Optimal Traffic Control via Smartphone App Users

A Model for Actuator and Departure Optimisation

Daphne van Leeuwen, Rob van der Mei and Frank Ottenhof

Abstract For many years traffic control has been the task of traffic centres. Road congestion is reduced via traffic control based on the sensor information of the current traffic state. Actuators are used to create a better spread and throughput over the network. A powerful means to further reduce congestion is to shift from the classical reactive paradigm to a proactive paradigm. In this concept the traveller is included in the traffic control process in the sense that travellers are given advice about their travel scheme. This travel scheme presents the predicted travel time depending on time of departure and selected route. Today people use their smartphones to navigate. Via GPS and smart phone applications they optimise their route. Most of these applications use static traffic state information. In our research we develop a method to reduce congestion delay by including user decisions. According to the travel time preferences of the user a departure time/travel time curve is presented to the user. This curve shows the expected travel time corresponding to a specific departure time. Actuators are adapted according to the expected departure times of the app users. By including travellers information and preferences we want to analyse the resulting throughput and corresponding travel time in the network. To this end we study these effects for a small network with large peak arrivals in a short time period. Actuators in this network are adapted to the expected traffic flow and optimised accordingly.

Keywords Dynamic traffic management · Event control · Routing · Scheduling · Queueing theory

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1   Introduction

Informing and routing travellers used to be primarily a task of the government. Due to the availability of real-time travel information this has been shifted to market parties. Nowadays numerous market initiatives have been developed to influence travellers via their own channels including travel apps, websites, navigation systems etc. These initiatives inform the traveller in route and departure time. Users can adapt their route and departure time choice according to this information. This concept should result in a more efficient use of the road network. Unfortunately this approach still lacks some important aspect. The user can only adapt his or her decision whereas the network actuators are taken as static tools. Traffic actuators only respond to current arriving traffic and do not adapt to decisions made by the user. By adjusting not only the users departure time and route choice, but also traffic actuators accordingly a tremendous decrease in delay could be established.

   A concept is initiated to tackle this problem. This concept has been initiated by the name the Digital Road Authority. In this concept the road network is divided into small sub-areas and the road authority of each sub-area is coupled to a virtual road authority; the Digital Road Authority. This tool merges all traffic data into a smart travel advice system. It establishes a connection between public and private parties. Through a collaboration of the connected parties a more effective advice can be given. Via a smartphone application users can receive updates of the current traffic state relevant for them. This user, in his turn, sends information regarding route and departure time decisions to on-route traffic actuators. These traffic actuators collect information and adapt their setting accordingly. The Digital Road Authority plays a coordinating role between traveller and traffic actuators. The platforms in which this concept is developed consists of an unique collaboration between Dutch companies, knowledge institutes and the government (the triple helix). Thereby ensuring theoretical correctness and applicability.

2   Case Study: Traffic Control at Events

To test the Digital Road Authority in a real-life setting a case study will be used. For this case study it is essential to inform a significant amount of travellers in the studied area. A case study that satisfies these requirements would be during a large event. We introduce an area manager that coordinates the arena area. In this section this problem will be outlined.

   During events large delays are often encountered for which not only the visitors of the event encounter delay, but also travellers with another destination. These events regularly cause problems in the nearby network, despite the fact that the number of visitors is known beforehand. These visitors depart their home unco-ordinated and unaware of the choices made by other travellers. Traffic actuators are not adapted to the expected peak arrivals and therefore do not respond accordingly.

This is where the Digital Road Authority comes in. The Digital Road Authority coordinates, routes and informs travellers to facilitate the traveller to arrive at the event location with a minimal delay. Thereby collecting the user decisions and adapting the network to the expected peak arrival. This approach coordinates both travellers and actuators to facilitate an optimal throughput and minimal delay for the network around an event.

As a specific test case the area ArenaPoort in Amsterdam the Netherlands is used. This area is known for its event locations, Ziggo Dome, Arena, Heineken Music Hall. These locations attract many visitors. Problems arising during these events are:

- Parking problems, visitors driving around to search for available parking spots.
- Traffic jams due to long lines for parking lots.
- Large delays to exit the area after the event.

Via the Digital Road Authority a framework is created to inform coordinate and advice visitors and based on the visitor decisions controls traffic actuators. To accomplish this three phases can be distinguished.

