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Determining and Presenting an Optimal Movement Strategy for Desired Routes of Passengers Using Dynamic Programming

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A B S T R A C T

Recent advantages in the field of the Internet of Things (IoT), big data, and intelligent transportation systems (ITS) have provided suitable opportunities for providing suitable services to passengers. In this article, an intelligent transportation system is presented to provide the optimal route to passengers according to requested routes. The architecture and algorithm of this system are described. The purpose of this system is to optimize the cost and travel time of passengers. The dynamic programming method has been used to optimize the travel route, and by minimizing the cost function defined for the route requested by the passenger, the optimal route is presented to the passenger. In this article, the presented method has been implemented in the transport system of Tehran city (including metro lines and bus rapid transit (BRT) lines), and the optimal movement strategy has been extracted and provided to passengers for the routes chosen by the passengers.

1. Introduction

The concept of big data was presented in 1997 and provided the context for many concepts and changes in traditional systems in various industries [1]. One of the areas in which the use of big data has undergone change is transportation systems. With the presentation of the idea of intelligent transportation systems in 1980 and its great acceptance, researchers have done a lot of research in this field in the last decade, and systems have been proposed in this field [2]. Travel and traffic management systems, travel demand management systems, public transport systems, commercial vehicle operation systems, electronic toll collection systems, emergency management systems, advanced vehicle control, and safety systems are areas that have been the focus of many researchers in intelligent transportation systems [3]. Positioning systems, which include sensors for determining the position and speed of vehicles, are one of the most important parts of intelligent transportation systems. Algorithms presented in the field of big data have greatly helped traffic management systems by tracking vehicles such as taxis, buses, trains, airplanes, etc. [4].

For traffic flow prediction, several models have been proposed so far. One of these methods is to use interacting multiple models with the multi-Kalman filter (IMM and MKF) [5], another is to use a fuzzy ARTMAP neural network (FAMNN) [6], and another is to use NN and gaussian process regression (GPR) [7]. For traffic time prediction, several models have been proposed so far; one of these methods is to use

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an information fusion model with data fusion [8]. For traffic speed prediction, one of the methods is to use support vector regression with instance-based [9].

In order to provide suitable services to passengers in intelligent transportation systems, the optimization of various parameters plays a fundamental role [10]. In order to find the optimal route according to the request of the passenger in intelligent transportation systems, fuzzy control has been used, in which the optimal route is identified and informed to the passenger according to the traffic in the transportation lines [11]. Using the fuzzy method, the optimization of the waiting time of passengers along the route has also been done [12]. Other methods in which clustering algorithms are used have been implemented to optimize the traffic and travel time of passengers [13].

On the other hand, a methodology for travel cost optimization for the requested routes of passengers for intelligent transportation systems is presented [14]. Therefore, research has been done to optimize the travel time and cost of an intelligent transportation system. However, the issue that has not been addressed so far is optimizing these parameters while making trips through the combination of existing transportation systems.

The purpose of this article is to optimize travel time and cost for routes requested by travelers. To achieve this goal, an intelligent transportation system (ITS) is provided, which includes subway lines and bus lines. Information related to the location and the movement schedule of vehicles in the mentioned systems is collected in a centralized database.

Information related to passengers' requests, including the requested route and parameters to be optimized, is received by the system. The intelligent transportation system determines all possible routes to the destination and, using dynamic programming, determines the optimal route by minimizing the cost functions.

In the following sections, the architecture of the proposed system will be described first, and then the subway and bus lines of Tehran will be introduced, and the route optimization algorithm will be determined. At the end, an example will be given, and the process of choosing a path will be explained.

2. Problem Statement

In the future, one of the industries that will undergo tremendous changes from the Internet of Things (IoT) is transportation systems. The communication between transportation systems is one of the issues that sooner or later should be paid attention to by active people in this field. Suppose the information on all transportation systems and related vehicles is available in a database.

In this case, in order to move passengers, a suitable strategy can be offered to them through various optimizations and minimizing different parameters such as travel time, fuel consumption, and traffic reduction in a specific transport system. Suppose a person wants to move from an origin to his desired destination. In this case, if the information on all the vehicles and transportation systems is available, it is possible to tell him which vehicle and transportation system to use for moving with the aforementioned optimizations based on his priority.

