INTEGRATED ANTICIPATORY CONTROL

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INTRODUCTION

Traditional traffic control is in most cases local and reactive: it responds to certain past and/or current traffic conditions. In the design of traffic control plans, past conditions determine the off-line or on-line implementation of traffic control plans. Also, most current on-line traffic control systems (local or area wide) only take the current traffic conditions into account or, at the best, make predictions for the arrival pattern at the stop-line. In most cases motorways and urban roads are operated and maintained by different road managers. In practise these road managers are only responsible for their own part of the network.

In the paper integrated anticipatory control is studied. Integrated control means that the network is considered to be one network. Anticipatory control means taking not only the current, but also the future traffic conditions into account. These future traffic conditions are related to the behaviour of road users, not the short term driving behaviour, such as choice of lane or speed level, but the long term behaviour such as route choice and choice of departure time. Traffic control should be able to anticipate this behaviour.

The paper shows the advantages of working together and anticipating the future traffic conditions to decrease the congestion problem. In The Netherlands a structure for cooperation is given in the Dutch National Traffic Management Architecture, which is described in the first paragraph. After that the problem is described in more detail and the studied control algorithms are given. The simulation and assignment methods are formulated and the results for two examples are described. Finally, some conclusions are drawn and a perspective for further research is given.

SUSTAINABLE TRAFFIC MANAGEMENT

Traffic Management Architecture

"The purpose of traffic management is to inform, induce and, if necessary, direct road users towards a safer and more efficient use of the existing infrastructure while safeguarding the quality of the environment of those living and working in the vicinity of the road network." With this definition of traffic management the introduction the Handbook Sustainable Traffic Management of Rijkswaterstaat (1) opens. The Handbook is part of the Dutch National Traffic Management Architecture.

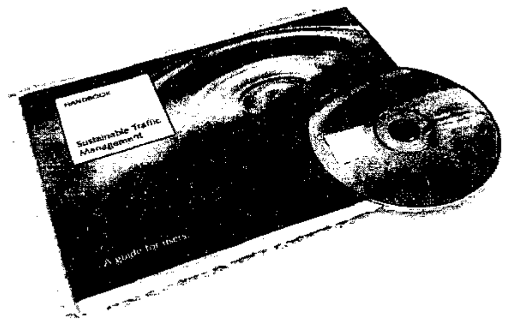

Figure 1: Handbook Sustainable Traffic Management

The Traffic Management Architecture (TMA) is a structured description of the complex system of traffic and traffic management measures. It can be used to develop and implement a consistent and accepted (in terms of political objectives) set of traffic management measures and the necessary technical and information infrastructure.

The TMA consists of five sub-architectures, each describing one aspect of traffic management. For defining and using a consistent set of traffic management measures the Traffic Control Architecture is used. For the integration of the hardware and software an Application Architecture is defined. The Architecture of the Technical Infrastructure describes the general ICT services in traffic management systems. The Information Architecture should harmonise the exchange and use of information and finally the Organisation Architecture gives a picture of the organisation required to facilitate traffic management. Of these five sub-architectures, the Traffic Control Architecture is the most developed one and plays a leading role in the design, implementation and operational use of traffic management (2).

Traffic Control Architecture

The Traffic Control Architecture (TCA) describes the process to get from policy objectives to operational traffic control. In this process cooperation with all parties involved is a key issue. Parties involved can be national, regional and local road authorities or operators, public transport companies, chambers of commerce, major companies, road user associations, police departments, etc. With these parties policy objectives are discussed and defined. These are concretised by linking them to a specific route or location and translating them into specific traffic variables, such as speed or travel time. Comparing the actual situation with the target situation, gives the locations with problems and bottlenecks. The next step will be to agree on traffic management measures to solve or decrease the problems.

Also the operational side of traffic control, such as defining, testing and implementing control scenarios for road works, incidents, football matches, etc., is part of the TCA. In the operational part the use of models to assess different control scenarios becomes very important (3). To structure the process to come to a, widely accepted, traffic control architecture the Handbook Sustainable Traffic Management was developed.

