An integrated multi-discipline dynamic traffic management system, based on information, objects and inter-object communication

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Abstract

The more traffic related problems arise, the better traffic management system is needed by professionals (or the public). Traffic engineers need to design and implement these systems. One of the main objectives of this project is to develop a framework to integrate planning, traffic management, traffic control, information and simulation systems into one multi-user, multi-discipline traffic management system, creating one network integrating all people involved in transportation. Arguably there is no need for totally new and different parts. We require an integrated system, incorporating already operational systems combined with new additional ones.

1 Introduction

This project, which is part of the research program IDEE (Integrated Disciplines Engineering Environment), deals with a preliminary research for a new, integrated and dynamic traffic management system. The reasons for undertaking such a project are plentiful. In the last decades traffic has become both a social and economical problem: traffic congestion, road safety, (im)mobility and environmental implications of traffic are considered important issues. A possible cure is to build more and safer roads, but this is clearly unacceptable as a long term solution due to limits of available space, limited resources and environmental reasons. Transportation is vital to the competitiveness of major cities. The need for better traffic management systems arises from the social and economic dependencies on transportation in our modern world. As traffic is becoming more complex, a better traffic management becomes more vital. Furthermore there seems to be a need for better information towards the public as well as between individuals, dealing with traffic management on the same or different levels. As with all demand-supply problems, solutions made by traffic management can be viewed as one of increasing capacity to meet demand or stretching demand to a level deliverable under certain conditions.
2 Dynamic traffic management

Dynamic traffic management can be defined as:

“Dynamic traffic management employs technologies for real-time traffic management: the management of traffic flows, traffic adaptive control to respond to changing conditions in the transportation system while improving the efficiency, safety and travel conditions of the overall transport network”.

Traffic management can be distinguished in three different levels of decision making each with its own data demands [5]. Firstly, there are decisions to be made concerning short term control. Traffic management with a time-frame of a few minutes, implemented in so-called traffic control systems; in most cases no human actions are required. Secondly there is medium term traffic management (a few hours), normally implemented in traffic management systems. The last level concerns with long term planning (days to years), called traffic planning systems. The different levels of decision making have some consequences for the required data. Long term planning can be done with aggregated, thus semi-dynamic, data and is not used by travellers. Much more detailed data as well as more accuracy, reliability and actuality are required for medium term planning. Highly accurate, up-to-date data is needed for short term planning. To be able to get the necessary data, on-line monitoring the states of traffic is crucial for traffic control.

With the development of faster computers, better and cheaper electronics and telecommunications further research towards new models and applications becomes possible and worthwhile. There has been a great deal of study on the subject of congestion on highways using traffic flow theory. Prigogine & Herman [4] show that flow and kinetic theories are not appropriate ways of modelling traffic in urban areas; even current flow-theoretical traffic models do not sufficiently account for the specific problems in urban traffic. It is suggested that many non-linearities can be expressed in terms of the interactions of traffic participants. Given they are the smallest item in the transportation chain, individual participants play a major role in the process. Usually they can choose between the different modes of transport. Given enough information the chosen mode of transport can differ from the usual thus reducing the overall transportation time (expressed in time/cost ratio). A good multi-modal information forecasting system is essential in this process. By co-ordinating, (re)directing and managing of traffic processes, a substantially higher level of quality and effectiveness of the infrastructure should be achieved.

3 One integrated system

The economical, environmental and social impacts of an integrated system will be significant: more traffic control possibilities, more co-operation between users, lesser unexpected traffic jams and quicker journeys due to better forecasting, better road safety and integration of all traffic, including public transport. The road users, engineers, scientists, as well as those in charge of traffic control and politicians can use such system as their information system. Standardisation is a necessity enabling users to access all information and the simulation models of the system. As it is an integrated, interconnected system, special user groups as traffic engineers, politicians and environmentalists can use each others’ models and verify each others’ results. It is advantageous to
accommodate the new models into one integrated system, thus giving them a testbed and taking care of data collection and aggregation. The different levels of decision making, policy and operational levels, need to be integrated in the system. For policy makers there is the possibility for data exchange, model exchange and communication. The policies to be integrated are social policies (in the interest of the public), traffic policies (politically justifiable) and traffic laws (legally flawless) [9]. Also a large number of organisations have to take part in the design process: not only vehicle manufacturers, electronics industries, public and private telecom providers, but also the public, several different governmental layers, the different road authorities, the police, etc. In this complex setting a change of roles and responsibilities is unavoidable.

