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A Routing Method in Smart Cities Based on Destination Type and Network Traffic Flow

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Abstract—**The optimal routing will only be possible if the link weights are calculated correctly. Also, the weight of the links should be different based on the type of destination nodes and the traffic flow of each path in the network and should be updated in real time. In this study, using multi-criteria decision-making techniques, the criteria related to each type of destination node and the importance of that criterion according to the type of the destination node, are considered. This research is applied based on the purpose. Library studies have been used to extract criteria related to each type of the destination node. Also, the field method has been used to calculate the weight of each criterion. The simulation of the proposed method showed that this method has reduced the average weight of links in routing by about half compared to the method that considered only the "distance" criterion.**

Keywords: multi-criteria decision-making, routing, smart city, Type of the destination node, urban network, weight of links

Article type: Research Article

I. INTRODUCTION

The spatial structure of cities is studied and analyzed with two general views, quantitative and qualitative, or various patterns and models. In the meantime, the study of the urban network and network resilience is very important. Unfortunately, resilience has mostly been assessed in network-related research only in light of the structural properties of the network. The information about network flow has mostly been ignored. Also, in the existing methods, usually all nodes in the urban network are of the same type (for example, street intersections) and also only one criterion (for example, distance criterion) is used for routing. Using only one criterion, such as distance, causes all vehicles to be routed to the shortest path. As a result, the network flow will be very high on that path, while other paths will have no flow. This will disrupt the urban network. Also, usually in times of crisis in the city, destinations such as gas stations and hospitals increase and the number of people waiting in line for such place's increases. Therefore, in routing, finding more secluded destinations for these types of places should be considered in order to develop urban network

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resilience. In fact, different criteria such as lack of traffic, route security, etc. should be considered in determining the weight of the destination nodes in addition to the distance criterion.

In this study, two types of nodes are introduced in the analysis of an urban network. The first type is the parts of the city where the streets intersect. For example, city squares. The second type is places that provide services. Examples of the second type of nodes include ATMs of banks, hospitals, bakeries, and so on. Also, in this network, the links are the streets and boulevards that connect the nodes with each other. Depending on the network, nodes and links defined and depending on the type of the destination node, there are different criteria for calculating the weight of links. For example, if the destination node is a service provider such as a bank ATM, there are various criteria such as street traffic, distance, route security, and the number of people in the bank ATM queue. Also, if the destination node is a city square, there are different criteria such as traffic, distance, security, and so on. Also, the importance of each criterion varies according to the type of the destination node. For example, if the destination node is a hospital, the time criterion is more important than the other criteria. Another point to note is that some criteria affect other criteria. For example, the distance criterion affects the time criterion.

According to the points mentioned, it is necessary to identify the criteria based on the type of destination node in an urban network. Then the weight and importance of the criteria should be obtained based on multi-criteria decision-making techniques. Due to the impact of the criteria on each other, it is necessary to use a technique such as analytic network process (ANP). In the next step, the values of the stated criteria must be extracted. The Internet of Things can be used to calculate the values of each criterion. Then a formula must be given to combine the values of the criteria to calculate the weight of the links. Based on the weights obtained for the links, the optimal path from the source node to the destination node can be identified. In this paper, the proposed method, which includes the cases mentioned, is presented.

In the following, section 2 describes prerequisites such as Internet of Things and multi-criteria decision-making techniques. Then, in Section 3, the related work and the disadvantages and limitations of the existing methods are discussed. In Section 4, the proposed method is described along with the pseudocode. Then, in Section 5, the proposed method is simulated and compared with single-criteria and random routing methods. Finally, Section 6 concludes.

II. THEORITICAL FRAMEWORK

In this section, the technology and techniques used in the proposed method are described. These include Internet of Things and multi-criteria decision-making techniques.

A. Internet of Things

The term "Internet of Things" was first coined by Ashton in 1999. He described a world in which everything has a digital identity of its own and computers are allowed to organize and manage them. The Internet connects people, but with the Internet of Things, all objects are connected, which can be controlled and managed with the help of applications [1]. In fact, the Internet of Things is a new concept in the world of technology and communication that, as modern technology, provides the ability to send data through communication networks to anything (human, animal or object) [2]. The Internet of Things is a universal concept that can be used in all areas of transportation, energy, health, manufacturing and the like to create an intelligent world [3, 4].

In the proposed method, the Internet of Things is used to extract data. For example, by using the connection between the bank ATM and the smartphone of the people standing in line, the number of people waiting to receive services from the ATM can be obtained. Fig. 1 shows the connection between an ATM and a smartphone of people waiting in line, in the Internet of Things environment.