If it is possible to collect information about vehicles in transportation systems, such as taxis, buses, airplanes, railway lines, etc., in a database, it is possible to offer the best strategy for the combination of transportation means to reach the destination to the passengers based on the routes requested by passengers.

Communication between the components of the proposed system can be shown in Figure 1.

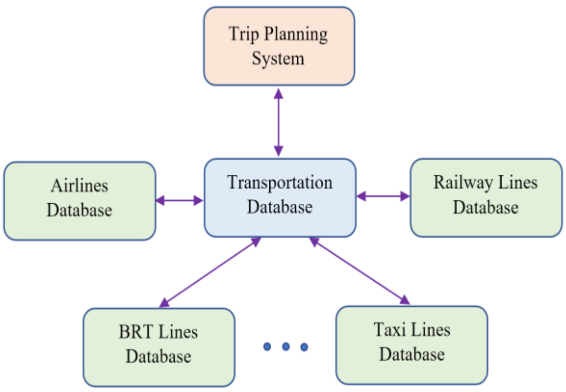

Figure 1: Communication between the components of the proposed intelligent transportation system.

In this article, the subway and bus rapid transit (BRT) lines of Tehran are considered for the design of the intelligent transportation

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system, and based on these two systems, the necessary optimizations will be made for the movement of passengers, and an optimal movement plan will be presented based on the route requested by the passengers. To choose the right strategy, we consider the parameters of travel time and cost, and for each of these parameters, we define a cost function to optimize the mentioned parameters. In the following sections, we first draw the map of the metro and BRT lines and also check the stations and vehicle schedules in these two systems, which are announced to passengers. We then draw the algorithm of the trip planning system, examine how to perform the optimization process, and determine the optimal movement strategy.

Then, based on the routes requested by passengers, we will optimize the mentioned cost functions based on the travel time between two stations by metro and BRT and the cost of travel in each of the systems and lines, and we will finally choose the best strategy for passengers.

2.1. Map of Tehran Metro Lines

Seven metro lines have been operated in Tehran, which are shown in Figure 2.

For each of the lines shown in Figure 2, a schedule is provided to passengers, which specifies when the train will enter the station and pick up passengers during the operation period. To determine the optimum strategy for the movement of passengers, we need these schedules, which are specified for all lines in Table 1.

Table 1: Schedule of trains movement in Metro lines.

Metro Line	Operation Time	Headway
Line 1	05:30 – 22:00	5 minutes
Line 2	05:30 – 22:00	5 minutes
Line 3	05:30 – 22:00	8 minutes
Line 4	05:30 – 22:00	6 minutes
Line 5	05:30 – 22:00	15 minutes
Line 6	05:30 – 22:00	15 minutes
Line 7	05:30 – 22:00	12 minutes

