Reserve Capacity of Mixed Urban Road Networks, Network Configuration and Signal Settings

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ABSTRACT

The authors formulate the transportation mixed network design problem (MNDP) as a mixed-integer bi-level mathematical problem, based on the concept of reserve capacity. The upper level goal is to maximize the reserve capacity by signal settings at intersections, determine street direction and increase street capacities via addition of lanes. The lower level problem is a deterministic user equilibrium traffic assignment problem to minimize the user travel time. The model being non-convex, meta-heuristic methods are used to solve the problem. A hybridization of genetic algorithm with simulated annealing and a bee algorithm are proposed. Numerical examples are illustrated to verify the effectiveness of the proposed model and the algorithms.

KEYWORD

Bee Algorithm, Bi-Level Programming, Hybrid Genetic Algorithm, Mixed Road Network Design Problem, Reserve Capacity

INTRODUCTION

Network designers seek ways to improve transportation networks to satisfy the growing traffic demands in an urban transportation network. There are several ways to improve the network performance, such as street expansion, street construction, signal setting in signalized intersection, toll setting and proper street direction setting. The problem dealing with such issues is called Road Network Design Problem or Network Design Problem (NDP).

In general, NDP can be considered as a combination of hierarchical decisions in transportation planning including strategic, tactical and operational (Magnanti and Wong, 1984). Strategic decisions or long-term decisions are related to the infrastructure of the transportation network, such as building new streets and expanding streets by addition of lanes to the existing streets. Tactical decisions are concerned with the effective infrastructure and resources. Determining the allocation of street lanes and street direction settings are tactical decisions. Operational decisions or short-term decisions are more concerned with the flow of traffic and demand management or scheduling problem. Signal settings at intersections and scheduling of repairs on streets are examples of short-term decisions.
In general, based on the nature of the decision variables, NDP can be categorized into three groups. The first group is the Discrete Network Design Problem (DNDP), which deals with constructing new streets or adding lanes to the existing streets. Continuous Network Design Problem (CNDP) is the second group of NDP, which is about continuing design decisions. Continuous capacity expansion of the existing streets, signal settings and toll settings are examples of continuous decision in CNDP. The third group, Mixed Network Design Problem (MNDP) is a combination of the discrete design and the continuous design. These problems consider both discrete and continuous decision variables simultaneously and present more realistic models of the transportation planning decisions. MNDP is more effective, but it is more difficult in comparison with CNDP and DNDP.

LITERATURE REVIEW

Farahani et.al. (2013), a review of the definitions, classifications, objectives, constraints, decision variables and solution methods of the urban transportation network design problem are provided. This review shows that most studies on NDP are about CNDP. Most studies on CNDP lead to the development of algorithms and most problem definitions are similar (Abdulaal and LeBlanc, (1979); Marcotte, (1983); Davis, (1994); Ziyou and Yifan, (2002); Chiou, (2005); Gao, et. al. (2007); Chiou, (2008); Xu et. al. (2009)). Studies on DNDP are more limited, in comparison with CNDP because of the discrete variables. Researchers have mostly used heuristic and meta-heuristic algorithms to solve DNDP (Lee and Yang, (1994); Drezner and Salhi, (2002); Drezner and Wesolowsky (2003); Zhang and Gao, (2007); Poorzahedy and Rouhani, (2007); Wu et.al. (2009); Wang and Lo (2010)). Work on MNDP has been scarce in the past decade; the studies are summarized in Table 1.

Table 1. A summary of existing studies on mixed network design problems

<table>
<thead>
<tr>
<th>Source</th>
<th>Objective</th>
<th>Decision Continuous</th>
<th>Decision Discrete</th>
<th>Solution Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yang and Bell (1998)</td>
<td>General weighted sum multi-objective</td>
<td>Street capacity expansion</td>
<td>Constructing new streets</td>
<td>Enumeration scheme with other methods</td>
</tr>
<tr>
<td>Cantarella et al. (2006)</td>
<td>Min. total travel time</td>
<td>Traffic signal setting</td>
<td>Orienting sequences of streets</td>
<td>Hill climbing, simulated annealing, tabu search, genetic algorithm, hybridization of tabu search</td>
</tr>
<tr>
<td>Dimitriou et al. (2008)</td>
<td>Max. profit</td>
<td>Road toll settings</td>
<td>Street capacity expansion</td>
<td>Genetic algorithm</td>
</tr>
<tr>
<td>Zhang and Gao (2009)</td>
<td>Min. total travel cost and construction cost</td>
<td>Street capacity expansion</td>
<td>Constructing new streets</td>
<td>Gradient based method with penalty function</td>
</tr>
<tr>
<td>Gallo et al. (2010)</td>
<td>Min. total travel time</td>
<td>Traffic signal setting</td>
<td>One way street setting</td>
<td>Scatter search</td>
</tr>
<tr>
<td>Luathepa et al. (2011)</td>
<td>Min. total travel time</td>
<td>Street capacity expansion</td>
<td>Constructing new streets</td>
<td>Cutting constraint method</td>
</tr>
</tbody>
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