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A demand based route generation algorithm for public transit network design

Fatih Kılıç [a,*], Mustafa Gök [b]

[a] Adana Science and Technology University, Adana, Turkey
[b] Cukurova University, Adana, Turkey

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ABSTRACT

This paper presents a public transit network route generation algorithm. The main contribution of this work is the introduction of new route generation algorithms. The proposed route generation algorithm is tested on Mandl's Swiss Road network and the four large networks presented in recent previous work. Three parameters are used to evaluate the route sets generated by the proposed algorithm. These are the zero transfer percentage, the average travel time, and the total route cost. The route sets generated for the large networks have better parameter values compared to recent previous work.

1. Introduction

Public transportation service is an integral part of a modern society [1]. A public transportation system orchestrates complicated routing and scheduling tasks to satisfy the demands of the stake holders. The main stake holders of the transportation service are the passengers, operators, and local authorities. The efficiency of a public transportation system is measured by its cost, demand coverage capacity, and transfer time. The stake holders often have contradicting interests. For example, passengers are interested in paying low ticket prices and reducing their travel time, while operators are interested in reducing the operating costs and increasing their profits. The local authorities set rules to balance these demands to guarantee secure and reliable transportation services.

The construction of the road network is the first and definitely the most important part of transportation system design. This task is done by the city planners by taking account of geographical conditions, demographic structure, and social demands. The public transportation network is a subset of the road network. Transit route network design problem is the generation of efficient routes in the public transportation network. The contradicting interests of the stake holders and the rules set by authorities bring additional constraints to the problem, which requires the use of complex combinatorial search techniques. The optimum solution cannot be found in a practically useful time even by using supercomputers [2]. Temporal planning such as setting time tables and the bus frequencies, and scheduling of the buses and drivers are determined after the generation of the routes [3].

Efficient routes can provide great savings in public transportation services and increase the quality of the service for passengers. For these reasons a continuous interest exists for the development of route generation algorithms. The algorithms can be classified in different ways. For example, a classification can be made based on the number of routes: One class of algorithms generates a predetermined number of routes [4–7], while another class generates minimum number of routes based on the demand such as Route Generation Algorithm [8] and its variant Pairwise Insertion Algorithm [9]. The algorithms can be also classified based on the type of their search procedures: some algorithms use local search methods [7,10]; some use Genetic Algorithm [5,11]; and some algorithms apply heuristics procedures to generate initial route sets and use genetic algorithm on those route sets to obtain solutions [12,13].

The efficiency of the route generation algorithms mainly depends on two factors: (1) the quality of the initial solution set, and (2) search procedures used to explore the solution space. Often the quality of the initial solution set has a higher impact on the quality of the solution than the type of search algorithm. We did not include the representation methodology into these factors, since the representation methodology usually depends on the search algorithm. For example, methods that use Genetic Algorithm method encode routes as a binary string [12,13]. However, the ordered list representation is also quite popular [7,10,11].

A good coverage of the previous work on route generation algorithms is presented in the review papers [1,14]. A brief discussion of the previous work that we significantly benefited from is given in the following.

* Corresponding author. Tel.: +90 322 4550010; fax: +90 322 4550009.
E-mail addresses: fkilic@adanabtu.edu.tr (F. Kılıç), musgok@cu.edu.tr (M. Gök).

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Mandl's work [4] is considered as the pioneering work in transit network route planning research and inspired much of the work that came after. Mandl's algorithm first finds the shortest paths between all pairs of nodes, then constructs routes using the shortest paths that contain most of the nodes. The algorithm aims to optimize in-vehicle travel time. Another major contribution of Mandl is his 15 node Swiss Road Network, which has been used by many researchers as a benchmark.

Chakraborty and Dwivedi's work shows that a good initial route set can be efficiently optimized using Genetic Algorithm [11]. Their algorithm generates initial route set by converting the activity on each node into a discrete probability for that node. The probability values are used in the construction of routes. The algorithm optimizes the weighted sum of the following parameters: average in-vehicle travel time; the percentages of zero, one, and two transfers; and the percentage of unsatisfied travel demand. Though the idea is useful in a general context, using the activity on the nodes may be deceiving when estimating the efficiency of routes, if the nodes are shared by many links that carry low demand. Finally, we would like to note that the solution sets for Mandl's network reported in [11] have loops, which breaks a constraint shared by most previous research. Thus, we have not compared the results in [11] with our results.

