Comparison by Simulation of Different Approaches to the Urban Traffic Control

1. Introduction

In recent years, many cities suffer from traffic congestion, which is a major problem in managing urban traffic. The goal of traffic control systems is to optimize traffic flow and reduce congestion. This is achieved by providing real-time traffic information to drivers and traffic management staff. The model described in this paper is a traffic management system that uses simulations to predict traffic flow and congestion. The model is periodically updated based on real-time traffic data.

2. Problem formulation

Our goal is to develop an urban traffic control system that will be able to react on measured traffic data and optimize a criterion based on the ideas in [5]. In the first phase, described in this paper, we will attempt to minimize travel times by minimizing the weighted sum of queue lengths at all approaches of all controlled intersections. To achieve our goal, we will derive a feedback system for urban traffic control based on a simple input-output model of a traffic region. The model will use the on-line measurement of traffic volumes and the state of the controlled system will be statistically estimated from currently measured data. On the basis of the estimated model and its state vector, the signal splits will be set so that the weighted sum of the predicted queue lengths at the intersection achieves its minimum. The optimization will be based on linear programming and it will use a rolling horizon for better stability of the control.

3. Model of traffic region

To be able to optimally control a system, we have to model it first and the model needs to be a good approximation of the reality. A typical urban traffic region shows a great amount of noise in the measured data, and therefore its state is to certain degree uncertain. In order to take count of the uncertainties, the model variables are considered to be random variables with estimated mean and variance, and the uncertainty is usually modelled by additional noise with given distribution.

Our model has a form of a discrete-time state-space model and it is based on the model of Horováková and Nagy [6]. We will briefly overview its main components, the state equation and the output equation.

3.1. Model of the queue

The state of the system is described by two sets of variables - queue lengths $q$ at all signalised approaches and the corresponding detector occupancies $o$. The part of the model that describes the evolution of the queue follows a simple conservation law [7] that has been modified to keep $E>0$:

$$E_{t+1} = E_t + (q_t -zerosize=0.4) - s_t H + q_t G, \quad E_t \geq 0, \quad s_t \in \{0,1\} \quad \text{otherwise.}$$

It expresses the fact that at the end of the $t$-th cycle the residual queue length $E_{t+1}$ increased by the arriving flow (or demand) $q_t$ and decreased by the flow equal to lane capacity - the lane capacity is given by the saturation flow $s_t$ and the relative green length for the approach, $g_t$ given as a ratio of the cycle time when the green signal is on. If the lane capacity exceeds the total demand, the residual queue is approximated by the number of vehicles arriving on red, assuming uniform arrivals.

3.2. Model of the detector occupancy

The detector occupancy $o$ is defined as a ratio of detector activated time and the length of the detection period. It has been shown by Diakaki that in certain range the occupancy at the detector has almost linear dependency on the queue length. This leads to the relation

$$o_{t+1} = w o_t + \lambda$$

where $\lambda$ and $\lambda$ are coefficients of the linear dependency. Their values depend mostly on the detector distance from the stop-bar.

3.3. Model of the output

The model describing the output of the system computes the number of vehicles leaving the intersection given the number of vehicles queuing on its approaches, the turning ratio $\alpha$ between the $i$-th and $j$-th approach, and the number of vehicles arriving during the cycle. The output model has also to take into account different possibilities of queue formation described by (1). The resulting model, although in parts linear, becomes quite elaborate and due to space constraints we refer the kind reader to the original paper for detailed explanation:

$$y_{t+1} = \delta_t + (\delta_t s_t + (1 - \delta_t) y_t) \frac{d_j}{d_j} + \eta t$$

where $\eta$ is the output intensity over some approach, $s_t$ is the set of all approaches of the intersection, $\delta_t$ is the turning rate from the $i$-th approach to the output and $d_j$ is the boolean residual queue flag honouring the two variants of equation (1), $d_j = 1$ if $q_t > 0$, otherwise.

3.4. The final model

Using the above building blocks a linear state space model can be built,

$$x_{t+1} = A x_t + B z_t + F w_t,$$

$$y_t = C x_t + G + v_t,$$

where the state vector $x_t$ is composed from queue lengths $q_t$ and modelled output occupancy $o_t$, the vector represents the green $s_t$ splits, the output vector $y_t$ is composed from the modelled output intensities and modelled input occupancy $o_t$, the matrios of the system contain appropriate parts of equations (1)-(3) and the noise vectors $w_t$ and $v_t$ cover all uncertainties and disturbances in the model.

3.5. Filtration

The state-space model described by (4) and (5) depends on a number of parameters. Should we consider these parameters known and fixed and all inputs to the system being measured, the model is known completely and its state (queue lengths) can be...
estimated based on measurements using the simplest version of linear state estimation – the Kalman filter [9]. However, for a robust practical application these conditions do not hold. The values of parameters \( S \) and \( A \) are usually not constant, the turning rates change in the course of the day and not all inputs can be measured, mostly due to budget restrictions. Only the parameters \( c \) and \( A \) can be considered constant and their values can be pre-computed.

In such a case, the process of simultaneous estimation of the system state and its parameters leads to non-linear estimation and filtration. Numerous methods exist that allow simultaneous estimation of state and parameters, their main problem being numerical instability. In our system we opted for the DDA1 filter [10]. This method proves to work well provided that the noise covariances from the model (4), (5) are determined with sufficient accuracy.