Handbook

The handbook describes nine steps. The first step is to initiate and organise the project, bringing together the relevant parties. The next step is to formulate the common policy objectives in a clear and unambiguous way, such that the target situation is clear. After that a control strategy has to be developed, which defines the way to handle the traffic in a region in case of problems and sets priorities to areas and routes (step 3). Attached to the control strategy a frame of reference is needed, which quantifies the control strategy (step 4). It includes measurable criteria and thresholds to indicate the acceptable situation. An example for road works is given by Kock and Van den Hoogen (4).

In the fifth step the target situation is compared with the actual or future situation. From this comparison traffic problems and bottlenecks are derived in step 6. To solve or decrease the traffic problems for these bottlenecks services (desired effect on a location in the network) can be defined (step 7). Step 8 consists of linking the services to one of more traffic management measures.

The final step completes the project by integrating the products from the previous steps into one document and formulating an implementation plan and policy document.

Next Steps

Of course, the steps described in the handbook are very important to implement successful traffic management, but the next steps are even more important, namely to realise the goals and measures defined and to come to operational traffic control at a network level. To get this far more research is needed on the subject of integrated traffic control. One of the aspects related to this subject is the interaction between traffic control and behaviour of road users. This paper is an attempt to show the benefits of cooperation between road authorities if the behaviour of road users is taken into account.

PROBLEM DESCRIPTION

Interaction

Traffic control and road user's behaviour are two processes that influence each other. The two processes have different 'actors' who may have different goals. The road authority will try to achieve a network optimum and will try to control traffic in such a way that this optimum is reached. Tools for controlling traffic are for example traffic signals, traffic information, ramp metering, etc. The optimum for the road authority can be minimum network delay or a preferential treatment for certain user groups, e.g. public transport or pedestrians (system optimum). The road users will search for their own optimum, e.g. the fastest, cheapest or most convenient way to travel from A to B (user optimum).

Decisions taken by the road authority to control traffic with a certain strategy, have an influence on the possibilities for travellers to choose their preferred mode, route and time of departure, and vice versa. A change in traffic control may have the impact that traffic volumes change. If, for example, traffic control is modified such that congestion on a certain route disappears and delays on intersections decrease, traffic might be attracted from other links where congestion still exists or which are part of a longer route. This might have the consequence that queues, which originally disappeared, return. Delays may reappear at the original levels as reported by Van Zuylen (5). The question is then whether there still is a net profit for the traffic system as a whole. The same question arises with respect to new traffic that may emerge as a consequence of shorter travel times, due to either elastic demand or induced demand. Another example is that public transport gets priority in intersection control. The delay for other road users may increase and thus force these road users to search for other routes, departure times or even transport modes in the network as suggested by Mordridge (6) and a recent simulation study on the effects of all kinds of traffic management measures related to the large-scale road maintenance on the A10-West, which is part of the ring road around Amsterdam (7). In this study it was shown that giving priority to busses, lead to an increase of the delay for other traffic.

Solution Approach

If it is assumed that a modification in traffic control gives a change in travel behaviour, it is necessary to anticipate this change. If delays are optimised, it should be done for the traffic volumes that will be present after the introduction of the optimised traffic control and not for the traffic volumes that existed before the implementation. If the reaction of travellers is neglected in the optimisation of traffic control, the results may even be just opposite to the desired improvement. The control problem is therefore to optimise traffic control in such a way that the system is at a certain, prescribed optimum, taking into account the reaction of travellers. This is called the combined traffic assignment and control problem. More than 25 years this problem has been the subject of study. Taale and Van Zuylen (8) give an extensive overview of the available literature on the problem and show in (9) that for some small networks with signal control anticipatory control is beneficial.

CONTROL ALGORITHMS

In this paper the effects of several control algorithms for intersection control and ramp metering on route choice and network performance are compared. It deals with integrated networks (motorways and urban roads) and the accompanying control measures (ramp metering and intersection control).
In the following sections the different algorithms studied are given. The simple metering algorithm described below is used in combination with the local intersection control algorithms. Anticipatory control and system optimum control also determine the green times for ramp metering.