Pre-event planning During this phase a plan is defined to give a personal departure and route advice to each traveller in a coordinated manner by using the available information. The available information that is used consists of three types. Via the ticket information the number of visitors and their area of departure is approximated. Secondly, the availability of parking lots and their capacity is known and last a map of the possible routes including their switch points are necessary. At a switch point a decision between two or more routes have to be chosen. A graphical representation can be seen in Fig. 1. Given these input sources an optimal arrival plan can be determined. The objective is to route visitors with minimal delay through the network by taking their preferred arrival time into account.

On-route adjustments As soon as the first travellers depart, adjustments can be made to the predefined plan. Given current road conditions it might be optimal to change parts of the route plan. Departed travellers are assumed to be fixed in departure time, hence they already left. They can however be rerouted or redirected to a different parking lot. Due to unpredicted events on the road or deviations from the original expectations the plan of the individual traveler can be optimised for the current state. An example of such a monitoring system is shown in Fig. 2. The occupation at the parking lots is shown, at the right from this the percentage of arrived visitors is monitored. Also the occupancy for each road is indicated by colour. Nearby visitors are monitored by counting these arrivals on each approaching road.

After-event The outflow after an event is easier to control by controlling the outflow pace from each parking lot. Given the current traffic state the optimal outflow stream can be determined in order to avoid congestion. Traffic actuators can be programmed in order to create nonconflicting routes to exit the event area to nearby highways.
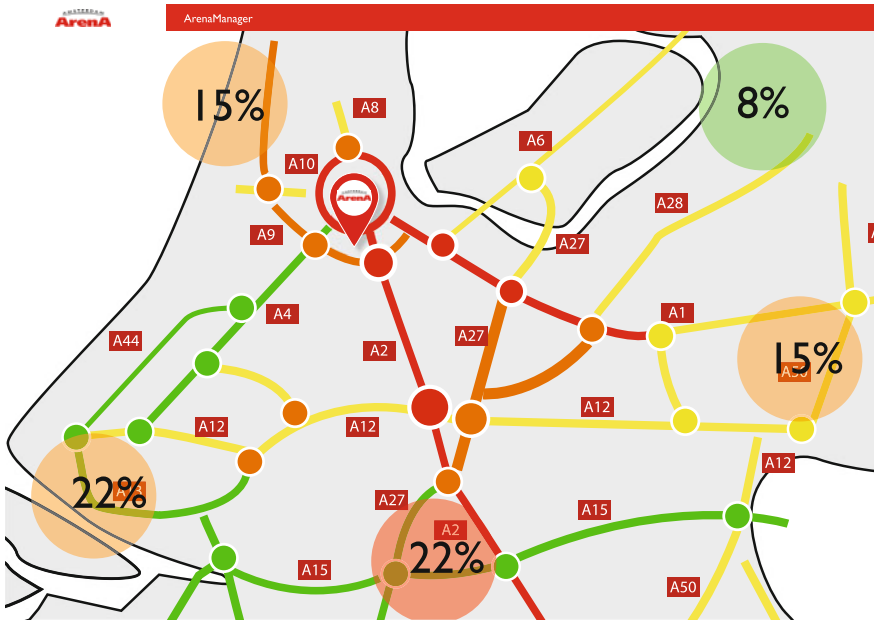
Fig. 1 A representation of the pre-event information regarding the origin of the event visitors and switch points
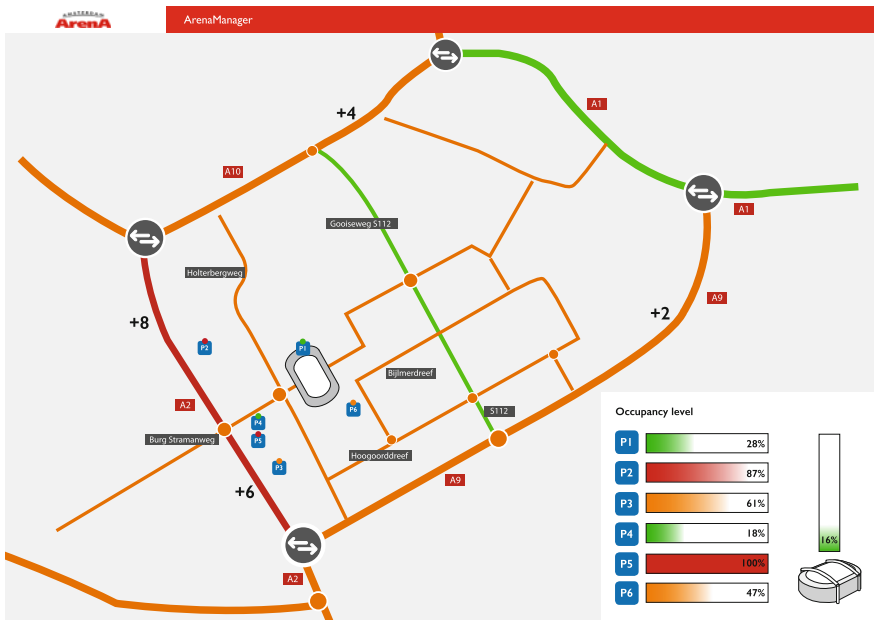

