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Research Article

A PUBLIC TRANSPORT ROUTE RECOMMENDER MINIMIZING THE NUMBER OF TRANSFERS

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ABSTRACT

Public transport is preferred by most of the people since it provides various advantages. As a result, many route-planning applications are developed for users of public transport. The general aim of these applications is proposing the ideal route for a given destination; however, there are various route-planning criteria for public transport. According to our research, “the number of transfers” is seen as the primary criterion for the route planning by most users. In this study, an approach for public transport is proposed in order to recommend the route that is comprised of minimum number of transfers. In this approach, Space P and a pareto optimal solution are used for modelling network, then Breadth First Search is modified to plan the ideal route on the modelled network. Furthermore, the proposed approach is experimented on the public transport network of Izmir. It is proved that from any source to any target, our route recommender returns the path with the minimum number of transfers optimally within milliseconds.
Keywords: Breadth first search, number of transfers, public transport network, route planning.

1. INTRODUCTION

Public transport is one of the favored ways to travel in urban areas. It is actively used by different kinds of users in today's world. Public transport is used more intensively than other modes of transportation (taxicab, hired buses etc.), and there are many reasons behind this tendency. Firstly, most people who do not own vehicles prefer public transport because of its more affordable fees compared to other transportation modes. On the other hand, some people who have their own vehicles may also prefer public transport. This is because the public transport creates much less stress compared to driving in certain people and can be faster than driving during the rush hours.

Because of the fact that public transport is preferred by many people, many applications are developed for the related users. The primary aim of these applications is planning the ideal route using means of public transport from any origin to any destination in urban areas. However, the ideal route for public transport varies depending on the preferences of users. This is because the ideal route can be planned based on different criteria by each user. For example, a group of users may state that the primary criterion of the ideal route is the distance of path, while another group

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of users may express that the primary criterion is the price of the trip. Generally, the applications try to propose the ideal route according to generally accepted main criteria such as the number of transfers or the distance of route etc.

Most of the studies state that the number of transfers is the primary criterion for the public transport route planning e.g., [1-3]. Additionally, we have conducted a case study [4] based on eighty-one residents of Izmir, Turkey. In the study, what is aimed is to learn participants' experiences and ideas about route planning applications. It is observed that participants have many criteria for the public transport route planning such as; the number of transfers, the travel time, the distance of the route, and the price of the trip. Nevertheless, "the number of transfers" is mostly preferred criterion according to our case study. Thirty-two people out of eighty-one (thirty-nine percent of participants) preferred this criterion as the primary factor for the route planning in the survey.

It is concluded that the number of transfers is mostly preferred criterion in the public transport, according to our research and survey. Thus, a new route recommender approach is proposed in this paper to determine the path with the minimum number of transfers for a given destination in any public transport network (PTN). Our approach is developed by extending a study that is presented by Li and Zhu [5]. Li and Zhu model the bus transport network (not including walking connections) to an unweighted complex graph by using Space P and then they use just simple Breadth First Search [6] algorithm in their model to find the bus routes with the minimum number of transfers. In our study, in addition to the bus transport network, all types of PTN (bus, ferry, underground etc.) are modelled by using Space P technique. Additionally, the optimal distance for walking adjacency is determined by using a pareto optimal solution (the first contribution of our study will be detailed in subsection 4.1). Then, the stations within the determined distance are connected to each other in the modelled network. Breadth First Search based route planning method (the second contribution of this study), which considers walking connections and constraints, is modified for the modelled complex network. Furthermore, the proposed approach is proved and it is experimented on a real-world transport network (Izmir, Turkey). It is observed that the proposed method optimally calculates routes with the minimum number of transfers in a few milliseconds.

2. BACKGROUND

In this chapter, the used model (Space P) and the modified algorithm (Breadth First Search) in our approach is explained briefly in the following parts.

2.1. Space P Model

In this model, station v_i is assumed adjacent to another station v_j if v_i is reachable from v_j by at least one transit line. For instance, there is graph $G = (V, E)$ that is the representation of some PTN in Figure 1. The red straight lines refer to a bus line, and the yellow straight lines refer to a tramline.