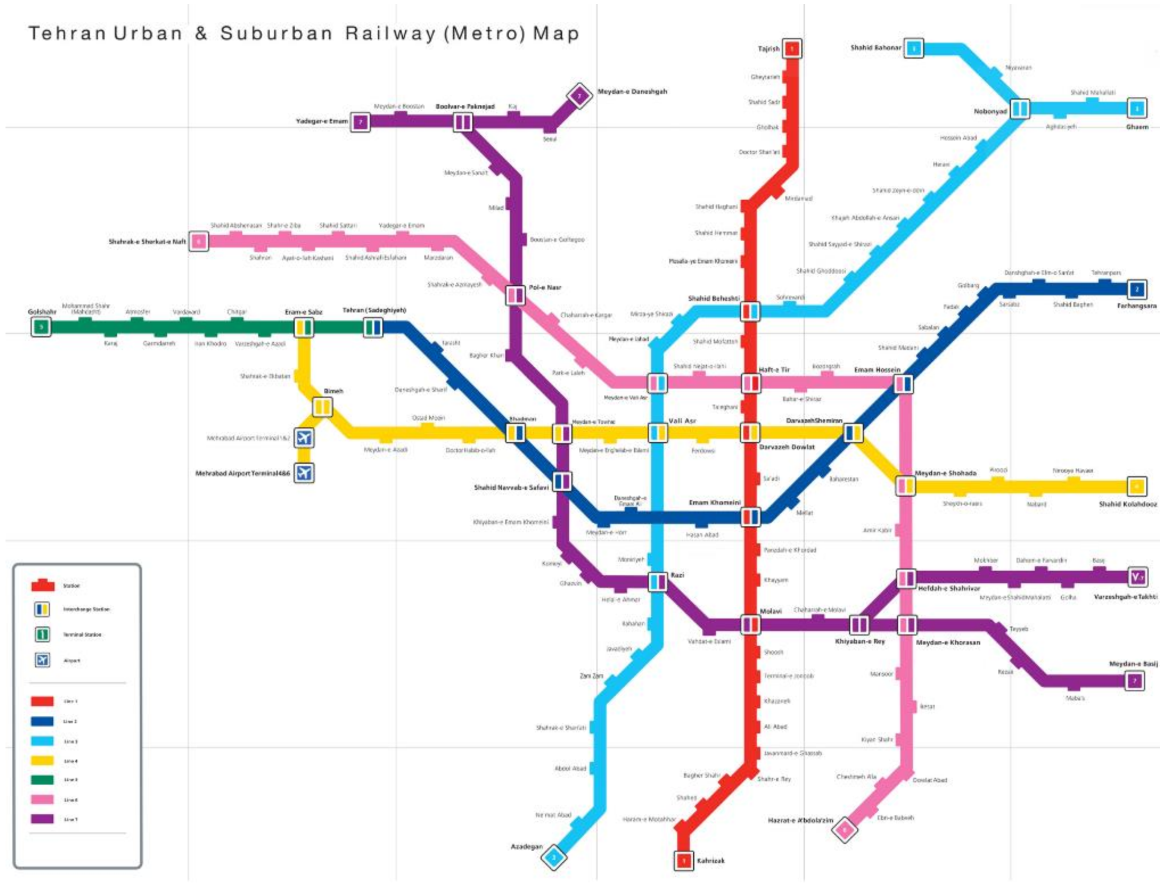

Figure 2: Map of Tehran Metro lines.

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2.2. Map of Tehran BRT Lines

The Tehran BRT lines and stations for each of them, which are currently in use, are shown in Figure 3.

The schedule of bus movement in these lines, which is specified in Figure 3, is shown in Table 2. Information about subway and bus schedules is aggregated in a data center, which we call a transportation database.

To choose the optimum route, another factor that is important for the passengers is the cost of travel. If we consider the cost of a trip by bus as 1, the cost of a trip by subway is equal to 1.6.

Therefore, by determining the priority of passengers in terms of time and cost and determining the weighting coefficients of the cost function, it is possible to choose the appropriate route by optimizing the cost function.

Table 2: Schedule of bus movement in BRT lines.

BRT Line	Operation Time	Headway
Line 1	24 hours	2 minutes
Line 2	24 hours	2 minutes
Line 3	24 hours	3 minutes
Line 4	24 hours	3 minutes
Line 5	24 hours	5 minutes
Line 6	24 hours	5 minutes
Line 7	24 hours	5 minutes
Line 8	24 hours	3 minutes
Line 9	24 hours	3 minutes
Line 10	24 hours	3 minutes

