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 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.

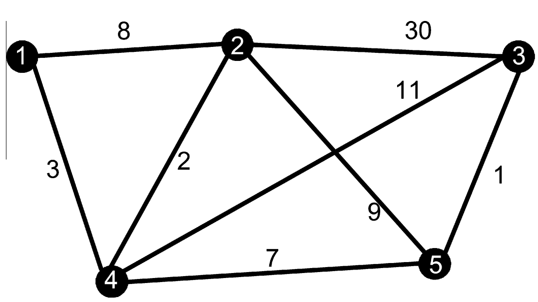


**Fig. 1.** Mathematical model of graphs.

## 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.

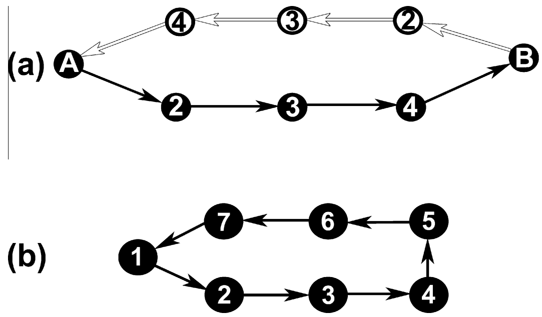



**Fig. 2.** Configuration of bus route: (a) two-way bound route; (b) circular route.

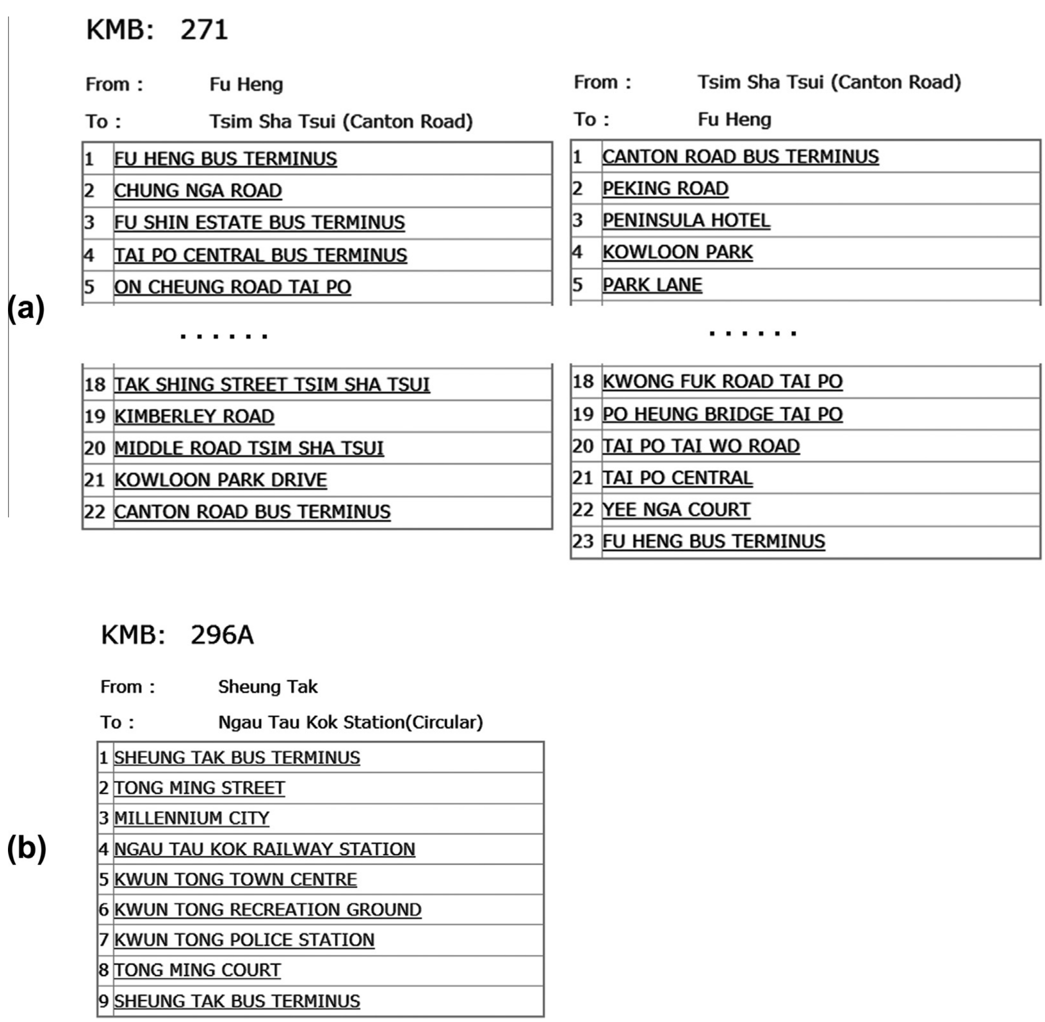
For route searching, it is necessary to clearly separate different networks for different time periods, such as that for day and night, weekdays and weekends. Else, the problem of impossible transfers between two routes of different time periods may result. However, database designers may also be posed with the difficulty of handling overlapping operation hours and days especially for a city with very dense network of public transport services.

