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Transit network design by Bee Colony Optimization

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ABSTRACT

The transit network design problem is one of the most significant problems faced by transit operators and city authorities in the world. This transportation planning problem belongs to the class of difficult combinatorial optimization problem, whose optimal solution is difficult to discover. The paper develops a Swarm Intelligence (SI) based model for the transit network design problem. When designing the transit network, we try to maximize the number of satisfied passengers, to minimize the total number of transfers, and to minimize the total travel time of all served passengers. Our approach to the transit network design problem is based on the Bee Colony Optimization (BCO) metaheuristics. The BCO algorithm is a stochastic, random-search technique that belongs to the class of population-based algorithms. This technique uses a similarity among the way in which bees in nature look for food, and the way in which optimization algorithms search for an optimum of a combinatorial optimization problem. The numerical experiments are performed on known benchmark problems. We clearly show that our approach, based on the BCO algorithm, is competitive with other approaches in the literature, and it can generate high-quality solutions.

1. Introduction

Urban road networks in a lot of countries are extremely congested. The consequences are high travel times, unforeseen delays, increased travel costs, increased air pollution, noise level, and number of traffic accidents. Transportation engineers and city authorities have developed and implemented various Travel Demand Management (*TDM*) techniques that increase travel choices to travelers (''Park-and-Ride facilities'', ''High Occupancy Vehicle (HOV) facilities'', ''Ride-sharing programs'', ''Telecommuting'', ''Congestion Pricing''). Still, the raising of the modal share of public transit in the cities is one of the major activities to be performed by traffic planners and city authorities. This could be done by proper design of public transit networks, expansion of existing lines and park and ride spaces, increasing the availability of direct service among origin–destination pairs, frequencies increase, development of the bus systems separated from the rest of the traffic network, transit service on nights and weekends, improving passengers' comfort and schedule reliability, better information systems for passengers (visual terminals and broadcasting information), etc.

Properly designed public transit network can significantly increase public transport mode share. The public transit network design problem is one of the most significant problems faced by bus operators and city authorities in the world. This transportation planning problem belongs to the class of difficult combinatorial optimization problem, whose optimal solution is difficult to discover. The bus network shape, as well as bus frequencies, highly depend on both passenger demand, and on the number and type of available buses (fleet size), and/or available budget. Poorly designed bus network can cause very long passengers' waiting times, and/or inexactness in bus arriving times. In addition, inadequately designed network can show high inappropriateness among the designed bus routes and paths of the majority of users.

Many of the factors that should be taken into account when designing bus network are mutually in conflict. For example, the shorter passengers waiting times, the higher the number of buses needed, etc. When designing the bus network, the interests of both the operator and the passenger must be taken into account. Due to the conflicting nature of these interests, we treat the bus network design problem as a multicriteria decision-making problem. When designing the transit network, we try to maximize the number of satisfied passengers, to minimize the total number of transfers, and to minimize the total travel time of all served passengers.

In this paper we develop the model for the bus network design problem. Our approach is based on the Bee Colony Optimization (BCO) metaheuristics. The BCO algorithm is a stochastic, random-search technique that belongs to the class of population-based algorithms. This technique uses a similarity among the way in which bees in nature look for food, and the way in which optimization algorithms search for an optimum of a combinatorial optimization problem. The numerical experiments are performed on known benchmark problems, as well as on the problems generated by the authors of the paper. Our approach is competitive with

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other approaches in the literature, and it can generate high-quality solutions within negligible CPU times.

The paper is organized in the following way. Literature review is given in Section 2. Section 3 contains statement of the problem. Proposed solution to the problem is given in Section 4. The BCO approach to the transit network design problem is explained in details in Section 5. Experimental evaluation of the proposed approach is given in Section 6. Recommendations for future research and conclusion are given in Section 7.

2. Literature review

Various models for transit network design have been developed in the literature.