Local Intersection Control

Fixed-time control. The most simple control algorithm is fixed-time control. The control plan has fixed green times for the whole period. For the simulations the values for the green times for each intersection were calculated for the busiest time period using the well-known Webster formulas (10).

Webster control. For the Webster control algorithm also the Webster formulas are used, but, in contrast with fixed-time control, the green times are calculated every time period. So, the control plan varies in time and reacts on changing traffic demand due to route choice. Webster control does not have an objective function that is optimised. It uses a heuristic to determine cycle time and green times

GA control. This algorithm also reacts on changing, local traffic conditions, but it uses an optimisation procedure. For the optimisation a genetic algorithm (GA) is used, described by Houck et al (11). The GA uses the traffic demand and other traffic variables to optimise an objective function (in this study total delay per intersection) by varying the green times. Previous research by Taale (12) has shown that this is a promising control method, especially in changing conditions.

Ramp Metering

For the on-ramps with metering a simple control algorithm is used. The difference between the capacity of the motorway downstream and the flow on the motorway upstream of the on-ramp, determines the amount of green time (in a fixed cycle of 12 seconds) given to the traffic on the on-ramp.

Anticipatory Control

The previous control algorithms are local algorithms and react only on the local traffic conditions, except fixed-time control which does not react at all. On the other hand it is possible to control traffic in such a way that future condition, related to route choice, are taken into account. The assumption is that traffic control plans influence route choice behaviour of road users. With anticipatory control the changes in traffic flows due to route choice are predicted for a certain combination of green times for the whole network (intersection control and ramp metering). With a GA the green times are selected, which lead to the best network performance (in terms of total delay) after route choice (see figure 2).

System Optimum Control

The system optimum is a theoretical benchmark situation in which green times and route choice are chosen in such a way that total network delay is minimised. It assumes total cooperation of the road authority and road users. In this study also a GA is used to determine this optimum.

SIMULATION AND ASSIGNMENT

Simulation

Simulation is used in two different ways: as the objective function for the GA for anticipatory and system optimum control and as a tool to assess the traffic control plans. In the case studies for this paper the same simple macroscopic traffic model was used for both roles, but it is possible to use different models, e.g. a simple model for the objective function and a microscopic simulation model for the assessment of the control plans.
The model used in this paper is a macroscopic model that propagates traffic flows through the network using travel time functions formulated by Akçelik (13) and the Highway Capacity Manual (14). Input for the model is a network consisting of links and nodes. Important attributes for a link are length, capacity and type (uncontrolled or controlled). For nodes the type is important (origin, destination, normal node, controlled node) and the incoming and outgoing links. Other input is an OD matrix per time period and a specification for every OD pair of the routes used. The simulation period is divided into time periods to make the demand dynamic and variable and time steps for internal calculations. For every times step a procedure is followed:

- determine the free flow travel time and capacity per link;
- calculate the real travel time with the travel time functions, based on the current link flow and link attributes;
- calculate the outflow per link, taking downstream queues into account;

- for every node calculate the incoming and outgoing traffic flows;
- for every link determine the flow for the next time step.

Of course, at the start of the simulation an initialisation is needed. After the final time step the output can be calculated, such as the travel time per route and per time period and network indicators, such as the total distance travelled and the total delay.

Assignment

For the traffic assignment a stochastic assignment is used, taking route overlap into account, as described by Cascetta et al (15). Together with the simulation model the stochastic assignment is used in an iterative process, which is shown in figure 2 for anticipatory control.

