State-of-the-art in Real Time Dynamic Forecasting Models

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1. INTRODUCTION

In the Netherlands the BOSS project (part of the DACCORD project in the Transport Sector of the Telematics Applications Program from the European Commission) aims to develop a decision support system for use in a Dynamic Traffic Management System. As part of this work a requirements analysis has been made for Real Time Dynamic Forecasting Models. This paper reports about state-of-the-art developments in this field.

With the availability of advanced technologies, the amount and diversity of instruments available to the traffic manager has increased the complexity of traffic management considerably in the last decades. Part of this added complexity can be reduced by automatic control systems. Not all decisions can be automated however. The traffic manager therefore needs tools to assist in taking decisions. A decision support system needs to be able to distil the essential information out of all the available sources of information and to present the manager/operator with a set of choices or scenarios for possible actions. Rather that relying only on problem *solving* a decision support system should also be able to *warn* for oncoming problematic traffic situations. Hence the need for a real time dynamic forecasting model within BOSS.

Traffic models have come a long way since their introduction halfway this century. Especially in the last decade the models have evolved rapidly. In order to deal with the variability of traffic demand, the increasing mobility, and the need to use more effectively the available road capacity (building new roads is no longer the default answer), dynamic traffic models have been developed. The state-of-the-art in these models consists largely of models that work fine in an *off-line* setting. Different is the situation when it concerns the application of these models in real time.

In the past the reason not to apply models in real time might have been partly because of the lack of computer power. With the rapidly increasing computer power this can no longer be the reason. More importantly, however, is the problems these models in general have in tracking the real traffic situation. Models, perfectly able to model traffic flowing through a network, with all of its dynamic aspects cannot exactly reproduce the situation observed in real time. Part of the reason for this is the lack of model input. Observed are point measurements of flows, speeds and occupancies. Unobserved remain the movements of the traffic itself, the origin destination information, let alone the route choice behaviour. Another part of the reason is the ability to model route choice it self and the ability to adapt the model parameters in order to track the prevailing traffic conditions.

In this paper the requirements for a real time traffic forecasting model as needed within BOSS will be presented, followed by some results of a survey of real time traffic forecasting systems (existing and/or under development).

2. FRAMEWORK

This paper reports of research conducted in the Netherlands in the framework of the BOSS project. The BOSS is a project which aims to develop a practical decision support system. BOSS will be applied first of all in the Amsterdam region in the Netherlands. The BOSS project is the Dutch counter part of the international project DACCORD.

2.1 DACCORD Project

The Telematics Applications Programme (TAP) of the Fourth Framework is an initiative of the European Commission. Within the Transport sector of this initiative, DACCORD is one of the main projects focused on dynamic traffic management and control on inter-urban motorways. DACCORD stands for *Development and Application of Co-ordinated Control of Corridors*. Its main objective is to design, implement and validate a practical Dynamic Traffic Management System (DTMS) for integrated and co-ordinated control of inter-urban motorway corridors. An additional objective is to further develop an open system architecture for inter-urban traffic management.

Within DACCORD the problem of developing a DTMS is approached in two very different and complementary ways: a pragmatic “bottom-up” approach geared towards practical experimentation with a large number of traffic management and motorway control tools, and a “top-down” approach oriented towards the development of an open system architecture for DTM systems in general.

The activities carried out within DACCORD cover a very broad range, from development of new methods, enhancement and/or integration and/or field evaluation of previously developed tools, to application and evaluation of methods and tools at different test sites. The DACCORD project builds upon the earlier experience within the DYNA project, the EUROCOR project, the GERDIEN project and the SATIN Task force, all former European activities.

The DACCORD consortium consists of 22 partners from 8 different European countries, and includes site owners, research institutions, universities, consultants and software developers.

The DACCORD project benefits greatly from the presence of three well equipped test sites (Amsterdam, Paris, and Brescia-Venice) and the commitment of the corresponding responsible authorities. The three site owners share similar operational objectives, and their respective interests in particular technical solutions and in integration issues overlap to a great extent. This provides the project with unique possibilities to gain practical operational experience with the tools involved, and to carry out a comprehensive evaluation.

2.2 BOSS Project

The BOSS project is a project in the Amsterdam Region in the Netherlands from the Dutch Ministry of Transport; in particular the Transport Research Centre and the Directorate North Holland. BOSS stands for BeslissingsOnderSteunendSysteem which is Dutch for Decision Support System. The objective of BOSS is to develop a decision support system, which will support the traffic operator in making decisions in complex and unforeseen circumstances. The BOSS system can in principle be implemented in any traffic control centre as long as the road network is equipped with a data collection system.

The BOSS consists of a traffic estimation and prediction system, in combination with a scenario-evaluation capability. Based on the predicted outcome of different management scenarios a choice can be made. A possible future extension of BOSS could be the automatic generation of the optimal management scenario. See also appendix A.

3. DECISION SUPPORT

3.1 The objective of the DSS

The main objective of a decision support system is obviously to support decisions. However, this is easily said, but what does it really mean:

- which decisions precisely, and whose are they to make ?
- what is exactly meant by support ?

To answer these questions we took a look at a study done in the Netherlands that aimed to form a longer term view on traffic management, see de Groot et al. (1996). First the main result of this study —a level of service model— will be presented, followed by a further analyses of the decisions and decision support, and lastly the determination of the of role of decision support within BOSS.

