a bundle of measures. Traffic control has of course one of the most important impacts on the quality of mobility. However, for most cases control methods and the respective system architectures are not designed due to this requirement. Even in the rare situation that adaptive network control methods are applied these methods normally are operating without being integrated on a higher, more strategic level.

Most of the known approaches to strategic traffic management have a static character, i.e. they use predefined scenarios and corresponding predefined control measures. However, these static solutions do not meet the need to respond to frequently changing situations.

In the Munich based project MOBINET [1], which is a large scale demonstration funded by the German Ministry of Education and Research within the initiative “Mobility in Metropolitan Areas”, a major emphasis is given to find a better solution for this unsatisfactory situation [2]. In this context MOBINET has developed an open system architecture for the control of road traffic which provides a consistent approach for the strategic management. Due to the modularity the City of Munich intends to use the opportunity and to migrate in an evolutionary approach from inefficient legacy systems to an advanced traffic management.

2. Methodology

MOBINET aims to further develop and in particular to implement and demonstrate adaptive control methods in the greater Munich area. The respective control methods will be embedded in a distributed and modular system architecture and a strategic component will guarantee an integrated approach of
traffic control according to overall traffic policies. Following requirements guided the design of the system architecture:

- Modularity – each part of the system can be specified and provided separately;
- Robustness - the consequences of failure by different parts of the system can be analysed and protection to ensure continued (if limited) operation can be provided;
- Evolutionarity – control systems can be extended independently from the original configuration
- Inter-operability - the parts of the system communicate through standard interfaces so that they can be enhanced and upgraded without affecting the operation of other parts;
- Integrated Data Management - the data used by the system can be managed and stored in the most efficient way.

In order to migrate from the existing legacy control system to the envisaged advanced system a new system architecture was developed and is now being implemented.

The overall road traffic control and monitoring system is decomposed into three logical levels, i.e. a local, a tactical and a strategic level.

**Figure 1:**  *Schematic system architecture*

1. On the local level the adaptive control methods respond to short term variations in traffic demand and to stochastic events (e.g. priority request of a public transport vehicle) according to a predefined objective function. This reaction may take place within a given frame that is provided by the tactical level. At the same time the microscopic data which are collected on this level on a second by second mode are being aggregated and transmitted to the tactical level.

2. The adaptive control methods on the tactical level use the aggregated traffic flow information, estimate origin-destination relations for the network they are responsible for and accomplish short to medium term demand forecasts. On this basis and under use of
appropriate impact models optimal frame plans due to a given objective function are determined.

3. On the strategic level, the control and the calculated traffic state is monitored. Also, software tools on this level assist the traffic experts and operators to customise the parameters of the respective objective functions for the different control systems according to the transport policy for the metropolitan area. In this way consistency of objectives for different control systems (interurban, urban, public transport, etc.) can be achieved. The strategic level may from the physical point of view also be distributed and may comprise different control centres, which may reflect existing organisational structures. However, an integration of these traffic control systems is extremely important for implementing the common transport policy in a most efficient way and for optimising the capacity of all these transport systems as a whole.

According to the decomposition this design provides subsidiarity of each single component on the one hand. On the other hand due to the clear hierarchical structure it guarantees consistent accomplishment of every control decision which is given by a higher level. By excluding central control methods the system is very robust and each single component may operate even if a component on a higher level fails. However, the system is at the same time fully integrated since a common policy is respected by all actors in a concordant way. The relevant information on strategic goals is being exchanged by the parameters of the objective functions of the adaptive control methods.

A commonly agreed objective function comprises in a linear combination all the characteristic criteria which are of relevance for sets of links of the road network. The sum of all weighted and normalised criteria within the considered network are forming the performance index (PI) due to which the control is optimised. As mentioned above the objective function is not being optimised on the strategic level but decentrally by the respective subsystems within the distributed system. A variety of possible PI’s can be chosen for optimisation according to the multiple different traffic policies. Relevant for the selection of criteria are of course the possibilities which are given by the traffic models used in the control methods.

With respect to traffic policies we distinguish user and system optimal solutions. Whereas user-optimal control

$$\min PI = \sum_{\text{control device}} c_i \quad (1)$$

with $c_i$ general average costs

may lead to traffic situations which do not reflect the objectives of city planning (i.e. bundling traffic on major roads) system-optimal control

$$\min PI = \sum_{\text{control device}} c_i \cdot q_i = \sum_{\text{control device}} C_i \quad (2)$$

with $q_i$ traffic volume $C_i$ general total costs

may not be accepted by the road users.

