Transportation Research Part C 22 (2012) 58–75

Contents lists available at SciVerse ScienceDirect

Transportation Research Part C

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

Transit route network design-maximizing direct and transfer demand density

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ARTICLE INFO

Article history:
Received 29 December 2009
Received in revised form 2 December 2011
Accepted 5 December 2011

Keywords:
Transit network design
Demand density
Transfer coefficient
ACO

ABSTRACT

Transit network design is an important part of urban transportation planning. The purpose of this paper is to build on *direct traveler density* model and extend it to design transit network considering demand density relating to direct demands and transfers, and lengths of routes. The proposed method aiming to maximize demand density of route under some resource constraints divides transit network design problem into three stages, i.e., skeleton route design, main route design and branch route design, based on the objective functions with different transfer coefficients. An ant colony optimization (ACO) is used to solve the model. The model and algorithm are illustrated with data from Dalian city, China and results show that the approach can improve the solution quality if the transfer coefficient is reasonably set.

1. Introduction

Transit network design is an important problem in transportation planning and development, which has been studied for several decades. There have been many worthwhile researches on transit network planning. Dubois et al. (1979) designed transit network by identifying the roads needed for bus routes and choosing the set of bus routes. Then, frequencies of the designed routes were computed through a model aiming to minimize user waiting time. Hasselstrőm (1981) proposed a mathematical programming approach for transit network design by choosing the routes and determining frequencies concurrently. The methodology was capable of implementation and application for realistic network sizes. Ceder and Wilson (1986) summarized the bus network design approaches and presented a new approach and an algorithm to design bus routes based on both passenger and operator interests. Baaj and Mahmassani (1995) argued that a bus network could be generated by optimizing the route and the frequency, simultaneously. Van Nes et al. (1998) presented a transit route design method, in which route or frequency optimization was based on an economic criterion. Gao et al. (2004) presented a bi-level programming model for transit network design problem, which incorporated a transit equilibrium assignment model. Guan et al. (2006) used integer programming to optimize the line layout and assign trips in a given network, simultaneously. The model can be solved by standard branch and bound method. Pattnaik et al. (1998) presented a genetic algorithm (GA)-based optimization method to design transit network. The objective of their optimization model was to minimize the total cost of user and operator. Agrawal and Mathew (2004) presented an optimization model for transit network aiming to minimize the total system cost which is the sum of the operating cost and the generalized travel cost. They used parallel GA to solve the model. Bielli et al. (2002) developed a heuristic based on GA to design transit network. In the heuristic, a multi-criteria analysis was used to estimate the fitness values. Furthermore, they also applied an external envelope of an assignment algorithm when computing the fitness function. Yang et al. (2007) proposed a mathematical model for transit network design aiming to maximize direct traveler density that meant the number of direct travelers carried by per unit length of a route. The direct traveler density

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doi:10.1016/j.trc.2011.12.003

method was superior to the traditional direct trip method aiming to maximize the number of direct transit trips, since the method considered the route length while it maximized the direct transit demand.

However, in metropolitan areas, transit service cannot always provide direct service among all origins and destinations. Although much progress in transit network design has been achieved in the past several decades, the methods that can consider the total demands of the routes including direct trips and transfers in transit network optimization have received relatively little attention. Zhao (2004) proposed a model for large-scale transit network aiming to minimize transfers and optimize the route/network directness. Mauttone and Urquhart (2009) presented a constructive algorithm for transit network design problem, which took the interests of both users and operators into account. In the model a parameter was defined to describe the proportion of the total demand covered by routes indirectly. Schöbel and Scholl (2006) presented integer programming models and suggested a solution approach using Dantzig–Wolfe decomposition for solving the LP-relaxation. The model was aimed to minimize the number of transfers or the transfer time. Borndörfer et al. (2007) proposed a column-generation approach for route planning in which the passenger paths can be routed freely, and the routes were generated dynamically. In the model, transfers between different modes were handled by linking the networks with appropriate transfer edges, and the edges were weighted by estimated transfer times.