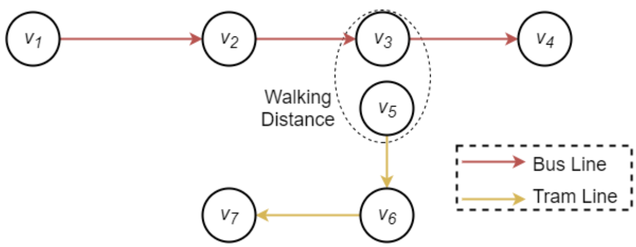

Figure 1. A Public Transport Network Instance

By using Space P, all types of the PTN is modelled to an unweighted complex graph in Figure 2.

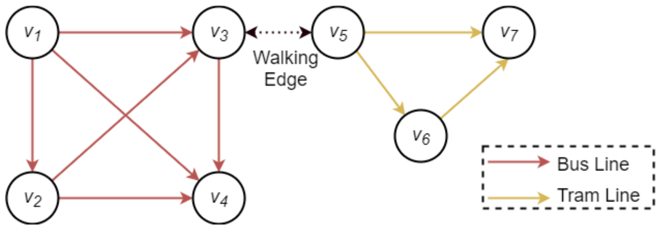

Figure 2. The Public Transport Network Model in Space P

Thus, for each node, all nodes reachable by using a single transfer can be obtained in a constant time.

2.2. Breadth First Search Algorithm

Breadth First Search is a well-known search algorithm that is guided by using a queue data structure. This search algorithm is fair while choosing the next vertex; it explores vertices in ascending order of distance from a source vertex. Thus, each node would be labeled with a shortest distance from the source in the algorithm. The distance gives the number of edges in the shortest path from the source vertex to the related vertex. The pseudo-code of the algorithm is given in Figure 3.

Input: Adjacency lists of n-sized Graph; $adjacencyList[n]$ and source vertex; s
Output: N sized integer array that stores the number of vertices in the shortest path; $dist[n]$
Function Breadth First Search ($adjacencyList[n], s$)
Initialize a N sized integer array of vertices; $dist[n]$
Initialize a new queue; Q
Enqueue s to Q
$dist[s] \leftarrow 0$
for each vertex v **in** $adjacencyList[s]$
    do $dist[v] = \infty$
while Q is not empty
    $current \leftarrow Q$.Dequeue()
    for each vertex $adjacent$ **in** $adjacencyByTransit\ [current]$
        if $dist[v]$ is ∞
            Enqueue $adjacent$ to Q
            $dist[adjacent] \leftarrow dist[current] + 1$
        end if
    end for
end while

Figure 3. Breath First Search Algorithm

3. RELATED WORK

Actually, Space P modelling is mainly used in studies that analyses the topologies of transport networks, e.g., [7, 8]. In Space P, two stations are considered as adjacent if there is at least one transit line that stops at both of these stations [9, 10]. On the other hand, two stations are adjacent in the topology of real-life infrastructure only if there is no station between them.

Li and Zhu presented a study in which only bus transport network is modelled in Space P, then, the route that has the least number of stops is determined in this model by using Breadth First Search algorithm. In addition to these, we have considered other types of public transport and walking connections in the model, then, we have developed the public transport route-planning algorithm that minimizes the number of transfers.

Wang and Yang [11] also presented a study that uses Space P for public transport route planning. However, Wang and Yang used matrix multiplication for each transfer that increases the time complexity of the algorithm dramatically.

As distinct from studies using Space P, Gao [12] presented a study that introduces a novel network representation including layers for each route in order to propose the least number of transfers route selection by a matrix multiplication. Li et al. [13] classified PTN into complicated topologies based on the path-stop network, and then proposed a new transfer route model. A transfer penalty system was implemented to Dijkstra's Algorithm by Bozyiğit et. al. [14] for decreasing the number of transfers while planning a route in their algorithm. Xiaoyong and Xueqin [15] proposed a heuristic approach to recommend a route for given destinations with regard to the number of transfers and the distance of the route. Haqqani et. al. [16] adapted a route recommender system regarding the relevant user preferences, e.g., the fastest, the minimum transfer etc. In addition to these studies, Nasibov et. al. [17] presented a two-criteria fuzzy approach for planning a route in public transport that is based on maximizing the route's preference degree. However, our proposed approach is the more efficient way in terms of running time while meeting most of the users' expectations.