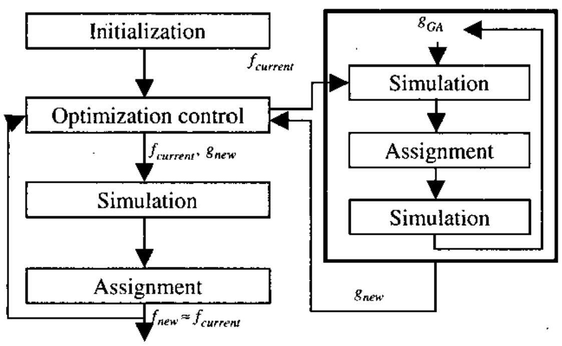

Figure 2: Simulation and assignment procedure for anticipatory control

After the initialisation, first the control plans are optimised, as described in the section on control algorithms. In the optimisation algorithm for anticipatory control (figure 2) an extra assignment is done to predict future traffic flows and to use traffic control to anticipate on this future flows. The assignment is based on the current flows ($f_{current}$) and travel times and green times generated by the GA (g_{GA}). After a number of generations the best green times are selected. With the optimised control plan (g_{new}) a simulation is run to determine the travel times. These travel times are then used to calculate a new distribution of the traffic demand (f_{new}) on the available routes and these new flows can be used in the next iteration for the optimisation. This process is repeated until an equilibrium is obtained, defined as the situation in which no or only small changes in the traffic flows occur ($f_{new} = f_{current}$). For this equilibrium the perceived travel times (definition stochastic assignment) are equal for all routes and time periods of every OD pair (dynamic stochastic user equilibrium).

EXAMPLES

The simulation and assignment procedure described in the previous section was used to study the effects of the different control algorithms for two different networks. These networks are sketched in figure 3. They consist of a motorway and metered on-ramps (gray dots). The networks also include an arterial with one or two controlled intersections (black dots).

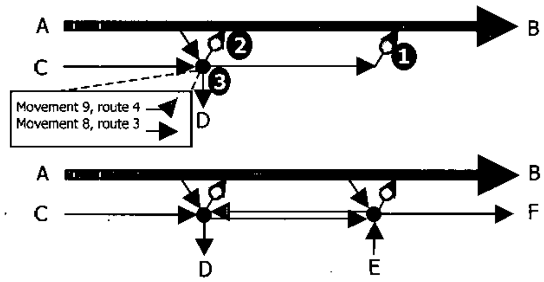

Figure 3: Example networks

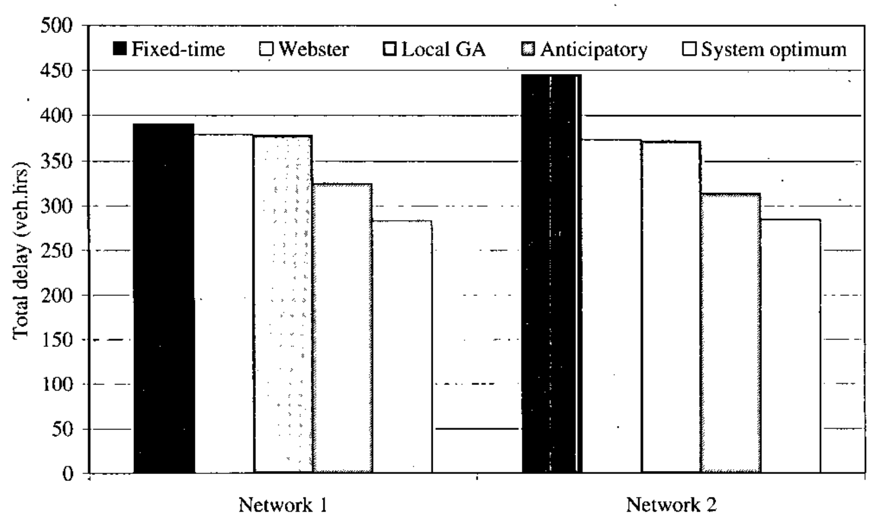

Figure 4: Results for the two example networks

TABLE 1: Improvements of the control algorithms

	Compared with fixed-time control				Compared with Local GA	
	Webster	Local GA	Anticipatory	System optimum	Anticipatory	System optimum
Network 1	3,0%	3,4%	16,6%	27,3%	13,7%	24,7%
Network 2	16,2%	16,6%	29,6%	36,0%	15,5%	23,2%

To simulate these example networks, all kinds of assumptions have been made, for example on the changes of the traffic demand in time, the traffic control parameters, the possible routes, simulation and assignment parameters, etc. For this paper it is not necessary to discuss all these assumptions. The only thing that can be said is that all assumptions have been made in accordance with reality as much as possible.