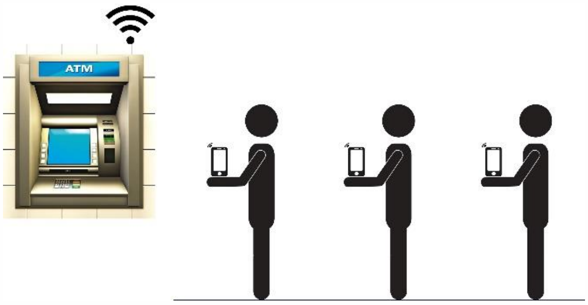

Figure 1. The connection between the ATM and the smartphone of the people waiting in line using the Internet of Things

Also, the number of people waiting to receive medical care in a hospital, or the number of people waiting in line at a bakery, or the number of cars on a street, can also be calculated using the Internet of Things.

B. Multi-Criteria Decision-Making Techniques

In recent decades, researchers have turned their attention to multi-criteria decision-making techniques for complex decision making. Today, multi-criteria decision-making techniques are widely used in many different fields. The reason for this is the high ability and capability of these methods in modeling real problems and their simplicity and comprehensibility for most users. In these decisions, instead of using one criterion, several measurement criteria may be used. Multi-criteria decision-making techniques are commonly used to prioritize and weight criteria.

In the proposed method, multi-criteria decision-making techniques are used to extract criteria based on the type of destination node in the urban network and calculate the weight and importance of each criterion. Also, the point that has been considered in the proposed method is that the criteria used in routing are not independent of each other. For example, the criterion of "distance" affects the criterion of "time". Therefore, the ANP technique has been used to calculate the weight and importance of each criterion. The first step in the ANP technique is to define the problem and draw the network. In this step, the problem is clearly defined and a network of objectives, criteria, sub-criteria and alternatives are drawn. Fig. 2 shows the network hierarchy layer structure of the problems. In the structure, there exists interdependency within each layer and loop arcs are used to indicate feedback relationships [5].

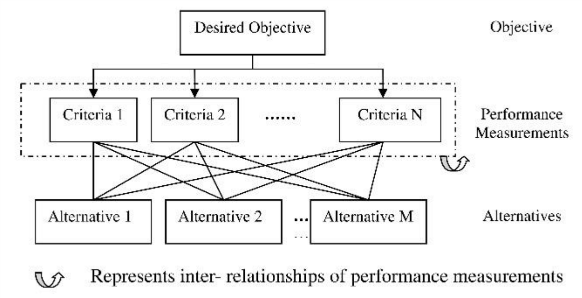

Figure 2. ANP network hierarchy layer model architecture [6]

Then, considering all the relationships resulting from the hierarchical structure as well as all the internal and external relationships of the groups, the pairwise comparison matrix is formed. For this purpose, experts are asked to make pairwise comparisons. The elements of each level are compared to other elements at a higher level and pairwise comparison matrixes are formed. Also, at the end, a pairwise comparison of internal relations should be formed. The values of related importance are expressed by "Saaty" in the range of 1 to 9, so that the number 1 indicates the equal importance between the two elements and the number 9 indicates the extremely high importance of one element over the other element. The inconsistency rate of all comparison matrixes must be less than 0.1. Otherwise, pairwise comparisons should be reconsidered. Using the weight of the obtained pairwise comparisons, the super matrix is formed. A super matrix is a separate matrix, each part of which represents the relationship between two clusters in the system [7]. The general form of the super matrix can be described as Fig. 3.

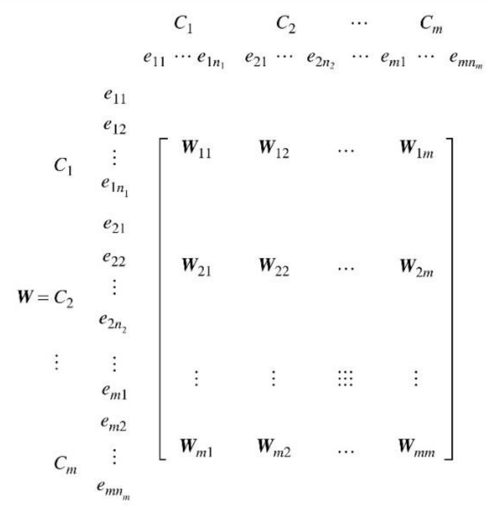

Figure 3. The general form of the super matrix [6]

Where $\mathbf{C_m}$ denotes the mth cluster, $\mathbf{e_{mn}}$ denotes the nth element in the mth cluster, and $\mathbf{W_{ij}}$ is the principal eigenvector of the influence of the elements compared in the jth cluster to the ith cluster. In addition, if the jth cluster has no influence on the ith cluster, then $\mathbf{W_{ij}} = 0$. Therefore, the form of the super matrix depends heavily on the variety of the structure. After forming the weighted super matrix, it must be infinitely powered according to Formula 1 so that each row converges to a number whose weight number is the criterion, sub-criterion or alternative [7].

$$\lim_{k\to\infty} W^k \tag{1}$$

III. RELATED WORKS

In this section, routing methods researches are reviewed. Chow et al. provide an adaptive linear quadratic optimal traffic control system. Control strategies are solved through a decentralized approach and complemented by a user-optimal network traffic router. The routing algorithm presented in this article helps drivers find the fastest route to their destination based on the available traffic. The proposed control system has been implemented and tested in London. This study shows that the proposed system can provide similar performance to its centralized routing counterpart even in crowded conditions [8].