3.1.1 The Level of Service Model

One of the main results of the aforementioned study was a management model which distinguishes four traffic situations that are characterised by increasing congestion. Each of these four traffic situations has its own traffic management requirements, described as four service levels. For each of the service levels this study describes who is, when, and for what responsible and which action/duties are involved. The level of service model and its associated traffic control strategies and traffic control measures is presented in Table 1.

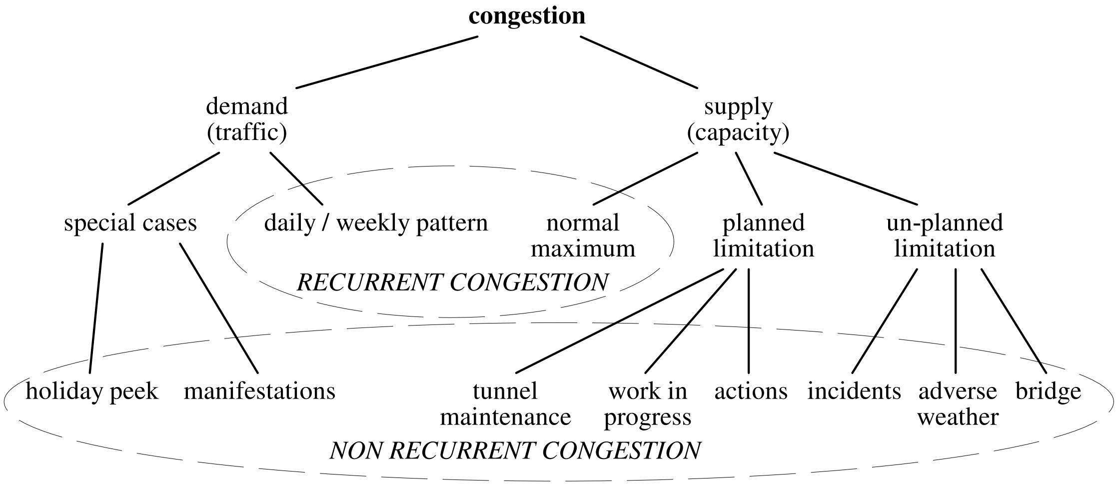
Table 1. The Level of Service Model. It relates levels of increasing congestion with associated control strategies and measures.

Level Of Service Model			
service level	**level of congestion + area of control**	**purpose of control-strategy**	**example traffic control measure**
0	*no* congestion	prevention	-safety-measures
1	*some* congestion, no network effects (e.g. no back blocking)	reduction	- optimise throughput - speed-advice - homogenisation - plan or stop work in progress - radio information - ramp metering (smoothing)
2	*considerable* congestion, severity remains regional	spreading and local limitation of demand	- main line metering - co-ordinated metering - re-routing - target groups - radio information
3	*extreme* congestion, at national level	prioritising and global limitation or blockage of demand	- truck-prohibition - priority for target groups - radio information - ramp metering (restricting)

This table is a translation from de Groot et al. (1996)

The same report also provides a clear overview of congestions and their causes, see Figure 1. In an appendix of the report a strategic vision is presented on Dynamic Traffic Management in which the report makes an important distinction between required traffic management for recurrent and non-recurrent congestion. It is stated that for recurrent congestion in which the disruptions are not too large, local traffic control would suffice. However, in case of non-recurrent congestion's or in case of extreme developments of recurrent congestion's a central co-ordination is required. It also formulates requirements for further research. For recurrent congestion it suggests the further development of real-time models, that form an essential part of traffic control, and the further development of ex-ante models for the well considered application of traffic management. For non-recurrent congestions it suggests the development of real-time models; prediction of incident characteristics, prediction of traffic flows, decision support via calculation of scenario's.

Figure 1. Classification of congestion and its possible causes.



This figure is a translation from de Groot et al. (1996)

3.1.2 Decisions and decision support

This study is aimed towards the development of a decision support system for a Traffic Control Centre (TCC). It is meant to be used by the overall co-ordinator, who is called the region operator. This operator has a growing number of instruments available to perform dynamic traffic management. The operator needs to decide 'if', 'when' and 'how' to use these instruments.

The 'when'
Under normal conditions (service level 0) the operator will only monitor the traffic system in operation. When a 'situation' emerges in which action is required (service level 1), the operator would like to know this immediately. Using a monitoring system problems can be detected and the operator can take control measures to *reduce* the congestion. However, when more severe situations are emerging (service levels 2 & 3) then the operator would preferably know this before the situation actually arises. In this case a system monitoring the traffic state would not suffice, since it can only *detect* problems. The operator then

requires a system predicting the future performance of the traffic system. Incidents can of course never be predicted (at most the likeliness of them to happen) but congestion due to a demand exceeding capacity can be foreseen.

In other words, the operator would like to have a system which can predict the emerging traffic situations (the service levels) in which both recurrent but especially incidental situations are predicted. This of course only answers the ‘when’ question.

The ‘if’ and ‘how’
At the moment that the operator knows that action could be required he/she needs to determine what actions to take (‘how’) and whether they have the desired effect (‘if’).

The operator thus needs to know the effects of individual instruments, but also of their combined use. For recurrent situations the operator will probably know what to do based on experience (service level 1). The most complex decisions (service levels 2 & 3) however need to be made in case of incident situations. The DSS requires that the prediction horizon exceeds the duration of the incident (or at least the situation would need to be recovering).

