Coordinated Control of Regional Networks

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1. Introduction

Integrated Network Management (INM) aims at deploying traffic management measures in a coherent way in order to improve the (traffic) conditions in a regional network. Although this concept is not new, only limited practical experience has been gained with deploying the concept in the field. This is partly due to the fact that many of the approaches put forward, such as Optimal Control (OC) or Model Predictive Control (MPC) are too involved, non-scalable and insufficiently transparent for field implementation, or are simply not taking into account the limitations of, for instance, available data in terms of quality and content that control decisions can be based on. In the full paper, we will discuss the different approaches proposed in literature in more detail.

In the Field Operational Test Integrated Network Management Amsterdam a control system has been designed, specified, implemented and tested in simulation and in the field. The functional system architecture is based on a *hierarchal control philosophy*, where the local, arterial, subnetwork and network levels are distinguished.
The overall controller (network supervisor) identifies archetype problem situations (e.g. bottleneck on the freeway, bottleneck on the urban arterial, spill back from the urban arterial to the freeway, and finally spill back from outside the controlled region); we refer to [1] for details on the overall controller design.

2. Study objective

In this paper, we focus on preventing or removing congestion on the freeway by means of metering the inflow from the urban arterials to the freeway. By doing so, we prevent or remove the capacity drop (difference in free capacity and the queue discharge rate of 10-15%). Since traditional ramp metering has limited effectiveness due to the scarce amount of space available to buffer traffic, the concept proposed in this paper uses *relevant bufferspace on the urban arterial* by coordinating the intersection controllers. *Relevance* is in this case predominantly determined by the fraction of traffic in the buffer heading for the freeway (referred to as the turn fraction in the remainder). Moreover, the buffers will be chosen such that queues in these buffers will not hamper traffic that is not heading towards the freeway too much.

A key functional requirement is that the control method can be implemented in practice and will be able to determine (near) optimal control actions in real-time. The coordinated urban arterial approach should also function as part of a coordinated freeway controller (i.e. coordinated ramp-metering).

3. Controller design and Methodology

The controller consists of a set of functions that will be described in detail in the full paper. One of these functions determines the metering rate $q_m(t)$ from the on-ramp to the freeway for time period t (usually a minute). This rate is determined such that congestion on the freeway is prevented, for instance using isolated or coordinated ramp-metering strategies; see for instance [1] and [2]. Given this metering rate and the amount of buffer space $s_r(t)$ still left on the on-ramp r, a second, composite function determines the changes in the traffic signal plans that realize the required reduction of inflow towards the on-ramp for all relevant intersection controllers on the urban arterial. In doing so, traffic is buffered on the arms of the intersections feeding the on-ramp allowing the ramp meter to meter longer and thus longer prevent the capacity drop.

We have developed two different algorithms that will work in conjunction to realize this buffering strategy: a *direct algorithm* that uses the required metering rate and determines the reduction in green time of the relevant phases of the signal control plan and a *feedback algorithm* that realizes an equal distribution of queues over the relevant buffers.

For the buffers j in the set J of buffers allocated to it, the direct algorithm determines the change in the green times of the phase to which the buffer belong is such a way that the joint flow towards the on-ramp is equal to the metering rate $q_m(t)$. In doing so, the queue on the on-ramp will not increase further and the ramp-meter can continue to meter. As a consequence, the available bufferspace $s_j(t)$ will change. Note that the direct controller needs the demand towards the buffer and the turn fraction towards the on-ramp to make this calculation.

Let the set O denote the buffers allocated to the feedback controller. For buffers $i \in O$, we use a feedback rule to determine the desired outflow from the buffer:

$$r_i(t) = r_i(t-1) + K_1 e_i(t) + K_2 \Delta e_i(t)$$

where $e_i(t) = \theta^*(t) - \theta_i(t)$ and $\Delta e_i(t) = e_i(t) - e_i(t-1)$; $\theta_i(t) = s_i(t)/s_i^{max}$ denotes the relative bufferspace left on buffer $i \in O$ at time t; the target value $\theta^*(t)$ denotes the average relative bufferspace of the buffers $j \in J$ controlled by the direct controller. The gains K_1 and K_2 are parameters of the feedback controller. A major benefit of the feedback controller is that it does not require demand predictions or the turn fractions.

The testing and tuning of the controller is done in four steps that are explained further in the paper: macroscopic simulation using simple queuing models, digital controller analysis, microscopic simulation using Vissim, and finally field implementation. In doing so, we gain insight into the controller behavior, enabling us to choose the optimal controller configuration (e.g. which buffers are controlled directly, which are controlled by the feedback controller). We can also choose the optimal set of controller parameters, and gain insight into the overall benefits of the controller (ex-ante and ex-post assessment).

4. Results and contribution

The full paper will show the results of all steps of the controller analysis and application, including the results from the field test.

A key contribution is the use of *digital controller design theory* to analyze the controller characteristics: we use the so-called z-transform to determine the controller transfer function $H(z)$, allowing us to analyze controller stability behavior by looking at location of the singularities of $H(z$\$ in the imaginary plane. As a result, we can analytically test and optimize controller design choices, and compare these to the outcomes of the macroscopic and microscopic simulation results. The use of this theory provides new avenues for traffic controller design.

Furthermore, we will present results of the field implementation of the controller and compare them to results from the desk research. This will reveal which practical issues, such as monitoring error, high levels of uncertainty in demands, etc., play a crucial role in the controller effectiveness, and will allow us to draw conclusions concerning the design methodology used to develop our system.

References

[1] Hoogendoorn, S.P., R.L. Landman, J. van Kooten, H. Taale, and M. Schreuder (2014). Integrated Network Management Amsterdam: Towards a Field Operational Test. Presented at the 93th Annual Meeting of the Transportation Research Board

[2] Papamichail, I. and Papageorgiou, M. (2008). Traffic-responsive linked ramp-metering control. Intelligent Transportation Systems, IEEE Transactions, vol.9, pp. 111--121