Ingole et al. have developed a routing approach aimed at minimizing traffic across the network. This problem is formulated as a linear programming problem. The results show that the proposed method improves the average of the total time spent in the network [9].

Lin et al provide a way to route Connected and automated vehicle (CAV) technology in grid networks. The authors integrate the proposed framework of a rhythmic control method with an online routing algorithm to achieve collision-free control of all CAVs in a network and achieve superior performance at average vehicle latency, network throughput, and computational scalability. Implementation results have shown that the framework is able to achieve minor delays and increase network throughput [10].

Guo et al. have routed city buses that have path flexibility. The authors consider bus stops as different destinations. They create a mixed-integer programming model to formulate the problem. They also develop a hybrid metaheuristic (combining tabu search and variable neighborhood search) to solve the model. Finally, the proposed method has been studied in a sample on an urban scale, which has been satisfactory [11].

In their study, Wang et al. presented a vehicle routing approach aimed at minimizing total carbon emissions. A mathematical programming model is established to minimize the total carbon emissions, and then a tabu search hybrid algorithm is proposed to solve the minimization problem. The computational results confirm the advantage of the model and show that the proposed method can reduce the total carbon emission [12].

Kancharla and Ramadurai have proposed a routing method aimed at reducing fuel consumption. In this study, modified versions of several standard vehicle routing problems (VRP) instances are used to test the effect of estimated fuel consumption using driving cycles. The experimental results show that the proposed method can lead to fuel consumption savings of 8 to 12% [13].

As can be seen in the related works, most of the researches have done routing based on only one criterion. For example, traffic criteria, total carbon emissions, fuel consumption, route length and so on. But in fact, different criteria need to be considered in routing and managing network flow. The selection of criteria is also different based on each type of destination. For example, if the destination is a bank ATM, in addition to traffic, distance and route security, there are other criteria such as the number of people waiting in line at the bank ATM. But if the destination is a bakery, in addition to the number of people waiting in line, there is also the price of bread as a criterion. Also, the weight and importance of each criterion varies depending on the type of destination. For example, if the destination is a hospital, time may be more important than cost. In this research, different criteria have been considered according to the type of destination. Also, the weight and importance of each criterion is determined according to the type of destination. The Internet of Things is used to extract value from each criterion. The proposed method, which utilizes modern technologies, can increase the resilience of the urban network by balancing the network flow and optimization and intelligent routing.

IV. THE PROPOSED METHOD

The type of this research, based on the purpose, is applied research. Library studies have been used to extract criteria according to the type of destination. Also, the field method has been used to calculate the weight and importance of each criterion. The phases and steps of the proposed routing method with the aim of developing the resilience of the urban network based on network flow are described in the following.

a. Determining the types of destination nodes. In the first phase, it is necessary to specify the types of destination nodes. Destination nodes can be street intersections, such as a city square, or service nodes, such as a bank ATM, a hospital, a bakery, a gas station, and so on.

b. Determining the criteria based on the type of the destination node. Once the types of destination nodes have been identified in phase 1, the criteria related to the type of destination node need to be identified. For example, if the destination node is a hospital, the criteria could include the number of people waiting, the cost of the visit, traffic, and so on. Criteria related to the type of destination node can be extracted from library studies and review of articles as well as questions from experts.

c. Calculating the weight and importance of each criterion. The weight and importance of each criterion varies according to the type of the destination node. For example, if the destination node is a hospital, the weight and importance of the number of people waiting may be greater than the fee. On the other hand, if the type of the destination node is a bakery, the weight and importance of the bread cost criterion may be greater than the criterion of the number of people waiting in line. Therefore, after the criteria related to the type of destination node were determined, it is necessary to determine the weight and importance of each criterion according to the type of the destination node. It should also be noted that some criteria affect other criteria. For example, the traffic criterion affects the time criterion. According to the points mentioned, multi-criteria decision-making techniques can be used to calculate the weight and importance of each criterion according to the type of the destination node. Among the multi-criteria decision-making techniques, the ANP technique can be used, which also considers the effect of criteria on each other. This phase of the proposed method can be done using the field method. The point to be noted is that phases 1 to 3 of the proposed method only need to be calculated once for each urban network.

d. Extracting values related to each criterion. In this step, the Internet of Things is used to extract the values of each criterion. For example, to extract the values of the number of people waiting in line at the bank ATM, the number of people waiting in line at the hospital, the number of people waiting in line at the bakery, we can use the connection between the smartphone and the bank ATM or machines placed in the hospital, bakery, etc., to identify the number of people waiting in line. Figure 1 showed the smartphone connection of the people waiting in line with the bank ATM. Also, to extract the values of other criteria, such as traffic criteria, the amount of traffic on each street can be obtained from the connection that is established between cars or people's smartphones. To extract the values of the doctor's visit fee or the measure of patients' satisfaction with a doctor, we can use the information placed on Google Maps and the likes that people have given to each doctor.