Fig. 2 A representation of on-route monitoring of the current state

3 Model Explanation

The developed model for this case study focusses on pre-event planning. The model will coordinate travellers via a managing agent defined as the Arena Poort area manager. Via a three fold optimisation model we can route the individual traveller and use its information to optimise traffic actuators for pre-event planning. The first part of the model maps the users to their destination without area manager interference, i.e. the current state of the traffic during events. Given these routes we can indicate whether unnecessary delays occur. If so, actuators can be controlled at switch points to redirect the traffic. These settings are used to see whether we would obtain a problem for the current number of expected visitors for an event. To improve the current situation we optimise in two directions. The actuators in the arena area are adapted to the expected arrivals due to the event and the visitors of the event are given a departure and route advice based on the users preferred arrival time. These steps influence each other and are optimised by iterating between both. Each step will be outlined in more detail.

Step 0: Initial setting

The origin of event visitors and the parking possibilities in the arena area are used to determine the expected route and delay. From each traveller the preferred arrival time is estimated. Based on this information the current delay during an event is measured. The delay obtained during this event is calculated.

Step 1: Actuator optimisation

In this model actuators along the routes to the arena area are adapted to improve the throughput in the arena area. Actuator settings are adapted according to the expected arrival stream of visitors before the event. These settings depend mostly on the throughput at parking lots per unit of time. A large amount of arrivals during a small time interval results in queues at the entrance of parking lots. Actuators have to respond to these expected queues by redirecting traffic to nearby parking lots. A queue before the entrance causes extra travel time for the visitor, if the queue exceeds a certain length this will cause spill backs to upstream roads. It is important to keep in mind that the adapted actuators not only influence the travel time of event visitors, but also the normal traffic through the area.

Step 2: Travel advice

A departure time is given to each user depending on the calculated routing possibilities, the amount of travellers and the parking capacities at the destination. The preferred arrival time, referred to as PAT, and departure location of the user are used as input parameters. Collecting this information from all users results in a large puzzle with numerous solutions. Via our model we want to find the optimal value of this puzzle. In other words, an optimal departure moment given the preference time of the user for which the overall delay is minimised. We can capture this in the following formula based on Vickrey's model [1]:

$$U(\tau) = \alpha D(\tau) + \beta ES(\tau) + \gamma LS(\tau),$$

where τ gives the expected arrival time, $D(\cdot)$ the deviation from preferred arrival time and $ES(\cdot)$, $LS(\cdot)$ give the penalties for early and late scheduled arrival times respectively. The parameters α, β, γ determine the penalty for a deviation from each of the parameters. The preferred arrival time deviations are calculated by:

$$ES(\tau) = \max(PAT - \tau, 0)$$

$$LS(\tau) = \max(\tau - PAT, 0)$$

The minimal value U for this formula has to be found. Each traveller wants to arrive as close as possible to their preferred arrival time combined with a minimal delay. Unfortunately, due to capacity limitations, people have to deviate from their preference during peak arrival periods. To model the expected delay over time for a predicted arrival pattern we obtain a waiting time curve over time, a visual representation can be seen in Fig. 3. Via this method the delay obtained by scheduling many users during the same time periods is captured. Via an optimisation algorithm using the above formula we can optimally spread the arrivals over time.

