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Transit network design by genetic algorithm with elitism

Muhammad Ali Nayeem, Md. Khaledur Rahman, M. Sohel Rahman *

AℓEDA group, Department of CSE, BUET, Dhaka 1000, Bangladesh

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ABSTRACT

The transit network design problem is concerned with the finding of a set of routes with corresponding schedules for a public transport system. This problem belongs to the class of NP-Hard problem because of the vast search space and multiple constraints whose optimal solution is really difficult to find out. The paper develops a Population based model for the transit network design problem. While designing the transit network, we give preference 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 Genetic Algorithm (GA) optimization. The Genetic Algorithm is similar to evolution strategy which iterates through fitness assessment, selection and breeding, and population reassembly. In this paper, we will show two different experimental results performed on known benchmark problems. We clearly show that results obtained by Genetic Algorithm with increasing population is better than so far best technique which is really difficult for future researchers to beat.

1. Introduction

With the increase in population and urbanization, efficient public transport systems are urgently needed. But finding an efficient public transport system is very difficult. This is why extensive research work has been conducted on relevant topics in the literature. Although achieving a major increase in public transit usage is an extremely complex issue, frequent and reliable cost-effective services are center of focus.

One important issue in transit network design is the vast search space. There are many factors that are mutually in conflict with each other while designing transit networks. For instance, the shorter the passengers' waiting times, the higher the number of vehicles necessary. When designing the transit network, the interests of both the operator and the passenger must be taken into account. Because of these conflicting nature of interests, we treat the transit network design problem as a multicriteria decision-making problem. In this paper, we investigate the problem from a different perspective. While designing the transit network, we aim to maximize the total number of satisfied passengers, to minimize the total number of transfers, and to minimize the total travel time of all served passengers.

Basically, route designers have relied much on historical experience, simple guidelines, local knowledge and ad hoc procedures. However, in recent years, several major studies have revealed that computer based tools should be employed more for designing and evaluating public transit networks. In the present paper, we are mainly concerned with route planning which involves the following objectives (Nikoli and Teodorovi, 2013): (a) to maximize the number of satisfied passengers, (b) to minimize the total number of transfers and (c) to minimize the total travel time of all the served passengers.

* Corresponding author. Tel.: +880 1552389480; fax: +880 448712475276.
E-mail address: sohel.kcl@gmail.com (M.S. Rahman).

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The transit network design problem can be subdivided into two major components, namely, the transit routing problem and the transit scheduling problem (Chakroborty, 2003). Generally, the transit routing problem involves the development of efficient transits routes (e.g., bus routes) on an existing road network, with predefined pickup/dropoff points (e.g., bus stops). On the other hand, the transit scheduling problem is charged with assigning the schedules for the passenger carrying vehicles. In practice, the two phases are usually implemented sequentially (or iteratively), with the routes determined in advance of the schedules.

In this paper, we discuss the transit routing problem and present a metaheuristics framework for solving it. We introduce two different versions of Genetic Algorithm (GA) for the transit network design problem, that allow us to concentrate on the key issues of minimizing the travel time and the number of transfers simultaneously. We show the effectiveness of our schemes, by comparing our results with previously published results on a benchmark instance. Furthermore, we explore the scalability of our approach by testing it on some larger instances, generated by Nikoli and Teodorovi (2013).

The rest of this paper is organized as follows. Literature review is given in Section 2. Section 3 formally defines the problem. Proposed solutions to the problem are given in Section 4. Experimental results and analyses are provided in Section 5. Finally, we briefly conclude in Section 6 with some future research directions.

2. Literature review

In this section, we briefly review the relevant literature for the transit network design problem. Lampkin and Saalmans proposed the first heuristic algorithm to design a transit route network (Lampkin, 1967). In the first step, the proposed algorithm produced an initial skeleton route. In the next steps, the other nodes were inserted one by one into the skeleton route. The case study of a small town in the North of England was also presented in the paper.

Simman, Barzily, and Passy proposed a two-staged approach for the problem (Simman et al., 1974). They first generated a set of route-candidates through several iterations. The authors determined the optimal vehicle frequencies in the second stage. They tried to minimize passengers travel time, while simultaneously taking care of the total number of passengers who cannot find seats. Byrne considered the case when the region served by the public transit is a segment of a circle and may be defined in the polar coordinates (Byrne, 1975). He proposed the model of a transit system that is built in the polar coordinates with radial transit lines.

In his pioneering work, Mandl proposed a heuristic algorithm to find the set of the best transit routes (Mandl, 1979). He developed a solution in two stages: first a feasible set of routes was generated, and then heuristics were applied to improve the quality of the initial route set. The route generation phase involved first computing the shortest paths between all pairs of vertices by Dijkstra's algorithm or Floyd–Warshall algorithm (Cormen et al., 1990), and then seeding the route set with those shortest paths that contained the most nodes, respecting the positions of any node designated as terminals. Unserved nodes were then iteratively incorporated into routes in the most favorable way, or new routes created with unserved nodes as route terminals.

In Newell (1979), Newell performed a theoretical analysis of the bus route network design problem. He discussed various aspects of the problem and reached to the following conclusion: " 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 published a model (Ceder and Wilson, 1986) that focused on two routines for generating and testing candidate route sets: Level 1 considered only the passengers' viewpoint, and was aimed at minimizing the total travel time, while Level 2 considered both passengers' and operators' viewpoint and balanced travel time and waiting time with the number of vehicles required. Vehicle frequencies and timetables were also set at Level 2. The general idea of the route construction algorithms was to start from the terminal nodes having the largest demand and expand the routes incrementally by including more nodes.

Baaj and Mahmassani described and implemented a heuristic route generation algorithm for the route network design (Baaj and Mahmassani, 1995). Generally it determined an initial set of skeletons and expanded them to form transit routes, which heavily depended on the travel demand matrix. In this algorithm, the designers knowledge and experience were also used to reduce the search space.

Ceder and Israeli defined an objective function that takes into account the interests of both passengers and operators (Ceder and Israeli, 1998). The proposed model for the transit network design problem combines mathematical programming, and decision-making techniques.

The last two decades have seen a rapid growth in computing power and, as computers have become faster, metaheuristic techniques have become ever more popular for solving hard combinatorial problems. Methods such as genetic algorithms, tabu search and simulated annealing have all played important roles in recent research on transit network design.

When solving the bus route network design problem, Pattnaik, Mohan, and Tom proposed a two step procedure (Pattnaik et al., 1998). 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. They used a binary encoding scheme to identify candidate routes. In general, their initial candidate route sets were produced using heuristic procedures, applying shortest path calculations moderated by user-defined guidelines. The genetic operators, mutation and crossover, produced new route set variations for selection, giving the population scope to improve over time, provided selection is biased towards saving the better solutions over the poorer ones.