e. Determining the weight of each link. Once the type of destination node has been determined, the weight of the links needs to be calculated based on the extracted criteria, the weight and importance of each criterion, and the extracted values associated with each criterion. Suppose the extracted criteria based on the type of destination node v_f contain the criteria $c_1, c_2, \dots, c_k$ and the weights of the criteria are $l_1, l_2, \dots, l_k$. Also, the values associated with each criterion are $a_1, a_2, \dots, a_k$. The weight of the w_i link is equal to formula 2.

$$w_i = l_1 a_1 + l_2 a_2 + \cdots + l_k a_k \qquad (2)$$

Fig. 4 shows how to calculate the weight of the w_i link based on the extracted criteria, the weight and importance of each criterion and the extracted values associated with each criterion obtained from phases 1 to 4 of the proposed method.

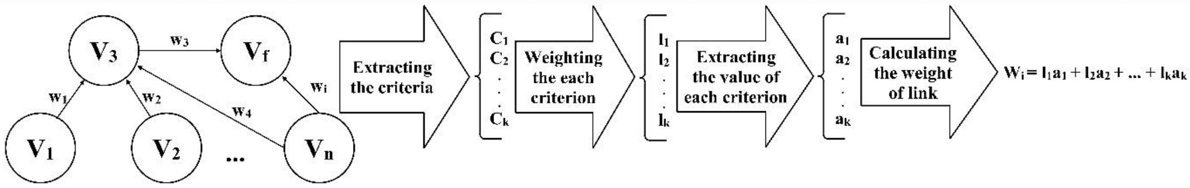

Figure 4. Calculation of w_i link weight based on criteria, weight and importance of each criterion and values related to each criterion

f. Routing. Once the weight of the links has been obtained based on the type of the destination node, it is necessary to determine the optimal path, which includes a set of nodes and links from the source node to the destination node. This phase includes the following steps:

- Is the destination node type of service provider (such as hospital, bank ATM, etc.)? If yes, go to step (b) and if no, go to step (d).
- Is a specific place of the city chosen? For example, if the destination is a bank ATM, is it an ATM located in a specific location in the city, or any ATM that the routing algorithm identifies based on optimization in terms of the number of people waiting in line, traffic, and so on? If the answer is no, go to step (c) and if the answer is yes, go to step (d).
- Declare the optimal route to one of the destinations of the service provider based on the weights obtained for the links and using the Dijkstra's algorithm. Then go to phase 7 of the proposed method. For example, if the destination is a bank ATM and the specific location of the city is not considered, based on the weights obtained for the links, check the different routes with the destination of the ATMs located in the city and announce the optimal route. Fig. 5 shows an example of different routes marked with different colors, from the v_s start node to one of the ATMs in the city (without specifying a specific location in the city), which will be determined the optimal route based on the weight of the links.

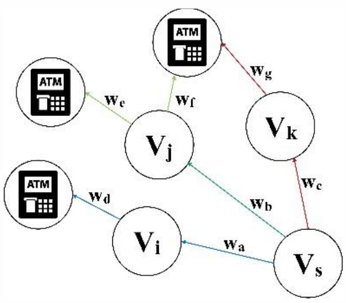

Figure 5. Determining the optimal path when the type of the destination node is important, not the location of that node

- Declare the optimal route to the specified location of the city based on the weights obtained for the links and using the Dijkstra's algorithm. Then go to phase 7 of the proposed method. Note that although there is a specific location of the city, but there are different paths and links to reach the specified location and the weight of the links is different based on traffic, distance and so on. For example, in Fig. 6, although there is only one destination node, there are different paths and weights based on different criteria for reaching the destination node

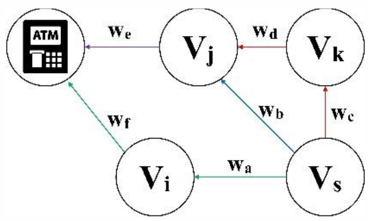

Figure 6. Routing when the destination node location is specified

g. Updating the criteria values. The criteria and weights obtained for the criteria from phase 1 to 3 of the proposed method are constant. But the values associated with each criterion may change. For example, traffic on a street may increase or the number of people waiting in line may increase or decrease. Therefore, after determining the optimal path, the values of the criteria and the optimal path need to be updated. Also, in this phase of the proposed method, it is checked whether we have reached the destination node or not? If we reach the destination node, the proposed method terminates. Otherwise, phases 4 to 7 of the proposed method are repeated, and the weight of the links and the optimal route are updated based on the location of the city where we are currently located.