RESULTS

The results of the simulation for the different control algorithms are given in figure 4 on the previous page and table 1. Figure 4 shows the total delay in the network for the equilibrium situation after the iterative procedure of optimisation, simulation and assignment.
The results show that anticipatory control is better than local, reactive control, even if the control plans are optimised for the current traffic conditions. If future changes in route choice due to intersection control and ramp-metering are taken into account, total delay decreases and comes closer to the system optimum.
The results of the local Webster control and GA control do not differ very much and will be presented as one result in the following discussion.
In table 1 the improvements of the control algorithms in comparison with fixed-time control and in comparison with the best local control strategy (Local GA) are given as a percentage. From the table it is clear that fairly large improvements can be obtained with anticipatory control. These improvements are possible due to the different distribution of the traffic demand on the available routes, caused by the different signal settings for the intersections and metering systems.
To illustrate this, the flows per route and green times per signal for Local GA and Anticipatory Control for the six time periods are given in table 2. Controllers (CTR) 1 and 2 are the metering systems. The movements (MOV) 8 and 9 of controller 3 control the two alternative routes (see also figure 3). Table 2 shows that there are clear differences in the green times per signal and per time period. In the end, this has led to a different distribution of the traffic demand on routes 3 and 4 (see figure 3 again) and a better performance for the network as a whole.

DISCUSSION AND CONCLUSIONS

Anticipatory control, taking into account route choice behaviour of the road users, can lead to better network performance in terms of total delay. Savings of 10%-15% compared with optimised local control plans are possible for the example networks studied. A part of the improvement is due to the integrated optimisation of the control plan for the intersections and for the metering systems.
Therefore, the conclusion can be drawn that cooperation between road authorities has operational possibilities. Using the Traffic Management and Traffic Control Architecture can lead a better network performance.
Also other research by Van Zuylen and Taale (16) for an example with two road authorities shows that sepa-

TABLE 2: Flows and green times per period for two control strategies

Local GA Control

Flows per period

	1	2	3	4	5	6
Route 3	726	745	363	278	482	221
Route 4	274	755	837	722	118	79

Green times per period

Ctr	Mov	1	2	3	4	5	6
1	1	4.4	2.1	2.1	2.5	9.8	11.3
2	1	6.9	2.6	4.0	7.5	12.0	12.0
3	8	25.4	34.1	21.9	18.6	17.3	10.5
3	9	11.1	34.0	29.5	25.5	9.2	7.2
3	11	7.2	8.8	9.0	7.3	7.2	7.2

Anticipatory Control

Flows per period

	1	2	3	4	5	6
Route 3	736	1131	1164	921	400	219
Route 4	264	369	36	79	200	81

Green times per period

Ctr	Mov	1	2	3	4	5	6
1	1	7.1	6.3	10.3	9.4	11.0	9.2
2	1	8.5	9.7	8.0	7.5	7.2	8.8
3	8	31.3	24.2	33.2	35.2	35.2	26.6
3	9	19.4	14.3	8.8	14.6	22.8	22.7
3	11	20.4	32.6	23.1	16.9	10.5	11.5

rate or integrated anticipatory control gives better results than iterative reacting to the current situation. If one road authority takes the lead and anticipates the reactions of both the road users and the other road authority a sub-optimum is reached. The model calculations give evidence that cooperation of road administrators improves the utilization of the infrastructure and that a global optimization does not necessarily give a worse situation for one road administrator.

Another conclusion is that the genetic algorithm used is very suitable for the optimisation problem, which forms part of this work. Good solutions are found within a reasonable time. The number of function evaluations (a complete simulation) varied between 1400 and 3300 and the CPU time between 61 and 172 minutes on a system with an AMD Athlon 1700+ processor. For small networks this is acceptable, but for larger networks the CPU time can be a problem. Therefore, further research will focus on speeding up the simulation.

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