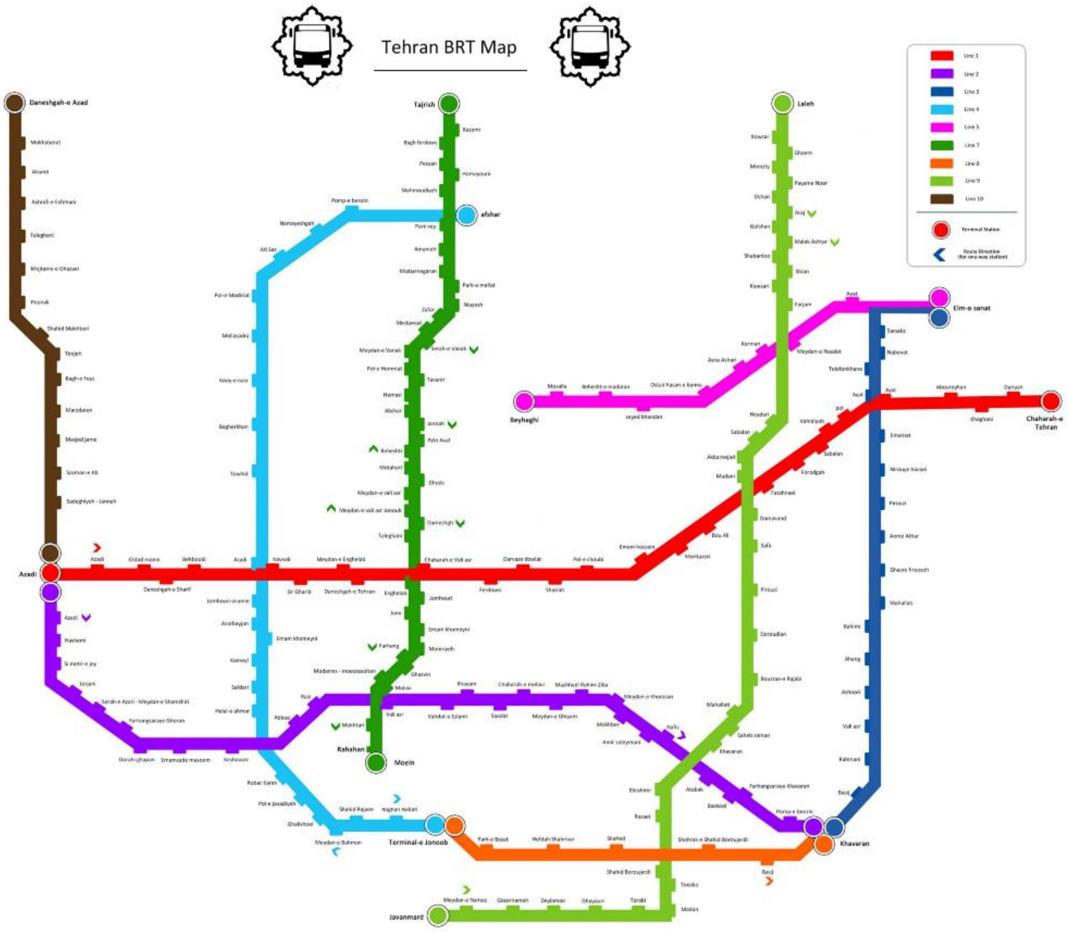

Figure 3: Map of Tehran BRT lines.

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3. Routing Process

According to Figure 1, the databases related to each of the transportation lines have two main tasks. First, they collect the data related to the vehicles and transfer it to the trip planning system through the transportation database. The trip planning system, after receiving all the information from the databases and according to the passengers' requests, made the necessary optimizations (such as time and cost of the trips, operation costs, wear and tear, etc.), and while sending the optimal movement strategy to the passengers, also sent the vehicle movement schedule of all the transportation lines to the relevant databases. Next, the databases control the movement of the vehicles based on the received movement schedules.

Consider a transportation system. To access data related to the position of vehicles, they must be equipped with positioning systems. On the other hand, due to the fact that the principles of the intelligent transportation system are based on the Internet of Things, positioning is realized using wireless sensor networks. As a result, each station of transportation lines should be equipped with a local communication system and undertake the operation of transferring information between vehicles and the database. After determining the position using wireless sensor networks of vehicles and Internet of Things communication protocols, the relevant information is sent to the local communication systems of the stations, which are connected and exchange information. Finally, the local communication systems of the stations transfer the received information to the trip planning system through the transportation database. After determining the timing of the movement of vehicles, the trip planning system sends the information to the databases.

After analyzing the received data, the databases send the movement schedules through local communication systems, based on which vehicles move in lanes. The proposed routing process algorithm is shown in Figure 4.

According to Figure 4, it can be seen that the routing process is done in such a way that the passengers first request a route by specifying the origin and destination. Afterwards, weight coefficients also announce their priorities to the system. Based on the selected origin and destination, the planning system determines all the possible routes to reach the destination and, by comparing the cost function of the routes, selects the optimal route from among all possible routes.

