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Transportation Research Procedia 10 (2015) 61 – 70

Transportation Research Procedia

www.elsevier.com/locate/procedia

18th Euro Working Group on Transportation, EWGT 2015, 14-16 July 2015, Delft, The Netherlands

Combined solution of capacity expansion and signal setting problems for signalized road networks

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Abstract

Traffic congestion has been growing at an unsustainable rate and decreasing the quality of life of people living in many countries especially in last few decades. At the same time, congestion causes decreasing accessibility and mobility whereas it leads to increase travel time and air pollution. Although various optimization techniques in determining signal timings or optimal capacity expansion have been discussed separately in the literature, few studies have been considered for solving the both problems simultaneously. Thus, it can be emphasized that the majority of literature fails to highlight an indispensable relationship between these two problems. To fill this gap, a bi-level solution methodology based on Differential Evolution (DE) algorithm is proposed in this study. The upper level deals with minimizing total system travel cost under given budget and signal timing plan while the User Equilibrium link flows are determined by VISUM at the lower level. In this study, the DE based solution algorithm is coded in VBA which is combined with VISUM for solving the problem. In order to illustrate the efficiency of the proposed algorithm, it is applied to real data of Sioux-Falls city network which has 76 links, 24 nodes and 552 OD trips. In this network, 7 nodes are considered as signalized junction, and 16 links which connect these nodes are chosen as candidate for capacity expansion. Results indicated that the proposed algorithm shows significant performance in solving the combined problem for signalized road networks.

Keywords: Capacity expansion; signal optimization; differential evolution; VISUM

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doi:10.1016/j.trpro.2015.09.056

1. Introduction

Since most of transportation problems are considerably complex and their solutions depend on large number of parameters, it is generally preferred to separate such problems into sequence of sub-problems. However, due to high interdependence of capacity expansion and signal setting problems, an indispensable relationship between these two problems should be taken into consideration. Since a Signalized Road Network Design Problem (SRNDP) with link capacity expansion has multiple objectives, it is common to formulate it using a bilevel model. As known, road users make route choice decisions based on the link capacities and signal settings in the process of traffic assignment at the lower level and planners try to redesign the capacity expansion plan and the signal settings based on road users' behaviour and the state of the road network at the upper level. Therefore, both problems should be solved simultaneously and thus more reliable results can be provided to decision makers/planners to design the signalized road networks. From a capacity expansion viewpoint, the first formulation for the Continuous Network Design Problem (CNDP) was proposed by Abdulaal and LeBlanc (1979). After this study, Suwansirikul et al. (1987) proposed equilibrium decomposition optimization heuristic for solving the CNDP and tested this heuristic on several networks. Following, a number of heuristic algorithms were developed for the CNDP (Friesz et al., 1990; Friesz et al., 1992; Friesz et al., 1993; Yang, 1995; Yang, 1997). Moreover, Chiou (2005) used gradient-based methods to solve the CNDP, and numerical applications are conducted in several test networks. Karoonsoontawong and Waller (2006) presented several heuristic methods for solving the resulting problem. Li et al. (2012) presented a global optimization method and converted the CNDP into a sequence of single level problems. Baskan (2013, 2014) attempted to solve the bilevel formulation of the CNDP using Cuckoo Search and Harmony Search algorithms, respectively. On the other hand, from the point of signal setting problem, Allsop and Charlesworth (1977) proposed a mutually consistent approach for signal setting problem. Heydecker and Khoo (1990) proposed a linear constraint approximation to the equilibrium flows and solved signal setting problem as a constrained optimization problem. Yang and Yagar (1995) proposed a sensitivity analysis based algorithm to solve the SRNDP. Moreover, Cascetta et al. (2006) discussed models and algorithms for the signal setting problem with stochastic traffic assignment where numerical tests are reported on a small-scale real network. Teklu et al. (2007) considered the problem of signal timing optimization in a road network and GA based algorithm is proposed for solving the resulting problem. Dell'Orco et al. (2013) presented a bi-level formulation for finding optimal signal settings under Stochastic User Equilibrium (SUE) conditions.

An overview to the literature reveals that finding of optimal signal timings or capacity expansion plan has been discussed separately in most cases. However, considering both problems together, few studies have been carried out in the literature. That is, Ziyou and Yifan (2002) raised that solving signal setting problem with link capacity expansions provides more realistic information for planners. Chiou (2008a) considered a signalized road network where the set of link capacity expansions and signal settings are simultaneously determined. Promising results are obtained after numerical calculations performed. Similarly, Chiou (2008b) presented a solution model for a signalized road network with link capacity expansions by considering the maximum possible increase in travel demands. Karoonsoontawong and Waller (2010) developed a robust optimization formulation that simultaneously solves capacity expansion, signal optimization and dynamic traffic assignment problems.

The organization of this paper is as follows. In next section, problem formulation is given. The solution algorithm is presented in Section 3. Numerical applications are explained with the results of the proposed model in Section 4. In last section, conclusions and future studies are remarked.

2. Problem formulation

The notations used in this paper are given as follows:

A the set of links in the network

K_{rs} the set of paths between O-D pair $rs \forall r \in R,\ s \in S$

R the set of origins in the network

S the set of destinations in the network