Most decisions are made by means of comparing alternatives. A decision support systems should enable the user to make this decision well-considered and efficient.

Decision support systems range from basic information systems to fully automatic systems that leave only the final decision to the user, see Ritchie (1990). Note that decision support systems are quite different from automatic control systems. In automatic control systems the operator does not *need* to intervene. Decision Support Systems are meant for situations in which automatic control is not (yet) possible. In general this concerns complex situations were momentarily only the operator can make the (final) decision. The DSS will thus need to support the operator, pointing out problem situations, preventing information overload, etc., but leaving the decision to the operator.

In general three levels of decision support can be distinguished, see Fedra (1994): information systems, scenario analysis (what if ?) and rational maximisation (how to ?). An information system provides the problem context in a convenient way, to draw the attention of the operator. In case of scenario analysis the decision maker is presented a set of most likely alternatives and their impact. In case of rational optimisation the above is taken one step further. Using expert systems, multi-criteria analysis techniques, utility optimisation, etc. one alternative is proposed.

3.1.3 BOSS and DSS requirements

In the framework of the BOSS-project the intention is to take the first steps in developing a decision support system. This means that the initial objective is to realise an information system and to take a step towards scenario analysis.

Basically BOSS will thereto perform the following functions:

(1) problem identification (identification of abnormal developments),
(2) simulation of Dynamic Traffic Management alternatives (by different scenarios),
(3) scenario analysis.

Based on the above, the following requirements for the DSS have been formulated:

(1) the DSS must be able to predict the autonomous development of the traffic system,
(2) the DSS must be able to predict the effects of all Dynamic Traffic Management (DTM) measures,
(3) the set of criteria needs to be identified to evaluate the scenarios,
(4) the prediction horizon of the DSS needs to exceed the duration of an affected traffic situation (or al least the traffic system should be recovering).

3.2 The need for real time dynamic forecasting models

Forecasting in real time has been identified as one of the main requirements for a DSS. In BOSS two main types of forecasting models have been recognised: traffic propagation models and behavioural traffic models. The basic difference between these types is that the former mainly models the supply side of the traffic system while the latter models both the demand, the supply and the behavioural side.

Within the framework of BOSS a traffic propagation model has been developed, which is called the STM. It is a macroscopic traffic flow model which allows for predictions of up to 15-20 minutes ahead. The current study is first off all meant to establish the need for a behavioural traffic model (BTM) in light of the available traffic propagation model, and secondly to determine the requirements of such a model.

To establish the need for a BTM the abilities of both type of models in simulating the DTM measures needs to be determined.

The DTM measures considered in this study are listed in Table 2, see the appendix B for a brief description. In Table 2 the demand, supply and behavioural side of the traffic system have been translated into for modelling aspects (1) demand modelling, (2) route choice modelling (3) modelling of capacity, and (4) modelling of traffic speed. The effect of each DTM measure can be characterised by these modelling aspects. Table 2 then shows the best type of model (STM or BTM) capable to model that particular aspect. Without going into the details of the Table 2 the conclusion is drawn that in order to perform traffic forecasting taking account of all DTM measures (clearly a need for scenario analysis) the DSS needs both a traffic propagation model (STM) and a behavioural traffic model (BTM).

Table 2. Dynamic Traffic Management (DTM) instruments and the best type of model (STM or BTM) to model the associated part of the modelling process

DTM instruments	effected part of the traffic modelling process			
	demand	route choice	capacity	speed
A. Road-Side Route Information		BTM		
B. Pre-trip Route Information	BTM	BTM		
C. In Car Route Information		BTM		
D. Dynamic Speed Control			STM	STM
E. Dynamic Access Limitations	STM		STM	STM
F. Dynamic Lane Configuration		BTM	STM	STM
F. DLC — target group specific		BTM	BTM	BTM
G. Dynamic Driving Limitations			STM	
H. Toll Measures		BTM		

3.3 The requirements of a behavioural traffic model

Behavioural traffic models have been studied at length in the past. However, one difference with the current study is the requirement for the model to be a real time model. Although this might seem to be a small step forward from off-line models, in reality it is a very important and often underestimated step.

The studies performed in literature will not be duplicated here. A reference to former studies will have to suffice. However, a list of criteria for comparing available models will be presented. The following list of 13 classification criteria were recognised that are based on previous classifications, see Watling (1994), Watling and van Vuren (1993), Taale (1996) supplemented by a few new ones: (1) Supply (spatial dimension, temporal dimension), (2) Demand (temporal dimension, level of aggregation), (3) Traffic metaphor (temporal dimension, level of aggregation), (4) Route choice modelling, (5) Route choice variability (*pre-trip, en-route),* (6) Time base definition, (7) Departure time elasticity, (8) Consistency, (9) Queuing, (10) Tracking, (11) OD matrix, (12) Computing time, (13) Availability and adaptability (see the appendix for a brief description). Not all criteria are equally important. Based upon a discussion with experts in the field of transportation modelling the following 5 criteria where recognised as the most important ones.

Tracking — tracking is the ability of the model to adjust the modelling in such a way that while time progresses in the real traffic system the model remains close to reality. Tracking is possibly one of the most essential elements in the development of the BTM for real-time applications. In many models this issue is underestimated. In reality tracking forms its own dimension of practical problems. The tracking-ability should form one of the major points of attention.