Then the passenger starts moving based on the determined optimal route, and during the movement of passengers, the trip planning system continuously determines the possible routes based on the passenger's position and calculates the cost functions. It should be noted that if a better route is found, it will announce the new optimal route to the passenger.

This process continues until the passenger reaches the destination of the requested route. Suppose that the optimal routes are determined by optimizing the time and cost of the trips. Therefore, the cost function is defined so that these two parameters are minimized. Therefore, we define the cost function as Equation (1).

$$J = J_t + J_c \qquad (1)$$

The first part of the second side of the equation is related to the time cost function, and the second part is related to travel costs. In order to compare and correctly analyze the cost functions, they should be normalized in accordance with the maximum value of time and cost of all the possible routes.

In order to normalize, we must have the maximum amount of travel time and cost. According to the map, for the maximum amount of time, the travel time of the longest possible route from the southeast to northwest of Tehran city (Farhangsaraye-Quran station located on BRT line 2 to Ghaem station on line 3 of Tehran Metro) that includes six stations in Bus line 2, six stations on metro line 4, and 15 stations on metro line 3 in the route - taking into account the two-minute travel time between every two stations for both metro and BRT lines, and the maximum waiting time for 4 minutes in BRT line 2, 5 minutes for metro line 4, and 7 minutes for metro line 3- will be about 70 minutes in total.

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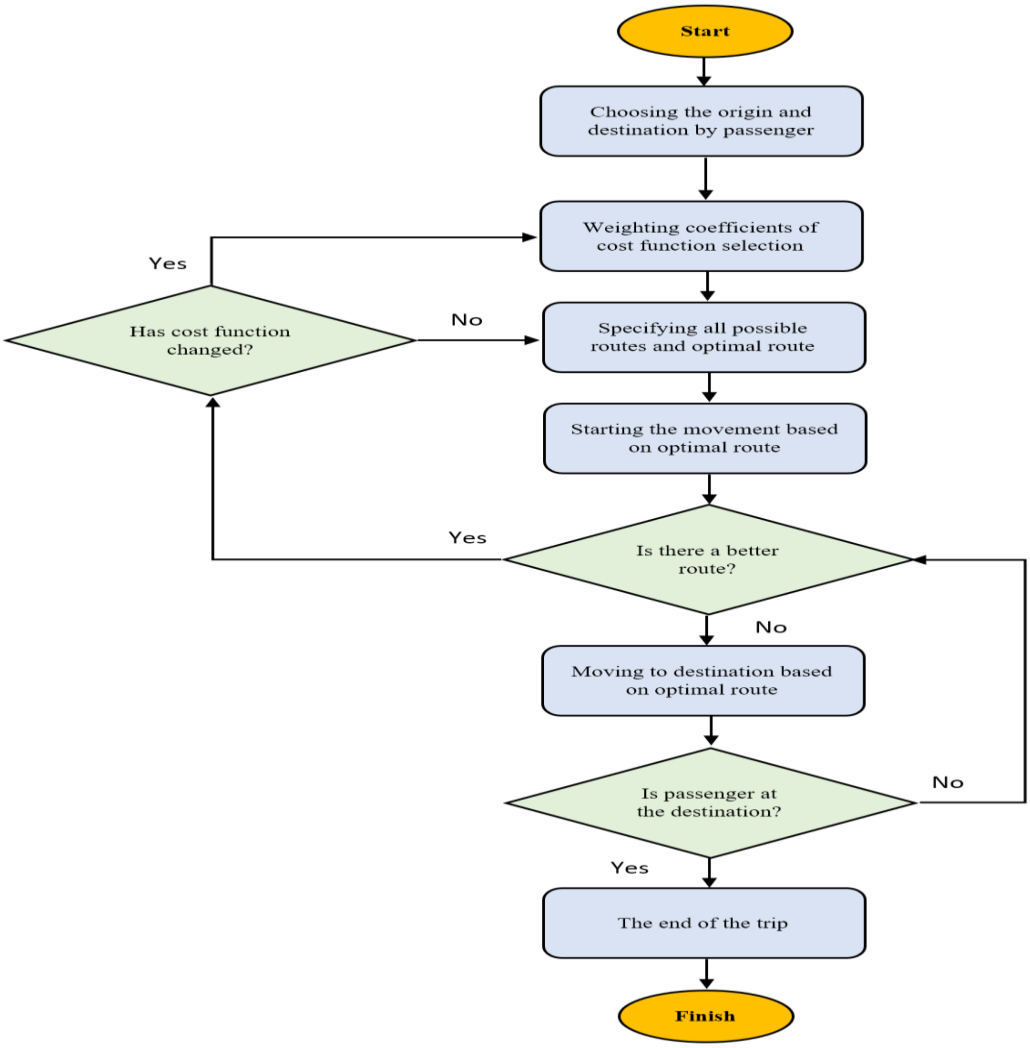