Some of the signalled problems can be solved by better co-ordination and information in and between different levels in the transportation sector [7]. In this part of the project the focus is mainly on the information system part. To be able to provide good quality information, an integrated system is needed. The required system is more then existing applications connected to each other; it consists of a network where applications play a role dependent on the situation.

In the case of urban traffic management we can integrate the stream of urban traffic, traffic light systems, re-routing systems, parking management systems and so forth. Integrated inter-urban traffic management focuses on integrated network control, forecasting, incident detection, re-routing systems, tidal flow, etc. There is a need for correct and integral data collection, data processing and traffic control actions as well as travel and traffic information provided for public use. Presentation of such information can in different ways, but preferably it should be provided before and during journeys to improve travel conditions.

4 DTMS

The project described in this paper is part of a DTMS “Dynamic Traffic Management System”. Following is a short summary of an overall traffic management strategy based on an object-based model more detailed described by Johanns & Roozemond [1].

We propose a traffic management system, in which intelligent control systems play a prominent role in the management and control of inter- and inner-urban traffic. The proposed overall traffic management system is based on several individual parts working together, thus creating one large system that can easily include other options. The individual and modular parts are chosen to keep information local and to deal with possible introduction of chaotic behaviour, incorrectness or errors of the system. Smaller, intelligent parts can more easily organise themselves. The individual parts of the system should be able to take action, based on the rules implemented in the system and based on actual information gathered by the system. This requires modular systems that can operate within an open architectural framework, consistent with a given standard at each level. For the different levels we support the multi-layer OSI model. An object oriented design enables this integration capability as well as presenting great flexibility; carefully tailored to reflect issues of flexibility, communications bandwidth and other practical aspects. To handle the information requirements (forecasting) for intelligent traffic control, route-guidance and so on, specific models are needed. The processing power requirements of the system become far too big for centralised computing. Therefore, a decentralised, distributed network is needed [1, 9]. A user-centred
design is essential to ensure co-operation of the users. For the standardisation of the network, inter-object communication and applications, specific standards should be met.

The system is divided in four large sub-systems on a geographical basis. There is an international level, dealing with information exchange between countries. There is a national level dealing with the national traffic. This information is available in the whole country. There is an inter-urban or regional level; dealing with a specific region. Finally, there is a local or urban level. All levels jointly form the system; sharing information, models, etc. An application or sub-system may belong to more than one level.

5 DTMS/city

DTMS/city is the sub-system dealing with traffic management and traffic control in cities: the most problematic and complicated part of the whole system as well as the most challenging and least researched. Smaller parts of the sub-system, for very specific uses, are still being developed. An implementation of an object-oriented traffic light control system is shown to be a feasible alternative to conventional designs [6]. The next step of this project is to implement several intelligent controlling agents dealing with the specific rules in specific areas. The rules can be implemented in an agent but rules can also be implemented in objects in the control space of that agent. An agent gets its rules from the objects involved and acts accordingly. Arguably this can be implemented in a distributed and co-ordinated way: some information per object and some overall rules per agent. As agents can be objects to agents, a tree-like structure is formed and all rules are available downwards. Developing some kind of voting mechanism is thought of to take care of all requirements. Meta-rules will be included for traffic control situations when operational goals are contradictory.

Designing a good data structure is essential, as each object wants some, but not all, of the available data. As the design is an object oriented one, the data structure should also be object oriented. We are also in need of good on-line monitoring devices for correct data input; for management and control systems, as well as for good dynamic user information. The objects to be integrated in the DTMS/city are at least: monitoring systems, route guiding systems, parking systems, warning systems, traffic light systems, eventually debiting systems and other traffic management systems not limited to public use. A distributed design, based on dynamic locations of traffic participants, is needed to prevent co-ordination problems. It becomes clear that an on-board information transmission device with computing power and database system is essential to prevent the potentially enormous traffic load on the network. To achieve a fully dynamic system, radio data exchange in stead of roadside beacons, is an expensive but essential solution. For remote area’s roadside based processing units are expensive and not adequate. A combination of both systems might be a solution to spread the network load and to have some sort of back-up system.