Availability — availability has to do with development time. If a model is available, then it is not necessary to redevelop it. From a modelling point of view availability is not a good argument for choosing a model. However given time-constraints concessions need to be made and the initial use of a non-optimal, but operational model-system can give a head-start and may allow for further development later on.

Adaptability — adaptability is another practical argument. A model is defined adaptable when the users can and are allowed to change the source-code of the model. Adaptability is essential, as this is the only practical way to adapt a model to a new modelling environment.

Route Choice — as already has been established in the preceding chapters route choice modelling is the essential contributing element of a BTM to the real-time modelling of DTM-instruments within BOSS. The question to be answered is whether route choice should be modelled explicitly or implicitly. See section 4.1 for an elaboration upon this.

OD-estimation/prediction — as input to the models, and thus determining the upper limit of accuracy of the estimations/predictions this is another aspect of major importance for the development of a real time traffic modelling system. Naturally the OD estimation/prediction should also be real-time, which again imposes special requirements.

4. STATE-OF-THE-ART: AVAILABLE MODELS

After the requirements analysis a review has been made of the available models. To obtain this overview a literature study has been made. A list of literature consulted and the models that were considered can be found in the Appendix C. From this review 5 model(-systems) were selected based mainly on their availability and the fact that they (potentially) agreed with a majority of the other criteria. These five models are

- METANET / METACOR / SIMRES
- DynaMIT / MITTNS
- 3DAS
- DNL (DYNA-model)
- MOLA (MCONTRAM)

A brief description of these five models is given in the appendix D.

The review did not result in a single model which agreed to all requirements as they were formulated. During the review one particular issue became more and more important. This is the criteria for Route Choice. The question here is whether route choice modelling should be implemented via explicit modelling of routes or could it be done via splitting rates. To understand the importance of this issue a brief explanation will be given in section 4.1.

In view of the results of the review and with the notion that Dynamic Traffic Management is applied throughout the world it has been decided to perform an e-mail survey among leading institutions in the area of transportation. The question posed was whether the recipient knew of an operational real time dynamic traffic modelling system. The complete question asked in this e-mail survey can be found in section 4.2.

4.1 Route choice modelling

If route choice is modelled explicitly for each traveller or group of travellers, the route which is travelled is modelled from start to end. In assignment models this type of route choice modelling is common. Routes are modelled implicitly if the routes travellers take are not determined individually. This might be done via the use of splitting rates. When splitting rates are used then a fraction is determined of the traffic that turn off at each bifurcation. Implicitly routes are then followed, but it is not simple to determine for an individual traveller which route is taken. This means that if DTM measures are modelled the influence of route choice can be more accurately modelled using an explicit modelling technique. By using destination specific splitting rates more control is possible over the route choice. This is implemented in SIMRES, which is derived from METANET. Destination specific splitting rates means that at each bifurcation the splitting fraction depends on the destination of the traveller. This requires of course the knowledge were travellers are heading for.

From the above the conclusion seems simple since the explicit modelling of route choice is more accurate. However the reality is more complicated since a model needs to be calibrated and a real time model needs to track the real world traffic process. For explicit route choice modelling it is essential that there is an accurate origin-destination matrix available and a thorough knowledge of the route choice behaviour. The estimation of origin destination matrices and of route choice behaviour is no simple matter. A static (time independent) origin destination matrix can be determined easily from a representative survey and a good knowledge of demographics. A time dependent matrix is much more difficult, but given a representative survey still possible. However when the only available information are traffic counts at locations in the network, which is the case for an on-line traffic model then the origin destination matrices can be estimated/predicted only approximative. The use of splitting rates might be less accurate, but if the explicit route choice models cannot be supplied with enough accurate input the result might not be better (or even worse).

Currently the available information in real time is data from induction loops. In future this might be supplemented by floating car information and toll system information. Both types of information form direct measurements of the origin destination matrix. Clearly this issue requires further investigation.

4.2 E-mail survey

The following question was sent to a number of leading institutions in the area of transportation.

“Did you develop, or do you use an operational Behavioural Traffic Model (BTM) which models traffic in real time, which is able to model all the well-known traffic management & control measures, and which is able to predict the traffic conditions for the coming hour (both for “do-nothing” and for alternative scenarios) ?”

We have given the words and terms used in this question the following meaning:

operational:	implemented and working in real time in a Traffic Control Centre, and in use or usable by the traffic operators/managers
BTM:	Behavioural Traffic Model; a complete traffic model (demand, supply and route choice behaviour) in which the behaviour of the drivers is central to the modelling.
real time:	using traffic detectors that measure the current traffic, and processing it instantly to make estimates of the current traffic conditions on the road; the estimation should be available within a few minutes after measuring.
traffic management & control measures:	measures taken by operators to influence the current or emerging traffic situation, e.g. ramp meters, homogenisation, VMS, RDS-TMC, etc.

The result of this (always limited) survey was —not surprisingly in view of our own conclusions— negative in the sense that no recipient knew of such an *existing and operational* system. At best a number of recipients were dealing with the problem themselves.

