HIERARCHICAL REGULATOR OF TRAFFIC FLOWS

Jitka Homolová[1,2]

[1] *Adaptive Systems Department, Institute of Information Theory and Automation, P.O.Box 18, 182 08 Prague 8*
[2] *Faculty of Transportation Sciences, CTU Prague, Konviktská 20, 110 00 Prague 1, Czech Republic*
E-mail: jkratoch@utia.cas.cz

Abstract: The traffic flow control by traffic lights is the way how to decrease negative impacts of daily traffic in cities. The paper introduces a concept of the hierarchical traffic flow regulator for a urban area. The aim is to derive an optimal setting of signal scheme parameters according to actual traffic conditions with maximum utilization of available traffic information. Main principles of modelling, state and parameter estimation and control strategies are briefly described for each control level.
This task is trivia in case of complete knowledge of all measured traffic quantities and parameters (like saturation flows, turning ratios, etc.) for all junction arms. However, the net of all needed detectors is not usually complete and some significant traffic flows (parking cars, etc.) are not measurable in practice. The problem of low accuracy of model parameters or missing measurements is also discussed. The efficiency of proposed method is demonstrated by several experiments.

Keywords: traffic flow, control, modelling

1 INTRODUCTION

The traffic and its control are an inseparable components of all big cities in these days. Moreover, the quality of the traffic control impacts various human activities and it can be considered as one of the faces of the total society adulthood. The way how to decrease congestions during the peak hours is to apply a proper control via traffic signal lights. Then the passage time through a traffic area and the lost time spent by queuing can be reduced. It brings strong positive environmental impacts and improving the quality of a daily human life (Kratochvílová and Nagy, 2003). There are many control systems for urban traffic (Papageorgiou *et al.*, 2003) but the universal and definitive solution was not still found because of the stochastic and area depended nature of the traffic.

The aim of this paper is to design the concept of the hierarchical regulator of traffic flows. The basic principle of such control is traditionally minimization of the lost times, the passage times and the number of stopping during a journey. All these characteristics are proportional to the queue length (Diakaki, Dinopoulou, Aboudolas and Papageorgiou, 2002). The proposed local model counts and estimates the queue length using maximum available traffic information. This task is trivial in case of complete knowledge of all measured traffic quantities for all junction arms. However, the net of all needed detectors is not usually complete and some significant traffic flows (parking cars, etc.) are not measurable in practice. In this case, the model estimates the queue length relative to modelled and estimated traffic characteristics.

The coordination level of the controller ensures minimize blocking of a crossing area for component microregions in the traffic region. The aim is to balance traffic loads of microregions. Model for this control level counts amounts of vehicles within microregions. The state estimation is precise enough on the local level, therefore no other estimation is needed at the coordination level.

2 TRAFFIC DATA

The basic data that are necessary for an on-line traffic flow control are measured by traffic detectors. These devices can measure several traffic characteristics like occupancy, intensity, velocity or density. The first two of them are most important for the proposed regulator.

Intensity denotes the number of vehicles which have passed a detector during sample period $[uv/h]$. Occupancy determines relative time of the detector activation during sample period [%]. Intensity captures the queue dynamics in the sense of the queue protraction but it does not fully determine the actual situation - the value of intensity can be low because of low traffic or high density which are two converse traffic situations. Occupancy has similar meaning as density and together with intensity, describes the actual traffic situation unequivocally.

3 DESIGN OF A HIERARCHICAL CONTROL

It is assumed that the regulator has three control levels in total: (i) junction level, (ii) local level, and (iii) coordination level. Control of a single junction is realized through a traffic distributor implemented in signal traffic lights equipment of the junction. This control level is already implemented in practice. Therefore, in this paper, only design of local and coordination control levels is considered.

The controller levels communicate with each other in terms of intervals of green splits. The optimized green splits are not used directly in their absolute values but they are supposed to be changed incrementally. The coordination level prescribes the splits bounds for the local level and then these bounds can be changed again by the local level. The final splits bounds are given to the junction control level.

4 LOCAL LEVEL

The local level state space model counts queue lengths that are formed on junction arms in consequence of light signal control. The model consists of two basic equations for each arm in a microregion where vehicle queueing is possible. The first one is a hydrodynamic analogy for a queue length and traffic inflows and outflows:

$$\xi_{t+1} = \xi_t + I_t - P_t, \tag{1}$$

where

ξ_{t+1} queue length at time $t+1$ $[veh/T_p]$;

I_t input intensity $[veh/T_p]$;
P_t output intensity (passage) $[veh/T_p]$;
T_p sample time $[h]$.

As can be seen, no queue length can be counted without prior information. However, it is easy to assume that there are zero queues at night. Passages from arms depend on the actual traffic situation. According to initial traffic conditions, a passage through the junction can be less or equal to the maximum number of vehicles that can pass safely the junction during the green light (i.e. saturation flow). The passage from an arm can be determined by the following equation:

$$P_{i;t} = (1 - \delta_{i;t})(I_{i;t} z_{i;t} + \xi_{i;t}) + \delta_{i;t} K_{i;t}, \tag{2}$$

where

$P_{i;t}$ passage from arm i at time t;
$I_{i;t}$ input intensity of arm i;
$\delta_{i;t}$ indicator of passage from arm i;
$z_{i;t}$ split (relative green time) for arm i at time t.

