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RESEARCH ARTICLE **Open Access**

Designing an Integrated Model of Mathematical Planning and IoT with Emphasis on Cost-Time-Routing Optimization of Intercity Transportation Systems

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Abstract
The issue of transportation, which today as a socio-political phenomenon plays a very sensitive and important role in the quality and socio-economic structure of a society, forms the basis of modern urban life and the needs of human movement. In this research, our goal is to design a system dynamics model in the form of combined transport system to try to reduce costs, time and increase customer satisfaction by taking into account the uncertainty in the combined transport system, especially uncertainty in demand. Considering the productivity required by both of passengers and urban management, the importance of the issue and its impact on other sectors, as well as the lack of sufficient research in this field, in this study, the design of intra-city transportation system will be studied. The purpose of this planning is to determine the location of stations for public transportation as well as to determine the best route to reach the next station. Initially, the IoT system is used to collect and analyze historical data. Then the effective parameters and input values of the mathematical programming model are determined. The implementation of the model determines the appropriate outcomes for the decision variables. In other words, this leads to determining the optimal stations and the appropriate route to transport passengers between stations so that travel time and cost are minimized. In addition to material profitability, this includes passenger satisfaction, increased willingness to use public transport, reduced traffic, and reduced environmental impact, increased reliability of public transport and more accurate forecast of vehicle arrival at the station.

Keywords: Mathematical planning; IoT, Cost-time optimization, Intra-city transportation systems routing

Introduction

One of the ways to reduce the problems of urban transportation system and get rid of the problem of car dependence is to realize a comprehensive system of public transportation system with a level of quality and efficiency that makes users prefer to choose this method of travel. The bus system, which is part of the public transportation system, can provide citizens with satisfaction as one of the best options for transporting a large number of

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passengers in continuous networks in the city, if it provides services with a high level of quality and increase the tendency to use this transportation system. In this regard, to optimize the public transportation system in order to provide safe, continuous, cheap, fast and desirable services to applicants for intercity travel should be launched (Amanpour et al., 2016).

One of the most important types of urban services is public transportation system, which is one of the challenges in today's world. The factor of transportation system affects the development of regional maps, economic existence, the impact of environmental factors and finally the quality of life of the middle class (Amanpour et al., 2016). The issue of transportation system, which today as a socio-political phenomenon plays a very important role in the quality and socio-economic structure of a society, forms the basis of modern urban life and the needs of human movement. Therefore, in the process of urban development, the development of transportation system must have a detailed plan, because the use of incorrect methods and decisions and neglect in using the principles of urban planning and traffic, will affect the situation of citizens in various areas (Amanpour et al., 2016).

Transportation system infrastructure of a city is of special importance for the quality of roads, the level of access to public transport and neighborhoods to access them, and determine the degree of access of people to buildings, places and spaces (Yazdan Panahi & Maleki, 2011). Another aspect is the important role of the urban transportation sector in creating jobs and economic development of the city. In many countries, public transport occupations account for between 1 and 2 percent of the country's total employment. Transportation is an essential element for economic performance and also a key part in creating employment, from building vehicles in factories to refining fuel, managing transportation services and developing and maintaining infrastructure (Aghdas Vatankhah & Gharib, 2009).

On the other hand, the current transportation systems, which are mainly based on personal vehicles, are inherently unjust and an obstacle to reducing poverty and creating justice for all sections of society to benefit from urban mobility and mobility. In many developing countries, there is a large gap between different income groups in terms of access to asphalt roads, as well as safe and affordable transportation system. Therefore, investing in transportation system, such as public networks that are accessible, reliable, and affordable for all, can reduce poverty by providing job opportunities for individuals and facilitating access to services. Creating a local economic stimulus can reduce travel costs and time, which in turn will lead to cheaper services. These networks also protect individuals in the community against the harmful effects of transportation system such as traffic accidents and air pollution (Chang et al., 2018). In the first five-year plan of the Islamic Republic, an annual growth of 12.3% in cargo transportation and 8% in passenger transportation has been considered. But in the first year of the program (1989), we have witnessed a decrease in freight transportation by 4% and an increase in passenger transportation by 5%. Obviously, achieving the goals requires a program of change and transformation in technical and administrative systems and the use of new technology (Mehdizadeh et al., 2010).

Urban transportation networks can be considered as a set of urban road network and public transportation networks active in it. A transportation system can be defined as a set of fixed facilities, flow entities and a control system that allows passengers and goods to overcome geographical constraints and participate in the desired activities in a timely manner.