On the other hand, individual bus route can also have different configurations and alignments – two-way bound route or circular route. The former is a bi-terminal configuration whereas the latter a single terminal one (Fig. 2) due to the lack of land to set public transport interchanges or terminals and the need to reduce operation cost. Fig. 3 shows the databases of these two types of routes. The major difference lies in their bound number and sequence number in which circular routes have the same stop for both the starting and ending stops. For the latter case, special route or stop searching logic has to be applied to avoid selecting the closest stop but with a much longer travelling journey. This will further be explained and exemplified in later sections.

Least fare is another important and almost essential requirement in route searching. Disregarding first concession fare for transfer between two modes or two routes, there may be three kinds of fare structure even for a single route (Leung, 2004). The simplest is the flat fare structure, that is, passengers need to pay the same fare no matter where the boarding stop or the alighting stop is. For routes with longer travelling distance, uni-directional section fare is sometimes applied. It is a one-way step down fare system in which the fare depends on the boarding stop. Passengers who get on the bus at or after the intermediate stop of the bus route have a lower fare. A more complex structure is the two-way section which is based on the distance between boarding and alighting stop. Fig. 4 shows all these three kinds of fare structure.

## 3. Enhanced algorithm for special route structure

In public transportation network, arcs are directed. Each arc is assigned a value corresponding to the cost for travelling between



(a)

KMB: 271

From : Fu Heng
To : Tsim Sha Tsui (Canton Road)

| | |
|---|---|
| 1 | FU HENG BUS TERMINUS |
| 2 | CHUNG NGA ROAD |
| 3 | FU SHIN ESTATE BUS TERMINUS |
| 4 | TAI PO CENTRAL BUS TERMINUS |
| 5 | ON CHEUNG ROAD TAI PO |
| | ...... |
| 18 | TAK SHING STREET TSIM SHA TSUI |
| 19 | KIMBERLEY ROAD |
| 20 | MIDDLE ROAD TSIM SHA TSUI |
| 21 | KOWLOON PARK DRIVE |
| 22 | CANTON ROAD BUS TERMINUS |

From : Tsim Sha Tsui (Canton Road)
To : Fu Heng

| | |
|---|---|
| 1 | CANTON ROAD BUS TERMINUS |
| 2 | PEKING ROAD |
| 3 | PENINSULA HOTEL |
| 4 | KOWLOON PARK |
| 5 | PARK LANE |
| | ...... |
| 18 | KWONG FUK ROAD TAI PO |
| 19 | PO HEUNG BRIDGE TAI PO |
| 20 | TAI PO TAI WO ROAD |
| 21 | TAI PO CENTRAL |
| 22 | YEE NGA COURT |
| 23 | FU HENG BUS TERMINUS |

(b)

