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Control Engineering Practice 14 (2006) 1297–1311
CONTROL ENGINEERING PRACTICE
www.elsevier.com/locate/conengprac

A signal timing plan formulation for urban traffic control

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Received 5 November 2004; accepted 29 June 2005
Available online 15 August 2005

Abstract

This paper addresses urban traffic control using an optimization model for signalized areas. The paper modifies and extends a discrete time model for urban traffic networks proposed in the related literature to take into account some real aspects of traffic. The model is embedded in a real time controller that solves an optimization problem from the knowledge of some measurable inputs. Hence, the controller determines the signal timing plan on the basis of technical, physical, and operational constraints. The actuated control strategy is applied to a case study with severe traffic congestion, showing the effectiveness of the technique.

Keywords: Urban traffic control; Urban traffic model; Discrete time systems; Timing plan formulation; Optimization

1. Introduction

Traffic congestion of urban roads undermines mobility in major cities. Traditionally, the congestion problem on surface streets was dealt by adding more lanes and new links to the existing transportation network. Since such a solution can no longer be considered for limited availability of space in urban centres, greater emphasis is nowadays placed on traffic management through the implementation and operation of intelligent transportation systems (Di Febbraro & Sacco, 2004). In particular, traffic signal control on surface street networks plays a central role in traffic management. Despite the large research efforts on the topic, the problem of urban intersection congestion remains an open issue (Lo, 2001; Papageorgiou, 1999). Most of the currently implemented traffic control systems may be grouped into two principal classes (Papageorgiou, Diakaki, Dinopoulou, Kotsialos, & Wang, 2003; Patel & Ranganathan, 2001): (i) fixed time strategies, that are derived off-line by use of optimization codes based on historical traffic data; (ii) vehicle actuated strategies, that perform an on-line optimization and synchronization of the signal timing plans and make use of real time measurements. While the fixed time strategies do not use information on the actual traffic situation, the second actuated control class can be viewed as a traffic-responsive network signal policy employing signal timing plans that respond automatically to traffic conditions. The main decision variables in a timing plan are *cycle time*, *green splits* and *offset* (Diakaki, Papageorgiou, & Aboudolas, 2002). Cycle time is defined as the duration of time from the centre of the red phase to the centre of the next red phase. Green splits for a signal in a given direction of movement is defined as the fraction of cycle time when the light is green in that direction. Moreover, offset is defined as the duration from the start of a green phase at one signal to the following nearest start (in time) of a green phase at the other signal. A phase (or stage) is the time interval during which a given combination of traffic signals in the area is unchanged. In a real time control strategy, detectors located on the intersection approaches monitor traffic conditions and feed information on the actual system state to the real time controller, which selects the duration of the phases in the signal timing plan in order

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0967-0661/$ - see front matter
doi:10.1016/j.conengprac.2005.06.013

to optimize an objective function. Although the corresponding optimal control problem may readily be formulated, its real time solution and realization in a control loop has to face several difficulties such as the size and the combinatorial nature of the optimization problem, the measurements of traffic conditions and the presence of unpredictable disturbances (Papageorgiou et al., 2003). The first and most notable of vehicle actuated techniques is the British SCOOT (Hunt, Robertson, Beterton, & Royle, 1982), that decides an incremental change of splits, offsets and cycle times based on real time measurements. However, although SCOOT exhibits a centralized hardware architecture, the strategy is functionally decentralized with regard to splits setting (Diakaki et al., 2002). A formulation of the traffic signal network optimization strategy is presented in Wey (2000), that models traffic streams and includes constraints in the signal controllers. However, the resulting formulation leads to a complex mixed integer linear programming problem solved by branch and bound techniques. In addition, Lo (2001) adopts a cell-transmission macroscopic model that allows stating optimization problems providing dynamic signal timing plans. However, solving the resulting mixed integer program is computationally intensive and the formulation for real networks requires heuristics for solutions. Furthermore, Diakaki et al. (2002) propose a traffic-responsive urban control strategy based on a feedback approach involving the application of a systematic and powerful control design method. Based on the store and forward modelling approach and the linear-quadratic methodology, the technique proposed in Diakaki et al. (2002) designs off-line and employs on-line the traffic-responsive coordinated urban network controller. Despite the simplicity and the efficiency of the proposed control strategy, such a modelling approach can not directly consider the effects of offset for consecutive junctions and the time-variance of the turning rates and the saturation flows. On the other hand, a traffic-responsive plan is proposed in Lei and Ozguner (2001). Such a method needs as inputs the data relevant to traffic flows approaching the intersections, provided in Di Febbraro, Giglio, and Sacco (2004) by a hybrid Petri net model.

This paper proposes an urban traffic actuated control strategy to determine in real time the green splits for a fixed cycle time in order to minimize the number of vehicles in queue in the considered signalized area. The aim of the paper is to give a contribution in facing the *apparently insurmountable difficulties* (Papageorgiou et al., 2003) in the real time solution and realization of the control loop governing an urban intersection by traffic lights. To this aim, the paper pursues simplicity in the modelling and in the optimization procedure. Moreover, the macroscopic model introduced in Barisone, Giglio, Minciardi, and Poggi (2002) is revisited and modified to describe the urban traffic network (UTN). Although such a model is compatible with real time optimization and is suitable for vehicle actuated signal setting, it does not take into account realistic situations like the changing traffic scenarios, the different types of vehicles in the signalized area, the presence of vehicles in upstream junctions that reduce the travelling time of downstream vehicles, the pedestrian movements, the amber phases and the intergreen times. Hence, to give a more accurate and valid representation of real traffic systems, this paper considers in the model the presence of pedestrians, the classification of vehicles in the area, a proper evaluation of the travelling times and different levels of traffic congestion. Describing the system by a discrete time model with the sampling time equal to the cycle, the timing plan is obtained through the solution of a mathematical programming problem that minimizes the number of vehicles in the considered urban area. The minimization of the objective function is subject to linear constraints derived from the intersection topology, the fixed cycle duration and the minimum and maximum duration of the phases commonly adopted in practice. The optimization problem is solved by a standard optimization software on a personal computer, so that practical applications are possible in a real time control framework. The green phase durations are optimized on the basis of the real traffic knowledge and the technique requires traffic measurement in a prefixed set of cycles. In addition, the problem of synchronization of subsequent intersections is addressed to allow uninterrupted traffic flow. Indeed, an incorrect synchronization between successive intersections in the same direction may cause spillback phenomena: vehicles proceeding from one intersection to the downstream junction find only the concluding part of their green phase, and therefore line up in a queue which may produce oversaturation, blocking the upstream junction.

Finally, the actuated control strategy is applied to a case study representing a real signalized area with severe traffic congestion, located in the urban area of Bari (Italy), which includes two coordinated intersections. On the basis of limited traffic observations, appropriate selections of offset and optimal choice of the green phases are performed under different congestion scenarios. Several defined performance indices show that the introduced control strategy is able to reduce congestion even in oversaturated conditions and is attractive for use in real applications.

This paper is organized as follows. Section 2 describes the UTN model. Furthermore, Section 3 presents the actuated traffic control strategy and Section 4 presents the heuristic strategy for coordinating local traffic control signals. Moreover, Section 5 describes the case study and reports the results of the optimization performed under different traffic scenarios. Finally, Section 6 summarizes the conclusions.