Fixed facilities are the physical components of the transportation system that are located in a fixed location and include network links (such as roads, rails and pipes) and nodes (such as intersections and terminals) of the system (Yazdan Panahi & Maleki, 2011).

Theoretical Foundations

Intra-city transportation system

An intra-city transportation system refers to a set of vehicles and their activities that are used to move people or goods within the city from one point to another. Public transportation services can be based on distance fares based on distance and as a profitable service, or it can be funded by the government as a subsidy, in which case the fare for passengers will be fixed. These services are completely profitable and recoverable for the people who use them, or if possible, they can be controlled locally or by the government by paying subsidies. Of course, in some small and large cities, these subsidies are fully paid and these services are provided to the people at no cost (Chang et al., 2018).

Transportation system planning

Transportation system planning is the process of deciding on the future of a transportation system and issues such as the demand for future transportation system, the interaction of different transportation systems and facilities, the relationship between land use and transportation system, the different ways of operating transportation systems, the social, economic and environmental implications, and the proposed transportation systems. (Dalkmann & Sakamoto, 2011). Thus, the purpose of transportation system planning is to create a transportation system that can provide the movement of people and goods with sufficient safety and economics, while travel should be comfortable and simple. Plans are usually presented in three time periods: short-term, medium-term and long-term. In short-term and medium-term planning, the maximum utilization of facilities is available.

Internet of Things (IoT)

In general, the concept of IoT is the connection of different devices to each other through the Internet. With the help of the Internet of Things, various programs and devices can interact with each other and even humans through an Internet connection. In fact, the Internet of Things enables people to manage and control the objects they use remotely with the help of Internet infrastructure (Yazdan Nejad & Momeni Bashusqeh, 2016).

The Internet of Things creates opportunities for the direct integration of the physical world and computer-based systems. Systems such as smart cars, smart refrigerators and smart homes, which are mentioned in various topics and meetings these days, are among the Internet of Things (Ghasemi et al., 2016).

Background Research

Aghdas Vatankhah & Gharib (2005) in their article have studied the effects of land use and urban development on rapid public transportation. They merely examine the effects of different uses and the role of urban design in reducing or increasing the demand for transportation systems. They also examined three important and influential factors on transportation system demand, including space organization, congestion zoning, and urban design, and their effects on transportation system demand.

Anvari Rostami & Sattari Ardabili (2009) have designed the planning model of Ardabil city bus transportation network. This research is designed with the aim of optimizing the transportation network of the city bus company. For this purpose, the problem is first explained based on the important criteria of time, cost, quality of transportation and passenger movement; Then, due to the multiplicity and contradiction between the objectives of the problem, the ideal planning model of lexicographic type has been formulated to optimize the urban bus transportation system.

Babagheybi Azghandi (2010) has introduced futures studies as a new approach in the comprehensive management of urban transportation. In this paper, while designing and reviewing the two major challenges in the comprehensive management plans of the urban transportation system, futures research knowledge is introduced as a new approach that can be effective for solving the problems of the transportation system; By explaining the fields of futures research, its effects on urban transportation and the field of application of this science in transportation topics are expressed.

According to Papageorgiou et al. (2009), building more roads alone will not solve the problem of traffic congestion. Therefore, instead of increasing the capacity of roads, efforts should be made to find new ways to increase the level of public transportation services, especially with the use of new and efficient technologies such as computers and information technology for transportation systems.

Hayat (2010) has modeled traffic operations disruptions for public transportation networks. In a descriptive analysis, he stated that the factors causing the disturbances were time, space, passenger volume and repetition of the trip. He attributed the cause of these factors to road accidents and breakdowns, maintenance time, inability to replace the service, inability to provide equipment for the disabled, driver delays, planning errors, lack of passenger control, reduced safety, and passenger problems such as traffic jams.

Tierney et al. (2014) used the integer programming model for inter-terminal transportation analysis (ITT) to expand seaports. ITT considers the movement of containers between terminals (sea, rail, etc.). Their model is used to analyze the effect of the new structure, the location of terminals and the investment of vehicles. The paper model considers various aspects of ITT such as traffic congestion, container delay penalties, multiple ITT transportation models, and port infrastructure reform. An objective function of minimizing container shipping delay is designed in this study, which results in optimal vehicle route and container flow.