6 Information system approach

One of the main objectives of the project is to design an integrated, multi-user, multi-discipline traffic management system; creating a network connecting all working with or using infrastructure. The travellers, engineers, scientists, as well as politicians can use the system as a general mean for obtaining the required information. The whole system is designed to keep the data as local as
possible. Therefore, the monitoring objects can retrieve the historic data. This data is mostly wanted for policy making. Travellers need more dynamic data, as well as forecasts about traffic condition in the near future. Forecasting should be implemented in specific simulation objects getting instructions from users and appropriate data from the monitoring objects. In the information system we try to introduce some fuzzy logic principles. Fuzzy logic seems to be quite promising to deal with some of the rather stiff simulation and information retrieval rules. At this stage it is not certain whether this is a workable solution, but the preliminary results of other applied and operational fuzzy control and management systems seem very promising [8].

Traffic participants who do not have an active system, can be forced to have a passive system as a kind of identification tag, which will include some relevant information. This may contribute to easier data collection. Important aspect of velocity, acceleration and so forth is that they are car-driver dependent as well as depending on the dynamically changing road conditions. An on-board computer will be exchanging the users' data with the DTMS. There are many different kinds of data available and many traffic participants need only a small part of it [3]. Personal tailoring of data depending on needs as well as technical capabilities should be made possible to meet the personal needs as well as lowering traffic load on the network. The effectiveness of systems that provide traffic information, such as route advise to drivers and their potential for reducing congestion, depends heavily on drivers' reaction to additional information. Decisions by drivers made about which road to use and which to avoid during their journeys, are influenced by the purpose of their journey, their personal knowledge of the locality and transportation network, road signs as well as travel information broadcasts. The dynamic capacity of these kinds of information is limited. Benefits of good travel advise can be derived from a study by KLD associates; although completed in 1986 presumably not so different from today's traffic [9]. They found that due to poor navigation skills 6.4 % of distance and 12% of time is wasted, pointing to an arising need for a dynamic traffic advising system.

7 Choosing routes

Fully dynamic route guidance systems offer additional benefits over semi-dynamic ones, in that they can be responsive to random fluctuations of actual traffic conditions. Those random fluctuations may be due to accidents or just some fluctuations in actual traffic conditions. The common feature of those random effects is that there is no way to predict them from historic data alone. In a case of an accident traffic can be redirected to avoid congestion through a new optimum route. One specific function of a dynamic route guidance system, of particular interest here, concerns route choice calculations. The algorithm used to perform this task is the basis of the success of this part of the system; response time, performance, effectiveness and detailedness are all important. Criteria for the “best” route are: shortest, cheapest, fastest, prettiest, etc. Several known principles from the operation research can be used.

When viewing a large road system, every part of the system must be represented. Theoretically even the smallest section can be of importance. Given a road map, the possible roads can be represented by several section-objects, each with their own characteristics. Every section has an entrance and an exit
gate; in combination with the distance and the speed the traversing time can be calculated. Every road sub-system has the underlying smaller-road-set that will only be used for transport inside the section and adjoining sections. Several specific road segments can be combined to a traversing link, thus creating a higher level for non local traffic. Example: Travelling from origin to a destination in an other city; the system start using the most detailed network with all routes bottom-up wards, until you are on a tertiary road-network; from there you are directed to travel further upwards until you use the main road-net (highways). Coming close to the destination the system uses the road-networks the other way around (top-down).

If a person can address the travel times on all possible routes and links, one can calculate the overall travel time of a proposed journey. The road segment as an object ‘knows’ the equations, actual conditions and constraints and, in combination with the actual vehicle/driver information, future situations can be calculated. If the desired information is not in the near future, this can be simulated or calculated as accurate as possible. The kind of simulation proposed is effectively a state prediction model: predicting the states on time $t_j$, given the state on time $t_j - dt$. Every segment has its travel-prediction at a certain time. Nowadays route choice programs use shortest path algorithms. Faster algorithms, suitable for distributed computers can be useful [2]. As distance and travel time are loosely coupled; quickest, shortest and cheapest routes are not always the same. A route choice calculating algorithm is a necessity as is a hierarchical way of calculating the objective function fast and reliable.

For the several possible routes from origin to destination the chosen objective (time) should be calculated by formula’s like:

$$
total \text{ travel time} = \sum_{\text{All links}} \Delta t_{j,k} \cdot \xi_{j,k}, \quad \text{where}
$$

$$
j = \text{Start Node of link } j,k
$$

$$
k = \text{End Node of link } j,k
$$

$$
\Delta t_{j,k} = \text{Traveltime on link } j,k
$$

$$
\xi_{j,k} = \text{Correctionfactor for link } j,k
$$

Travel times consisting of several adjoining links can be calculated easily by calculating the solely links and adding them to one total trip-time. The travel time of a certain link is calculated on the moment that, real or virtual, car comes from the adjacent link, node or gate and enters the new link. So the correct entering time-state is known or, in case of a virtual car, calculated.

