Travel Behaviour and Society 3 (2016) 71–77

Contents lists available at ScienceDirect

Travel Behaviour and Society

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

Optimal route computation for circular public transport routes with differential fare structure

Lilian S.C. Pun-Cheng *, Albert W.F. Chan

Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University, Hunghom, Kowloon, Hong Kong Special Administrative Region

ARTICLE INFO

Article history:
Received 5 March 2015
Received in revised form 16 September 2015
Accepted 22 September 2015
Available online 23 October 2015

Keywords:
Route computation
Optimal path
Public transport
Circular routes

ABSTRACT

In many public transport information systems, route searching for pre-trip journey planning is an essential and important function. While different types of route query and path finding algorithms have been proposed to solve the problem of optimum route or path searching, there remains no single answer to the best solution for all public transportation networks in the world. As a result, customization of the optimum route computation is needed. In this paper, a structural analysis of public transport routes in terms of fare and operation patterns has been conducted. An enhanced route computation algorithm has been proposed in order to provide more reasonable and logical results for different structures. The development and implementation of the programming logic, together with the validation of the enhanced algorithm are also presented. It is found that the traditional approach of selecting closest stops to origin, destination or interchange stops may not satisfy all patterns, especially for cities with a very dense network of public transport stops and for circular routes. To cater for a lot of these special cases, the new approach of stop selection adopts a comparison of the stop sequence within a route with a threshold of commuting behaviour. Real cases from a governmental public transportation enquiry system in Hong Kong are extracted for implementation and evaluation; results from which have been proved satisfactory to both system planners and users.

1. Introduction

Public transportation plays an important role in any highly developed and densely populated city. Its huge capability to carry passengers to and from the urban area or inside the city helps to reduce traffic congestion and improve air quality. Past researches have mostly been focusing on planning bus stop locations to address travel demands and to improve transit accessibility (Wiransinghe and Ghoneim, 1981; Chien and Qin, 2004; Bagloee and Ceder, 2011) including the consideration of local topography (Furth and SanClemente, 2006). With the already planned and existing public transportation network, a guidance and decision-support information system is necessary to facilitate its use. This has been developed by many cities worldwide such as the Transport Direct in UK, Trip Advisor in Helsinki and HKeTransport in Hong Kong. An accurate and detailed public transport journey planner system can provide multi-modal public transport information on the internet, supports public access for pre-trip planning and optimal route searching. Users can search their optimal routes based on their own preferences such as shortest travelling time, least cost, least transfer, least walking distance or even a preferred mode of transport.

Route computation, being a branch of path finding, has largely been evolved from the graph theory of spatial computing. From a transportation database, transport routes are modelled as a topological network based on the graph theory. Generally speaking, a graph refers to a collection of vertices or nodes and arcs that connect pairs of nodes. The arc can be a directed or single way only. Nodes represent entities or places with a pair of geographic coordinates. An arc is a physical entity to connect two or more nodes together. It includes roads, bridges, tunnels, and so on. Also, an arc could be uni-directional or bi-directional to indicate the traffic flow along the arc. In the context of public transportation, a route, being a service with defined directed way provided by public transport operators such as railway, bus and ferry, could be described as a sequence of arcs and nodes. Terminals, bus stops, rail stations and ferry pier are all represented as nodes along a route, whereas any point of interest such as a building or site will be modelled as another set of nodes for representing origin or destination locations. In this network model, although it is necessary to model all nodes accurately in space and time, the alignment of

* Corresponding author. Tel.: +852 2766 5959; fax: +852 2330 2994.
E-mail address: lspun@polyu.edu.hk (L.S.C. Pun-Cheng).

http://dx.doi.org/10.1016/j.tbs.2015.09.001
2214-367X/

an arc can just be virtual (i.e. without following the real alignment of a route on the ground) if its associated journey time and fare information can be provided from a reliable source other than derived by spatial computation.

Mathematically, the public transportation network may be expressed as follows: let $G = (N, L)$ be a multimodal public transport network, where N is the set of n nodes and L is the set of m directed links, connecting node i to node j in the network, denoted as $L(i, j)$. Each distinct node (N) represents a specific stop and is assigned a stop ID. Each link $L(i, j)$ has a weight associated with it, which can represent either time or fare required to travel from node i to j. In Fig. 1, graph G is denoted by (N, L) where $N = \{1, 2, 3, 4, 5\}$ and $L = \{(1, 2), (1, 4), (2, 3), (2, 4), (2, 5), (3, 4), (3, 5), (4, 5)\}$.