Dobson (2015) presents human and ergonomic factors in transportation control systems. The considerations of human factors in advanced train control systems and the move towards automation and the effects of these new technologies on operations are discussed in his paper. His descriptive research has shown that the integration of human factors into the design of work systems, equipment, environments and tasks is essential to support the passenger; to ensure that the operator will respond appropriately and safely within the time frame.

Kocken & Sivri (2016) have raised the issue of fuzzy transport system that has coefficients of fuzzy cost, fuzzy supply, fuzzy demand and fuzzy transport; and to solve the problem of transportation system, they have used mathematical programming. The goal of their math programming is to minimize costs.

Yazdan Nejad & Momeni Bashusqeh (2016) focusing on the importance of intelligent electricity distribution networks and its interaction with the smart city, have studied the Internet of Things in the country's electricity industry. In this study, first the definitions and basic concepts of the Internet of Things are stated; then the intelligence and IoT applications in different parts of the smart city and in particular smart power distribution networks have been studied. Conclusion of this article is the implementation of intelligent electricity distribution network design at the macro level and at the level of regional electricity companies; This plan points to the great importance of the interaction of IoT technology and electricity distribution networks.

Also, Ghasemi et al. (2016) have prioritized the applications of IoT technology in the Iranian health sector. According to the research findings, indicators of economic success and quality of life are of the greatest importance for the sustainable development of the Internet of Things in the Iranian health sector, respectively. Also, based on the results of the research, the most important priorities in Iran for the use of IoT technology in the health sector were recognized as the applications of "chronic disease management", "patient monitoring", "infection control" and "diagnosis", respectively.

Ronaghi and Hosseini (2018) in their article also identified and ranked IoT services in the field of health. This research is of applied type and has been done in two stages using a combined approach in 2018. In the qualitative stage, library resources are used and in the quantitative stage, the pair wise comparison questionnaire is used. IoT services are rated by a group of seven experts.

Zhang and Yu (2019) examine the value-added of the Internet of Things and pricing decisions. This study examines a company's decisions about IoT capability with three types of pricing policies: low pricing, high pricing, and conditional pricing. Although IoT capability may instinctively see conditional pricing in reducing demand uncertainty; this research suggests that the company may achieve optimal profit by using conditional pricing. Interestingly, improving the value of the IoT product indirectly reduces the value provided by conditional pricing.

Research Methods

Execution stages of Research

Given the productivity that both passenger and urban management require; The importance of the issue and its impact in other areas, as well as the lack of sufficient research in this area if it had been done; We faced a significant reduction in traffic and transportation problems; In this research, the design of intra-city transportation system will be studied. The objectives of this planning are to determine the location of stations for public transportation as well as to determine the best route to reach the next station in order to obtain the most optimal response. The steps of this research can be shown in Figure 1.

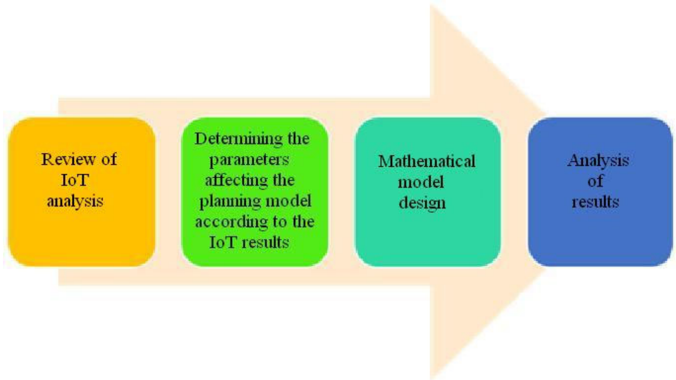

Figure 1. *Diagram of research implementation steps*

Problem Modeling

An intelligent transportation system can transmit public transport information to many consumers by choosing the right route. One of the most important applications of IoT technology is to maximize the security of the transportation network. In the IoT-based intelligent transportation system, a safe speed can be defined for some roads and accident hotspots on a vehicle; In this case, through intelligent and interactive control and monitoring of the road, vehicles and smart devices on the route in the form of a network, the possibility of heavy traffic and road accidents is reduced. On a large scale, this system can be used to improve urban activities such as counting the number of empty spaces in parking lots or checking the quality of urban climate and traffic situation.