4. PROPOSED APPROACH

In this study, a public transport route recommender is proposed to determine the route with the minimum number of transfers for any given origin-destination pairs. The proposed approach consists of two main steps; modelling the public transport network and developing the route planning method for the modelled network. In the first part, PTN is modelled by using Space P and walking connections is added to the model. In the second part, Breadth First Search based method, which considers walking connections and constraints, is modified for the modelled network to determine the ideal route regarding the number of transfers.

4.1. Modelling Public Transport Network

In the proposed study, all types of PTN are modelled to an unweighted complex graph in Space P (explained in 2.1). The main advantage of this complex graph for this approach is all reachable stations from a station by using single transfer can be determined in constant time.

Furthermore, walking connections between stations within specified walking distance are added to the model. Remark that, tram station v_5 is within the specified walking distance of bus stop v_3 in Figure 1, and vice versa. The walking connection between v_5 and v_3 is added as an edge to the modelled graph in Figure 2. The operation of adding walking connections is a problem to deal with since the distance for walking adjacency (denoted by *d*) needs to be determined.

Specifying the distance for walking adjacency is crucial for route planning problem since it directly affects the connectedness of PTN. Generally, PTN contains many connected components consisting of different bus lines, tram lines etc. For instance, there are two connected components in PTN given in Figure 1. To connect these components, walking connections between stations within the specified distance are added to the model. If the specified distance is less than the certain threshold, PTN would not be connected. However, each station in the model should be reachable from any other station. In other words, if a user wants to go from v_1 to v_6 in the PTN given in Figure 1, the proposed method for the model should advise at least one proper route. Thus, the specified distance should be greater than or equal to the certain threshold to connect the components of the model.

Remark that "the number of transfers" is the primary criterion of the proposed work. Increasing the walking distance between stations a little can decrease the number of transfers dramatically while planning a route. For instance, an illustration of this argument is presented in Figure 4. Note that there are two bus lines; Line 1 stopping at S_{source}, S_x, S_y and Line 2 stopping at S_y, S_{target}. Assume that there is a passenger who wants to travel from bus stop S_{source} to S_{target} and walking distance in the model is set to 200 m. In this case, the passenger has to make one transfer from Line 1 to Line 2 at S_y, since S_{target} is not the walking adjacent of S_y in this model. If the walking distance was set to 210 m, the passenger would make no transfers in their trip. Therefore, using the minimum distance (denoted by d_{min}) connecting the components of PTN would not be efficient. On the other hand, increasing the distance too much would cause undesirable routes for users such as ones that contain long walking paths. Thus, an optimal distance for walking adjacency (denoted by d_{opt}) is calculated by using a pareto optimal solution in this study.

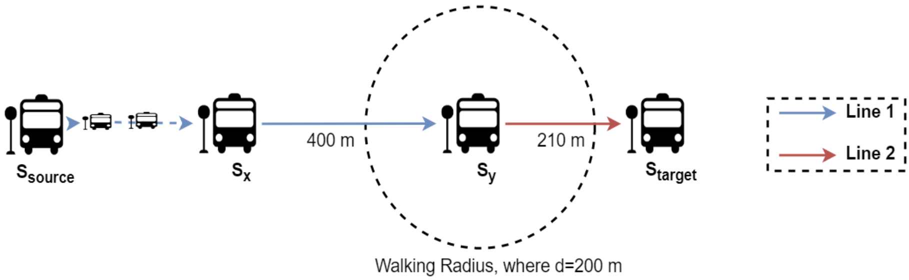

Figure 4. The Relationship between Walking Distance and Transfer

In a pareto optimal solution, there is no objective function that can be improved except decreasing some of the others' values [18]. In the proposed study, the objective functions are the number of transfers and the total walking distance in a route *r*, denoted by $t_r(d)$ and $w_r(d)$ respectively. The domain of the objective functions is only *d* (the distance for walking adjacency) since other inputs are trivial for the solution.