Figure 4: Routing process algorithm.

It should be noted that the calculations were made assuming no disruptions in the transportation systems or the schedules of the vehicles' movements.

Considering that the destination can be reached from any point in Tehran with a maximum of two changes of the route between BRT and metro lines, the maximum trip cost occurs when the metro lines are used first, then the BRT lines, and finally the metro lines again are used, respectively. In this case, the cost will be equal to 4.2. In accordance with the maximum values for travel time and cost, the normalized cost function of time and travel cost will be as in Equation (2).

$$J_t = \frac{t_T}{t_{\max}} = \frac{t_T}{70},\ J_c = \frac{c_T}{c_{\max}} = \frac{c_T}{4.2} \qquad (2)$$

Due to the fact that the priority of passengers may be different in terms of time and cost, weight coefficients for each of the cost functions corresponding to the parameters will be considered, and the final cost function will be in the form of Equation (3).

$$J = K_t.\frac{t_T}{70} + K_c.\frac{c_T}{4.2}, K_t = 0.85, K_c = 0.15 \qquad (3)$$

4. Results

Suppose a passenger intends to move from an origin to a specific destination, as shown in Figure 5.

According to information available in the database of the transportation system for the subway and buses, and based on the algorithm of the routing process described in the previous section, the planning system optimizes the route based on the passenger's request.

Assume that the priority of the passenger's choice is such that the travel time weighting factor is 85% and the travel cost weighting factor is 15%. In this case, the optimization of the defined cost function will be done based on these coefficients, and the final route will be announced to the passenger accordingly.

According to the routing process algorithm, the trip planning system first determines all the possible routes to reach from the origin to the destination according to the requested route, and based on the defined cost function and the weight coefficients, the values of the cost function of the routes are calculated. Next, each of the routes that have a lower cost function value is selected, and the travel strategy is informed to the passenger.

It should be noted that the waiting time for each route is based on the headway specified in the schedules of trains and bus movement in metro and BRT lines. Suppose the passenger requested this route at 7:00. In this case, the possible routes to reach the destination are shown in Figure 6.

Figure 5: Requested route.

According to Figure 6, node a is the origin selected by the passenger, node j is the destination of the route, the nodes marked in green are intermediate stations of bus lines, and the nodes marked in orange are intermediate stations of subway lines. At the specified nodes in Figure 6, the path changes between lines.

As mentioned before, we use dynamic programming to optimize the route. Moreover, the information for the requested route is listed in Table 3. In this table, using the dynamic programming method in each row and from each node in Figure 6, the cost function values of all possible paths from the selected node to the destination are calculated, and the optimal path to the destination is determined for each node.

According to the dynamic programming algorithm, after specifying all the optimal routes from each selected node to the destination, we start from the origin and reach the destination based on the specified optimal routes.

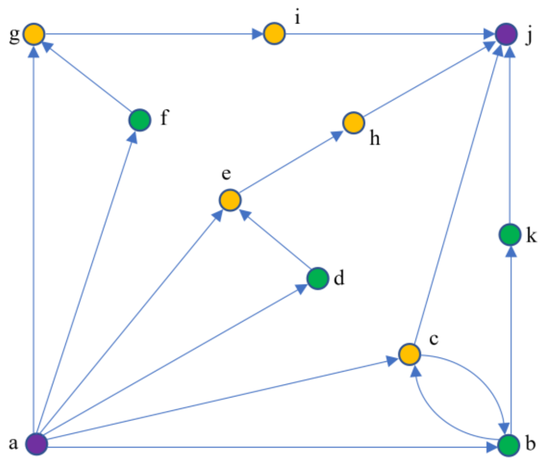

Figure 6: Possible routes to reach the destination according to the requested route.

