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The Memetic algorithm for the optimization of urban transit network

Hang Zhao [a,1], Wangtu (Ato) Xu [b,*], Rong Jiang [c,2]

[a] School of Geographic and Environmental Sciences, Guizhou Normal University, Guiyang 550001, Guizhou, China
[b] School of Architecture and Civil Engineering, Xiamen University, Xiamen 361005, China
[c] School of Materials and Architectural Engineering, Guizhou Normal University, Guiyang 550001, Guizhou, China

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ABSTRACT

This paper employs the Memetic algorithm (MA) to optimize the urban transit network. Aiming at the optimal route configuration and service frequency for the urban transit network, the objective function of the proposed mathematical model is to minimize the passenger (user) cost and to reduce the unsatisfied passenger demand at most. MA is one of the recent growing evolutionary computation algorithms. It is imbedded with the local search operator based on the classical genetic algorithm (GA) to improve the computational performance. We represent the solution with two single link lists (SLL), and design four types of local search operators: 2-opt move (Type A), 2-opt move (Type B), swap move and relocation move to obtain the better chromosomes for the GA. At the same time, an effective try-an-error procedure for verifying the local search operator is presented to increase the search efficiency. The algorithm has been tested with benchmark problems reported in the existing literatures. Comparing the results obtained by our algorithm and traditional algorithms which have been proved to be efficient, it demonstrates that the proposed algorithm could improve the computational performance relative to other algorithms.

1. Introduction

The transit system plays a significant role in the urban transportation system. Planning, operation and the optimal design of the transit system directly influences the service quality of the urban transportation system. In practice, the transit system plan consists of the following parts: (1) the transit network design; (2) the vehicle schedule plan; (3) the drivers dispatching plan. Among these three aspects, transit network design (TND) is one of the most important parts which determine the benefits of the transit operators, the costs of the users and the relevant social costs. It generally refers to restructuring the existing transit routes or adding new routes into the current transit network. Furthermore, it also includes the design of service characteristics (such as the fare cost, vehicle schedule and so on) for the transit routes.

In practice, when traveling by transit, a path with more than two transfers between the starting and terminating stations is commonly unacceptable. A transit network on which the majority of passengers could not travel directly from their origin to the destination should be reconstructed. Therefore, given transit stations as well as the direct travel passenger demands, how to determine the configuration for the transit routes is the most critical. On the other hand, it is apparent that the total travel cost between an origin–destination (OD) pair is depending on not only the configuration of the transit network, but also the service frequency of each transit route. So that we should determine the optimal service frequency of each transit route based on the passenger demand between all OD pairs. In a word, we would determine the optimal transit network structure for most of the direct travel passengers and the corresponding service frequency simultaneously.

In the academic research field, up to now nearly 100 years of the transit network design problem (TNDP), academic achievement could be described as voluminous. Vuchic (2005) had presented the textbook-style framework for TND process. Generally speaking, most of the research in this field presents two forms: the discrete and the continuous. Commonly, discrete formulations for TNDP are always designed as mix-integer programming or combinatorial optimization models. At this circumstance, these optimization models trended to lead to NP-hard problems (Frantti & Majanen, 2014; Irani & Nasimi, 2011; Nikolić & Teodorović, 2013; Xu, Wei, & Hu, 2009; Xu, Wei, & Wang, 2009). Although these formulations

* Corresponding author. Tel./fax: +86 592 2183505.
E-mail addresses: wazua@163.com (H. Zhao), ato1981@xmu.edu.cn (W. (Ato) Xu), littlefish_jiang@163.com (R. Jiang).
[1] Tel.: +86 851 6702162.
[2] Tel.: +86 851 4351718.

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for TNDPs were prone to be solved, they commonly could not reach to the global optimum. At the same time, NP-hard formulations for the large-scale TNDPs had to spend a lot of computational time during the solving process. Aiming at the tradeoff between the optimal solution and the computational resource, several researchers employed the continuous models for TNDPs (Asadi Bagloee & Ceder, 2011; Freyss, Giesen, & Muñoz, 2013; Gallo, Montella, & D'Acierno, 2011; Gao, Sun, & Shan, 2004). These studies were commonly based on the principle of transit equilibrium assignment and put forward a series of formulations to capture the transit flow assignment scheme as well as the optimal configuration and service attributes for the transit network.

Regardless of the form of the mathematical formulation, there are two main approaches for urban transit route designs. That is, to restructure the configuration of a single transit route and to optimize the total network. Objective functions of TNDP of these two approaches frequently involve the following considerations: (*a*) tradeoff between operator profit and cost (Asadi Bagloee & Ceder, 2011), (*b*) fleet size (Asadi Bagloee & Ceder, 2011; Langford & Cherry, 2012), (*c*) passenger's generalized cost (De-Los-Santos, Laporte, Mesa, & Perea, 2012; Guan, Yang, & Wirasinghe, 2006), (*d*) transfer time saving and transfer optimum (Navarrete & Ortúzar, 2013; Sivakumaran, Li, Cassidy, & Madanat, 2012) and (*e*) schedule optimization and coordination (Guan et al., 2006; Hadas & Ceder, 2010; Jin, Tang, Sun, & Lee, 2014).

