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A memetic algorithm for real world multi-intersection traffic signal optimisation problems

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ABSTRACT

Traffic signals play a significant role in the urban transportation system. They control the movement of traffic on urban streets by determining the appropriate signal timing settings. Due to the stochastic nature of the traffic flow, deciding on the best signal timing settings is a computationally complex problem, with the result that traditional analytical methods have been found to be inadequate in dealing with real world scenarios. This issue has already been tackled using computational intelligence algorithms such as the genetic algorithm (GA). However, despite good results, GA may experience slow convergence, especially when dealing with constrained optimisation problems. To address this issue, we propose an adaptive memetic algorithm (MA) for optimising signal timings in real world urban road networks using traffic volumes derived from induction loop detectors. The proposed MA combines the strengths of GA with the exploitation power of a local search algorithm, in an adaptive manner, so as to accelerate the search process and generate high quality solutions. In this work, we propose two important techniques for improving the performance of a traditional MA. First, we use a systematic neighbourhood based simple descent algorithm as a local search to effectively exploit the search space around GA solutions. Second, to achieve a proper balance between the exploration of GA and the local search algorithm, we propose an indicator scheme to control the local search application based on the diversity and the quality of the search process. The proposed MA was tested in two different case studies for the cities of Brisbane, Australia, and Plock, Poland, using the well-known microscopic traffic simulator, AIMSUN. Results demonstrate that our MA is better than GA and traditional fixed-time traffic signal settings.

1. Introduction

The efficient operation of traffic signals is essential to the urban transportation system (Hunt et al., 1982). Traffic signals govern the movement of traffic on urban streets by manipulating the signal timing settings. Good timing settings increase traffic capacity and reduce delays and travel times, which in turn affect fuel usage and emissions (Akcelik, 1981). In practice, good settings deliver less congestion and smoother movements of traffic, whereas poor settings can result in a congested network. Thus, decisions driving the selection of signal timing settings will have a significant impact on the urban transportation system. As the volume of traffic in cities continues to grow, traffic signal timing settings become more and more challenging, and less able to cope with future demand. Indeed, it is very difficult, if not impossible, to design a precise model for generating signal timing settings that can capture all situations and/or uncertainties at urban intersections. Consequently, the urban transportation system needs to find an effective and efficient solution methodology to meet the ever increasing demand from traffic (Zhao et al., 2012).

Traffic control systems have been well-studied in the literature and various types were developed (Zhao et al., 2012). Existing systems have been categorised into two types: pre-timed (or fixed-time) and adaptive (Zhao et al., 2012). In fixed-time systems, the signal timing settings are determined based on historical traffic data and remain constant over pre-specified time periods. Although they are easy to implement and produce satisfactory results for a predictable traffic pattern, they do not capture the uncertainties of traffic demand, and they require regular updates to avoid loss of capacity (Bell, 1992). Adaptive systems, on the

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other hand, generate signal timing settings in a real time based on prevailing traffic conditions, and continuously adapt to the real-time traffic flow. These are more practical than fixed-time systems and can more efficiently cope with escalating demand (Zhao et al., 2012).

In this work, we consider the development of an adaptive, signal timing settings system, featuring multi-intersection traffic signal optimisation, which we test on two real world problems. The proposed algorithm uses traffic volumes derived from induction loop detectors to generate the signal timing settings in an on-line manner. Traffic signal optimisation is a computationally complex problem that needs an effective and efficient solution methodology (Zhao et al., 2012). In addition, owing to the stochastic nature and the uncertainties of traffic flow, traditional analytical methods have proven to be inadequate to the task of tackling real-world scenarios. Researchers and practitioners have therefore resorted to computational intelligence algorithms that can return good quality signal timing settings within an acceptable amount of time (Zhao et al., 2012).

Population based computational intelligence algorithms (Araghi et al., 2015) such as the genetic algorithm (Ceylan and Bell, 2004; Chin et al., 2011), harmony search algorithm (Ceylan and Ceylan, 2012), cross entropy algorithm (Maher et al., 2013) and particle swarm optimisation (Garcia-Nieto et al., 2013) have been widely used to generate the signal timing settings, with different levels of adaptability. Reinforcement learning (Khamis and Gomaa, 2014) has also been used. Reviews for the application of computational intelligence algorithms for traffic signal optimisation are available in Araghi et al. (2015) and Zhao et al. (2012).