Fan and Mumford presented a metaheuristic approach for transit network route planing [15]. The algorithm randomly generates an initial route set based on general constraints: (1) the entire demand is served, (2) the percentage of demand satisfied by zero transfer is high, and (3) average travel time is as low as possible. The algorithm uses Hill Climbing or Simulated Annealing methods to perform a local search. The same solution modification procedure is used for both local search methods which performs a small modification on a route set by adding or deleting a node or inverting the order of nodes. The algorithm uses a single objective function that aims to reduce the travel time and the number of transfers. The same optimization function is used in this paper.

The latest work by Mumford [5] employs multi-objective optimization using evolutionary operators. Genetic Algorithm optimization method is especially useful for the problem of multi-objective route planning [16]. The work improves the results obtained for Mandl's network in [15] and also presents new results obtained from four larger networks. Recent work in [5,7], and [15] has shown that there is not much room left for improvement in Mandl's network, so the networks proposed in [5] can be used as new benchmarks for testing the new route generation algorithms.

In [7] we proposed a novel initial route generation method which takes into account usage statistics. The proposed algorithm performed local search using the simplest local search algorithm Hill Climbing and was tested on Mandl's network. The algorithm generated compatible average travel time (ATT) and cost results compared to the latest work available at that time.

In single-objective route planning, the search space can be quite large but feasible solutions can be found very quickly by using local search algorithms provided that the search starts from a good initial route set. This is due to the nature of the public transportation network where some routes are more likely to be used. For example, routes to the point of interests such as down town locations, central university campuses, major public health institutions, and business centers have higher demand compared to other routes. A good initial route set must contain the most used roads so that search algorithms are able to get a good head start. In most of the previous work, the initial route set is generated either randomly or guided by the shortest paths of the network. One exception is in [11] where the node activities are used to construct the routes of the initial set. However, none of the existing algorithms use the demand for the links, which can provide excellent guidance for the construction of the initial solution. The implementation of this idea is one of the major contributions of this paper. This paper extends our previous work in [7] the following ways:

- A new initial route generation method that dynamically adjusts the usage probabilities during the construction of a route is proposed.
- The insert node and delete node functions are improved and a swap node function is included in the solution modification procedure.
- Our previous and current initial route set generation methods are tested using Hill Climbing and Tabu Search algorithms on Mandl's network and four larger networks proposed by Mumford in [5].

The rest of the paper is organized as follows: Section 2 describes the route generation problem. Section 3 explains the proposed algorithm. Section 4 shows the test results, and Section 5 presents the conclusions.

2. Problem definition

A public transportation network can be modeled by using an undirected graph. Fig. 1 shows an example of such a graph, which consists of five nodes and six edges. This graph can be expressed as $G=(V,E)$, where V is the set of vertices $\{v_1, v_2, v_3, v_4, v_5\}$ and E is the set of edges $\{e(1,4), e(1,2), e(2,3), e(3,4), e(3,5), e(4,5)\}$. Each vertex v_i in V represents a stop or another type of transfer point and each edge $e(i,j)$ in set E represents a link between nodes i and j. A weight may represent the distance or the travel time between nodes or it may be a function of these parameters. In Fig. 1, each edge is associated with a positive integer weight, $w(i,j)$, which represents the travel time or distance between the nodes i and j. The travel demands on a transportation network are expressed by using a matrix called the demand matrix, D. Each d_{ij} element of D represents the number of passengers traveling from node i to node j. Though the transportation demands are dynamic by nature, the elements of D are usually calculated for a specific period within a day. A demand matrix for the graph in Fig. 1 is given as

$$D=\begin{pmatrix} 0 & 2 & 6 & 0 & 4 \\ 2 & 0 & 4 & 6 & 2 \\ 0 & 4 & 0 & 6 & 8 \\ 2 & 6 & 6 & 0 & 4 \\ 8 & 6 & 8 & 6 & 0 \end{pmatrix}$$

A D matrix and a graph G are sufficient to describe the transit network route finding problem. A solution to this problem consists of a set of routes on the transportation network that satisfies the travel demands. The routes in the solution set must cover all the nodes given in the D matrix. The network constructed from the routes of a solution set is a sub graph of the transit network and because of that some of the demands are only satisfied by transfers.

Route finding algorithms search the solution space to find the best solutions according to the objectives reflecting the interests of passengers', operators', and/or transportation authorities'. As mentioned before, the interests of those stake holders often

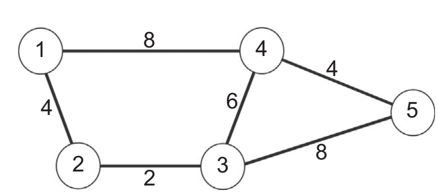

Fig. 1. A sample graph with 5 nodes and 6 edges.