KMB: 296A

From : Sheung Tak
To : Ngau Tau Kok Station(Circular)

| | |
|---|---|
| 1 | SHEUNG TAK BUS TERMINUS |
| 2 | TONG MING STREET |
| 3 | MILLENNIUM CITY |
| 4 | NGAU TAU KOK RAILWAY STATION |
| 5 | KWUN TONG TOWN CENTRE |
| 6 | KWUN TONG RECREATION GROUND |
| 7 | KWUN TONG POLICE STATION |
| 8 | TONG MING COURT |
| 9 | SHEUNG TAK BUS TERMINUS |

**Fig. 3.** Database of bus route: (a) two-way bound route; (b) circular route.

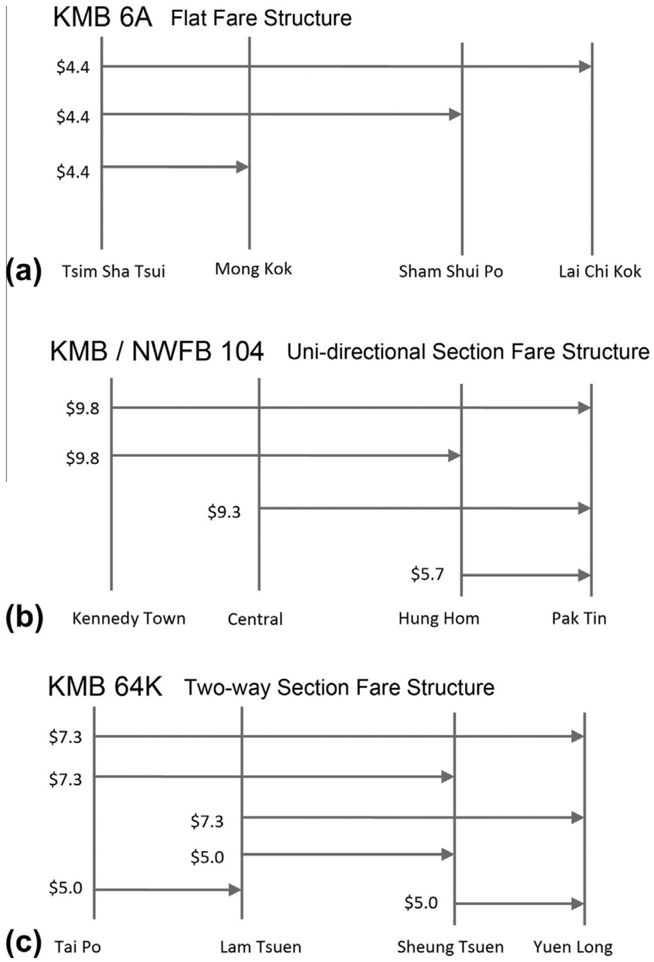



**Fig. 4.** Three kinds of fare structure: (a) flat fare; (b) uni-directional section fare; (c) two-way section fare.

the from-node and to-node. The cost can be fare or time. To start the search, the user indicates an origin or destination which is not necessarily a stop location. Origin and destination itself are also represented by a node in the data model. A radial search will then be conducted to identify all transportation stops within a buffer zone of reasonably walking distance such as 400 m. The reason that all stops within walking distance are searched rather than just the closest one is that the closest stop may not be on the optimal route path. Once the user has specified the origin and the destination, the system can search for all possible direct and indirect links in accordance with the bound direction and stop sequence. In other words, impossible routes such as involving boarding and alighting stops of different bound directions or boarding sequence number greater than alighting stop sequence number will not result. The displayed options will also usually filter out those with many transfers, higher fare or travelling time. Yet, because of closely placed stops inside a densely populated urban area, within the 400 m buffer zone, several stops of the same route within the same bound may be found. To minimize the walking distance between the origin and the boarding stop, the nearest stop of each route will usually be selected for display.