5. CONCLUSIONS AND FURTHER DEVELOPMENT

Within the framework of the BOSS project it has been established that for decision support the capability of traffic forecasting is essential. The forecasting model must be able to model the effects of Dynamic Traffic management measures. Two types of models are identified; traffic propagation models and behavioural traffic models. Both are required, but the current study focuses on the behavioural traffic model because the traffic propagation model is already part of BOSS. A review of classification criteria and discussion with experts in the field have resulted in set of criteria that represent the most essential requirements for a real time behavioural traffic model for BOSS; tracking, availability and adaptability, route choice and OD estimation/prediction.

Based on a literature study in which a large number of models were considered a selection of about 5 models were specifically considered. Neither of the traffic models that together form the state-of-the-art in dynamic traffic models satisfied all requirements that were formulated for a real time dynamic traffic forecasting system. During this study one issue became increasingly important. The issue is whether route choice modelling should be implemented via explicit modelling of routes or could it be done via splitting rates. Based on the fact that the available on-line information is currently limited to induction loop systems the question is whether the more accurate but also more complicated route choice modelling can be defended in comparison with the less accurate but less complicated use of splitting rates. However, the availability of floating car and toll system information in the (near) future again complicates this issue.

An e-mail survey among leading institution in the field of transportation led to the conclusion that at present no operational real time traffic modelling system consist that complies with the requirements formulated in this paper.

In the near future a visit will be paid to a few Traffic Control Centres were operational models are being used. This visit, together with a further investigation of the available models, should help defining the direction of further development. The most important decision point being the choice between explicit and implicit route choice modelling.

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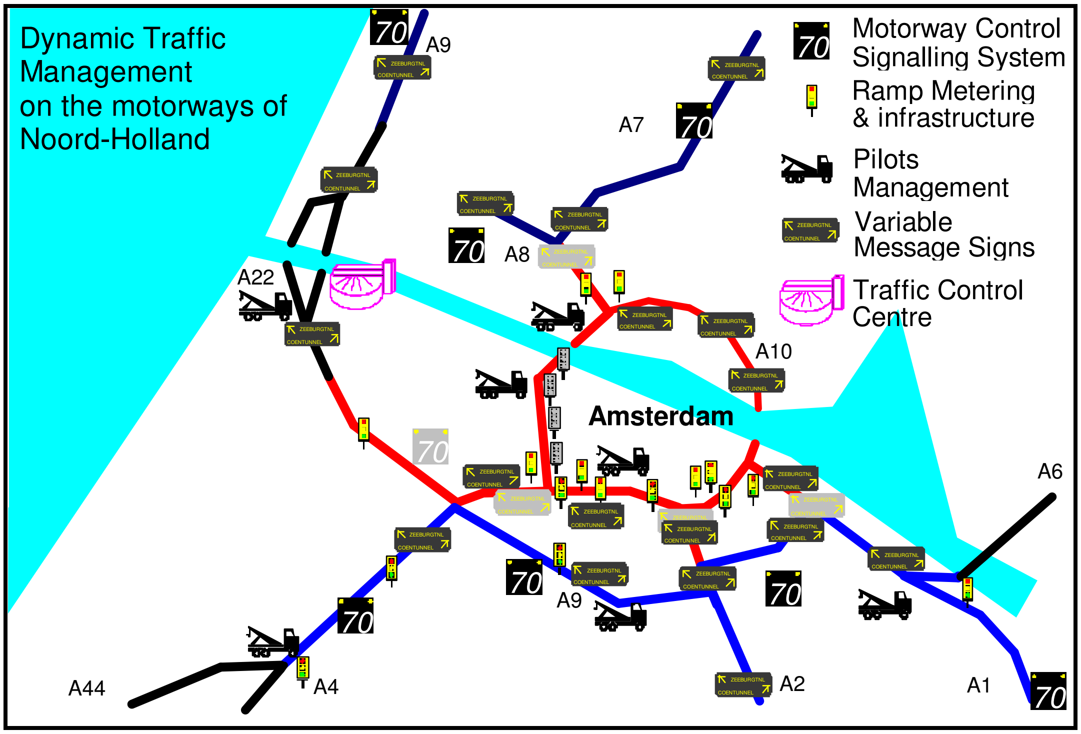
APPENDIX A: BOSS — THE SYSTEM

5.1 The Amsterdam Region

The region around Amsterdam is one of the busiest road networks in the Netherlands. The region knows several bottlenecks that block the road system daily in morning and afternoon peak. The road network is equipped with a number of traffic management instruments, among which a dens system of induction loops, a number of variable message signs, several ramp meters, a traffic signalling system, etc. In 1997 a new Traffic Control Centre for the entire Amsterdam region was taken into operation officially. See Figure 2 for an overview of the region and the current and planned equipment.