The purpose of this paper is to build on direct traveler density model proposed by Yang et al. (2007), and extend it to design transit network aiming to maximize transit trip density that is related to the total demands and the lengths of routes under the length, the directness and the demand constraints and so on. To compute transfer demands of the designed routes, incremental assignment method (Ferland et al., 1975), as an approximate equilibrium assignment approach, is used to assign passengers to transit route network. During passenger assignment, each proportion of passenger demand is placed to the path with the shortest travel time. The travel time of the shortest path contains waiting time at stops that is related to frequencies of routes (the waiting time = $1/2 * 60/\text{frequency}$), running time and the penalty of transfer. i.e., travel time = running time + waiting time + penalty of transfer.

Usually, many big cities in China all have a great population. And passenger transportation in these cities mainly relies on efficient public transportation systems. For large cities, public transit network can be divided into three levels: skeleton routes, main routes and branch routes according to the features of bus routes. Skeleton routes are main transit corridors with large passenger demand in urban public transit network. These routes are usually covered by some fast, large capacity transport modes, such as rail routes or bus rapid transit (BRT). Skeleton routes are mainly in relatively prosperous district, for example, large commercial center, regions with better transportation facilities or central residential areas. Main routes provide transit service between subway stations and nearby residential areas. They usually lay in the major trunk road with a high passenger demand. Compared with skeleton routes, main routes can cover larger areas. Skeleton routes and main routes together become the main forces in urban transit passenger transportation. The last one is branch route network. Branch routes link the road far away from the central city to skeleton routes or main routes. These routes are often covered by village buses, and mainly for transfers. They expand the coverage and accessibility of transit network. Although passenger volume on these routes is relativity small, they can extend within the community, thus improving the convenience of public transportation trips.

In this study, transit network design is divided into three periods according to the feature of transit routes. In the first period, skeleton routes are firstly designed based on transit trip origin–destination (OD). Then, main routes are designed based on the transit trip OD left by the designed skeleton routes. Lastly, branch routes are designed to cover the left transit trip OD by the above designed routes as possible.

For transit network optimization, e.g., skeleton, main or branch network, it is difficult to be solved through classical optimization techniques (Newell, 1979; Agrawal and Mathew, 2004). Recently many studies have proved that heuristic algorithms are suitable for large-scale transit network optimization problems, such as ant colony algorithm (Poorzahedy and Abulghasemi, 2005; Yang et al., 2007), genetic algorithm (Pattnaik et al., 1998; Chien et al., 2001; Bielli et al., 2002; Chakroborty, 2003; Agrawal and Mathew, 2004) and simulated annealing algorithm (Zhao and Zeng, 2006), etc.

Transit network design stated simply, relates to the determination of a set of routes with satisfying some pre-defined objectives. Transit route is designed by deciding the sequence of the stations including the origin terminal, intermediate stations and the destination terminal. Ant colony optimization (ACO) (Dorigo et al., 1996), inspired by the behavior of ants seeking food in the real world, is a probabilistic technique, and it has been used for solving approximately combinatorial optimization problems. The process designing transit route is very similar to the ant-foraging process in the real world, which may be described as follows. Ants start from the nest (i.e., the origin terminal) and search the food (i.e., the destination terminal). During the searching process, ants select the passing nodes (i.e., intermediate stations) according to some rules, and finally reach the food. If the origin terminal is considered as the nest and the destination terminal is considered as the food, transit route design can be described as the process of searching an optimal path from the "nest" to the "food". Thus, ant colony algorithm is used to solve the optimization model in this study.

This paper has been organized in the following way: Section 2 is about the optimization model, including the problem formulations and the basic notations of variables; Section 3 describes ant colony optimization for transit network design problem; numerical analysis is carried out in Section 4; and lastly, the conclusions are drawn in Section 5.

2. Optimization modeling

In this paper, transit route network optimization consists of three stages. At first, an empty network is built, and then skeleton routes are added in so as to maximize the direct traveler density until some constraints (e.g., route length con-