Some route options suggested in such route search rationale may be illogical and unreasonable. Circular bus route in Hong Kong is a typical example. The alignment of circular route is not in a two-way bound but in the form of circular loop. In conventional route computation, the system finds out all the stops of the same route within the search radius and then selects the nearest route. If the same route occurs in the buffer zone of destination or interchange locations, the route turns out to be a feasible option as there is only 1 bound in the database and so long as the boarding stop sequence is smaller than that of alighting stop. However, the system may give a suggestion that needs to travel a long way in the looping network. The interactive route searching function on the New World First Bus web site is a good example to explain the circular route problem (Fig. 5). Let the origin be Queen's Terrace and the

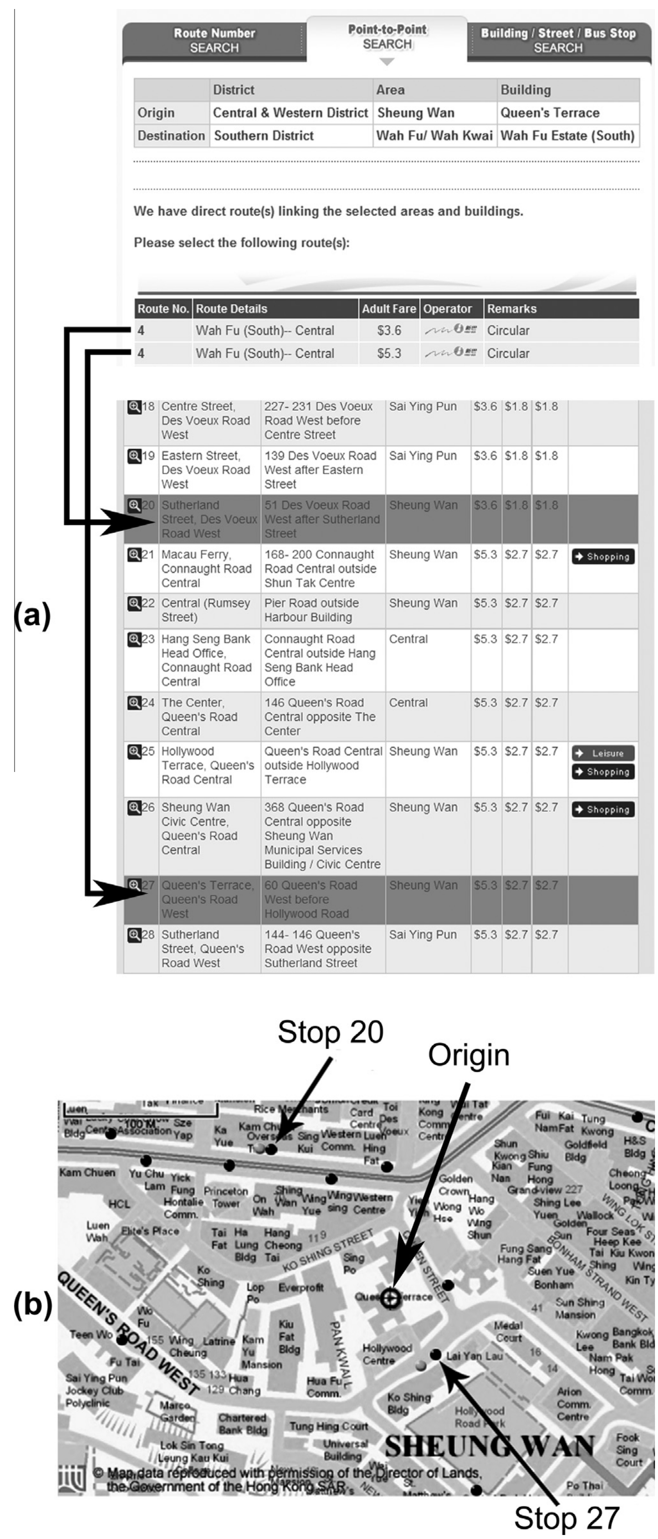



**Fig. 5.** Interactive route searching function on the New World First Bus web site.

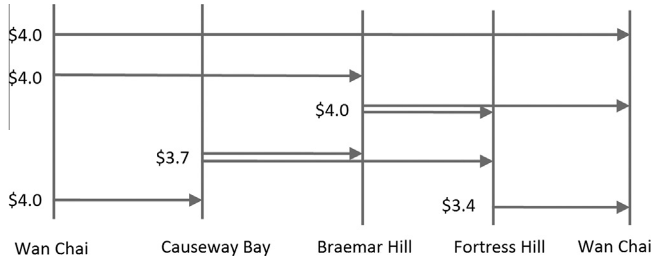



**Fig. 6.** An example of circular route with two-way section fare – bus route 25A.

destination be Wah Fu Estate. From the list of options provided in the bus company, system performs the route computation and then provides a list of option for the user. From Fig. 5, the first two options both suggest bus route No. 4 (Wah Fu South to Central) which is a circular route. There are two stops of the same bound within 400 m around the origin – stop 20 and 27 respectively. Passengers who get on at stop 20 need to travel along the loop from stop 20 to stop 26, then back to stop 27 before the bus actually heads to the destination. Similar cases occur numerously over the whole of Hong Kong. About 320 routes, accounting for over one-quarter of bus routes in Hong Kong are operated as circular routes (Transport Department, 2010a). The problem is aggravated by the different fare structure and operating modes of the circular routes. Apparently, improvement of the route search algorithm is needed when dealing with circular routes.

To handle the problems, we need to analyse the various patterns of circular routes. For some circular routes, passengers cannot really take the whole route as their journey. The bus starts picking up passengers from the terminus and upon arriving at a certain stop, all the passengers must get off before the bus can continue the journey. This stop is in fact a "pseudo-terminus". To cater for this case, the database can simply be converted to traditional two-way bounds so long as this pseudo-terminus can be identified clearly.