Fig. 7 shows the flowchart of the proposed method based on the phases and steps described. Also, the pseudocode of the proposed method is given in the following.

Function: Developing urban network resilience based on network flow

Input:
$v_1, v_2, \dots, v_n$: urban network nodes
$e_1, e_2, \dots, e_m$: urban network links
v_s: source node
v_f: destination node
t_f = type of destination node v_f
$c_1, c_2, \dots, c_k$: criteria based on t_f
For each criterion c_i **do**

l_i = the weight of criterion c_i using the ANP technique
End for
Do
For each criterion c_i **do**
a_i = value of criterion c_i using the Internet of Things
End for
For each link e_i **do**
$w_i = l_1a_1 + l_2a_2 + \cdots + l_ka_k$
End for
If t_f is a service provider **&** v_f==NULL **do**
Announce the optimal route to one of the specified service provider destinations based on the weights obtained for the links and using the Dijkstra's algorithm.
v_f = optimal route destination
Else
Announce the optimal route to the v_f based on the weights obtained for the links and using the Dijkstra's algorithm.
End if
v_t = current location
While (v_f != v_t);
End function

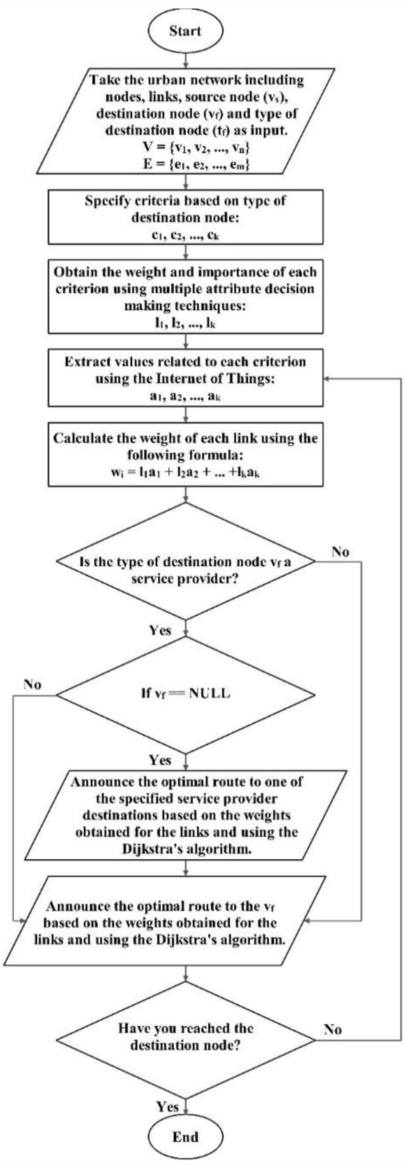

Figure 7. Flowchart of the proposed method

IV. RESULTS AND DISCUSSION

In this section, the proposed method is simulated. MATLAB software has been used for this purpose. Initially, a random network with 100 nodes and 486 links were created. Of these 100 nodes, 30 nodes were considered as service provider nodes such as bank ATMs, hospitals, etc. that the number of each character is randomly determined and distributed randomly in the network. Also, the choice of, for example, which of the bank's ATM is determined as the destination, is determined based on the weight of the nodes obtained by the algorithm. Fig. 8 shows the random network created using MATLAB software illustrated using NetDraw software. Also, Table 1 shows the characteristics of this random network. The colors and shapes considered for each type of network node are described in Table 1.

TABLE I. RANDOM NETWORK CHARACTERISTICS OF FIGURE 8

Characteristic			Number	Shape	Colour
Node	Intersection of links		70	Circle	Blue
	Service provider	Bank ATM	10	Square	Red
		Hospital	7	Up triangle	Yellow
		Gas station	8	Box	Green
		Bakery	5	Diamond	Brown
Link			486	Arrow	Black

According to the proposed method, after determining the types of nodes, criteria are extracted based on the type of the destination node. For this purpose, library studies and questions from experts have been used. Also, the weight and importance of each criterion were calculated using ANP technique and field method. Super Decisions software was used for this purpose. Fig. 9 shows the network structure for the case where the destination node is a hospital in Super Decisions software. For other destination nodes, the network structure was formed in this software and the weight and importance of the criteria were calculated.

Table 2 shows the criteria extracted based on each type of destination node and its weight and importance. The criteria for each type of destination node are extracted based on library studies. Also, field studies and questions from experts have been used to calculate the weight of each criterion. It should be noted that the inconsistency rate for all cases was less than 0.1, which confirms the reliability of the results. Note that the sum of the criteria weights for each type of the destination node is equal to 1. The criterion of "safety" means the safety of street asphalt.