To obtain the values of the objective functions, many source-target pairs are randomly selected from PTN. A linear sequence starting from d_{min} and increasing by ε (a small value like 1-2 meters) is created to list candidates for the optimal distance. For each candidate distance *d*, routes are determined for the selected source-target pairs by using the proposed approach. After normalizing (min-max) the values of the objective functions for the determined routes ($t_r(d)$ and $w_r(d)$), their averages ($t_{avg}(d)$ and $w_{avg}(d)$) are calculated with respect to each *d*. Lastly, a weighted function is defined in Equation 1, where α is the weight of the number of transfers. Note that α is set to 0.5 for the experimental study; however, α may vary depending on the preferences of the sample of users.

$$f(d) = \alpha * t_{avg}(d) + (1-\alpha) * w_{avg}(d), for\ d = \{d_{min}, d_{min} + \varepsilon, \ldots, d_{min} + n * \varepsilon\} and\ \in [0,1] \quad (1)$$

The optimal distance for walking adjacency is d_{opt} where $f(d_{opt}) \leq f(d)$ for all $d \geq d_{min}$. Then, walking connections between stations within the optimal distance are added as edges to the modelled graph. Thus, the modelled network by using Space P becomes connected. Additionally; the proposed method would prefer a short walking instead of making one more transfer before/after transfer points while planning a route.

4.2. Route Planning Method for the Modelled Network

Breadth First Search is modified in order to determine the route with the minimum number of transfers for a given destination in the modelled network. The pseudo code of the method is given in Figure 5.

Input: Adjacency lists of n-sized Graph $adjacencyByTransfer, adjacencyByWalking$ and source; s
Output: n-sized vertex array; $pre[n]$ and n-sized integer array; $transfer[n]$
Function RoutePlanningMethod ($adjacencyByTransfer, adjacencyByWalking, s$)

```
1.  Initialize a n sized array of vertices; pre[n] and Initialize a n sized integer array dist[n]
2.  Initialize a list of vertices; nextLayer
3.  Initialize a new queue; Q
4.  pre[s] ← null
5.  transfer[s] ← 0
6.  Enqueue s and each vertex in adjacencyByWalking[s] to Q
7.  for each vertex v in adjacencyByWalking[s]
8.      do pre[v] ← s and transfer[v] = 0
9.  while Q is not empty
10.     current ← Q.Dequeue()
11.     for each vertex adjacent in adjacencyByTransfer [current]
12.         if pre[adjacent] is null
13.             Enqueue adjacent to nextLayer
14.             pre[adjacent] ← current
15.             transfer[adjacent] = transfer[current] + 1
16.         end if
17.     end for
18.     if (Q is empty)
19.         for each vertex v in nextLayer
20.             for each vertex wadjacent in adjacencyWalking[v]
21.                 if pre[wadjacent] is null
22.                     Enqueue wadjacent to nextLayer
23.                     pre[wadjacent] ← v
24.                     transfer[wadjacent] = transfer[v ]
25.                 end if
26.             end for
27.         end if
28.         Q ← nextLayer.Copy
29.         Clear nextLayer
30.     end if
31. end while
```

Figure 5. Route Planning Method

Remark that two different adjacency lists are used as input in the given method. The first adjacency list (*adjacencyByTransit*) stores adjacent stations in Space P (at least one transit line stops at both of these stations) and the second list (*adjacencyByWalking*) includes connections of stations in the specified walking distance. Thus, the method can explore walkable stations from each transfer point and this way the number of transfers in the optimal path decrease by walking small distances (explained in 4.1). Note that "*pre*", one of the outputs, is used for storing the predecessor of a vertex in the optimal path from the source. Moreover, "*pre*" gives information about whether a vertex is visited while the method is running. That is to say; if the predecessor of a vertex is null then this vertex is not visited. The second output, *"transfer",* is used for storing the number of transfers in the path from the source vertex to the related vertex. The structure of the method is as follows;

1) Firstly, *s* (the source vertex) and vertices walkable from *s* are added to queue Q. Additionally, the predecessor of the added walkable vertices is assigned as *s*. (lines 4-8 of the

method)

2) For each vertex in the queue, that is denoted by *current*, the algorithm explores adjacent vertices in Space P by using the list named as *adjacencyByTransfer*. The explored vertices are added to next layer (*nextLayer*) and their predecessor are assigned as *current*, if they are not visited before. (line 9-17 of the method)

3) Whenever there is no element in *Q*, the walking adjacency of each vertex, that is denoted by *v*, in *nextLayer* is explored. If the explored vertices in this step are not visited before, then they are added to *nextLayer and* their predecessor is assigned as *v*. Lastly, each element of the *nextLayer* is added to the queue, then *nextLayer* is cleared. (lines 18-30 of the method)

4) Repeating of second and third steps until there is no unvisited vertex left in the graph.

