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Laboratory IBISC, Univ Évry, Université Paris-Saclay, Évry, France
gaoliping94@gmail.com,feng.chu@univ-evry.fr

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1 Introduction

Planning routes between two points over road networks is one of the most common travel planning tasks in modern metropolitan traffics [1].Traditional route planners usually focus on finding the shortest/fastest route over road networks. However, in real life, people occasionally tend to pay more attention to the process of the driving, such as enjoying the scenery while driving or looking for a safety route when driving at night. Thanks to the increasing popularity of GPS-equipped smart devices and location based social networks (LBSNs), the utility (e.g., beauty, safety/risky or happiness) on arcs can be modelled appropriately based on various user-generated data. As a result, route planning applications that can support personalized route queries have become a reality [2]. It requires us to optimize the route with more than one objective, according to the users' travel preference. For instance, people want the route with higher utility and less cost (e.g. travel time). However, in real cases, if the utility of route increases, the travel time may increase. Moreover, to satisfy the users' real-time requests, the fast response is usually mandatory.

Most of previous studies accomplish the route planning tasks on the basis of the *static* travel time and utility. However, in real-world scenarios, both travel time and utility on arcs are actually time-dependent. Specifically, the travel time between two points *varies* from time to time due to different traffic conditions. Likewise, the utility on each arc shall also be *dynamic*. For instance, some arcs are more worth to be enjoyed at nighttime because of a better sightseeing. We name such two-fold time-dependency on the arc as 2TD for short. The single-objective 2TD problem has been investigated and proved to be an NP-hard problem . It aims to find a route between two points by maximizing the accumulated utility within the given cost. To detect the cost and utility trade-off, we formulate the 2TD problem with a bi-objective framework. The two objectives are to minimize the total cost and to maximize the total utility of a route.

2 Solution method

We propose a bi-objective integer linear programming model for the 2TD problem. Due to the large-scale road networks which include hundreds of thousands of nodes and arcs, the problem has strong NP-hard nature, especially in the case that the 2TD characteristic is added. To solve the problem, we use the ϵ-constraint method which is known to be one of the most effective approaches for the bi-objective optimization problem [3]. To satisfy the users' real-time requests, we do not focus on finding the optimal solution by directly with LP solver (e.g., CPLEX). Instead, we develop an efficient ϵ-constraint-based heuristic algorithm to solve it. The main idea is to transform the bi-objective problem into a series of single-objective problems which can be solved to obtain an approximate Pareto front. In more detail, the proposed algorithm includes the following steps. Firstly, the objective of minimizing total cost is transformed into constraints, then, we get a series of single-objective problems which aim to maximize the utility of the route by bounding the cost with an allowable ϵ. Secondly, the ϵ's range is determined. Considering the requirement of the fast response time in the route planning, we propose an efficient approach to obtain the approximate ideal and nadir points. Thirdly, a two-phase heuristic framework is developed for the single-objective ϵ-constraint problems. Specifically, in the first phase, we construct the auxiliary data structure, i.e., the arc table, to manage the time-dependent information about arcs. In the second phase, the route is generated efficiently by an iterative arc table visiting process.

3 Computational results

The route planning algorithm is coded using Python language. All programs are run on an Intel(R) Xeon(R) Gold 6151 workstation with 192-GB RAM and running Windows Server 2019 OS. Small-scale synthetic road networks are used to evaluate the effectiveness and efficiency of our method, compared to the optimal Pareto solutions obtained by the CPLEX. Two real-world road networks are also used in our evaluations, including the city of Chengdu (CD) and the city of Chongqing (CQ), in China. CD road network contains 4,819 nodes and 6,385 arcs and CQ road network contains 5,056 nodes and 7,355 arcs. For both road networks, we use the time-dependent scenic score as the utility on each arc. The time-dependent travel time on arcs is generated by a travel speed model proposed in [4]. To verify the effectiveness and efficiency of the proposed algorithm, we randomly select the origin and the destination from the road network for testing. The results show the proposed algorithm is able to find high-quality Pareto solutions efficiently.

4 Conclusion and perspective

We propose a bi-objective integer linear programming model for the 2TD problem. An efficient ϵ-constraint-based heuristic algorithm is developed to solve it. Two real-world road networks are used for the evaluation. Results show the effectiveness and efficiency of the proposed algorithm. In the near future, we plan to improve the solution quality for 2TD large-scale problem by integrating some sophisticated meta-heuristic or math-heuristics. Then, we intend to extend the algorithm to work adaptively for more complex situations, e.g., the shared-route planning and the multi-preference route planning.

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