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Efficient Traffic Modelling and Dynamic Control of an Urban Region.

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Abstract

Traffic congestion in densely populated urban areas negatively impacts our standard of living. To mitigate these problems, a computationally efficient traffic model together with a hierarchal control strategy for traffic light timings is presented in this paper. While competing macroscopic models witness an exponential increase in computational complexities with every added junction, the proposed model adds only a linear computational demand per junction for comparable accuracy. The proposed model also accurately describes the block-back of upstream junctions due to the overflow of the queues from neighbouring urban intersections. A hierarchical control strategy based on this model is developed and tested in this paper. The comparative advantages of the hierarchical controller over decentralised control are highlighted through an example. Results will show that with minimal computational power, communication requirements and infrastructure investment, the hierarchical control strategy manages to minimise the effect of junction block-back by minimising the queues on critical road sections. The consistency of the results obtained is highlighted through a Monte Carlo run.

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1. Introduction

Continuous migration towards major cities around the world has brought an escalation in the number of inhabitants of urban areas. In this urban environment, mobility demands are exceeding the infrastructure capacity leading to increased traffic congestion. Expansion of the current road infrastructure is a possible

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solution, yet not always viable due to land-use restrictions and financial limitations. An alternative solution to the urban traffic congestion problem is a more efficient use of the current infrastructure through the adoption of dynamic and intelligent control strategies adaptable to prevailing traffic conditions. Such control strategies seek to increase the throughput of the urban traffic network by alleviating congestion at traffic bottlenecks often localized at the network intersections.

Dynamic control schemes applied to urban traffic control can be categorized as either centralized or decentralized strategies. A centralised control strategy seeks to find a global solution to optimise the traffic flow over the complete urban network thus obtaining a significant reduction in congestion and improved travel times. Nevertheless, centralized solutions require costly infrastructural investments for communication with the centralized controller as well as significant computational power at this central control unit. In a decentralised approach, an optimal solution is computed in real-time at each junction; a cheaper solution but with the significant setback that the local solutions do not provide a global optimum. In an effort to amalgamate both these ideas a hierarchical control strategy is being proposed, developed and tested in this work. The proposed methodology splits the complex control problem into multiple autonomous levels thus alleviating computational requirements while still approaching a globally optimum solution through the use of a centralised supervisory controller.

A number of dynamic control systems have already been implemented in various cities and have shown promising results. The two most popular implementations are SCOOT (Hunt, Bretherton and Royle, 1982) and the SCATS (Lowrie, 1982), which have been adopted in numerous cities around the world including Shanghai and Beijing. Both systems are fed with real-time information about current traffic conditions and apply changes to the split times, offsets and cycle times accordingly. The whole network is optimised centrally using a performance index. SCOOT and SCATS mostly focus on local level control by considering individual intersections or a small number of neighbouring intersections, thus their performance tends to deteriorate in heavy traffic (Papageorgiou et al., 2003).

A number of model-based control strategies have also been implemented including OPAC (Gartner, 1983), PRODYN (Farges, Henry and Tuffal, 1984) and RHODES (Sen and Head, 1997). Such systems can predict future traffic behaviour and apply appropriate control actions based on the dynamics of their models. The last decade also saw the introduction of the TUC system (Diakaki, Papageorgiou and Aboudolas, 2002), specifically aimed at urban traffic networks. The TUC system is based on a cost effective offline design of a feedback regulator aimed at controlling the traffic signals based on real-time measurements of traffic conditions. Although it has been successfully implemented in Greece and the UK, such an approach cannot handle constrains and hence requires a further sub-optimal tuning procedure.

Most model-based control strategies are developed on macroscopic models due to their low computational demands and control possibilities. Over the years, various macroscopic models have been introduced. In 1963, Gazis and Potts (1963) introduced the store and forward model on which the TUC system is based. This model represents the urban network as a graph of links and junctions, where each link is modelled using conservation theory. A model proposed by Kashani and Saridis (1983) and later extended by Van den Berg *et al.* (2003), models different traffic scenarios by updating a discrete-time model in small simulation time steps. Daganzo (1994) proposed the cell transmission model in 1994. This model is based on the kinematic wave equation, with average traffic flows and densities modelled on separate sections of each link. Although robust, this model is hampered by high computational requirements and thus might face some difficulties for real-time implementations. Recently Pecherkova, Dunik and Flidr (2008), proposed a novel computationally efficient model for an urban micro-region, which describes each junction through the dynamic evolution of the queue length, vehicle intensity and vehicle occupancy of the links leading to the junction.

The work in this paper expands on the model of an urban region as proposed by Pecherkova *et al*. and also provides a novel hierarchical control strategy to optimize the traffic flow within the region. The