TABLE II. EXTRACTED CRITERIA, WEIGHTS AND IMPORTANCE OF EACH CRITERION BASED ON THE TYPE OF NODES

Node type	Criterion	Criterion weight
Normal location	Distance	0.371
	Traffic	0.493
	Safety	0.136
Bank ATM	Number of people waiting in line	0.337
	Distance	0.258
	Traffic	0.282
	Safety	0.123
Hospital	Visit fee	0.174
	Satisfaction from the doctor	0.269
	Number of people waiting in line	0.153
	Distance	0.161
	Traffic	0.177
	Safety	0.066

Gas station	Number of people waiting in line	0.318
	Distance	0.277
	Traffic	0.291
	safety	0.114
Bakery	The cost of bread	0.227
	Bread quality	0.223
	Number of people waiting in line	0.188
	Distance	0.147
	Traffic	0.173
	Safety	0.042

Fig. 10 shows the weight and importance of the different criteria defined for each type of destination node. For example, for the "hospital" node type, it is possible to identify which of the criteria has the highest weight and importance.

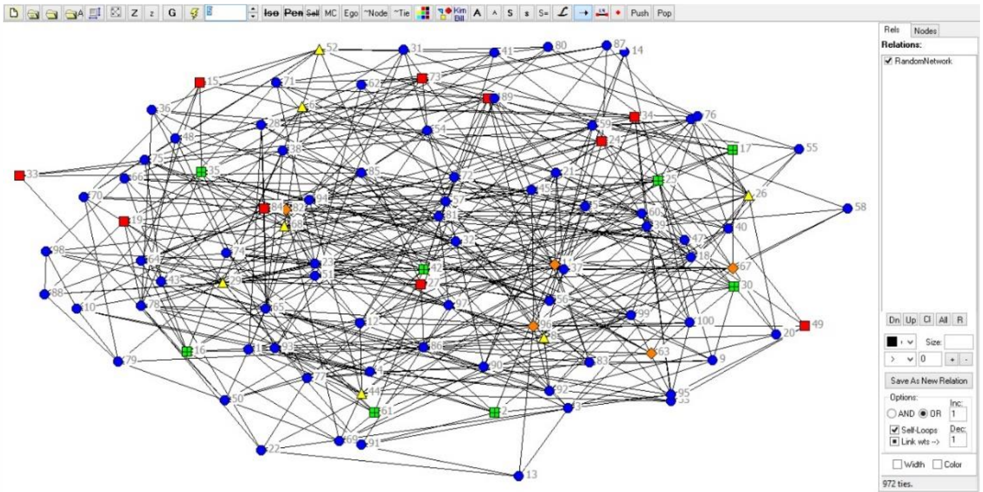

Figure 8. Random network illustration

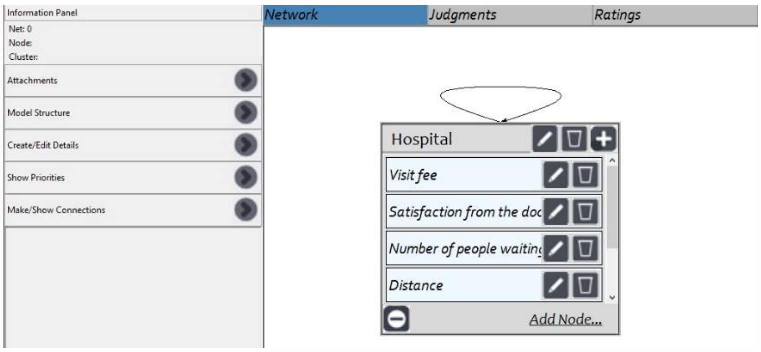

Figure 9. The network structure for the case where the destination node is a hospital, in Super Decisions software

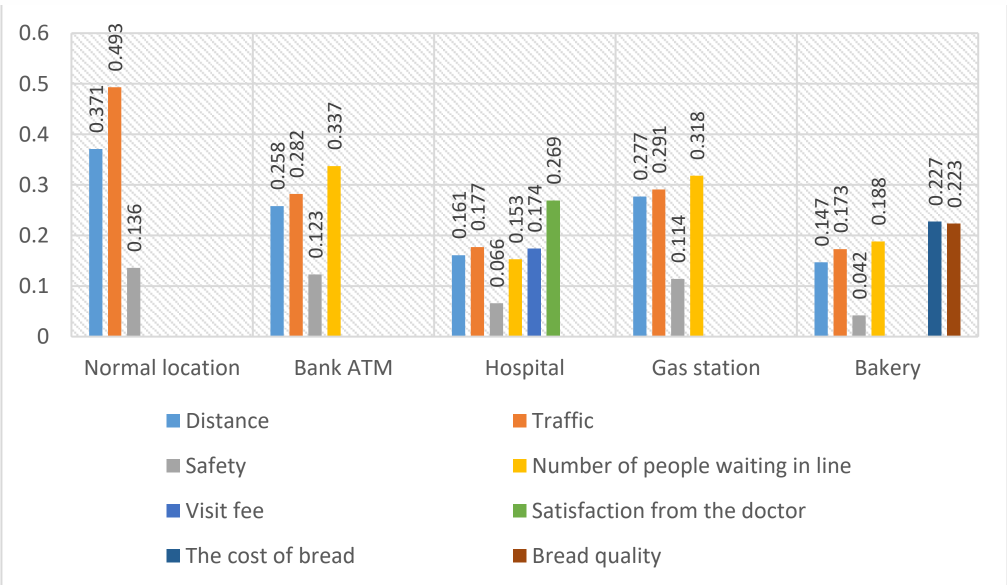

Figure 10. Weight and importance diagram of different criteria defined for each type of destination node