Figure 2. Dynamic Traffic management in the Amsterdam Region

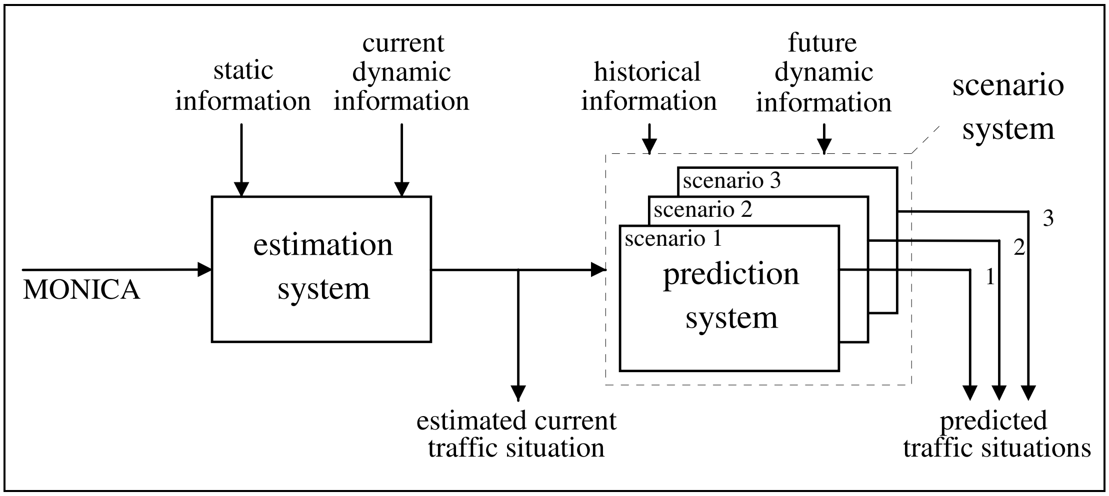


5.2 BOSS: the system

BOSS consists of an estimation system, a prediction system and a scenario evaluation capability. The estimation system tracks the current conditions on the network, while the prediction system predicts the short term future (1-60 minutes), given particular traffic management scenarios.

Figure 3 shows the functional decomposition of BOSS. From the left hand side the system is fed with traffic measurements from all parts of the network. In principle these measurements could come from any type of data collection system, but in case of the Amsterdam region the data comes from induction loops (MONICA). The estimation system is also fed with static information and dynamic information. With static information is meant information that does not change in time, such as the structure of the network. With dynamic information is meant information that changes in time, such as the weather, road works, incidents, but also traffic management measures, etc. The outcome of the estimation system is an estimation of the current state of the traffic. This current state is the basis on which the prediction is build. The prediction is also fed by historical information and future dynamic information. The historical information is formed by recorded historical patterns for certain traffic conditions (OD-matrices, inflow patterns, turning fraction patterns). The future dynamic traffic information is formed by planned road works, expected weather conditions, planned traffic management measures, etc. The prediction system produces predicted traffic conditions for a pre-set time horizon.

Figure 3. The functional decomposition of BOSS



5.2.1 The Estimation System

BOSS is fed by traffic measurements from the Monitoring Casco (MONICA), which is a nation wide system of induction loops. Each minute these induction loops provide measurements of speed flow, occupancy, a congestion indicator, etc. Although this data by itself has shown to be extremely useful for operators in a TCC, it is hard to manually derive network performance from it.

The estimation system processes the data and thereby has the following objectives:

a. to derive up-to-date *traffic information* (e.g. queue length and locations, travel time),
b. to estimate up-to-date *traffic characteristic* (e.g. capacity, fundamental diagram),
c. to track the current *traffic conditions* (e.g. flow, speed, densities).

Traffic information has a direct value to the operator as it is an indication of current network performance. Also for traffic control and traveller information systems traffic information is of vital importance. The *traffic characteristics* are important for the prediction system. The motivation for this task is the experience that traffic characteristics such as link-capacity are not constant in time; they can change for instance due to weather conditions. The *traffic conditions* form the input to the traffic prediction system. Given the measured data the tracking seems unnecessary, but the tracking mechanism corrects and completes the measurement data and thus provides the prediction system with a well defined basis.

Next to these objectives the estimation system also performs a practical role in forming the interface between MONICA and BOSS.

5.2.2 The Prediction System

The prediction system performs its predictions based on the current traffic conditions and traffic characteristics provided by the estimation system. Obviously the objective of the prediction system is to provide predictions of the future traffic conditions. To take care of this task, the prediction system basically consists of two models:

- a very short term prediction model (1-20 minutes ahead)
- a short term prediction model (5-90 minutes ahead)

This seemingly arbitrary split-up has the following background. For a sizeable network (such as the Amsterdam network) a large portion of the traffic will reside on the network for at least 15 - 20 minutes. This allows the assumption that the very short term prediction can be made by ‘simple’ propagation of the traffic through the network. These very short term predictions are taken care of by the Statistical Traffic Model (STM). For longer term predictions an increasing amount of traffic is renewed. A more “complete” traffic model is then required to allow for changes in traffic demand, route choice, traffic behaviour, etc. For this task a behavioural traffic model (BTM) is required. The outcome of the two predictions (speeds, flows and densities for all parts of the network) needs to be merged for the first 20 minutes and then forms the basis for predictions of traffic information such as queue lengths and travel time.

5.2.3 The Scenario Evaluation Capability

The decision support provided initially by BOSS consists of the prediction of traffic conditions according to different traffic control scenarios. The way in which this can be done within BOSS is depicted in Figure 3. Based on the current estimated traffic conditions the prediction system is applied to a set of possible scenarios. The resulting predictions can than be compared to help to choose the best management scenarios.

