Transportation Research Part B 91 (2016) 332–343

Contents lists available at ScienceDirect

Transportation Research Part B

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

Travel itinerary problem

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ARTICLE INFO

Article history:
Available online 10 June 2016

Keywords:
Travel itinerary problem
Implicit enumeration algorithm
Smart travel

ABSTRACT

In this study, we propose a travel itinerary problem (TIP) which aims to find itineraries with the lowest cost for travelers visiting multiple cities, under the constraints of time horizon, stop times at cities and transport alternatives with fixed departure times, arrival times, and ticket prices. First, we formulate the TIP into a 0–1 integer programming model. Then, we decompose the itinerary optimization into a macroscopic tour (i.e., visiting sequence between cities) selection process and a microscopic number (i.e., flight number, train number for each piece of movement) selection process, and use an implicit enumeration algorithm to solve the optimal combination of tour and numbers. By integrating the itinerary optimization approach and Web crawler technology, we develop a smart travel system that is able to capture online transport data and recommend the optimal itinerary that satisfies travelers' preferences in departure time, arrival time, cabin class, and transport mode. Finally, we present case studies based on real-life transport data to illustrate the usefulness of itinerary optimization for minimizing travel cost, the computational efficiency of the implicit enumeration algorithm, and the feasibility of the smart travel system.

1. Introduction

Travel is defined here as the movement of people between relatively distant places; it generally includes short stays between successive movements. Traditional travel decision-making problems use route choice behavior analysis (Iida et al., 1992), travel forecasting (Bar-Gera and Boyce, 2003), air-travel itinerary share (Koppelman et al., 2008), intersection movement-based dynamic route choice (Long et al., 2013), walk-ride itinerary optimization (Jonge and Teunter, 2013), among others. In the era of big data, however, there exists an emerging demand for smart travel: a traveler plans to depart from an origin city, visit n intermediate cities, and arrive at a destination city within a predetermined time horizon. First, the traveler determines the tour, i.e., the visiting sequence among intermediate cities. Second, he/she makes sound decisions about the transport modes and numbers for each section of the itinerary. During this process, the departure times and arrival times associated with transport alternatives and stop times at intermediate cities must be considered to ensure the feasibility and continuity of travel. The travel itinerary problem (TIP), which finds itineraries with the lowest travel cost, is extremely attractive to such travelers but difficult to solve. First, there is the need for a comprehensive optimization model to cover all of the constraints and objectives. Second, there is the need for designing a powerful algorithm to compare the numerous potential itineraries. To the best of our knowledge, no study has provided these tools.

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http://dx.doi.org/10.1016/j.trb.2016.05.013

The TIP has its roots in the traveling salesman problem (TSP), which can be simply stated as follows: given a collection of cities, find the lowest cost tour that visits each city exactly once and returns to the starting point. Compared with the TSP, the TIP has some special constraints. First, for each pair of cities, there are regular transport modes and numbers, and each transport alternative has a fixed departure time, arrival time, and ticket price. Second, there is a minimum stop time at each intermediate city. Third, the traveler must plan his/her journey within a time horizon. Although TSP variants and generalizations have been studied quite extensively (a vast collection of resources and information can be found at http://www.math.uwaterloo.ca/tsp/), including TSP with time windows (Dumas et al., 1995), TSP with deadlines (Campbell and Thomas, 2008), TSP with interval values on travel time (Montemanni et al., 2007), TSP with stochastic travel time (Toriello et al., 2014), TSP with time-dependent travel cost (Cordeau et al., 2014), and so on, restrictions on transport alternatives, stop time at cities, and time horizon have never been investigated. In this study, we consider all of these issues, and formulate the TIP into a 0–1 integer programming problem, which is proved to be a new extension of the TSP.

