European Journal of Operational Research 246 (2015) 762–771

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Discrete Optimization

Integration of selecting and scheduling urban road construction projects as a time-dependent discrete network design problem

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ARTICLE INFO

Article history:
Received 7 August 2014
Accepted 17 May 2015
Available online 23 May 2015

Keywords:
Transportation
Project selection
Network design problem
Scheduling of transportation projects
Genetic algorithm

ABSTRACT

Decision making on the selection of transportation infrastructure projects is an interesting subject to both transportation authorities and researchers. Due to resource limitations, the selected projects should then be scheduled during the planning horizon. Integration of selecting and scheduling projects into a single model increases the accuracy of results; however it leads to more complexity. In this paper, first, three different mathematical programming models are presented to integrate selecting and scheduling of urban road construction projects as a time-dependent discrete network design problem. Then, the model that seems more flexible and realistic is selected and an evolutionary approach is proposed to solve it. The proposed approach is a combination of three well-known techniques: the phase-I of the two-phase simplex method, Frank-Wolfe algorithm, and genetic algorithm. Taguchi method is used to optimize the genetic algorithm parameters. The main difficulty in solving the model is due to the large number of subsequent network traffic assignment problems that should be solved which makes the solution process very time-consuming. Therefore, a procedure is proposed to overcome this difficulty by significantly reducing the traffic assignment problem solution time. In order to verify the performance of the proposed approach, 27 randomly generated test problems of different scales are applied to Sioux Falls urban transportation network. The proposed approach and full enumeration method are used to solve the problems. Numerical results show that the proposed approach has an acceptable performance in terms of both solution quality and solution time.

1. Introduction

Transportation Infrastructure Project Selection (TIPS) is a common challenge in the field of transportation planning, particularly for transportation authorities, who always deal with a variety of potential projects, of which merely a limited number can be selected. The process of handpicking certain projects from the wide range of available options is of high complexity. Unless the TIPS process is planned with a scientific and comprehensive perspective, not only does the improvement of the available transportation system seem unlikely, but also it might worsen the status quo, which can in turn account for numerous negative outcomes such as increment of the direct and indirect costs (for both system administrators and users), jeopardy of human safety, public dissatisfaction with the transportation system, and so forth. Hence, the significant influence of the transportation system on the public life necessitates an in-depth and wise attitude toward the TIPS process.

Another issue that needs to be addressed along with project selection is project scheduling. In other words, it should be specified when the selected projects should be implemented along the planning horizon, because some constraints such as budget limitation may not allow these projects to be implemented simultaneously. Generally, two strategies for selecting and scheduling of projects can be considered. The first strategy involves the selection of projects prior to the scheduling, whereas the second strategy deals with the simultaneous selecting and scheduling of projects. It is more complicated to model and resolve the associated problems within the second strategy, though it provides more accurate and precise results for a variety of reasons such as those discussed in the following:

- The main constraint in project selection is the availability of resources such as budget. Annual resource constraint can be applied in the model only when the projects have time dimension. Otherwise, only the total resources over the planning horizon (and not in different years) can be considered in the selection process. This will reduce the precision and it is even possible to select projects whose implementation with the consideration of the annual resource constraints is infeasible within the planning horizon.
- To ensure that transportation system achieves the expected short- and long-term goals, it is necessary to know when selected

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http://dx.doi.org/10.1016/j.ejor.2015.05.039
0377-2217/

projects are to be operated, a fact, which is dependent upon the scheduling of projects.

Therefore, it will be more suitable to determine scheduling of projects concurrent with selecting projects. However, integration of selecting and scheduling of projects in a single model makes it much harder to solve. Suppose there are n candidate roads for addition to the network and the planning horizon includes T years. In case our goal is only to select the projects, the total number of scenarios for addition to the network is 2^n. However, should we consider selecting and scheduling of project simultaneously, i.e. to specify which projects should be executed and in which year, then the total number of scenarios will be $2^{n\times T}$ which is much greater than the previous case. For example, considering $n = 10$ and $T = 5$, in first case (i.e. project selection alone) we will have $2^{10} = 1024$ scenarios, while in second case (i.e. selecting and scheduling of projects simultaneously) $2^{50} = 1.12 \times 10^{15}$scenarios should be checked (i.e. about 10^{12} times more). Although many of these scenarios would be infeasible due to constraints such as budget limitation, we need to evaluate all feasible scenarios to find the optimal scenario because of Braess's paradox (Braess, Nagurney, & Wakolbinger, 2005). This fact, alone, reveals the complexity of the integrated problem of selecting and scheduling of projects.

An application of TIPS problem, especially in developing cities, is to select among candidate roads to be added to the existing urban transportation network. This problem is inherently a Network Design Problem (NDP). NDP is the problem of improving or expanding transportation networks to optimize certain objective(s) under resource constraint(s) (Poorzahedy & Rouhani, 2007). The NDP can be posed either in a discrete form, which deals with the addition of new links to a transportation network, known as Discrete Network Design Problem (DNDP), or a continuous form which deals with the optimal capacity expansion of existing links in the network, also known as Continuous Network Design Problem (CNDP). Moreover, there is a Mixed Network Design Problem (MNDP), simultaneously involving both the discrete and continuous decision variables to determine the links which need to be improved and the new links which need to be added to an existing network (Yang & Bell, 1998). Therefore, the problem at hand is a DNDP. We focus on this problem with the aim of extending models for selecting and scheduling road construction projects simultaneously, and to propose an appropriate resolution approach. This paper is organized as follows: First, a literature review on road construction project selection problem is provided in Section 2. Next, three mathematical programming models are extended in Section 3 to integrate selecting and scheduling of urban road construction projects. The proposed approach to solve the selected model is presented and discussed in Section 4. Numerical examples to verify the performance of the proposed approach are given in Section 5. Finally, Section 6 concludes the paper.

2. Literature review

TIPS is an interesting subject for researchers in the transportation planning field. Therefore, a variety of models and algorithms have been already developed about it. Many authors have investigated the TIPS in the context of NDP. From an optimization point of view, the NDP can be viewed as a bi-level programming problem that includes system planners in the upper-level and users in the lower-level. The system planners make decisions about network configuration to improve the performance of the system, and the network users make choices about the routes of their travel in response to the upper-level decision. Since users are assumed to make their choices to maximize their individual utility functions, their choices do not necessarily align, and often conflict with the choices that are optimal for the system planners. Some researchers have presented exact algorithms such as branch-and-bound to solve this problem (e.g. Farvaresh & Sepehri, 2013; LeBlanc, 1975). It should be noticed that due to some of the inherent difficulties of this problem, such as the combinatorial nature and the bi-level structure, the exact methods can only deal with small networks which are not realistic enough. Therefore, researchers have presented a wide spectrum of approaches to assess the trade-off between accuracy and speed of the solution. Some of these studies are reviewed in Poorzahedy and Rouhani (2007) and Farahani, Miandoabchi, Szeto, and Rashidi (2013). One of these approaches that has enjoyed a considerable popularity in the recent years is applying meta-heuristic algorithms (e.g. Gallo, D'Acierno, & Montella, 2010; Poorzahedy & Abulghasemi, 2005; Poorzahedy & Rouhani, 2007; Szeto, Wang, & Wong, 2014).

Despite numerous studies performed for the selection of urban road construction projects, scheduling of selected projects has been less considered. Weng and Qu (2009) presented a model to determine road-building schedule. In this model, it is assumed that certain roads should be built in a given planning horizon, and the purpose is to determine the construction time of each road regarding the budget limitation. Objective function of the model is maximizing the total net benefit obtained from reducing the shortest paths. Given the complexity of finding the exact solution of the model, they presented a heuristic algorithm. Another assumption in this study is that the time required to build each road is equal to one planning period. Some authors proposed optimization frameworks to integrate selecting and scheduling of transportation projects. Most of these studies only focused on the capacity improvement of existing roads and not on the constructing new roads (e.g. Jiang & Szeto, 2015; Lo & Szeto, 2003, 2009; O'brien & Szeto, 2007; Szeto, Jiang, Wang, & Sumalee, 2013; Szeto & Lo, 2005, 2006,2008; Ukkusuri & Patil, 2009). Our literature review revealed that the only studies in which selecting and scheduling of urban road construction projects are simultaneously investigated are those conducted by Kim, Kim, and Song (2008), Szeto, Jaber, and O'Mahony (2010), and Miandoabchi, Daneshzand, Farahani, and Szeto (2015). Szeto et al. (2010) proposed a model for road network design considering the land use transportation interaction over time. Both link addition and link expansion are considered with capacity modeled as a discrete variable. Multimodal transport interaction is also captured in their proposed model. However, they provided no solution approach for this model and instead used a commercial solver. Considering the high non-convexity and difficulty of the proposed problem, they suggested developing a link-based formulation and an efficient global optimization technique based on one or more heuristics like genetic algorithms. Miandoabchi et al. (2015) proposed a model to determine the sequence of link construction, the expansion projects over the planning horizon, the configuration of street orientations, and the lane allocations for morning and evening peaks in each year of the planning horizon. They formulated the problem as a DNDP with two objectives: total travel time and total CO emissions. They utilized two multi-objective metaheuristics to solve the problem. A simplified assumption in Szeto et al. (2010), Miandoabchi et al. (2015), and also in most studies on scheduling of roads capacity improvement, is that construction or expansion of a road does not last more than one period. This assumption is not always true, especially in large projects in which it may take several years to complete the project.

Kim et al. (2008) assumed that certain roads with specific capacity, construction duration, and annual costs are candidates to be added to the network in a given planning horizon and the purpose is to determine which roads should be added in which planning periods so that the total travel time in the planning horizon is minimized. They modeled the problem as a DNDP and then presented two meta-heuristic algorithms to solve it. The point to be noted in scheduling of projects is that construction time of each project is related to technical limitations, which do not allow the project to be completed sooner than a certain time. On the other hand, the construction time is dependent upon the budget allocation, i.e., if more (less) funds are