A new transit network design study in consideration of transfer time composition

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ABSTRACT

In order to minimize the total time cost of all the trips, a new transit network optimization model is developed in consideration of reducing not only time-consuming transfers but also trips which have to make relatively more transfers by optimizing the layout of the transit routes. In contrast to commonly taking the time cost of a transfer in a trip roughly as a constant in a public transit network design work, this research attaches much importance to the effect of the transfer time composition on the total time expense of a transit trip. A genetic algorithm is proposed to solve the newly developed optimization model. The bus route network in an urban region of a city in China is studied for example in this research. It is confirmed that the new optimization model solved by the proposed genetic algorithm is able to more rationally provide the optimal solution to the design of a relatively large-scaled transit network for its efficient operation. In future research, more experiments are necessary to further validate and improve the effectiveness and efficiency of applying the new model solved by the proposed genetic algorithm.

1. Introduction

The public transit network design which, in fact, from a mathematical viewpoint, belongs to the class of the combinatorial optimization (Nikolić and Teodorović, 2013) has been studied for a long time since the heuristic algorithm put forward in this research field by Lampkin and Saalmans (1967). In association with the operational characteristics of transit lines, such network designs attempt to develop rational route layouts for usually the most efficient transport services with the least costs (Ibarra-Rojas et al., 2015; Guihaire and Hao, 2008; Chakroborty, 2003). The influence of various factors including passenger demands, available vehicles, transport service frequencies, certain budgets, etc. is considered accordingly (Nayeem et al., 2014; Nikolić and Teodorović, 2013). Because different influencing factors often conflict with each other from the opposite interest perspectives of users and operators, the optimal solution to a transit network design task is generally not easy to be found (Ibarra-Rojas et al., 2015; Nikolić and Teodorović, 2013; Guihaire and Hao, 2008).

In order to optimally design transit networks in an efficient way, continuous efforts have been made on different aspects by researchers and practitioners in the world. For instance, from the perspectives of passengers, operators and overall system efficiency,
Shimamoto et al. (2010) evaluate an existing bus network by using a bi-level optimization model. In the work of Yu et al. (2012), the trips per unit length of a transit route are maximized by optimizing the route layout to improve transport efficiency of the whole transit network in consideration of the effect of direct trips, transfers and route length. Moreover, based on the bee colony optimization, a swarm intelligence based model is developed by Nikolić and Teodorović (2013) to maximize the travels with no or only one transfer per trip, and meanwhile, minimize the total transfers and time cost of all the trips. Thereafter, Nayeem et al. (2014) propose a similar model with the same objectives on the basis of a Genetic Algorithm (GA) with a changeable population.

Furthermore, Jiang et al. (2013) establish a mixed integer optimization model solved by a hybrid enhanced artificial bee colony algorithm to minimize the weighted sum of the transfers and the total travel time of all the trips by rationalizing the layout of the transit routes and the frequencies of the transport services. Szeto and Jiang (2014) develop a bi-level model made up of, at upper-level, a mixed integer non-linear model with the objective of minimizing transfers and, at lower-level, a transit assignment with the passenger capacity constraint, to optimize the layout of transit routes and the frequencies of transport services. A hybrid artificial bee colony algorithm is designed to solve the bi-level program. In constraints regarding transfer, infrastructure and passenger capacity, a mixed integer linear programming formulation extended based on bi-level mathematical programming is proposed by Cancela et al. (2015) to decide the number and itinerary of the bus routes and their transport service frequencies for the convenience of the users and the interest of the operators.

In addition, a multi-objective nonlinear mixed integer model solved by a GA is developed by Fan and Machemehl (2006) for the optimal design of a transit network with variable passenger demands, which is further improved with combining GA and simulated annealing algorithm (Fan et al., 2008). Afterwards, An and Lo (2016) put forward a two-phase solution algorithm combining the gradient method and the neighborhood search for a rapid transit network design under demand uncertainty. With regard to inter-urban transit services in a metropolitan area, Roca-Riu et al. (2012) propose a bi-level formulation to optimize the layout of bus routes and the locations of transfer stations for the minimal costs of users and operators in the effect of the user performances. A local search method based on the Tabu search algorithm (Glover and Laguna, 1997) is applied to guide the exploration in the solution domain. Moreover, according to the survey to potential users of a rapid transit network, a greedy heuristic procedure is presented by Escudero and Muñoz (2016) for generating the set of the transit lines under a budget constraint on the network construction cost.

Though many valuable research achievements have been made especially in recent years, the transfer time used in a transit trip has always been treated simply as an approximate constant value in transit network design studies. The effect of the exact transfer time consumed in a public transit trip on rationalizing the layout of the transit routes has not been fully considered. As a result, this research attaches importance to the impact of the transfer time cost changing mainly in accordance with the time expense for walking and waiting in a transfer of a transit trip upon the whole travel time of the trip. An optimization model is newly developed in this study to reduce the trips consuming relatively more time in a transfer and/or making relatively more transfers (i.e., in other words, over certain tolerable transfer times) per trip and minimize the total time expense of all the trips on a transit network by optimizing the layout of the transit routes. A new GA is proposed to find the optimal solution to the transit network design. A newly urbanized region of a city in China is selected as the study area in this research. The existing bus route network (with a relatively large scale) in the study area is optimized with the newly developed optimization model.

The remaining parts of this paper are organized as follows. The new optimization model is established in Section 2. Thereafter, Section 3 explains the proposed GA utilized to solve the newly developed model which is applied in Section 4 to optimize the bus route network in the study area. Finally, Section 5 makes the conclusions of this work and discusses some future research issues.
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