The Internet of Things can help users and the general public with their decision-making services by providing data and traffic information at a city level and indexing it. The Internet of Things, on the other hand, is one of the new topics that should be welcomed and used in the public transport fleet to increase the use of people at the community level. Using the Internet of Things, a range of environmental data and information can be absorbed, and by processing the information obtained, a more accurate decision can be made to create the necessary infrastructure, routes and cost-delay-pollution reduction.

Data Analysis

To show the efficiency of the proposed model and solution methods, we solve the problem in three different sizes (small, medium and large).

Whereas sample test questions are not available in the literature to examine the performance of the developed algorithms; A number of common test problems in the selected literature and the required characteristics of the studied problem were defined according to their needs. These features include a combination of items such as the number of lanes per ridge, free travel times and capacities based on the travel time function, line enhancement projects and budget levels.

Results

Three groups of test problems are prepared based on the size of the problem; Table 1 shows their general characteristics and the adapted reference.

Table 1.
Experimental problems and their specifications

Issue size	code Issue	Reference	Number of knots	Number of bows	Number of pairs of principles and purposes	Number of control nodes
small	ZY	Ziyou and Yifan	6	14	2	2
medium	TX	Tynes et al	6	18	2	4
	CG	Casetta et al	11	32	6	8
large	SF	LeBlanc et al network	24	76	552	11

Problem in small size

The grid has been used to test the integrated red deer algorithm and to simulated annealing for a small problem size (Ziyou G. and Yifan, 2002). This small network has 6 nodes and 14 links, and 2 ODs. Nodes E and F are control intersections. OD demand from A to B is 54 and demand from C to D is 18.

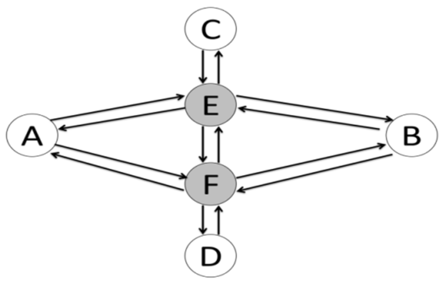

Figure 2. *Small ZY network*

Small problem results

The optimal network after applying the orientation changes is shown in Figure 3. The initial network storage capacity (with two-way links, without line enhancement and signal settings) was 0.75. Optimal storage capacity after changes is 1.12, which is 49% improved over the original network.

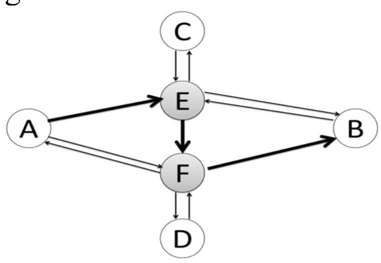

Figure 3. *Optimal orientation of the ZY network*

Problem in medium size TX

The network is shown in Figure 4. This network has 6 nodes and 18 links. Of these 6 nodes, 4 are control nodes, which are shown as shadows. Demand from six to one is equal to 5 and from six to one is equal to 10.

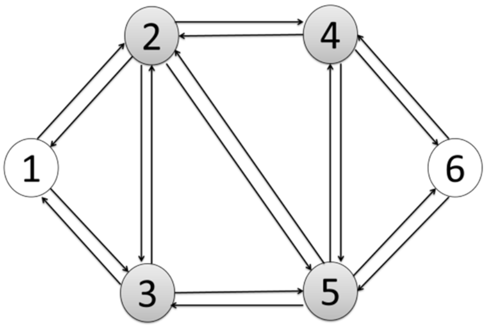

Figure 4. *Medium TX network*

Problem in medium size CG

The network presented in the work of Casetta et al. (2006) for the second test, the average network size is used. This network has 11 nodes, of which 8 nodes have traffic lights, which are shown in Figure 5.

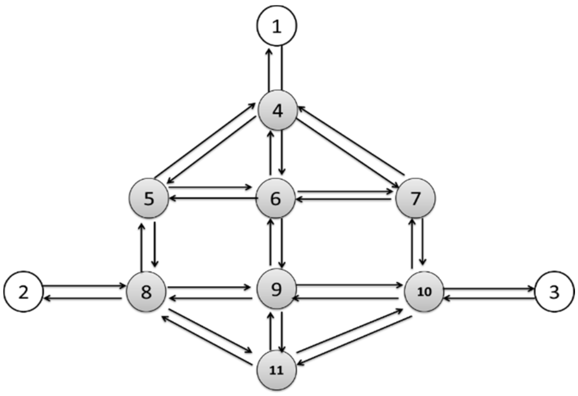

Figure 5. *Medium CG network*

Average CG size results

The optimal network after applying the orientation changes is shown in Figure 6. The initial network storage capacity (with two-way links, without line increments and signal settings) was 1.02. The optimal storage capacity after the changes is 1.25, which means that the network capacity has improved by 23%.

