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Transportation Research Procedia 10 (2015) 226 – 235

Transportation Research Procedia

www.elsevier.com/locate/procedia

18th Euro Working Group on Transportation, EWGT 2015, 14-16 July 2015, Delft, The Netherlands

Integrated signal control and route guidance based on back-pressure principles

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Abstract

Traffic signal control and route guidance are the oldest and most applied dynamic traffic management measures. Most of the time they operate in a local mode, although there is trend toward network-wide traffic management. For traffic signal control already several network systems existed, but so far the integration with route guidance is lacking. In this paper we describe a new strategy to integrate traffic signal control and route guidance, based on the principles of back-pressure control. The algorithms developed are tested in a theoretical network and it was shown that traffic signal control based on back-pressure control performs well. Using back-pressure for route guidance required some assumptions which are open for debate. The results show that the average density is not such a good measure for route pressure and that travel time as a pressure variable performs better. A combination of factors of pressure based on density and travel time seems to be the best choice. Using back-pressure for both signal control and route guidance gave promising results, although the differences with optimized local control were small. Future research is recommended on the fine-tuning of the back-pressure traffic signal model, and on further integration and coordination of the control strategies. On the part of route guidance, finding representative route pressure values and making the model applicable of larger networks requires more research.

Peer-review under responsibility of Delft University of Technology

Keywords: traffic signal control; route guidance; traffic modelling; back-pressure

1. Introduction

Traffic conditions, such as congestion resulting into travel time delays, can be improved by balancing traffic demand and network capacity. Dynamic Traffic Management (DTM) systems are developed to improve spatial and temporal utilisation of infrastructures and vehicle fleets by means of dynamic signals. By timely response to changing traffic conditions, DTM goals, in terms of effective, safe and reliable use of the infrastructure, can be met. A number of trends can be distinguished which influence the development of DTM (Hoogendoorn et al., 2012), but two trends

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Peer-review under responsibility of Delft University of Technology
doi:10.1016/j.trpro.2015.09.072

are relevant for the research in this paper: a shift from local control towards network-wide control and a shift from collective traffic information towards individual advice.

Local traffic control (for example signalized intersections or ramp metering) usually consists of standalone systems. Each system optimises its actions, based on local measurements, to improve the local situation. If these local systems are integrated, larger areas can be managed as a whole. An example is a system that combines neighbouring signalised intersections into one system that coordinates the traffic lights and let platoons of vehicles flow without delay. Various types of traffic control and DTM services could be conducted to work as one system. Network-wide traffic management involves integrating the data collection and measures of a larger network area. A trade-off between the interests of multiple road authorities can be necessary, such as the performance of urban versus highway network. The Praktijkproef Amsterdam (Dutch for Field Operational Test Integrated Network Management Amsterdam) aims at gaining practical experience with applying integrated network management in a large-scale regional (urban and motorway) network (Hoogendoorn et al., 2014).

Besides using roadside systems to manage traffic flows, there are measures that can be directed at the individual road user. Individual advice can be transmitted via in-car technology, such as navigational devices or radio (RDS). This advice can consist of directions for a route to follow, or warnings in case of congestion, weather or dangerous situations. Innovations in vehicle and communications technology makes vehicles increasingly 'smart' and connected, which creates the possibility of interactions between vehicles, road side systems, and road authorities. In-car technology could be beneficial for various applications within DTM, such as individual route guidance, effective car-following, lane-changing, or dynamic speed limits. Moreover, dynamic vehicle data could be added to conventional data collection (such as loop detectors) for better estimation of the traffic state. The Dutch Ministry of Infrastructure and the Environment is keen on further development of services required to provide road traffic and travel information. It initiated a 10-year programme that aims to provide better service to travellers and reaching policy objectives for accessibility, quality of life and safety (Connekt, 2013).

However, until now in-car systems are typically used to improve the route choice of the individual road user (user benefit), whereas DTM aims at improving the network performance as a whole (societal benefit). These different interests are potentially in conflict. New systems should provide a trade-off between user and system utility, user acceptance and social improvements. This paper aims at integrating route guidance with signal control to balance the interests of the road users and road managers. It will focus on the development of a route guidance algorithm, integrated with an algorithm for signalised intersections, both based on the principles of back-pressure control. This control concept stems from communication networks and has the properties of reactive and feedback control, and can be implemented as a distributed or decentralized system. It is a simple and flexible approach, making it potentially appropriate for real-time traffic control.

In the remainder of the paper we first discuss some literature on the topic of integrating route guidance and signal control and on back-pressure. After that we describe the algorithms developed and we will test them in a simulation environment. Finally, the results will be discussed and some conclusions drawn.

2. Literature review

2.1. Route guidance

Route guidance can be considered as a way to influence or override the route choice behaviour. The goal of route guidance can be to minimise the total travel time for the network as a whole, a system optimum situation, or a user optimum where no road user can change its own route to a faster route. A route guidance system can be of use in everyday traffic conditions, but especially when the traffic conditions are irregular, or in case of an incident. Then, people can benefit from the information provided by the route guidance system (Papageorgiou et al., 2003).

There are three ways to receive route information. The first is pre-trip information, for example by means of radio, tv or internet. Traffic updates or route planners can provide the first routing advice (or another advice, e.g. to go by public transport). Secondly there is roadside collective route information displayed by variable message signs at strategic points in the network. The third type is what is considered in this paper, en-route route guidance, which can be provided by in-car navigation systems or other nomadic devices (Papageorgiou et al., 2003).