Similarly, for circular routes with increasing two-way section fare, the route can also be divided into two separate bounds to account for the special arrangement in fare structure. Refer to Fig. 6, bus route 25A is a circular route with two-way section fare. Starting at Wan Chai, the fare is $4.0. It then reduces to $3.7 to travel to Braemar Hill. At Braemar Hill, the fare increases to $4.0 again. Hence in the database, this route can be divided into two bounds – one from Wan Chai to Braemar Hill and another backwards. However problems still occur for the above two cases if the pseudo-terminus and/or the section fare cover an area or more than one stop, making it difficult to separate into two distinctive independent bounds.

To avoid travelling a long loop, we suggest a new logic of selecting the least travelling stop for the whole journey to replace selecting the nearest stop to origin or destination. The least travelling stop is the stop having the maximum stop sequence number for origin and the minimum for destination within their buffer distances. This approach has the advantage of ensuring the shortest route with no detour suggested. For illustration purpose, imagine a scenario in which Stop 1 and Stop 9 are closest to origin and destination respectively in Fig. 7. The new logic would suggest a route to get on at Stop 2 and get off at Stop 4 instead of Stop 9 to avoid unnecessarily longer travels between Stop 1 and 9. One disadvantage is that passengers may need to walk a longer distance along the bus route for one or more stops, which is generally unacceptable for busy commuters. To enhance the algorithm, a difference in stop sequence number between the closest stop (C) and the least travelling stop (L) is computed. The difference is then compared to a threshold value. For a difference less than or equal to a threshold

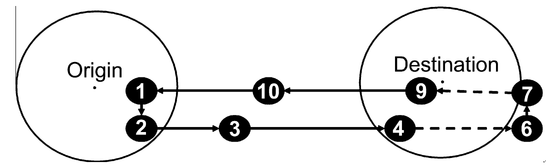



**Fig. 7.** The enhanced algorithm of adopting a threshold value for stop selection.

value, the closest stop is used, else the least travelling stop is chosen. The threshold value can be user- or system-specified and is indeed a measure of longer travelling time to be saved at the expense of the willingness to walk farther to the stops. Let's look at the example in Fig. 7 again. Assume the threshold value is 4. Around the origin, the nearest stop is Stop 1; the least travelling stop is Stop 2. The difference between the stop sequences is 2 – 1 = 1, which is smaller than the threshold value. The nearest stop is selected. Around the destination, the nearest stop is Stop 9; the least travelling stop is Stop 4. The difference is 9 – 4 = 5, which is larger than the threshold value. The least travelling stop is selected.