For instance, from v_1 to v_7 in Figure 2 the iterations of the route-planning method are illustrated Figure 6. Firstly, source vertex is added to the queue. Then, in the first iteration, each unvisited adjacent vertices of s (the only vertex in the queue) in Space P $\{v_2, v_3, v_4\}$ is added to the next layer. Then, each vertex in the next layer $\{v_2, v_3, v_4\}$ and their unvisited walking adjacents $\{v_5\}$ are added to queue. In the second iteration, for each vertex in the queue $\{v_2, v_3, v_4, v_5\}$, the unvisited adjacent vertices $\{v_6, v_7\}$ in Space P are added to the next layer and then queue.

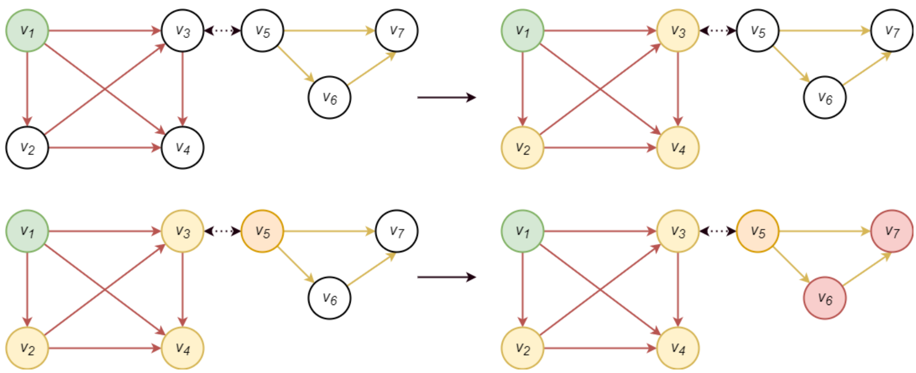

Figure 6. The Method Iterations

4.3. The Proposed Method's Proof of Correctness

Claim 1: In the proposed method, the order of vertices that are dequeued (removed from the queue) implies that if *u*
is dequeued before *v*, then $transfer[u] \leq transfer[v]$.

Theorem: At the end of the proposed method, for each vertex *v* that is reachable from source vertex *s*, the route with the minimum number of transfers from s is determined; the value of *transfer[v]* gives the minimum number of transfers from *s* to *v*.

Proof: Using proof by induction on *transfer[v]*. The source vertex is the only vertex for which *transfer* is zero, and it is correct value for the source. Assume that, for each vertices *u* such that $transfer[u] \leq k$ and *transfer[u]* is minimum number of transfers from the source to *u*. It must be shown that for a vertex *w*, $transfer[w] = k+1$. According to the structure of the method, if $transfer[w] = k+1$ then *w* was reached from a vertex *v* where $transfer[v] = k$. Assume a contradiction that there is a route $(s, \ldots, v^*, w)$ with the number of transfers is less than $k+1$. Then, it is concluded that there is a route between vertex v^* and *s* with the number of transfers less than *k* and so $transfer[v^*] < k$. Since $transfer[v]=k$, it is implied that v^* was dequeued before *v* because of Claim 1. When exploring adjacents of v^*, *w* should have been discovered and *transfer[w]* should be transfer[v^*] + 1. The contradiction is reached, thus, k+1 is the minimum number of transfers between the source and *w*. It is the end of the induction and proof of the theorem.

5. APPLICATION

To experiment the results of the proposed method, a visual desktop application is developed. Moreover, GMap.NET interface [19] is implemented to the application for visualization of the map. The developed application is illustrated in Figure 7.

The real-world public transport network of Izmir, Turkey is used as the dataset in the experimental study. The dataset is acquired from the internet site of ESHOT [20]. The used PTN consists of four types of public transport: bus, underground, ferryboat, and light rail. In this network, number of stations (ferry stations, underground stations, light rail stops, and bus stops) is 7,704. In the topology of real-life infrastructure, the number of public transit connections between these stations is 8,837. However, this number is 289,875 in our experimental study since all types of the PTN is modelled by using Space P.