The population based algorithms mentioned above presented improvements when compared to traditional analytical methods (Zhao et al., 2012; Araghi et al., 2015). However, despite these good results, most were developed to tackle only a single intersection involving a small number decision variables. In addition, it is well known in the scientific literature that population based algorithms often experience slow convergence especially when dealing with constrained optimisation problems (Moscato, 1989; Ong and Keane, 2004; Ong et al., 2006; Neri and Cotta, 2012). The work described here improves on the existing methodologies by considering multi-intersection traffic signal optimisation and proposes a hybrid optimisation scheme, called an adaptive memetic algorithm, to effectively solve the multi-intersection traffic signal optimisation in an on-line manner. More precisely, our work has the following features, which differentiate it from the work of other researchers:

1. We consider two real world traffic signal optimisation problems with very different characteristics: one in Brisbane, Australia, and the other in Plock, Poland. Both cases involve multiple intersections with various constraints and decision variables.
2. We propose an effective adaptive memetic algorithm (MA) to generate various traffic signal timing settings according to prevailing traffic flow conditions. The proposed MA combines the strengths of GA with a local search algorithm in order to accelerate the search convergence process and generate high quality solutions. Given the dynamic nature of the traffic flow, it is important that the developed algorithm should be able to adaptively explore and exploit the search space in order to accommodate changes in the problem. In our MA, GA is used to effectively explore the search space, while leaving the local search algorithm to fine-tune the generated solutions.
3. To effectively exploit the area around the given solution, we propose two important techniques to improve the performance of a traditional MA. First, we use a systematic neighbourhood based simple descent algorithm as a local search to effectively exploit the search space around GA solutions. Second, we propose an indicator scheme to control the application of the local search algorithm. The proposed indicator scheme uses the diversity and the quality of the search process to achieve a proper balance between exploration and exploitation as well as saving computational time. By controlling the local search application, MA can effectively adapt itself to dynamic changes in traffic flow, thus generating high quality traffic signal timing settings. Our aim is to address an important issue when developing an effective MA known as the local search application frequency (Ong and Keane, 2004; Ong et al., 2006; Sabar et al., 2016a).

To evaluate the effectiveness of the proposed MA, we coded it into the commercial microscopic simulator, AIMSUN, and tested it on two case studies for Brisbane and Plock. The computational results demonstrated that the proposed MA is better than GA and the traditional fixed-time signal settings.

2. Case studies

This section briefly outlines the case studies and introduces the problem formulation.

2.1. Brisbane

The Brisbane study area is located north of the Brisbane central business district (CBD) on one of this city's busiest urban corridors: the Bowen Bridge Road. The coded network is 673 m long, crossing two other busy roads: O'Connel Terrace and Gregory Terrace. For the purpose of implementing the proposed signal optimisation, stop-line detectors were installed to detect the passage of vehicles in all lanes approaching the intersections. Fig. 1 illustrates the Brisbane case study.

2.2. Plock

The Plock study area is a major signalised corridor, Wyszogrodzka Route 62, which traverses the CBD area from east to west. The coded network is a 1100 m section consisting of three key intersections and crossing roads near a shopping centre. Similarly to the Brisbane case, stop-line detectors were also installed. Fig. 2 illustrates the detector and lane configurations for the coded intersections.

2.3. Problem formulation

The case studies under consideration each have a network of signalised intersections. The set of signal timings to be optimised is referred as a solution $x = (x_1, x_2, \ldots, x_n)$, representing n green times of each phase at each intersection. The fitness function $D[\pi]$ is defined to evaluate each solution x in the set X of all possible solutions. Here $D[\pi]$ measures the traffic delay per vehicle exiting the study site, which is the difference between the estimated travel time to exit the study corridor and the free-flow travel time. $D[\pi]$ depends on a vector π of traffic-related variables from the loop detectors located under each lane at intersections. $D[\pi]$ is therefore estimated by a time-dependent form of Davidson's function, derived using the coordinate transformation technique in Akcelik (1981) and calculated as follows:

$$\min D = 0.25 \times T_f \times \left(z + \left(z^2 + 8 \times J_D \times S/(Q \times T_f)\right) \times 0.5\right) \tag{1}$$

where

$D =$ average traffic delay per unit distance (seconds per km).

$T_f =$ flow period constant (seconds), equals 7200 s in this study.