A review of the literature also reveals various algorithms for the optimization to routing, schedules and timetables of urban transit. Some of the literature focuses on investigating heuristic and metaheuristic algorithms to improve search schemes and enhance the convergence of the solution. In this part we will briefly examine the papers that deal with heuristic and metaheuristic algorithms. Mandl (1980) presented a heuristic algorithm to compare and select better route sets. A hybrid heuristic approach, which relied on AI heuristics and search techniques and incorporated domain-specific human knowledge and expertise, was developed by Baaj and Mahmassani (1991), and the approach was extended by Shih and Mahmassani (1994) with timed-transfer transit systems. Baaj and Mahmassani (1995) proposed a Lisp-implemented route generation algorithm for the design of transit networks, and the improvement algorithm constitutes one of the three major components of an AI-based hybrid solution approach to problems of transit network design. Lee (1998) presented a methodology for transit network design with integrated routing and scheduling, and using an iterative approach offered greater flexibility to simplify combinatorial approaches. Fan and Machemehl. (2004) proposed a heuristic search procedure that guides the search techniques, including the genetic algorithm, local search, simulated annealing, random search and tabu search. Zhao (2006) described a metaheuristic search method for optimizing both transit network layout and headways. Zhao and Zeng (2006) proposed a global search method that combines genetic algorithm (GA) and simulated annealing to improve the method. Zhao and Zeng (2008) proposed a meta-heuristic method for optimizing transit networks, including route network design, vehicle headway, and timetable assignment, the objective was to identify a transit network that minimizes a passenger cost function, and a search scheme is presented to combine simulated annealing, Tabu, and greedy search methods. Mauttone and Urquhart (2009) proposed a constructive algorithm for the transit network design problem, and the algorithm was called Pair Insertion Algorithm to generate initial solutions for a local improvement or evolutionary algorithm, as well as to complete an unfeasible solution with respect to demand covering constraints. Fan and Mumford (2010) devised a simple model of the urban transit routing problem (UTRP) and a validated approach was presented by using simple hill-climbing and simulated annealing algorithms. Zhang, Lu, and Fan (2010) used the simple multi-objective optimization algorithm to obtain the optimal results of the promoted model for the UTRP. Curtin and Biba (2011) presented an innovative divide-and-conquer solution procedure for determining optimal transit routes, and the model maximized the service value of a route. Gallo, Montella, and D'Acierno (2011) examined the TNDP under the assumption of elastic demand, and focused on the problem of designing the frequencies of a regional rapid transit network. Estrada, Roca-Riu, Badia, Robusté, and Daganzo (2011) put forward the conceptual plans for geometric idealizations which were taken to generate the hybrid transit network as Badia, Estrada, and Robusté (2014) did. Asadi Bagloee and Ceder (2011) presented a heuristic methodology for the transit network design based on the conceptual framework formulated by Asadi Bagloee and Ceder (2011), Ceder (2011), Ceder, Chowdhury, Taghipouran, and Olsen (2013), Ceder and Perera (2014), Hadas and Ceder (2010), Mazloumi, Mesbah, Ceder, Moridpour, and Currie (2012). Nikolić and Teodorović (2013) developed a Swarm Intelligence based model for the TNDP. The Bee Colony Optimization algorithm was proposed to the TNDP. They also consider the TNDP in a way that a simultaneous transit network design and bus frequency on each of the routes was determined, and their approach to the TNDP was also based on Bee Colony Optimization algorithm (Nikolić & Teodorović, 2014). Chew and Lee (2012) proposed the genetic algorithm to solve the UTRP. Sivakumaran et al. (2012) proposed a heuristic method for the rapid transit route design problem, which was modeled on an undirected graph and cast as an integer linear program. Kechagiopoulos and Beligiannis (2014) designed an optimization algorithm based on particle swarm optimization to the UTRP.

Metaheuristics have become dominant approaches for solving the TNDP. Some approaches use the same formalism for the modeling and try to minimize an equivalent fitness function. In the majority of papers, Metaheuristics are provided to the TNDP for high-quality solutions within reasonable CPU time.

In this paper, we focus on some vital issues for practical purposes. The key objectives to be minimized are the total travel time (in-vehicle plus waiting time plus transfer time) and the passengers who have to make more than two transfers with a penalty coefficient. And in practice the waiting time of passenger depends on the service frequency of each transit line, bus capacity and bus fleet sizes (presented in the Section 2.2). More realistic assumption is the assumption that passenger flows depend on the transit network design, and passenger assignment should be determined by the transit line configuration. Passenger assignment in this paper is based on the procedure presented in the papers: Baaj and Mahmassani (1995, 1991), Shih and Mahmassani (1994) and Zhao and Zeng (2008).

Moreover, in terms of optimization strategies, the heuristics and metaheuristics had been used in the reviewed papers. One vital property of the heuristics and metaheuristics is the fact that they are not designed for a particular mathematical model, so the most part of methods mentioned above defined very general search frameworks and can adapt to almost any form of constraint and objective. Because the general search frameworks added extreme computational burden to the stochastic optimization for the TNDP, the main motivation of this paper is to propose a Memetic algorithm based on a local search operator to consider more particular information and characteristics for transit network design problem. The local search operator is the additional search mechanisms to be used as stand-alone operator or as complements to standard mutation. To enhance the convergence capacity of the algorithms, the proposed algorithms improve Memetic algorithms based on local search with multiple different neighboring structures, which are combined with more features extracted from urban transit network.