3.6. Control

In order to control the system, we need to specify a control criterion that will be minimised. In our case, we aim to minimise travel time by minimising the number of vehicles queuing in the controlled traffic network. We define the control criterion as a weighted sum of the delay caused by vehicles queuing on road,

\[
f = \sum_{i=1}^{n} w_i \xi_i^2.
\]

where \( n \) is the number of controlled intersection approaches, \( w_i \) denote weight (importance) of the \( i \)-th approach and \( \xi_i \) represents queue length to maximum throughput ratio, allowing for longer queues at approaches that are able to again rapidly discharge them.

3.7. Model for control

The criterion (6) is expressed through the queue lengths. However, this variable is not directly measurable and we need a control model, connecting the queue lengths to other measurable variables. Such a model can be easily obtained using the state space model (4). We get

\[
x_{k+1} = Ax_k + Bw_k + F + w_k
\]

\[
x_{k+1} = Ax_k + F + w_k
\]

and computing new vector \( x \) as a concentration of \( \xi_i \) and \( \xi \), we finally arrive at the model for control in the form

\[
M = \begin{pmatrix} F & 0 \\ 0 & 0 \end{pmatrix}
\]

\[
m = Ax_k + F + w_k
\]

3.8. Optimization

With the control model formulated in the form of (7) we may minimise queue lengths by linear programming approach [11] by transforming (6) into linear programming criterion

\[
\min \sum_{i=1}^{n} \xi_i^2
\]

using \( c = (c_1, c_2, \ldots, c_{n-1}, 0, \ldots, 0) \) so that the values of relative greens do not influence the optimality criterion. Additional conditions for optimisation are \( c_0 = c_{\text{set}} \) and all relative greens at one intersection have to sum to one.

The optimization presented above will provide optimal green splits for a single cycle using variables measured during the previous cycle. Such a control criterion is very easy to compute, however, it could be unstable as the synthesised control action maximises the current profit and does not take into account historical data and predictions of future traffic situation. That is the reason why a suboptimal control with a rolling horizon is used instead of the above mentioned simple case. The only difference is that the control model (7) is constructed using predictions of input intensities up to the rolling horizon length (typically 5 cycles) and the criterion (6) is minimised taking into account all modelled queue lengths over the horizon. The intensity is predicted using an autoregressive model of order 2.

4. Simulated experiments

As a first step towards the real world testing of the system, the model and above proposed controller have been tested using the TSIS Almata micro-simulator equipped with additional interface to Matlab and simulated intersection controller. The tested network is located in the western suburbs of Prague, around Zlíchov public transport terminal and shopping center (13). It consists of two coordinated intersections and it is depicted in Figure 1.

5. Conclusion

We have proposed and tested in simulation an alternative urban traffic control system based on state-space model of the traffic network.

We were pleased to observe that the system was able to correctly detect the lower capacity of output in Scenario 3 and change the signal plan accordingly by shortening the affected greens and giving more time to alternative signal group. This could, in real situation, suggest drivers to change their directional preferences and prefer an alternative route to their destination.

On the other hand, the proposed system does not bring much improvement for the common traffic situation as shown by results for Scenario 1. These results clearly show that for a typical day pre-defined signal plan works quite well with traffic-actuation taking care of all small disturbances in traffic. The proposed control is still marginally better, but the overhead of redetuning the signal plan for the controller network may be in some situations even prohibitive. This is an interesting topic for future research.

Given the favourable results of the simulated testing, we will also try to obtain the permission to test the system in real traffic.
Increase the efficiency of the fleet management in the public sector on the example of the police

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ABSTRACT
Logistics costs are a major expense, accounts departments responsible for national security. Experience in business can be used, but must be taken into account the specificity of the public sector. The paper presents the results of the research project, during the study looked for the best tools to improve the efficiency of the fleet management of the police. Fleet economy is inefficient - both in terms of the use of vehicles and service. In the research project prepared solutions that reduce transport costs in the police, in particular, mostly are systems for monitoring fuel consumption. In addition, organisations changes are proposed which allow to reduce logistics costs and increase employee motivation.

KEYWORDS: logistics, police, transport costs, vehicle

1. Introduction

The observation of changes in the public sector (not only in Poland) suggests that the adoption of business solutions, may be a source of increased efficiency in this sector. A key instrument for the optimization of logistics processes are increasingly used in the logistics sector fleet monitoring systems based on telematics solutions (combining information technology and telecommunications). In particular, a vehicle tracking systems using satellite technology and systems available through the analysis of fleet operations in real time. Monitoring allows the assessment of efficiency of the fleet. This knowledge can also be used in operating activities of the Police. Vehicle monitoring system is the key, but only one of many organisational and economic solutions, which would be comprehensive prepared with a special reference the organisational and economic police. The transfer of relevant business solutions to public sector operating conditions requires consideration of different differences in organisational culture and specific salary systems.

2. Optimization of the police fleet management as a subject of research

The problem of optimizing fleet management using satellite monitoring system was the subject of research within the research and development project No. R00/01380/O1, which finalized on 09.01.2010 until 12.31.2011 year by a consortium consisting of the University of Economics in Katowice, in leader of the project, Vowodzhip Police Headquarters in Krakow, WASKO S.A. (a company operating in the IT sector, specializing in telematics hardware and software).

The project is designed to develop methods to optimize vehicle operating costs and increase efficiency of the fleet of the police. The project has been included analysis and studies, especially choice of method of measuring fuel consumption in vehicles. The demonstrator system has been installed in police cars selected.