Lampkin and Saalmans (1967) proposed the first heuristic algorithm to design transit route network. In the first step, the proposed algorithm produces an initial skeleton route. In the next steps, the other nodes are inserting one by one into the skeleton route. The case study of a small town in the North of England is also presented in the paper. Silman, Barzily, and Passy (1974) proposed a two-staged approach for transit network design. They first generated a set of route-candidates through several iterations. The authors determined the optimal vehicle frequencies in the second stage. Silman et al. (1974) tried to minimize passengers travel time, while simultaneously taking care about the total number of passengers who cannot find seats. Byrne (1975) considered the case when the region served by the public transit is a segment of a circle and may be defined in polar coordinates. He proposed the model of a transit system that is built in polar coordinates with radial transit lines. Mandl (1979) proposed heuristic algorithm to find the set of the best transit routes. He reported the gained experiences in the case of some real world problems. Newell (1979) performed theoretical analysis of the bus route network design problem. He discussed various aspects of the problem and concluded that "in essence, our conclusion is that it would require a large computer and a vast amount of data to determine even a nearly optimal route geometry". Ceder and Wilson (1986) described the bus network design problem, analyzed previous concepts and proposed a two-level methodological approach for solving bus network design problem. Baaj and Mahmassani (1995) proposed route generation algorithm (RGA) for the design of transit networks. The proposed approach combined expert's knowledge and search techniques using Artificial Intelligence tools. Ceder and Israeli (1998) defined objective function that takes into account both passenger and operator interests. The proposed model for the transit network design problem combines mathematical programming, and decision-making techniques. When solving the bus route network design problem, Pattnaik, Mohan, and Tom (1998) proposed two step procedure. They generated the set of the route candidates in the first step. In the second step, the authors decided about the final set of routes by using the genetic algorithms. Bielli, Caramia, and Carotenuto (2002) applied genetic algorithm approach when considering bus network optimization problem. They tested their approach in the case of city of Parma, Italy. Chakroborty (2003) also proposed procedures for solving the urban transit network design problem based on the Genetic Algorithm. Lee and Vuchic (2005) considered the transit network design problem in the case of variable transit demand, under a given fixed total demand. The authors offered iterative approach that takes care about the relationship between variable transit trip demand and transit network design. The proposed approach is tested on the relatively small transit network. Guan, Yang, and Wirasinghe (2003) proposed the model for simultaneous optimization of transit line configuration and passenger line assignment. The proposed model is solved by branch and bound method. Fan and Machemehl (2006) used the simulated annealing techniques to solve the optimal bus transit route network design problem. The proposed concept is tested in the case of three experimental networks. Zhao and Zeng (2006) combined genetic algorithm and simulated annealing while searching for the optimal route structures and headways. The authors tried to minimize transfers and total user cost, and to maximize service coverage. Zhao and Zeng (2007) developed the model for route network design, vehicle headways, and timetable assignment. The proposed approach combines simulated annealing, and tabu search. Desaulniers and Hickman (2007) reviewed the state-of-the-art models and approaches in solving complex public transit problems. Fan and Machemehl (2008) considered the design of public transportation networks in the case of variable demand. The authors developed multi-objective model. The solution methodology is based on Tabu search method. Guihaire and Hao (2008) classified 69 various approaches dealing with the transit network design and frequencies setting. They also indicated trends for future research. When solving route design and bus assignment problem, Pacheco, Alvarez, Casado, and Gonzalez-Velarde (2009) developed an algorithm based on local search strategy, as well as an algorithm based on a tabu search strategy. The authors showed the robustness of their approach with respect to variations in demand. The case study of the city of Burgos, Spain is presented in the paper. Mauttone and Urquhart (2009) developed Pair Insertion Algorithm (PIA) that can be used to generate initial solutions for a local improvement or evolutionary algorithm. The algorithm is inspired by the route generation algorithm (RGA) of Baaj and Mahmassani (1995). Kepaptsoglou and Karlaftis (2009) presented and reviewed research results in the area of transit route network design problem. Design objectives, operating environment parameters and solution approach are especially analyzed in the paper. Fan and Mumford (2010) proposed a model of the urban transit routing problem that evaluates candidate route sets. The proposed approach uses hill-climbing and simulated annealing techniques. Bagloee and Ceder (2011) studied the design a transit network for the actual-size road networks. The proposed algorithm was tested on the network of the city of Winnipeg, Canada, as well as on the transit network of Mandl benchmark. The review paper of Derrible and Kenneday (2011) is devoted to the applications of the graph theory in transit network design. Szeto and Wu (2011) studied the bus network design problem in the case of Tin Shui Wai, a suburban residential area in Hong Kong. The authors proposed the model that simultaneously performs the route design and bus frequency setting. The proposed solution method represents the combination of the genetic algorithm, and a neighborhood search heuristic. Miandoabchi, Farahani, Dullaert, and Szeto (2012) studied the design of urban road and public transit networks, The proposed multicriteria model decides about construction of new roads, adding lanes to the existing roads, lane allocation in two way streets, and the orientation of the one way streets. At the same time, the model proposes new routes of a given bus routes. Schoebel (2012) made the review of the various bus, railway, tram, and underground line planning models. Blum and Mathew (2012) studied the transit route network redesign problem. The proposed approach was tested in the case of city of Mumbai, India.

One can conclude that the majority of authors tried to minimize total travel time, or generalized cost. Simultaneously, greater part of papers introduced simplified assumption about fixed demand for transit services. More realistic assumption is the assumption that passenger flows depend on the transit network design, and that should be determined as a solution of an equilibrium problem. The decision variables are transit network route configuration and/or bus frequencies. Papers in the open literature also dealt with both type of passengers' assignment among possible transit routes: single path assignment and multiple path assignment. Due to the