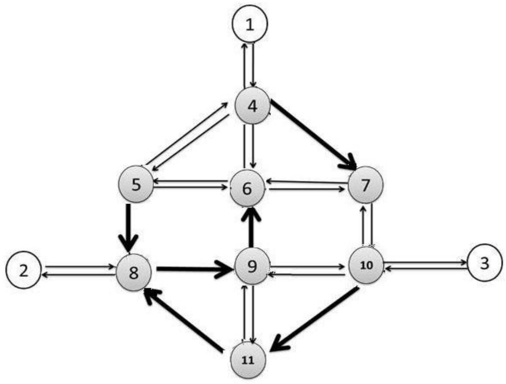

Figure 6. *Optimal orientation of the CG medium network*

Large size issue

To show the efficiency and capability of the proposed algorithm in large-scale problems, Sioux Fall City Network (data from the American rail transportation network on the site of Oregon Gerash[2]) has been used. The network has 24 nodes, 76 links, and 552 OD requests. The 11 nodes are the control junctions shown in Figure 7.

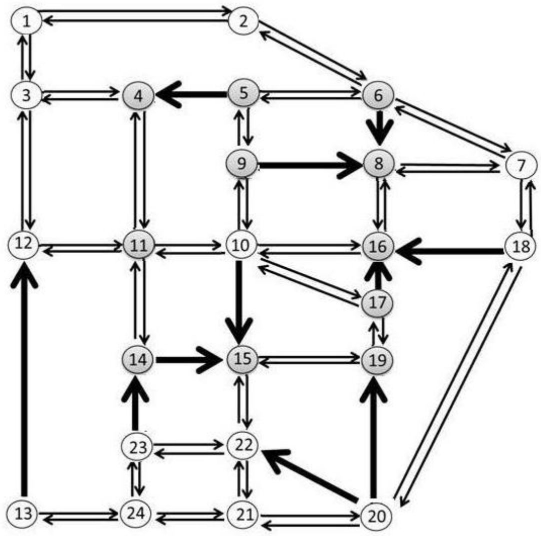

Figure 7. *Large SF network*

[2]https://www.oregon.gov/ODOT/DMV/pages/driverid/accidentreport.aspx

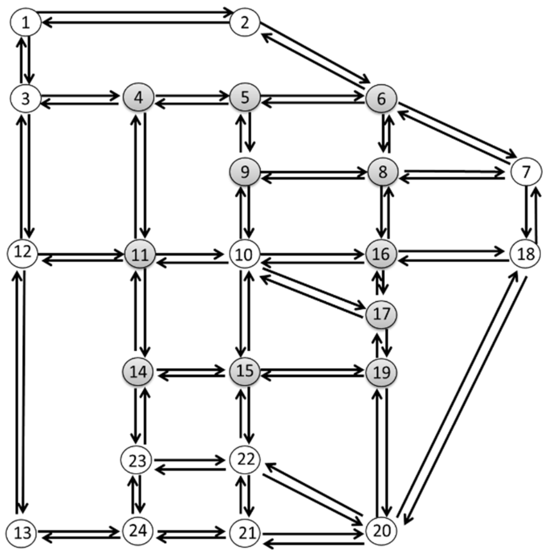

Figure 8. *Optimal orientation of the SF medium network*

SF network results

The optimal network after applying the orientation changes is shown in Figure 8. The initial network storage capacity was 0.75. The optimal storage capacity after the changes is 1.03, in other words, the network capacity has improved by 37%.

Check the capability of algorithms

In order to evaluate the capability of the algorithm in finding the optimal answer or close to it, the counting method has been used. Due to the fact that there is no similar model with the model presented in this study, there is no comparison criterion for the amount of validity; In addition to using the exact counting method and comparing the results with the combined red deer algorithm and simulated annealing, and since the time of solving the counting method for small problems is very high, this method is used only to solve small test problems. We obtained all possible scenarios for the problem and calculated the objective function for them. The elapsed solution time for the small test problem was 2 hours and 25 minutes. A summary of the computational results of the combined red deer algorithm and simulated annealing developed for the objective functions and the time to solve the test problems are shown in Table 2.