Step 3: *Stop condition*

To obtain the optimal setting multiple iterations of step 2 and 3 have to be performed. A change in departure time and route choice results in a changed delay function. This influences the performance of the actuator settings. We want to define the optimal actuator settings given the change in arrival pattern. Subsequentially the departure advice should be optimized according to the adaptation in the settings. The iteration steps will be performed until the difference between iterations is smaller than ε, for ε small.

Fig. 3 Representation of the delay for expected arrival flow

deadlines out of queue

arrival deadlines
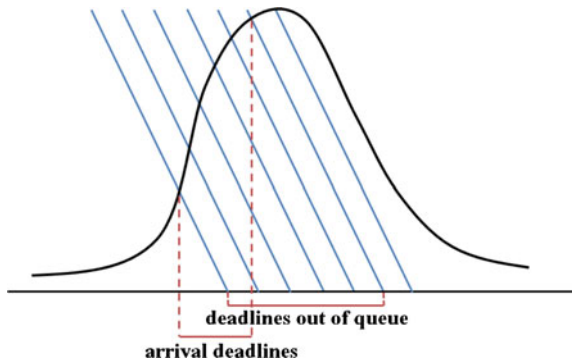
4 Preliminary Results

From a previous case study we have shown that a travel advice application can result in a significant reduction of average delay. In this paper we use the same approach, thereby including the optimisation of traffic actuators in the optimisation process. We will outline results from a couple of scenarios in which we show the performance of the travel advice application.

In Fig. 4 results from two scenarios are shown. In this scenario travellers from one origin pass a road with fixed outflow capacity and a varying inflow over time. A queue results when the arrival stream is larger than the departure stream. By influencing part of the users to choose a deviation from their preference we can reduce the average delay over time. These users are rescheduled via the application of the Digital Road Authority project.

Results are shown in Fig. 4. The first scenario shows a small deviation of expected inflow over time. For various percentages of participating app users the decrease in delay is shown. At the second scenario a large increase of arrivals for a short time period is modelled. Also in this case a significant reduction in delay is obtained when we can influence 25 % of the total amount of travellers to change their departure time.

A second scenario considers two routes with fixed outflow capacity and one stream of travellers passing either one of the routes. The routes differ in length, the second one is longer. Therefore the second route will only benefits the user when the waiting time plus travel time of the first exceeds the travel and waiting time of the second.

In Fig. 5 results for the same scenarios are shown. In this case the user has the option to choose the other road. This strategy is very useful to incorporate for the arena case study. This area consists of many parking lots, which all have a varying distance to the event. Depending on the delay at the entrance of each parking lot it might be beneficial to choose a parking lot that requires some additional walking.
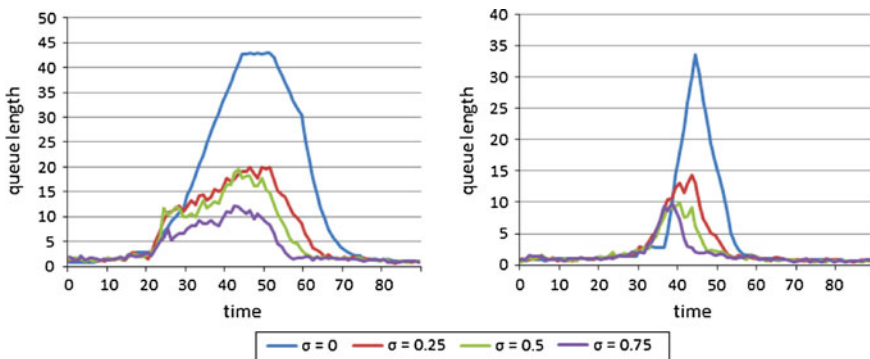
Fig. 4 Visualisation of the mean delay over time for two types of arrival scenarios for varying percentages of app user participants
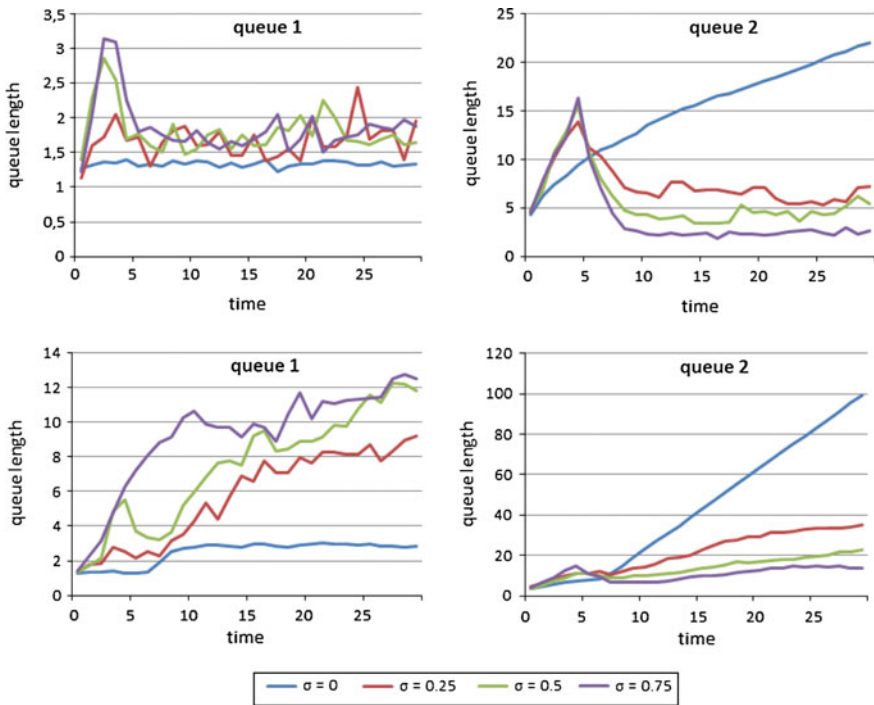
Fig. 5 Visualisation of the routing strategies over time for two arrival scenarios and varying percentages of app user participants