Also, in Fig. 11, we can compare the weight and importance of each criterion based on the types of destination nodes defined. For example, how important is the criterion of "number of people waiting in line" in different destination nodes, such as "gas station", "hospital", etc., and in which type of destination node is the weight of this criterion greater.

The data obtained up to this step of the proposed method include the types of nodes, the criteria extracted, and the weight and importance of each criterion are constant. In order to simulate the next steps of the proposed method, a number of different vehicles were randomly considered in different places of the urban network. Also, for each vehicle, a destination was randomly selected. To update the data related to the "number of people waiting in line" criterion, a random number between 1 and -1 is created. If the number is positive, one person will be added to the number of people in the queue, and if it is negative, one person will be deducted from the number of people in the queue. Also, when a vehicle moves from node v_i to node v_j, a unit is added to the value of "traffic" criterion of the link connecting the two nodes, and when it reaches node v_j, a unit is deducted from the value of "traffic" criterion of this link. Fig. 12 shows a part of the simulation using NetLogo software. In this part of the simulation, 40 cars are considered as "turtles". Also, "patches" represent the destination nodes. Types of destination nodes are shown based on the different colors stated in Table 1. Also, the chart on the right shows the average weight of the links.

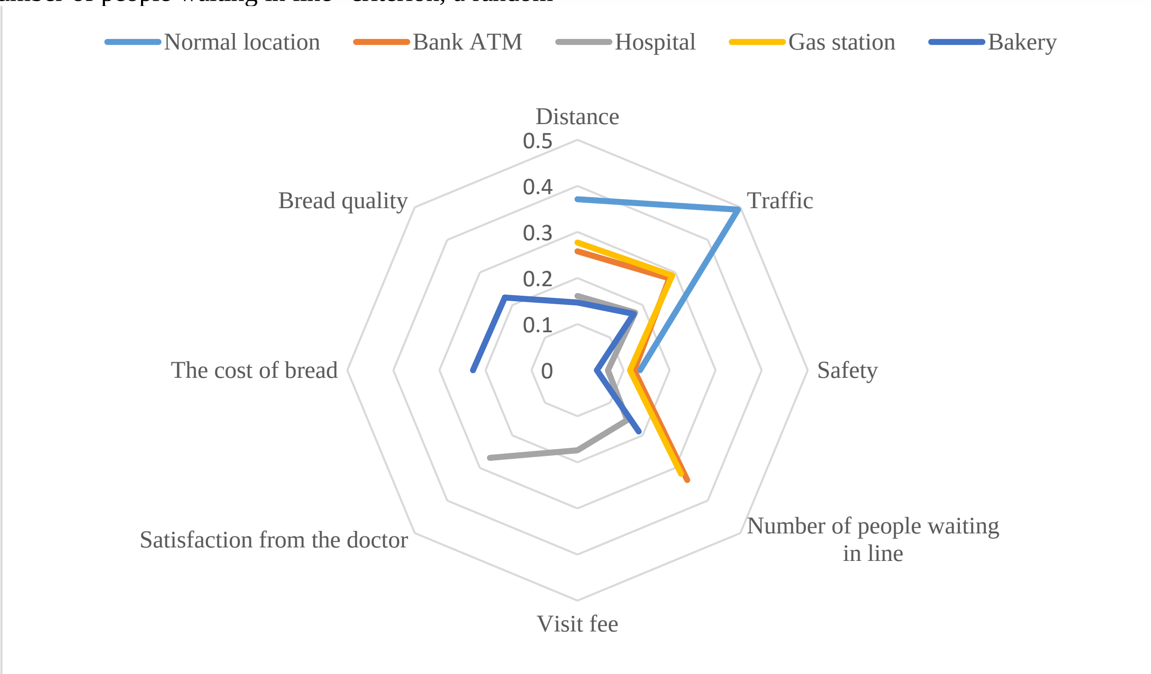

Figure 11. The weight and importance of each criterion is defined based on the type of destination nodes

