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A logic programming based approach for on-line traffic control

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Abstract

In this paper we describe an effective approach to design, implement, and operate a traffic control system based on logic programming. With this approach it is possible to implement very flexible control strategies that can be easily developed by traffic engineers using a simple description language. An important feature of the system is the use of a very efficient logic programming solver, the Leibniz System, which is capable of generating fast solution algorithms for the decision problems associated with traffic signal setting. A micro-simulator has been developed to verify the effectiveness of the method. It is a crucial tool of an integrated development system, that allows one to develop control strategies and to test them before their on-field implementation. An application to a real case is described and experimental results are presented.

Keywords: Intelligent traffic control; Logic programming; Traffic micro-simulation

1. Introduction

Traffic control systems are one of the key factors that affect mobility in large urban traffic networks. The term *Intelligent Traffic Control* has been adopted to address the latest generation of traffic control methods that employ sophisticated modelling and optimisation tools to try and meet the demand for a more efficient and effective traffic network management.

In this context, traffic signal setting plays a relevant role. In general, a traffic signal setting system automatically produces decisions for every signalised junction of the traffic network with respect to the cycle length, the sequence of the phases and the green times. Modern technologies allow the implementation of several strategies of traffic signal setting, which differ according to the models and methods on which they are based, the costs of production and maintenance, and the effects produced. One basic distinction can be made between strategies based on predefined plans and traffic-actuated strategies. In the first case, many methods may be used to construct predefined plans for the different periods of the day, based on traffic data that has been

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previously collected. In the second case, traffic-actuated strategies are constructed on the basis of the current configuration of traffic flows or on the quantity of vehicles present at the controlled junctions. The plan is then constructed or modified as the situation on the network changes.

Traffic-actuated systems are also referred to as systems with *adaptive control*. The adaptive control systems are more complex and expensive, as they need to reliably acquire and evaluate information in real time. However, it seems evident that these systems prove to be potentially advantageous, being based on a larger quantity of information and being able to optimise the use of the road capacity even when the traffic is irregular or in the presence of unforeseeable events or emergencies.

To carry out regulation, a method which determines the values of the decision variables on the basis of the network configuration and traffic conditions must be applied. A commonly used class of techniques is composed of models of mathematical programming, consisting of a set of given parameters (network topology, cost parameters and flow pattern), a set of decision variables related to the cycle time, phase length and green times, a set of constraints which relate the assigned parameters to the variables, and finally an objective function that represents the performance parameter to optimise in the system.

Several control methods have been proposed and implemented: Among others, Chin (1987); Heydecker and Dudgeon (1987); Hisai (1987); Moller (1987); Smith (1987) and Smith et al. (1987); Cantarella et al. (1991a,b) propose an iterative approach for equilibrium network traffic signal setting.

Successful examples of adaptive systems are the SCOOT system (Hunt et al., 1981; Luk, 1984; Robertson, 1986; Bretherton, 1996) SCATS (Luk, 1984), UTOPIA (Mauro and Di Taranto, 1990), COP (Head et al., 1992; Sen and Head, 1997). Applications of the same type are described in Chen et al. (1987); Gartner (1983); Yagar and Dion (1996), and Skabardonis (1996).

In this paper we describe a methodological approach originally proposed in Felici et al. (1995, 1996) that differs substantially from those proposed in current literature, as it uses logic programming to implement the control strategy of a distributed and actuated control system.

It is based on logic variables (variables that can assume the values *true* or *false*), which describe the state of the traffic and control decisions, and on relations of a logical type (conjunction and disjunction of logic variables) between the variables considered.

Logic programming represents the decision-making process through relationships that are very close to the reasoning of a traffic expert and produces decisions for which one may reconstruct the reasons that led to them. These characteristics make the control process closer to the experience of a traffic expert, avoiding the use of a mathematical model and simplifying analysis and development of a traffic control system.

We assume that, by means of proper traffic sensors (inductive loops or cameras), it is always possible to know whether there are stationary vehicles or moving vehicles in each one of the accesses to the intersection.

The system is characterised by independent control units, each associated with a single intersection in the network. Each control unit receives the traffic data related to the roads approaching the intersection. An additional limited exchange of information may occur between neighbouring intersections. There is no hierarchical relation between the different control units in the network and there is no central unit to master the control process: each unit acts independently according to local data and to a specific control strategy. As already observed, data communication between control units and sensors is very limited and low-cost connections can be used.

We assume that the cycles may differ for phase duration and also for phase sequencing. The main role of the method is therefore to decide the time to cut the current phase of the signal cycle and to select the next phase. The solution algorithm that solves this control decision problem is precompiled off-line according to the logic control strategy and is then operated on-line in real time with standard commercial computers.

The paper is organised as follows: In Sections 2 and 3 the methodology proposed to design a control strategy through a logic programming-based approach is summarised, with reference to simple examples of signal setting problems. Section 4 briefly describes a general development system where the logic strategy is embedded, with the purpose of supporting the traffic engineer in designing, tuning, and maintaining the control system. Section 5 presents an on-field application to a real signalised intersection. The results of this experiment are outlined and discussed in Section 6, together with some concluding remarks. In the appendix the Leibniz System, a solver adopted to generate fast solution algorithms and solve logic programming problems, is briefly described.