Pseudo code of this new route finding logic for circular routes is written as follows:

*Get the coordinate of origin*
*Get the coordinate of destination*
*Compute the optimal path*
*Select the route labelled as circular route*
*Select the circular bus route stop within 400 m searching radius around origin and destination*
*Find the nearest stop of origin*
*Find the least travelling stop of origin*
*Compute the stop sequence difference between two*
*If diff < threshold value*
  *Select the nearest stop*
*Else least travelling stop*
*Find the nearest stop of destination*
*Find the least travelling stop of destination*
*Compute the stop sequence difference between two*
*If diff < threshold value*
  *Select the nearest stop*
*Else least travelling stop*
*Select the route with computed start stop and end stop*

## 4. Cases for implementation and evaluation

Different threshold values have been tested using a trial and improvement process based on the user preference or behaviour of the HKeTransport, a product jointly developed by the Transport Department of the Hong Kong Government and the Hong Kong Polytechnic University mainly to compute multi-criteria optimal path routes for all public transport modes with a given user-selected origin–destination pair in Hong Kong (Pun-Cheng and Fung, 2008; Pun-Cheng, 2012). The system has been launched to the general public since April 2009, with an average of 10,000 visitors on route search per day. Feedback from users at the early stage was found that route searching results involving especially circular routes were not satisfactory. They were suggested to board at a stop that needs to travel a much longer distance and at a higher cost though closest at their chosen origin or destination. With the implementation of the enhanced algorithm, it is found that with a threshold value of 4, 80% of the optimal route computation results involving circular route have been improved to