$$
\Delta t_{j,k} = l_{j,k} / v_{j,k}, \quad \text{where}
$$

$$
l_{j,k} = \text{Length of link } j,k
$$

$$
v_{j,k} = \text{Mean velocity on link } j,k
$$

$$
\xi_{j,k} = \zeta(\chi_{j,k}(t),...) \quad \text{, where}
$$

$$
\chi_{j,k}(t) = \text{factor for congestion level at time } t
$$

A special zone for traffic control is the interaction zone in which the vehicle’s behaviour is restricted by other traffic participants [1, 2]. The presence of
vehicles, road edges, road signs, traffic signals, etc. in the vehicle interaction zone can be calculated by simple and fast algorithms using Cartesian coordinates [2] by the on-board processor. In the case of this system the interaction zone is a combination of vehicle and driver as well as the static road properties of the traversing road segment, weather conditions, etc. One important aspect of velocity, acceleration and deceleration limits is that they are partly driver dependent.

8 Benefits of a DTMS

Firstly; a DTMS is no cure for the traffic problems; it may streamline and reduce the traffic load, have more direct routes available, give good information and advises and still there would be a traffic problem. So research on changing attitudes, other ways of transport, etc. are equally important. To give a more explicit overview of the benefits of a DTMS there is a need for categorising the benefits. The comparability between categories, effectiveness and effects is explicitly not addressed here due to different view points; for instance the fact that the government has other goals than individuals. Benefits are not always easy to quantify as they are related to aspects like environment, information, safety and finance. Benefits and costs can be derived from individuals, but are far more difficult to quantify for groups or the whole system. Six categories of benefits can be determined and for each category some measurable effects are listed [5]:

a- Improved operational efficiency; throughput, travel speed, travel times, delay times, vehicle occupancy, predictability of travel times.

b- Improved safety; number of accidents, number of fatalities, accident costs, incident response time, driver's role in incidents.

c- Reduced use of energy and environmental impacts; fuel efficiency, fuel consumption, emissions, noise pollution, land-use.

d- Increase of productivity; operating costs, volume of moved goods, JIT delivery.

e- Improved comfort; motorists stress, drivers' fatigue, reduction of travel time, better use of transport means.

f- Improved co-operation between system users; sharing of information (individual as well as public transport), incident & congestion information, models between agencies and consultation between agencies.

9 Discussion

Finally we still need to introduce a distributed control strategy that can improve efficiency and availability of information. An integrated design that will easily include such options has yet to be developed. Seen from a broader perspective this should be the way and will allow a sensible traffic management strategy to be executed by a network of modular traffic control systems.

Not all traffic participants will participate with the system in the same way. There will be passive users; these occasionally gets data from the system and does not actively transmit data to the system. There will also be really active users gathering relevant data and having a two-way interaction with the system. Several on-board sub-systems should become available from different manufacturer, but they are all part of, and work with, the same system.
There is a certain difference of the required data and the three different levels of decision making. For planning systems there is a need for correct but rather crude aggregated data. Much more detailed, accurate and reliable data is needed for traffic management systems. Control systems need the most accurate data with almost no level of aggregation. Reliability of the control systems should be high as there is almost no time for interventions because no humans are involved. To be able to even partly solve planning, management and control problems, there is a definite need for more suited models and control strategies. The characteristics of these models are that they are capable of realistic, real-time simulations and suitable for calculating the effects of measurements.

Is DTMS a buzzword and will disappear or will it lead to a substantial improvement in our transportation system? Although DTMS might be beneficial for alleviating some congestion and may increase safety, increasing the use of public transport and improve travel conditions, it might be able to relieve congestion in the short term, improve capacity, etc. As seen in the past, the space will attract further travel demands. DTMS won’t be a remedy for the real causes of the problem of congestion, real problems like land use, car dependency and so forth are more important and cannot be solved with the aid of intelligent dynamic traffic management systems. Alternative solutions like other transport media are equally important to improve long-term situations.

Despite scepticism on DTMS, there are signs that at least part of this is becoming a fact. In Europe, USA and Japan governments as well as private companies are investing in the establishments of the, to be integrated, technologies to make these systems available. The level of policy making is in those systems not included compared to a DTMS.

**Literature**


[7] RWS; Ministry of transport, public works and watermanagement, DVK (1992), *Dynamic traffic management in the Netherlands*; RWS, Rotterdam