The NP-hard TSP (Garey and Johnson, 1979) has been more widely studied than other combinatorial optimization problems, as it is so intuitive and suitable (Hill, 1982) for formulating various practical issues, such as the order-picking problem (Ratliff and Rosenthal, 1983), school bus scheduling problem (Graham and Nuttle, 1986), mailbox collection route choice (Laporte et al., 1989), split-demand capacitated vehicle routing problem (Salazar-Gonzlez and Santos-Hernndez, 2015), and so on. (Khanra et al., 2015) considered a profit maximization problem with crisp expenditure and return, and handled the stop time at each city as the decision variable. In the TIP we proposed in this study, the stop times at each city are given as constant values according to the users' demands. The TIP aims to report the optimal route and tour selection strategy which forms the best travel itinerary for users. Smith and Thompson (1977) introduced a LIFO implicit enumeration search algorithm for the symmetric traveling salesman problem. Balas and Christofides (1981) solved the TSP by proposing a restricted Lagrangean approach. Crowder and Padberg (1980) presented cutting-plane methods for solving large-scale symmetric traveling salesman problems to optimality. Johnson and McGeoch (1997) surveyed a wide range of algorithms that run the gamut from implicit enumeration, through local search, simulated annealing, tabu search, and genetic algorithms to neural networks. For small-scale problems, the implicit enumeration algorithm has good performances for both optimality and computation time. For large-scale problems, heuristic algorithms are used to select optimal solutions among all of the possible ones, but they do not guarantee that the best solution will be found. As the scale of the TIP is generally small (almost no traveler plans to visit dozens of cities at one time), in our work we use the implicit enumeration algorithm is used to find the global optimal itinerary in this study.

Big data is one of the key factors driving the evolution of traditional travel into smart travel, which fuels an unprecedented demand for the study of the TIP. With the advent of big data, travelers have the opportunity to improve their travel by effectively using smart phones and other mobile terminals. If we can capture the online transport data and solve the TIP quickly, we can help travelers reduce travel expense and save planning time. In this study, we explore a smart travel system that integrates the data collecting, data processing, and itinerary optimization procedures.

This study of the TIP makes three contributions. First, it boosts the development of the tourism industry by bridging the gap between travel demand and supply in the era of big data, by extending the proposed smart travel system to different kinds of travel decision support systems on both websites and mobile applications. Second, the TIP meets users' personalized travel requirements, and is able to significantly reduce costs in a convenient way. Website and mobile applications inspired by the TIP can enrich travel options and ensure efficient travel itineraries by developing user-friendly interactive interfaces based on effective optimization methodologies. Third, the big data constantly generated by various TIP-related applications will definitely improve smart travel planning, tourism promotion operations, tourism management, among other aspects of the tourism industry.

The rest of this paper is organized as follows. Section 2 formulates the TIP into a 0–1 integer programming model, and decomposes the itinerary optimization into a tour selection process and a number selection process. Section 3 designs an implicit enumeration algorithm to find the optimal combination of tour and numbers. Section 4 proposes a smart travel system by integrating the data collecting, data processing, and itinerary optimization procedures. Case studies based on real-life data are presented in Section 5. At the end of this paper, a brief summary is given.

2. TIP model

Suppose that a traveler plans to depart from an origin city 0, visit a set of intermediate cities 1, 2, $\cdots$, n, and finally arrive at a destination city $n+1$. The objective is to minimize the travel costs under the following constraints:

- there are regular transport modes and numbers linking each pair of cities, and each transport alternative has a fixed departure time, arrival time and ticket price (although the ticket prices may vary as the discount policies change, we assume that they are unchanged during the optimization process);
- each intermediate city is visited exactly once;
- there is a minimum length of stop at each intermediate city, denoted by s_i; and
- there is a fixed time horizon for the travel, with the start time denoted by $\underline{T}$ and the end time denoted by $\overline{T}$.

Remark 2.1. It is possible that the origin city coincides with the destination city; for example, the traveler may start and end in his/her home city. In this case, we consider them two different cities: the origin city and the destination city.