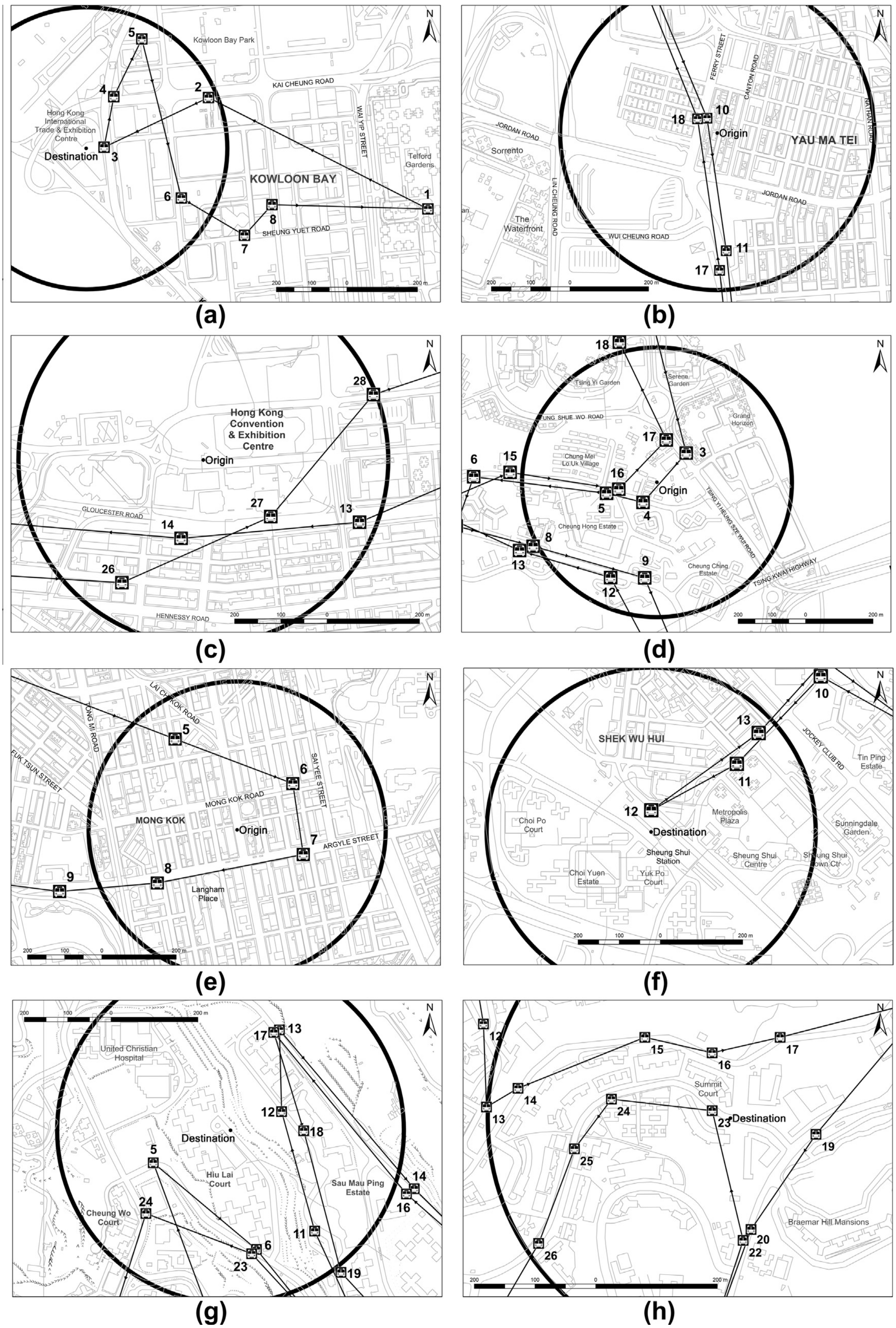



**Fig. 8.** Examples for implementation and evaluation. Data are extracted from the HKeTransport (Transport Department, 2010b).

become reasonable in terms of travelled time and cost. Some of these cases are illustrated here in Fig. 8 with the results in Table 1. For a suggested bus route upon user-selected origin and destination, case (a) will suggest users to alight from the closest stop as the number of travelled stops is less than the threshold, whereas all other cases (b)–(h) will suggest to board on or alight from the

**Table 1**
Enhanced optimal route computation results involving circular route with a threshold value of 4.

| Bus route No. | Origin (O)/Destination (D) | Closest stop (ID) | Least travelling stop (ID) | Result of enhanced algorithm | Accessible |
|---|---|---|---|---|---|
| a. KMB 224M | D | 3 | 2 | 3 | Yes |
| b. KMB 12 | O | 10 | 11 | 10 | Yes |
| c. NWFB M722 | O | 14 | 28 | 28 | Yes |
| d. KMB 249M | O | 4 | 17 | 17 | Yes |
| e. NWFB 701 | O | 7 | 8 | 7 | Yes |
| f. KMB 270 | D | 12 | 11 | 12 | Yes |
| g. KMB 13M | D | 12 | 5 | 5 | No |
| h. CTB 25C | D | 23 | 14 | 14 | No |

least travelled stops within the acceptable walking range of 400 m from the origin/destination. The appropriate suggestion of stops within a bus route is important in accurately comparing its travelled time and distance with other suggested routes of the same or different modes, especially in k-shortest path algorithms in which these criteria have to be ranked. Due to the uni-directional or two-way section fares of some routes, a longer travelling distance may incur higher cost which is not worth traded-off by a shorter walking distance. For example for case (c), if the user boards on stop number 28 instead of number 14, the distance and time of travelling 14 more stops can be saved to the destination. The same applies to case (d) in which 13 stops will be saved. But of course, the choice of a reasonable buffer for a reasonable walking distance and a threshold value will vary with the configuration, transit network planning and commuters' habit of different cities.

## 5. Summary and conclusion

As public transportation is characterized by a rather fixed direction and stop sequence, a virtual network connecting all these stops can save tremendous efforts in modelling real ground/distance network as that for car navigation. Nevertheless, accurate judgment on the effects of terrain or geographical barrier on walking paths to, from or between stops has to be sacrificed. Problematic search results occur for bus route KMB 13M and CTB 25C, as shown in Fig. 8(g) and (h) respectively. The scenarios are set on a hilly area where the suggested stops are not on the same level as the destinations and are not readily accessible. Possible solution would be grouping the points of interest and stops together in a table in which a road along a hilly area should form a buffer zone. This has been handled in another filtering algorithm.

