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Optimizing urban traffic light scheduling problem using harmony search with ensemble of local search

Kaizhou Gao*, Yicheng Zhang, Ali Sadollah, Rong Su

School of Electrical and Electronic Engineering, Nanyang Technological University, 639798, Singapore

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ABSTRACT

This study addresses urban traffic light scheduling problem (UTLSP). A centralized model is employed to describe the urban traffic light control problem in a scheduling framework. In the proposed model, the concepts of cycles, splits, and offsets are not adopted, making UTLSP fall in the class of model-based optimization problems, where each traffic light is assigned in a real-time manner by the network controller. The objective is to minimize the network-wise total delay time in a given finite horizon. A swarm intelligent algorithm, namely discrete harmony search (DHS), is proposed to solve the UTLSP. In the DHS, a novel new solution generation strategy is proposed to improve the algorithm's performance. Three local search operators with different structures are proposed based on the feature of UTLSP to improve the performance of DHS in local space. An ensemble of local search methods is proposed to integrate different neighbourhood structures. Extensive computational experiments are carried out using the traffic data from partial traffic network in Singapore. The DHS algorithm with and without local search operators and ensemble is evaluated and tested. The comparisons and discussions verify the effectiveness of DHS algorithms with local search operators and ensemble for solving UTLSP.

1. Introduction

With the increasing of population and vehicles, the traffic congestion becomes more and more serious in urban area. Thus, how to schedule traffic lights effectively turns to be more and more important for metropolises. A reasonable traffic lights scheduling can reduce the delay time in an urban traffic network system [1–4]. An urban traffic network consists of a set of road links connecting with each other via intersections. Each intersection consists of a number of approaches and the crossing area [5,6]. An approach may have one or more lanes but has a unique, independent queue. Approaches are used by corresponding traffic streams (veh/h), which means the number of vehicles through one intersection in one hour. Two compatible streams can safely cross the intersection simultaneously, while antagonistic streams cannot. In traditional traffic signal control, a signal cycle is one repetition of the basic series of stages at an intersection, where each stage consists of simultaneous traffic light signals allowing predefined compatible traffic streams to cross the intersection simultaneously. The duration of a cycle is called cycle time [7,8]. For safety reasons, constant lost (or inter-green) times of a few seconds are necessarily inserted between consecutive stages to avoid interference between antagonistic streams. For each traffic light, the ratio of the green time and the red time within one cycle is called the split, and the delay between the starting times of green periods of two neighbouring traffic lights along the same traffic route is called offset [9,10].

There are basically four types of characteristics that distinguish different traffic signal control strategies, i.e., fixed time strategies versus traffic responsive strategies, and isolated strategies versus coordinated strategies. Notable strategies proposed in the last few decades include, e.g., MAXBAND [11,12], TRANSYT [11,12], SCOOT [13], OPAC [14], PRODYN [15], CRONOS [16], and RHODES [17]. To solve the traffic light control problem, many researchers proposed various optimization approaches, e.g., particle swarm optimization [18], distributed coordination of exploration and exploitation [19] and Mixed-integer programming [20] and so on. Among the various approaches, meta-heuristics are very flexible and robust to the problem scale and random variables, have significant advantages in computational efficiency in terms of CPU time for large-scale real-lift applications, and become the new trend for solving real-life traffic light control problems. Existing models and approaches focused on many aspects of traffic light control problems. However, there are some insufficiencies. The first one is the limited prob-

* Corresponding author.
E-mail addresses: gaokaizh@aliyun.com, kgao001@e.ntu.edu.sg (K. Gao), yzhang088@e.ntu.edu.sg (Y. Zhang), sadollah@ntu.edu.sg (A. Sadollah), rsu@ntu.edu.sg (R. Su).

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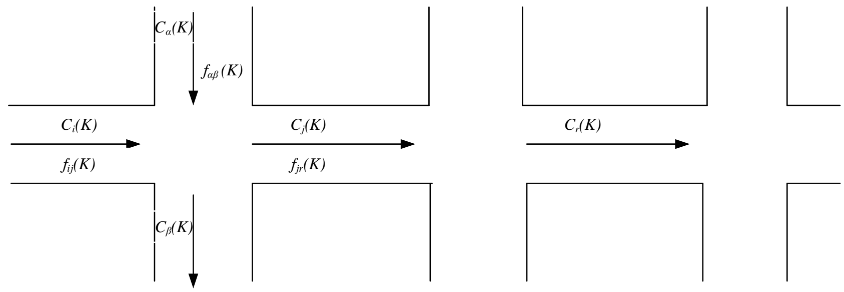

Fig. 1. Schematic view of a simple traffic network.

lem scale and constraints. Most models and approaches focused on one intersection or very limited regions. The second one is that most models and approaches have limitations in practical applications. The third one is most models are cycle programs and the light periods are fixed.