APPENDIX B: DYNAMIC TRAFFIC MANAGEMENT MEASURES

Based on a limited literature review, see van Toorenburg et al. (1996), van der Beek et al. (1993) the following Dynamic Traffic Management (DTM) instruments were identified:

Road-Side Route Information	- Current/predicted queue length information at well known downstream locations - Current/predicted travel time information to well known downstream locations - Variable Direction Signs (VDS) or Dynamic Route Information Panels (DRIPS) with route choice suggestions to specific locations (also Park & Ride)
Pre-Trip Route Information	- Radio, television, Teletext, etc.
In Car Route Information	- In-car information (e.g. RDS-TMC) on current traffic conditions - In-car route guidance based on current or predicted traffic conditions
Dynamic Speed Control	- Speed-advice or homogenisation (“signalerings systeem”) - Speed-limits (possible target group specific) - Block-driving
Dynamic Access Limitations	- Temporary closure of on-ramps (in general or target group specific) - Ramp metering (possibly excluding certain target groups) - Mainline metering or Motorway to Motorway control - Buffers (to prevent back-blocking)
Dynamic Lane Configuration	- Lane closure (general of target group specific) - Use of emergency lane during rush hour (general of target group specific) - Tidal flow (general of target group specific) - Downgrading
Dynamic Driving Limitations	- Overtaking prohibition (general of target group specific)
Toll Measures	- Dynamic tariffs (general of target group specific) - Pay lanes (general of target group specific)

APPENDIX C: CLASSIFICATION CRITERIA

The following list of classification criteria is a compilation of criteria found in literature, see Watling (1994), Watling and van Vuren (1993), Taale (1996) and those determined in the current research:

Supply — the level of detail in which the network and its characteristics are represented (the "supply model"). This concerns levels of aggregation in both time and space.
Required — a greater level of detail is in general preferable, but not required.

Demand — the level of detail in which the demand of traffic, as it appears at the entrances of the network, is modelled. This concerns levels of aggregation in both time and space.
Required — a time varying demand is essential, but and concerning the level of aggregation in space it is not necessary to model individual vehicles.

Traffic metaphor — the level of detail with which traffic is modelled as it flows on the network. This concerns levels of aggregation in both time and space.
Required — the traffic metaphor should be dynamic in time, but individual vehicles do not need to be modelled.

Route choice modelling — This refers to how explicit and flexible the route choice processes in the model are represented. This may be based on several types of optimality (user, stochastic or deterministic) of different cost/utility functions, and may or may not dependent on and react to disturbances (daily variability, incidents) and the availability of information on the traffic situation.
Required — Explicit route choice modelling would seem better but might not be defensible in view of the available information in real-time. Thus implicit route choice modelling should be considered as well.

Route choice variability — The routes that are used by the traffic may either be fixed (static) or dynamic. A distinction is made between pre-route and en-route route-choice.
Required — both should be dynamic.

Time base definition — If the model is dynamic then the flow of time may either be continuous or discrete. If discrete, the length of the periods or time-slices may vary from small to large (usually from seconds to several minutes).
Required — discrete, with a period length in the order of minutes.

Departure time elasticity — is the dependence of departure time of traffic at the origins of the network on the traffic flow characteristics (congestion) modelled
Required — no clear requirement here.

Consistency — The problem of consistency occurs at different levels in the real-time modelling framework: route-choice versus traffic performance, control instruments versus traffic performance, ...
Required — unclear, except that a possible inconsistency should not lead to large errors.

Queuing — Do queues have a physical length and therefore allow a representation of blocking back, or are they stacked "vertically" (zero length) to allow only for a delay computation? An intermediate way consists of a vertical representation with an additional estimation of the queue length.
Required — the blocking back phenomena should at least be modelled approximately.

Tracking — In real-time operation information on the current actual traffic situation become available regularly. The model may or may not take profit from this by dynamically adjusting its current estimate of the "state" of traffic (feedback).
Required — essential.

OD matrix — Does the model contain modules to estimate and predict OD matrices (dynamically, per user class etc. depending on the demand model). *Required* — depends on the route choice model, but it is an essential part of any form of route choice modelling.
Computing time — The ratio of simulated versus real time should be smaller than one, but some models will be faster than others. In order to carry out scenario analyses or to allow for iterations, the ratio should probably be much smaller than one. *Required* — the time required for a prediction should be less than the prediction horizon.
Availability and adaptability — This concerns the possibility to acquire the model for operational use. A step further is the possibility to modify and extend the model to meet specific requirements. *Required* — both are essential.

APPENDIX D: DESCRIPTION OF TRAFFIC MODELS

METANET

METANET (Modèle d'Écoulement de Trafic sur Autoroute-NETworks). This model has been developed at the end of the 1980-92s at the Technical University of Munich by the research team of Prof. M. Papageorgiou. During several EC-projects (Christiane, EUROCOR, DACCORD) the model has been developed further and applied by Prof. Papageorgiou's team after his move to the Technical University of Crete. Under a different name, SIMRES and via further development by J. Morin the model is now applied in France under near-real-time conditions. For more information see Mammar et al. (1996).

METANET is a model for motorway network simulation based on a purely macroscopic modelling approach. This leads to relatively low computational effort, which is independent of the load (number of vehicles) in the simulated network and allows also for a real-time use of the model. The overall modelling approach allows for simulation of all kinds of traffic conditions (free, dense, congested) and of capacity reducing events (incidents) with prescribed characteristics (location, intensity, duration).

METANET may be applied to existing (or partially hypothetical), multi-origin, multi-destination, multi-route motorway networks with arbitrary topology and geometric characteristics including bifurcation's, junctions, on-ramps and off-ramps. By use of a special modelling option (store-and-forward links), METANET provides also the possibility to consider non-motorway links in a simplified way.