This paper has revealed the inadequacy of relying merely on the nearest stop approach or the least travelling stop approach for public transport route computation. A variety of route operating patterns with different fare structures have been discussed and an enhanced algorithm has been suggested for especially circular routes. This is in fact an integration of the previous approaches while adding a behavioural threshold for comparison. It avoids detour most of the time while bringing passengers closer to the origin or destination occasionally. Although there can never be a perfect solution to all problems encountered in different cities, each having its own peculiar public transport operating mode and pattern, this paper has presented a route searching problem worthy of investigation and subsequently successfully implemented with the enhanced algorithm.

## Acknowledgements

The work described in this paper was substantially supported by a grant from the Research Grant Council of the Hong Kong SAR Government, project number PolyU 5259/07E. The authors would also like to thank the Transport Department for their generous support on this project.

## References

Bagloee, S.A., Ceder, A., 2011. Transit-network design methodology for actual-size road networks. Transp. Res. Part B 45 (10), 1787–1804.
Ceder, A., Butcher, M., Wang, L., 2015. Optimization of bus stop placement for routes on uneven topography. Transp. Res. Part B 74, 40–61.
Chien, S.I., Qin, Z., 2004. Optimization of bus stop location for improving transit accessibility. Transp. Plann. Technol. 27 (3), 211–227.
Dijkstra, E.W., 1959. A note on two problems in connexion with graphs. Numer. Math. 1, 269–271.
Evans, J., Minieka, E., 1992. Optimization Algorithms for Networks and Graphs, second ed. M. Dekker, New York.
Furth, P.G., SanClemente, J., 2006. Near side, far side, uphill, downhill: impact of bus stop location on bus delay. Transp. Res. Rec. 1971, 66–73.
Hart, P., Nilsson, N., Raphael, B., 1968. A formal basis for the heuristic determination of minimum cost paths. IEEE Trans. Syst. Sci. Cybern. SSC4 4 (2), 100–107.
Ibeas, A., Dell'Olio, L., Alonso, B., Sainz, O., 2010. Optimizing bus stop spacing in urban areas. Transp. Res. Part E 46, 446–458.
Kumari, S.M., Geethanjali, N., 2010. A survey on shortest path routing algorithms for public transport travel. Global J. Comput. Sci. Technol. 9 (5), 73–76.
Leung, S.W., 2004. A Review of Bus Fare Structure in Hong Kong (Master). The University of Hong Kong, Hong Kong.
Li, Q., Kurt, C.E., 2000. GIS-based itinerary planning system for multimodal and fixed-route transit network, Proceedings of the MID-Continent Transportation Symposium, pp. 47–50
Medina, M., Giesen, R., Munos, J.C., 2013. Model for the optimal location of bus stops and its application to a public transport corridor in Santiago, Chile. Transp. Res. Rec. 2352, 84–93.
Peng, Z.R., Huang, R., 2000. Design and development of interactive trip planning for web-based transit information systems. Transp. Res. Part C: Emerg. Technol. 8 (1–6), 409–425.
Pun-Cheng, L.S.C., 2012. An interactive web-based public transport enquiry system with real-time optimal route computation. IEEE Trans. Intell. Transp. Syst. 13 (2), 983–988.
Pun-Cheng, L.S.C., Fung, T.H., 2008. A public transport enquiry service (PTES) in Hong Kong [in Chinese], Proceedings of 2008 GHMT Guangzhou-Hong Kong-Macau-Taiwan Engineer Forum, Dec 11–12, 2008, Macau, China, pp. 111–122.
Ramirez, A.I., 2000. Transit System Design: A Model for Optimizing Bus Route Alignment (Master). Utah State University, USA.
Transport Department, HKSAR Government, 2010a. Transport in Hong Kong. [Online] Available at <http://www.td.gov.hk/en/transport_in_hong_kong/public_transport/index.html> (accessed 31 March 2010).
Transport Department, HKSAR Government, 2010b. HKeTransport. [Online] Available at <http://hketransport.gov.hk/> (accessed 31 March 2010).
Wiransinghe, S., Ghoneim, M., 1981. Spacing of bus-stops for many to many travel demand. Transp. Sci. 15 (3), 210–221.