Remark that specifying the distance for walking adjacency (d) is critical for route planning since it directly affects the connectedness of PTN. Except a few extraordinary outliers, the minimum distance connecting the modelled PTN (d_{min}) is determined as 272 meters for this experimental study. However, the optimal distance for walking adjacency (d_{opt}) is calculated by using a pareto optimal solution as stated in the proposed work (Section 3.1). Firstly, 500 source-target pairs are randomly selected from the stations of the PTN. Then, by using the proposed method for the selected destinations, the average of planned routes' number of transfers and walking distances (normalized) are calculated for some d $\geq d_{min}$. As a result, the optimal distance for walking adjacency is determined as $d_{opt}=347\ m$ where $f(d_{opt}) \leq f(d)$ for d $\geq d_{min}$. The walking connections between stations within 347 meters are added to the modelled network. The features of the modelled PTN in the experimental study is presented in Table 1.

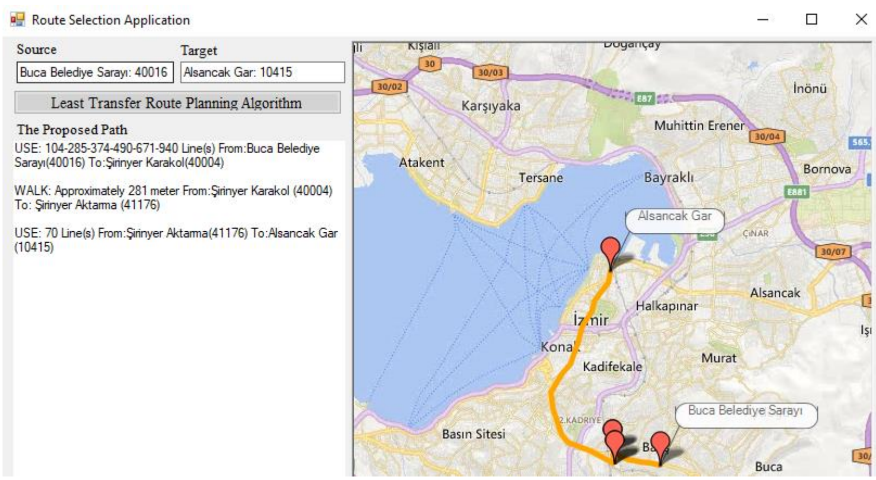

Figure 7. Route Planning Application

Table 1. The Features of the Modelled PTN

Network	***Number of Stations***	***Number of Transit Connections***	***Distance for Walking Adjacency***	***Number of Walking Connections***
The Modelled PTN	7,704	289,875	347m	43,764

In the application, the proposed method is experimented on the origin-destination pairs of the used PTN. For each origin-destination pair, a route is determined by using the method proposed in this study. Some instances of the experimental study are given in Figure 8.

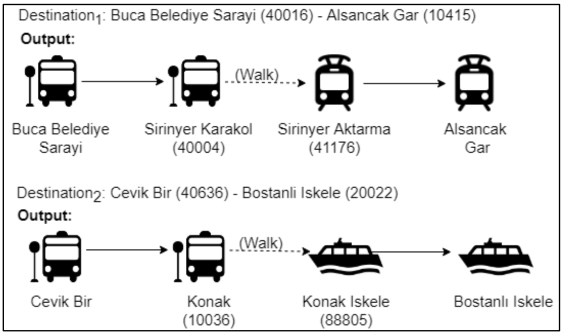

Figure 8. Some Outputs of the Experimental Study

It is observed that the proposed method determines the optimal route regarding the number of transfers for each given origin-destination pair. Additionally, the average running time of the method is 40 milliseconds and it is fast enough to use in responsive public transport route planning applications.

6. CONCLUSION

Public transport is a popular mode of transportation in cities. Many studies and applications aim to propose the ideal route for the related users. However, there are many criteria for the public transport route planning. According to our research and survey, it is observed that the number of transfers is the primary criterion for route planning. Thus, the route recommender minimizing the number of transfers is proposed in this paper by extending our previous conference paper published in Transist 2017 [21]. In the proposed method, all types of public transport network are modelled to an unweighted complex graph in Space P. The optimal distance for walking adjacency is calculated by using a pareto optimal solution in this extended version; thereafter connections between stations within the specified walking distance are added to the model. Then, Breadth First Search based method, that considers walking connections and constraints, is developed to determine the desired route from an origin to a destination in the model. It is proved that our method determines the route with the minimum number of transfers properly from any origin station to any destination station. Additionally, the proposed approach is experimented on the public transport network of Izmir. The average running time of the method is 40 milliseconds and it is remarkably fast enough to be used in the public transport route planning applications.

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