As a result, the final route is determined, and this route is announced to the passenger. In this example, if we start from node a, which is the origin of the passenger's requested route, and according to the table, it can be seen that the next node the passenger must reach is node c. Now, from this node, according to the row related to the start of the requested route in the dynamic programming table, we select the optimal path to the destination, which is according to the table of node j. In fact, we continue this route according

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Table 3: Choosing the optimal route using dynamic programming according to the possible routes.

Current Node	Next Node	Travel Time	Travel Cost	Cost Function	Optimal Path	Current Node Description
k	j	6	0	0.073	*	Ayat Station: BRT Line 1 and 3
h	j	15	0	0.182	*	Shemiran Station: Metro Line 2 and 4
i	j	10	0	0.121	*	Imam Hosein Station: Metro Line 2 and 6
b	c	2	1.6	0.397	*	Navvab Station: BRT Line 1 and 4
	k	34	0	0.486	-	
c	b	2	1	0.546	-	Navvab Station: Metro Line 2 and 7
	j	26	0	0.316	*	
d	e	2	1.6	0.384	*	Tohid Station: BRT Line 4
e	h	10	0	0.303	*	Tohid Station: Metro Line 4 and 7
f	g	2	1.6	0.433	*	Nasr Station: BRT Line 4
g	i	19	0	0.352	*	Nasr Station: Metro Line 6 and 7
a	b	8	1	0.530	-	Start Node: Komail Station: BRT Line 4 Destination Node: Sarsabz Station: Metro Line 2
	c	10	1.6	0.495	*	
	d	10	1	0.541	-	
	e	12	1.6	0.506	-	
	f	14	1	0.639	-	
	g	16	1.6	0.603	-	

to Table 3 until the passengers reach the destination. So, the optimal path in this example is that we must go to node c from the origin and move towards the destination from this node. Each node that belongs to the considered requested route and indicates a station on the subway and BRT lines is described in Table 3.

Following Table 3, the optimum movement strategy is determined, and the passenger will reach the destination in 36 minutes, and the cost of the trip to reach the destination is equal to 1.6.

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It should be noted that in case of any disturbance in any of the metro or BRT lines, it may be possible to choose a better route to reach the destination, so the system repeats its calculations until reaching the destination, and if a better movement strategy is found, it informs the passenger of the new optimal route.

5. Conclusions

In this article, an intelligent transportation system was presented that introduces the optimal route for the routes requested by the passengers by optimizing travel time and cost through dynamic programming. We considered the transport system of Tehran and implemented the proposed system on this system.

The subway and BRT lines were considered in the design of the proposed trip planning system. Meanwhile, if the information of other transportation systems such as taxi lines, tramway lines, monorail lines, etc. can be collected in the transportation database, a better movement strategy can be offered to passengers. Therefore, it can be considered in future works.

In accordance with the proposed planning system, for future research, other parameters such as the number of empty seats in each vehicle for the comfort of passengers, the distribution of traffic between the transportation systems to reduce the traffic and pollution production of the vehicles, etc. can be considered in the optimization process of the trip planning system.

In addition to reducing the time and cost of trips, optimizing fuel consumption, and also for the well-being of passengers, some of them may prioritize the comfort of travel and prefer to travel by private vehicles. Movement strategy should be chosen based on the preferences of passengers, including time and cost of travel, fuel consumption, and travel comfort.

On the other hand, to determine the best movement strategy for the vehicles and the passengers, in addition to the movement schedules, we need the traffic data and the number of passengers in each line and station, which can be investigated in future works and research. As mentioned before, collecting information of all the transportation systems can be done using wireless sensor networks (WSNs), the communication protocols of the Internet of Things (IoT), and the concept of Big Data, and finally, as a result, realization of the intelligent transportation system (ITS).

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