In this paper, we describe a traffic network by a dynamic flow model based on Daganzo's cell transmission models [21,22]. The novelty in this model is to describe each outgoing flow rate as a nonlinear mixed logical switching function over the source link's density, the destination link's density and capacity, and the driver's potential psychological response to the past traffic light signals. This outgoing flow rate model makes our approach applicable to both under-saturated and over-saturated situations. In our model, the traditional concepts of cycles, splits, and offsets are not adopted, making UTLSP fall in the class of model-based optimization problems, where each traffic light is assigned with a green light period in a real-time manner by the network controller. Upon this novel traffic flow model, we formulate the UTLSP, aiming to reduce the total waiting time over a given finite horizon by real-time scheduling the traffic signal (i.e., either GREEN or RED) for each traffic light in each intersection. The key technical idea is to coordinate traffic light signals in all intersections in response to real-time traffic conditions, which puts our UTLSP in the category of optimization-based coordinated traffic responsive strategies. Due to the large scale of an ordinary traffic network, which usually consists of hundreds of intersections and thousands of road links, the high computational complexity in optimization becomes the major hurdle for our real-time scheduling strategy.

In recent years, many meta-heuristics have been employed to solve many scheduling problems, especially Harmony Search (HS) algorithm. The HS is a relatively recent meta-heuristic method developed by Geem et al. [23] for solving optimization problems. It imitates the music improvisation process of musicians. A harmony in music is regarded analogous to a solution vector in the corresponding optimization problem, while the musician's improvisations are regarded analogous to local and global search processes in optimization algorithms. The HS and its variants have been employed to solve various optimization problems, e.g., water distribution networks [24], flow shop scheduling problems[25,26], job shop scheduling problems [27], knapsack problems [28], Electromagnetic Railgun problems [29], Distributed-Generation System [30], and so forth. Besides, an evolutionary harmony search algorithm was proposed for the loading pattern optimization (LPO) [31]. The literature [32] applied the HS algorithm to improve the connectivity in wireless sensor network. A quasi-oppositional HS algorithm is used to control automatic generation in power system [33]. Also, the HS algorithm is proposed for the vehicle routing problem with time window [34]. The literature [35] proposed an island-based model to improve the convergence of HS. HS and its variants were also employed for solving image reconstruction problems from projections [36], energy-efficient routing problems in wireless sensor networks [37], and highly constrained nurse rostering problems [38]. In these applications, HS is compared to many state-of-art meta-heuristics and the results and comparisons have verified that the HS algorithm can solve practical optimization problems with high competitiveness. The standard HS algorithm has some limitations. For instance, the large number of parameters used in the HS may be as its potential limitation. In each iteration, just one new harmony is generated. The population size should not be very large for the high speed convergence.

Building on the successful real-life applications and limitations of the HS algorithm, we propose a discrete harmony search algorithm to solve the UTLSP with minimizing the total network-wise delay time. In the DHS, a novel new solution generation strategy is proposed, and the number of new harmonies in each iteration is equal to the number of harmonies in population. Three local search approaches with different structures are proposed to improve the performance of DHS in local search space. An ensemble of local search methods is proposed to integrate different neighbourhood structures. The proposed DHS is employed to solving sixteen cases with different scales of the traffic network bearing features of the real traffic network in Singapore. The comparisons and discussions verify the effectiveness of the DHS algorithm with local search approaches and ensemble for solving UTLSP.

The remainder of this study is organized as follows. Section 2 describes the proposed model of the urban traffic light scheduling problem. In Section 3, the proposed DHS algorithm with ensemble of local search operators is presented in detail. The experiment design, comparisons and discussions are shown in Section 4. Finally, we conclude this paper with future works given in Section 5.

2. Urban traffic light scheduling problem

A traffic network consists of a set of links and intersections. For example, a simple unidirectional traffic network is depicted in Fig. 1, where each intersection has only two antagonistic traffic flows. We have proposed a discrete time model based on the cell transmission model. To simplify our technical discussions, some key notations in urban traffic signal scheduling problem formulation are listed as follows:

$C_i(k)$	The number of vehicles in link i in the time interval k.
$f_{ij}(k)$	The exit flow rate from link i to link j in interval k.
Δ	The sampling interval.
$\mathcal{L}$	The set of all one-way links.
$\mathcal{J}$	The set of all intersections.
ω	The stage in intersection, which consists of simultaneous traffic light signals allowing a predefined compatible traffic streams to cross the intersection simultaneously.
Ω_J	The set of stages in intersection J, $J \in \mathcal{J}$.
$\mathcal{F}_J$	$\mathcal{F}_J \subseteq \mathcal{L} \times \mathcal{L}$, the set of all streams in intersection J, i.e., $(i, j) \in \mathcal{F}_J$ means that there exists a traffic stream from link i to link j via intersection J.
$h_J : \Omega_J \to 2^{\mathcal{F}_J}$	The association of each stage to relevant compatible streams.

The following assumptions about a traffic network have been considered, which is suitable for a deterministic analysis: