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Prioritizing road extension projects with interdependent benefits under time constraint

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ABSTRACT

Since transportation projects are costly and resources are limited, prioritizing or sequencing the projects is imperative. This study was inspired by a client who asked: "I have tens of approved road extension projects, but my financial resources are limited. I cannot construct all the projects simultaneously, so can you help me prioritize my projects?" To address this question, the benefits and costs of all the possible scenarios must be known. However, the impacts (or benefit) of road extension projects are highly interdependent, and in sizable cases cannot be specified thoroughly. We demonstrate that the problem is analogous to the Traveling Salesman Problem (TSP). Dynamic change in travel demand during construction is another aspect of the complexity of the problem. The literature is yet to provide efficient methods for large cases. To this end, we developed a heuristic methodology in which the variation of travel demand during the construction period is considered. We introduce a geometrical objective function for which a solution-finding policy based on "gradient maximization" is developed. To address the projects' interdependency, a special neural network (NN) model was devised. We developed a search engine hybridized of Ant Colony and Genetic Algorithm to seek a solution to the TSP-like problem on the NN based on gradient maximization. The algorithm was calibrated and applied to real data from the city of Winnipeg, Canada, as well as two cases based on Sioux-Falls. The results were reliable and identification of the optimum solution was achievable within acceptable computational time.

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1. Introduction

Due to increasing travel demand, the need to provide new transportation facilities in addition to demand management policies is inevitable. Since resources are usually scarce, optimizing their use is imperative. This paper addresses the prioritization of road network expansion projects. Expansion projects include new road construction as well as capacity-additions such as adding lanes. Network expansion has been greatly discussed in the literature (Bagloee et al., 2013b) while less attention has been given to prioritization.

Prioritization is not limited to transportation and project management. Rather, it lies in the center of other disciplines dealing with a set of tasks to be processed in a timely manner or least cost or other concerns, such as prioritizing computation tasks waiting for CPU in computer science (Acton et al., 2012) and prioritizing customers (jobs) to be served (attended) in queue theory and industrial engineering (Homayoun and Ramanathan, 1994; Salvendy, 2001).

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The motivation of this study mainly arose from a request made by the authors' client in a municipality: "We have tens of approved road expansion projects; our budget and contractors' capability cannot handle them simultaneously. Simply help us prioritize the order of implementation." This question is also asked where a backlog of on-hold projects is waiting for decision (Berechman and Paaswell, 2005). Regardless, it may represent the situation in which the projects can have concurrent construction based on a steady stream of budget or resources but expecting an additional budget/resource (sometime at the beginning of fiscal phases) to be allocated. Hence, the question to be answered is which projects have highest priority to absorb the additional budget/resources.

Bagloee and Tavana (2012) try to address this question for sizable cases. In their analysis, the construction duration is not considered and the variation in travel demand during the projects' implementation is ignored. Bagloee and Tavana (2012) showed that when the problem is simplified by ignoring construction duration and demand variation, the problem is still highly intractable. In this study we add the time dimension to the attempt made by Bagloee and Tavana (2012). The problem is defined as follows: Given a number of projects and their construction times we seek for a priority plan based on which the contractor starts from the first project, and completes construction of each project consecutively until the end of the priority plan. The contractor cannot work on two projects concurrently. It is also assumed that the construction tasks of the projects are independent; otherwise the interlinked construction tasks can be tied together as a single project. Therefore the problem is to provide a priority plan, which says: project "x" has to be constructed first. Once it is finished, project "y", then "z" and likewise down to the end of priority list until all the projects are implemented. Since this definition includes consideration of construction duration time, we hereafter call it Dynamic Projects Prioritizing Problem (DPPP).

It is worth noting that the primary focus of this study is to address prioritization, better known as sequencing, which aims at identifying the order of projects. The output of the sequencing is then utilized for scheduling whereby methods such as 'resource based bound' identify a timetable of the tasks (Sprecher, 2000). This effort is referred to as scheduling with priority sequencing rules. For prioritization (or sequencing) the merits of the projects at a macro and strategic level are determined. However, for scheduling, the case is taken to a further micro level in which given the sequencing results, a detail plan of projects over time is produced (Nahmias and Cheng, 2009).

In some studies pertaining to time-dependent (dynamic) network design, where the demand varies over time, prioritization has also been discussed (Lo and Szeto, 2009; Salim, 1998; Wang et al., 2014). In these problems, a best (or good) subset of projects are sought and then prioritized based on some transport related merits. But in reality, external forces such as political factors, vested economic interests and agency rivalry may dictate some projects (Berechman and Paaswell, 2005). In some cases, the projects may have been put forward through local assessments, or un-finished projects are carried over from outdated evaluations. Subsequently, a common yardstick is required for prioritization. It is therefore more demanding to separate the prioritization from the network design. In fact, this study can be treated as the next stage after network design where the projects are already qualified and approved for construction. Having said that, one has to make the most of it, by ordering the constructions in a way that delivers as much benefit as possible. The benefit is identified in the customer market, where the market is mobility and the benefit is encapsulated as savings in disutilities involved in making a trip. The benefits can be normalized by the corresponding costs. Hence, under all things being equal, the less costly projects would have higher priority, leading to materializing benefit as early as possible.

The impact of project construction and prioritization may be observed in the resulting traffic flow. However, since the ultimate beneficiaries of road network expansion are its users, the benefit of prioritization may be defined as saved users' disutility or cost. In transportation, user cost is most often represented by "generalized" time. Generalized time is considered as the aggregation of various factors such as travel time, tolls, driving safety, and pollution costs (Sheffi, 1985). Throughout this study we refer to the generalized time simply as travel time (cost = time). To this end given the road network and travel demand the traffic assignment models render estimation for the users travel time.

Although the subject of this study is time-dependent and Dynamic Traffic Assignment (DTA) may seem more appropriate, we have opted for the use of statistic traffic assignment for two reasons: (i) the scalability of DTA to real size networks is still a prohibitive concern (Waller et al., 2013), and (ii) for long term planning, which is the case in this study, the statistic traffic assignment is widely used (de Dios Ortuzar and Willumsen, 1994).

The outcome of solving traffic assignment problem (TAP) is traffic flow across the network wherein every user chooses his shortest path and no user can find a shorter route unilaterally. As such, the users' shortest path is sensitive even to small changes in the road network, especially in a congested area. Any change in the road network may result in changes in travel times. Let us define a "Do-nothing" scenario consisting of a road network associated with its total travel demand. The benefit of a build scenario with a network change is defined as net saved travel time with respect to the Do-nothing scenario.

The contribution of projects to the overall benefit in different scenarios is highly intertwined and interdependent. To better understand this issue, consider two scenarios consisting of projects "x; a bridge" and "y; a ramp-access to the bridge" with benefits of "B_x" and "B_y" respectively. The benefit of a third scenario that has both projects is not necessarily "$B_x + B_y$". The only way to predict the benefit of this scenario is to solve the TAP. As the number of projects increases, the number of scenarios (which are composed of combinations of projects) will increase dramatically (for n projects, there are 2^n scenarios), hence it becomes computationally prohibitive. The DPPP stands visible among similar problems in scheduling theory due to the nature of the interdependency feature for which TAP (an equilibrium programing problem) needs to be solved. In fact, the DPPP can be viewed as a Mathematical Programming with Equilibrium Constraints (MPEC) with integer decision variables involved. The next section discusses how the aforementioned interdependency and the prioritization were addressed in the literature.

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