5   Conclusion and Further Research

This paper describes the model of an ongoing research project of the digital road authority. This case study focusses on the optimisation of the throughput in an area. Previously we focussed on establishing this goal via a travel advice, in this research we take the settings of the actuators into account in the optimisation process. Currently this research is still under development.

A detailed description of the model is visualised in Fig. 6. The arrivals are considered from four directions. At each input direction an actuator can define the split ratio of arrivals. The *p*-values along each road ending at the arena represent the sum of arrivals from the different directions. Depending on the parking lot capacity, arrival streams and the actuator possibilities a routing strategy is obtained. In the next step the travel advice algorithm improves the arrival streams over time.
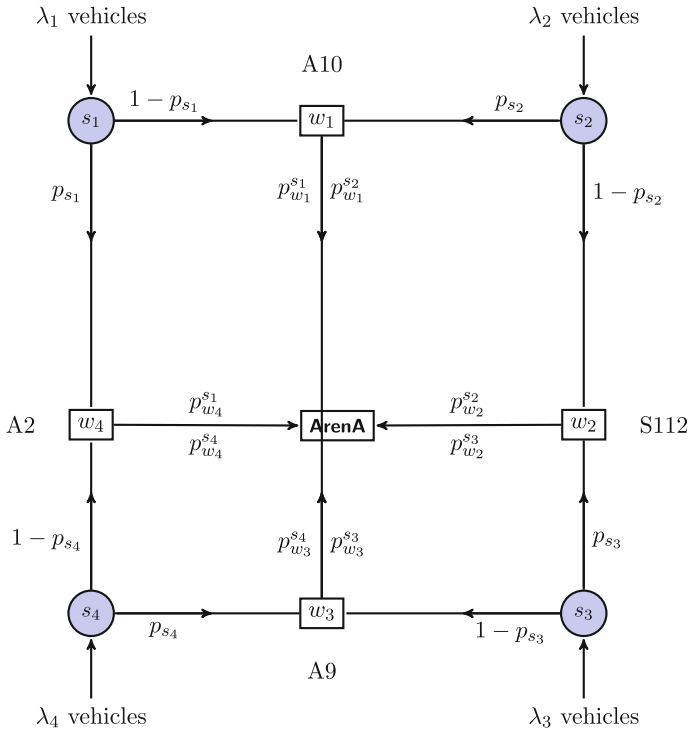
Fig. 6 Illustration of the arena area by the model parameters

Reference

1. Vickrey WS (1969) Congestion theory and transport investment. American Economic Review, Papers and Proceedings