METANET considers the application of traffic control measures, such as collective and/or individual route guidance as well as ramp metering and motorway-to-motorway control, at arbitrary network locations. Several options are offered for describing or prescribing the average route choice behaviour of drivers groups with particular destinations.

Simulation results are provided in terms of macroscopic traffic variables such as traffic density, traffic volume, and mean speed at all network locations on a chosen time interval basis (typically 5 to 20 s; the output interval may be chosen longer).

3DAS

3DAS (Three Dimensional Assignment) has been developed at the Delft University of Technology. The initiator was Prof. R. Hamerslag (~1988) who developed the model under the name of "Dynamic assignment in three dimensional time-space", see Hamerslag (1989). In a later stage (1988-1992) this model has been redesigned by van Grol (1992) and has been applied by de Romph (1994) to the Amsterdam ringroad and the Washington network (1990-1995). The latter two named the model 3DAS. In recent years the program has been used for small researches, but has had minor further development. CSST in Italy has independently developed 3DAS into an operational model.

3DAS is a dynamic traffic assignment model, currently based on a user equilibrium approach. In a way, it is an extended static assignment model, although this gives the impression that the model only approximates the third dimension: time. In reality, the time frame investigated (e.g. 2 hours) is divided into equal-sized periods (e.g. 5 minutes; there are no strict limitations, periods can take any size), the route choice is departure time dependent, the paths or better said, the trajectories are not instantaneous paths, but dynamic paths taking account of the future network conditions.

The route choice / assignment process is iterative of nature. After initial assignment the route choice is adjusted (shortest time paths) and the assignment is repeated. Then the previous and current assignment are combined to form the final result of the current iteration (important to note is that each iteration a prediction of the traffic conditions is computed for the entire time-frame). The iteration process is repeated until the travel time on the most recent path calculated is "equal" to the path calculated in the previous iteration (Wardrop principle).

DYNA

The DNL (Dynamic Network Loading) model has been developed during the EC-project DYNA (1992-1994) at the University of Naples by among others Prof. E. Cascetta, see Cascetta (1994). Working together with DNL an OD-estimation/prediction module was developed by CSST, among others by Dr. D. Inaudi.

The behavioural model used in DYNA consists of two components; an OD estimation / prediction model and a network loading model. It is mainly the latter that will be discussed here. The traffic is assigned/modelled by a Dynamic Network Loading model (DNL) This model adopts a continuous packet approach, where users are assumed uniformly spread between the first and the last point of the packet. Flow equations have been generalised in order to evaluate both the flow crossing a specific section of a link and the characteristic flow on the link. Diversion from initially chosen paths (en-route) due to changing traffic and/or network conditions is explicitly modelled.

DynaMIT

DynaMIT is a model system developed at MIT under Prof. M. Ben-Akiva in the early 90's, see Ben-Akiva et al. (1994). DynaMIT is a real-time Dynamic Traffic Assignment system that provides traffic predictions and travel guidance. Travel guidance refers to information provided to a tripmaker in an attempt to facilitate his/her decisions relative to departure time, travel mode and route. Clearly, departure time and (to some extent) travel mode recommendations are only effective prior to trip departure, whereas route guidance information may be useful both before and during a trip.

Part of DynaMIT is the mesoscopic traffic simulator called MITTNS. It is mainly this simulator that is under consideration within this document,. However, the entire framework, DynaMIT, is of interest to BOSS-DYTO as well. It serves as an example as to how a traffic model system can work real time.

MITTNS is a Traffic Simulation Model. The simulation is used in to capacities. In the NCE, (Network Condition Estimator) traffic simulation is used to obtain an estimate of the current state of the network, while in the NPP (Network Performance Predictor) traffic simulation is used to predict future network conditions. The requirements for NCE and NPP are different. The NCE needs an accurate model which works slightly faster than real time, while the NPP requires a model that runs much faster than real time. The running time and accuracy of the simulation model is controlled through aggregation of single vehicles into packets and the choice of time step.

MOLA

MOLA is the Motorway On-Line Assistant from TRL (Transport Research Laboratory). It is based upon two derivatives of CONTRAM, namely CONTRAMI (CONTRAM for Incident Management) and MCONTRAM (Motorway CONTRAM). CONTRAM itself is a packet-based dynamic assignment model developed in 1978 at TRL, see Taylor.

CONTRAM, CONTRAMI and MCONTRAM are all off-line models. MOLA has been developed especially to model real-time events. CONTRAMI is a version of CONTRAM developed to model incidents. CONTRAMI moves between two space-time states of the traffic, from the ‘normal’ state to the ‘incident’ state. The changes are related to the different routes chosen when in ‘incident’ state. Rules are devised as to when drivers divert and when they remain on their original route. MCONTRAM is a version of CONTRAM developed to model the effect of diversion strategies on motorways. It has mainly been used to study the effects of VMS (Variable Message Signs).

CONTRAM (**CON**tinuous-**TR**affic-**A**ssignment-**M**odel) is a packet based assignment model. It loads packets on a network on routes chosen generally based on optimal routes. After a packet is loaded the network conditions are recalculated. After all packets are loaded, the first packet is removed and reassigned. This process is repeated until no packet changes route.