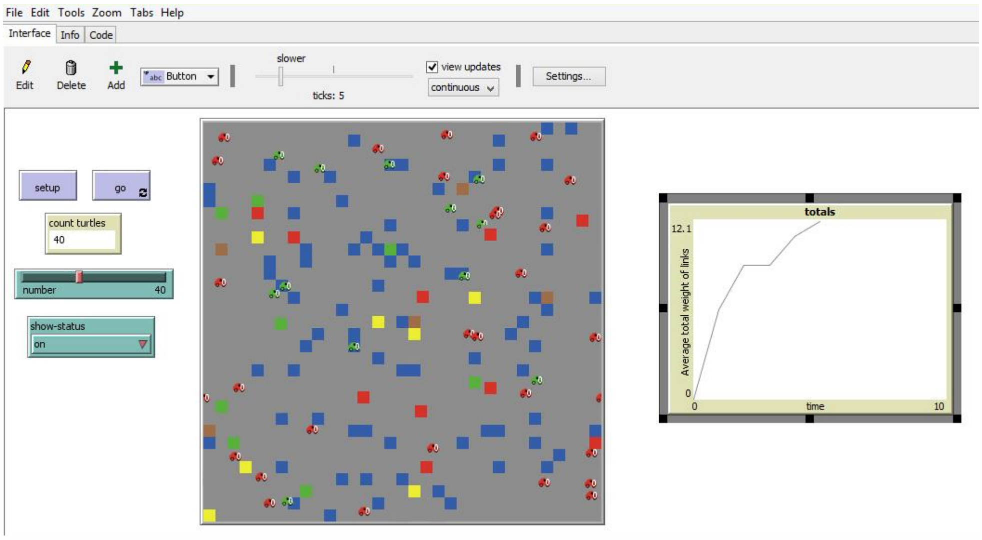

Figure 12. Simulation of the proposed method

The diagram in Fig. 13 shows the simulation results of the proposed method based on the number of vehicles and the average total weight of the links that this number of vehicles traveled to reach the destination node. Also, the method that considers only the "distance" criterion and the method that randomly selects from the links on the way to the destination are shown.

As shown in Fig. 13, the average weight of the links that the vehicles traveled from the source node to the destination node in the proposed method is less than half of the method that considers only the "distance" criterion. It is noteworthy that in the method that considers only the "distance" criterion, when the number of vehicles increases, it becomes worse than the method that randomly selects from the links that lead to the destination node. Because, in a method that only the "distance" criterion is considered, many vehicles are redirected to the same links, which increases the network flow on these routes and the value of "traffic" criterion is increased, while other routes have little or no flow. The proposed method, by considering different criteria and different weights for each criterion, achieves the optimal path, balances the network flow and thus develops the resilience of the urban network.

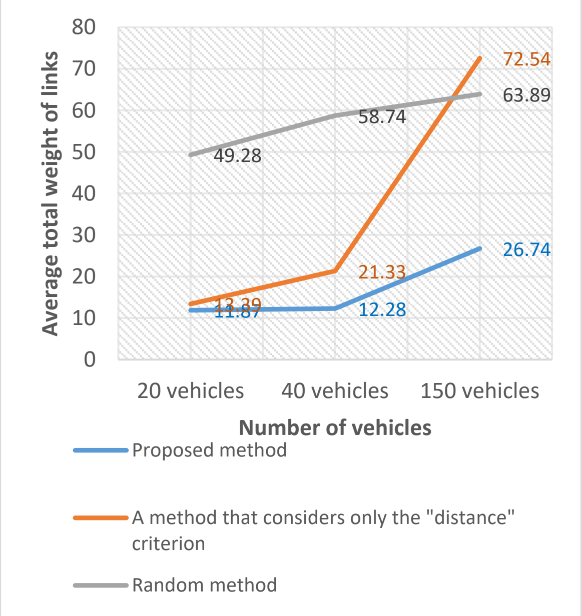

Figure 13. Results of the proposed method compared to other methods

V. CONCLUSION

In this study, a method for optimal routing and thus developing urban network resilience based on network flow by considering the types of destination nodes, different criteria according to the type of destination node and also the weight and importance of each criterion according to the type of destination node in the Internet of Things environment were presented. Unfortunately, in most existing studies, routing is based on only one criterion. Also, the weight and importance of each criterion is not included in the weight of the links. Another thing is that the weight of the links is assumed to be constant in most cases. Also, in the event of a crisis in a city, some service providers destination, such as gas stations and hospitals, will increase. Therefore, these items need to be considered in network flow, link weights and routing. In this study, a method was presented that uses multi-criteria decision-making techniques to consider the criteria related to each type of destination node and the weight and importance of that criterion according to the type of the destination node. It also uses the Internet of Things to instantly obtain and update criteria values. The simulation of the proposed method showed that this method has reduced the average weight of links in routing by about half compared to the method that considered only the "distance" criterion. The more vehicles there are, the more efficient this method will be compared to other methods. Because a method that considers only one criterion, such as "distance", directs most vehicles to the same route with a shorter length, which will increase traffic; and in cases where the number of vehicles is large, the network flow in this route will be so high that it will lead to disruption of the urban network. The proposed method, by considering various criteria such as "distance", "traffic", etc. and the weight of each criterion, can lead to optimal routing, and thus develop the resilience of the urban network based on network flow.

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