The second equation is a presumptive linear relation between occupancy and queue length. This relation is used for the correction of the first one (1) and it was derived theoretically:

$$O_{t+1} = \beta O_t + \kappa_1 \xi_{t+1} + \kappa_2, \tag{3}$$

where

O_{t+1} occupancy on an input junction arm at time $t+1$ [%];
κ_1, κ_2 coefficients of linear relation;
β coefficient of auto-regression;
ξ_{t+1} queue length on the same arm at time $t+1$.

5 STATE ESTIMATION

The net of junction detectors nets can be imperfect with respect to our measurement needs and some its parameters need not to be accurate or are driver-depended. That is why the state estimation is also realized on the local level. The state estimates are corrected through Kalman filter by prediction errors that are counted in dependence of actual measurements of output intensities and input occupancies. Thus the output vector consists of occupancies of all input arms (with input detector) and intensities of all measured outputs.

Two equations form the output model: equation for output intensity and an identity for occupancies. The output intensity for the junction arm is given by weighted sum of passages from remainder junction arms to this output arm:

$$y_{h;t} = \sum_{i \neq h} \alpha_{ih} P_{i;t}, \tag{4}$$

where

α_{ih} weights (direction ratios).

6 COORDINATION LEVEL

The coordination level of the controller ensures minimization of blocking of a crossing area for component microregions in the traffic region. The aim is to balance traffic loads of microregions that can lead to a displacement of an unwanted traffic behind the border of a microregion.

Each microregion is represented by sum of queues in the microregion with the exception of those on the microregion borders that are not between two optimized microregions. It means that there are added all queues with directly controlled or control-depended input intensity:

$$X_{m;t} = \sum_k \xi_{m,k;t} \tag{5}$$

where

- $X_{m;t}$ amount of vehicles inside the microregion m;
- $\xi_{m,k;t}$ length of queue k inside the microregion m.

Model for this control level models states by analogy to (1). The coordination level uses the state estimates of queue lengths, derived on the local level. The estimation is precise enough, thus no other estimation and, consequently, no correction equation at the coordination model is needed.

7 CONTROL

The traffic flows can be controlled only by changing of signal scheme parameters. In this paper, we focus only on control of splits (i.e. relative green time). We suppose that all coordination offset times between junctions are set optimally and all cycle times are constant.

All modelled relations and all traffic variables constraints considered for optimization are linear and this fact allows us to use linear programming as the optimization method for determination of the required control parameters. Besides the cycle constraint and the model equations, other constraints are given by non-negativity of all variables and minimal allowable green time (5 seconds in the Czech Republic).

The optimization criterion is minimization of the weighted sum of all queue lengths in a microregion for the local level. This requirement ensures the balanced queue lengths for each junction. The weights can be set with respect to the traffic preference of some directions in the traffic net or dynamically.

It is not easy to specify a control criterion for the coordination level. One possibility is to minimize the difference between the weighted amounts of vehicles inside the microregions. The weights are set with the respect to the sizes of the partial microregions.

8 EXPERIMENTS

The proposed local model and estimation algorithms were tested with respect to their basic properties and efficiency, including case studies of disturbances that can arise in practice, such as the memory defect, incorrect model parameters or a disruption of linear relation between occupancy and queue length. The results were very good and proved the meaningfulness of the proposed models and the estimation algorithm for different microregions.

These initial experiments allowed to test the whole conception of the traffic regulator. The tested region consisted of two microregions formed by 4 (first microregion, $M1$) and 6 (second one, $M2$) signal controlled junctions. The border between the microregions consisted of one input and one output arm for each microregion only. In the region, there were five measured inputs, three of them in the first microregion. There were also 3 measured output detectors for each microregion. The signal schemes for all junction were two-phased and we knew prior traffic solution (the consequence of phases and all junction parameters).

In the experiments, real input intensities were used in order to keep the experiment close to reality. The occupancies, output intensities and queue lengths had to be digitally simulated because the corresponding measurements were not at our disposal. The first experiment (Exp1) represents the situation without any control. The splits were constant during the whole day. Next experiment (Exp2) aimed at local control of microregions only and the third one (Exp3) at local together with coordination control.

The last experiment (Exp4) aims again at the local control but of the transformed microregion - the whole traffic region was reconsidered as one single microregion of 10 signal control junction. Such control should be optimal. This experiment was important for finding how close is solution of the coordination level to the optimal one.

The solutions were assessed by average queue length (AQL) that is the time average of sum of all queue length in a microregion. The results of the described experiments were the following:

Tab. 1: Average queue length

AQL	Exp1	Exp2	Exp3	Exp4
M1	236	100	65	-
M2	131	103	101	-
M1+M2	367	203	166	149

It is shown that each control level improves traffic situation over the fixed control and the suboptimal solutions are closed to the optimum.

9 CONCLUSIONS

The aim of this paper was to introduce new concept of a hierarchical traffic regulator, specially its local and coordination level. The local level controls traffic flows in a traffic microregion. A state space model for description of traffic microregions determines queue lengths formed on junction arms during the day in consequence of the traffic signal control. Some traffic net parameters need not to be accurate and therefore the state estimation is also realized on the local level.

The aim of the coordination level is to prevent negative influences between microregions. The model determines queueing vehicles within microregions. The coordination level uses the state estimates of the queue lengths, derived on the local level, thus no other estimation is needed.

All modelled relations and all traffic variable constraints considered for the optimization are linear and this fact allows us to use linear programming as the optimization method for determination of the required control parameters.

The basic properties and efficiency of the proposed models, estimation and control algorithms were tested. The results are very good and it is shown that each control level improves traffic situation over the fixed control.

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