Many researches have been conducted to develop the optimal path finding mechanism based on the graph theory (Peng and Huang, 2000; Li and Kurt, 2000). Notably among them is Dijkstra's Algorithm (Dijkstra, 1959). It is a label setting algorithm to figure out the optimal path from a single node to all the others node in a network. Basically, it compares all nodes connected from a specified origin to a destination with its cost of travel (such as distance, time or fare) until the shortest path has been discovered. One disadvantage of the original Dijkstra's Algorithm is its unnecessarily large searching area. This requires heavy computation and results in prolonged running time (Kumari and Geethanjali, 2010). Computational improvement for solving shortest-path problems has resulted subsequently to improve the data structures used to implement Dijkstra's Algorithm (Evans and Minieka, 1992). The total number of algorithms that have been developed over the years is immense. For example, Ford's Algorithm is used to solve the single source shortest path problem if the weight of an arc is negative. A* Algorithm (Hart et al., 1968) provides a heuristic search approach to consider the direction to the destination and reduce computation time (Kumari and Geethanjali, 2010). One important feature of all the above algorithms is that the solution is a single shortest path between the origin and destination in a network. This can be a problem as they are unable to provide alternatives paths apart from the shortest path. Practically, the public transport journey planner has to provide more options for the users to make their own decision in journey planning. It is therefore necessary for the searching algorithm to determine one or more optimal paths. The collection of paths derived is known as the k-shortest paths. It represents an ordered list of the alternative routes available between two specified nodes. The k-shortest paths problem is closely related to the well-known network optimization problem as discussed above. It is similar to finding the shortest path in a network except the aim is to identify a number of ranked shortest paths between two nodes, namely the origin to destination, in a network.

For a web-based public transport information system, the difficulty of finding the optimal routes comes from the size and complexity of the network in a modern city as well as the requirement to include user's preferences in the search. Bus stop spacing

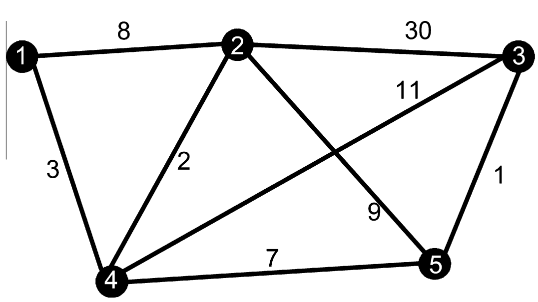

Fig. 1. Mathematical model of graphs.

are planned differently according to the city configuration, people's commuting culture and activity-generated demands (Ibeas et al., 2010; Medina et al., 2013; Ceder et al., 2015), thus limiting the generality of a path finding algorithm. Public transport journey planning is a multi-objective decision making process. Common options of user preferences used in optimal route computation are:

(a) *Minimum travelling time.* The route with the minimum total en-route time include the walking time from the origin to the stop and from the stop to destination, waiting time for the vehicles, travelling time in the vehicles and walking time for changing transportation modes.
(b) *Minimum fare.* Some travellers prefer a trip with a cheaper price even if the journey time is longer.
(c) *Minimum number of transfers.* Some travellers prefer a trip with a single mode of transportation only. They do not like to transfer from one mode to another mode. For example, travellers may prefer a trip with a single bus only rather than travelling the journey which requires transfer from bus to rail or from bus to bus.
(d) *Minimum walking distance.* A traveller carrying heavy luggage may prefer to use the nearest bus stop than walking a longer distance to another bus stop on a quicker route.

In short, due to the multi-objective nature of the problem and possible conflicts between different criteria in problem solving, there may be no single optimal solution, but rather a set of possible and potential solutions (Li and Kurt, 2000). In addition, differences in the transportation network among different cities make it impossible to find a single best approach. As some researchers point out, no perfect route searching approach can be fitted to the transport network all over the world. What seems optimum to one interested party may not be acceptable to the others (Ramirez, 2000). This may be illustrated by an in-depth study of Hong Kong's public transportation network, in which path finding algorithms in terms of least fare and time have to be specially developed for its own peculiar operating structure and fare system.

2. Structural analysis of public transport routes

With a land area of about 1100 km^2 in which usable area for human and urban development amounted to about 15% only, there are over 1300 public transport routes of different modes and 8000 stops/stations/piers (and hereafter all are referred to stops) for multiple routes in Hong Kong (Transport Department, 2010a). The average density of routes and stops per square kilometre is around 1.2 and 7.2 respectively. The city can therefore be considered as possessing a most complex public transportation system in the world in terms of not only its distribution and variety, but also its different operation modes, structures and patterns. Every day, over 11 million passenger journeys are made on a public transport system involving more than 10 different public transportation companies of different transportation modes – mass transit railway, buses from various companies, feeder bus for residential areas on outlying islands, minibus, tram, peak tram and ferry (Transport Department, 2010b). Apart from the large number of companies, there are also different patterns of operations even within the same transportation mode. For example, bus operation can be classified into three categories:

(a) Regular service – operates during daytime and whole week.
(b) Time-specific service – operates only for several hours in day-time or night-time.
(c) Special departure of regular services – operates as the supplementary to the regular services.