It therefore needs an objective function which will respect both requirements, i.e. the one of the community and the one of the individuals. A solution which will fulfils both requirements was found in the strategic system optimum.

$$\min PI = \sum_{\text{control device}} \sum_{\text{link set}} a_{ij} \cdot C_{ij} \quad (3)$$

with $a_{ij}$ coincident matrix of link sets over control devices

$$a_{ij} \begin{cases} > 0 & \forall i \neq j \\ = 0 & \forall i = j \end{cases}$$

The strategic system optimum allows for not optimal solutions in the overall system in order to protect sensible parts of the network (e.g. residential areas). In this respect the objective function needs to be extended by the dimension of the road classification in order to take into account location- and link-specific weights of the criteria. The classification of the road network is being reflected by the introduction of link sets. A set comprises the links of a certain road category. In this way the major arteries or a ring road may each represent a specific set.
In the given formula above the different criteria of the objective function are represented by the general term $C$ that stands for costs. This general formulation can be distinguished into the different criteria of relevance. These criteria typically are:

- delays of car traffic, public transport and pedestrians
- queue lengths
- number of stops of car traffic and public transport respectively
- noise and pollutant emissions of motorised traffic
- fuel consumption

With respect to the single impact criteria the general formulation of the strategic system optimum follows as

$$PI = \sum_i \sum_j \alpha_{ij} \cdot W_{ij}^{ov} + \beta_{ij} \cdot W_{ij}^{mlv} + \gamma_{ij} \cdot H_{ij}^{ov} + \delta_{ij} \cdot H_{ij}^{mlv} + \ldots + \ldots$$

(4)

3. Application

Having designed a clear system architecture according to the mentioned requirements (i.e. modularity, robustness, evolutionarity, interoperability, integrated data management) the authorities of the City of Munich and the State of Bavaria planning to equip the road network with advanced control methods which will be integral part of the new MOBINET system and thus comply with the system architecture. The different control and information systems will first be implemented and evaluated in large scale demonstration areas and will then be extended and transferred to usual day to day operation. Various demonstrations in the typical metropolitan area of Munich are planned as shown in the figure below.

Figure 2: Demonstration areas for integrated traffic control in the Munich greater area
NetzInfo

NetzInfo is an information system to be located on radial motorways just outside the city boundaries of Munich. Dynamic LED information signs will lead the inbound traffic on the optimal route to different parts of the city depending on the actual traffic conditions [3]. A prerequisite of this system is to recommend only major roads in order to avoid any through traffic disturbance of residential areas. Depending on their location the information signs will show the relevant part of Munich’s main road network. Coloured bars are representing the various levels of service. It depends on the driver’s own choice if he is choosing an alternative route or not.

Sektor-Steuerung

The next demonstration site, Sektor-Steuerung, plays an important role as a link between the regional motorways and the inner-city road network. NetzInfo is intended to give information on alternative routes including the whole Munich motorway net (A99). In contrast to this, the variable direction signs of Sektor-Steuerung suggest local alternatives within an limited part of the city’s road-network. As a corresponding measure to the route guidance the adaptive signal control system BALANCE [4] will be implemented in the respective network in order to response to changing traffic demand.

Ring-Steuerung

The objective of Ring-Steuerung is to enhance capacity on Munich’s Middle Ring Road by harmonising the traffic flow on the Ring Road and its major radials as well as to prevent oversaturation. After simulating, evaluating and ranking the best measures are considered for implementation. Four categories of control systems are most promising:

1. Dynamic LED information signs: before entering the Middle Ring Road the drivers will be informed on the current traffic situation on the various parts of the Middle Ring via large graphical displays [5].

2. Ramp metering based on a genetic fuzzy logic controller with added adaptive components [6].

3. Adaptive signal control (BALANCE): Advanced traffic signal control will be used for both, the enhancement of capacity at crucial intersections on the ring road and appropriate control of the major arteries leading to the ring in order to protect from overflow.

4. Variable lane assignment: Demand responsive assignment of the lanes within a weaving section to give priority to the direction with the highest traffic volume.

Quartier-Steuerung

Quartier-Steuerung concerns in particular traffic light control in complex urban road networks. Emphasis will be given to optimal control of the different traffic modes. In this context the adaptive network control method BALANCE will be applied in order to provide public transport priority with respect to the competing requirements of different public transport lines and under consideration of the needs of all other road users like pedestrians, cyclists and car traffic.

4. Perspective

Having developed the overall architecture of the future road traffic control system and having planned the application of a range of promising control methods in large scale demonstration areas the work in MOBINET will concentrate on the completion of the development of the control methods. In this context it is a distinct objective to achieve commercial quality for all the components and thus to provide a basis for exploitation and deployment to other metropolitan areas.

At the same time infrastructure will be installed due to the implementation plan and thus from mid of 2001 on simulation studies and trials will start in order to quantify impacts and to provide a basis for evaluation.
References