Table 2.
Summary of computational results

Objective functions	Small sample											
	1	2	3	4	5	6	7	8	9	10	11	12
Objective 1	184.82	184.10	185.42	185.28	182.33	185.47	184.17	183.75	183.81	183.20	183.92	182.95
Objective 2	310.42	319.51	318.76	319.92	328.26	323.20	317.76	319.59	310.70	327.36	321.14	301.60
	Medium sample											
Objective 1	143.00	143.53	142.91	143.85	142.00	143.10	141.95	143.65	143.00	143.33	142.66	142.40
Objective 2	225.57	229.16	219.60	231.53	222.44	229.02	235.93	222.62	226.93	230.04	227.92	233.18
	Medium sample											
Objective 1	129.59	129.11	128.61	127.68	128.71	128.55	128.56	129.08	128.99	129.44	129.00	129.33
Objective 2	197.71	196.98	195.42	196.71	199.13	198.87	199.65	195.96	199.41	198.77	200.69	197.94

Conclusion

Urban transportation network design issues include a hierarchy of long-term, medium-term and short-term decisions to improve the performance of the urban road network and public transport networks active in the network. In this research, a hybrid network design problem with two objectives was investigated. The first objective function consists of three parts. The first part is to minimize delays in the transportation system, in which any vehicle that is unable to meet the demand received at two points is fined. In other words, any curve that enters a time-location node of a requested destination; A special price is assigned and this price is calculated from the penalty function$p_\theta(t-u_\theta)y_{id_\theta\theta}$; Where θ is the demand or request, t is the time step and u_θ is the time interval between two requests. The second part of the objective function represents the minimum risk of movement between two points in the transportation system. The third part of this function also expresses the risks and human factors in the transportation system. Demand is influenced by various factors that can be used to calculate the Internet of Things as accurately as possible. Installing the app shows the amount of traffic on mobile phones, stations, as well as on public transport, helps passengers to choose the route to reach the final destination. This leads to a better choice of route-vehicle by the passenger, creating optimal changes in access time, satisfaction and traffic reduction. Also, if the passenger has several routes, he / she will request the use of a device / route in order to take him / her to his / her final destination with less delay. This leads to reduced traffic (resulting in reduced latency), reduced energy consumption and reduced pollution, as well as increased satisfaction. Therefore, it is worthwhile to estimate the dynamic demand using the IoT to achieve more reliable results.

Objective function number 2 is considered from the passenger (customer) point of view and from the transport organization point of view. For the transportation company, this objective function seeks to maximize total profit, which includes total customer revenue, fuel costs, depreciation costs, and parking costs. It is assumed that in case of difficulty in providing services by public transportation, passengers will use a taxi to complete their journey and the public transportation company will have to pay a fixed amount as a penalty. Delays are also subject to penalties depending on the quality of services provided.

It should be noted that the problem is modeled in the form of a bi-level mathematical model, which approaches the problem of low-level equilibrium trip allocation to calculate equilibrium flows for each of the network design scenarios. We considered the problem of orientation to the thoroughfares along with increasing the capacity of the existing thoroughfares and allocating lanes in the two-way thoroughfares and adjusting the traffic light signal at the intersections in order to maximize the storage capacity. These models are inherently NP-hard and non-convex. Therefore, we used the above innovative solution methods for them. The mathematical models presented in these problems have a high complexity both due to having discrete and continuous decision variables and due to the bi-level mathematical models, which makes it very difficult to solve these problems accurately.

According to the results obtained from the designed model, we found that by designing a coded information system through networks under the net, we will be able to accurately predict the amount of demand for intra-city transportation system. Accordingly, we will be able to have better and more efficient planning to deal with possible changes.

The Internet of Things can help users and the general public with their decision-making services by providing data and traffic information at a city level and indexing it. The Internet of Things, on the other hand, is one of the new topics that should be welcomed and used in the public transport fleet to increase the use of people at the community level. Using the Internet of Things, some of the data and information of the environment can be absorbed and by processing the obtained information, more accurate decisions can be made to create the necessary infrastructure, routes, cost-delay-pollution reduction.

According to the designed model and also the results, we found that parameters such as movement risks, fatigue and drowsiness while driving, demands at the source node, demands at the destination node, number of vehicles along the network, time interval between demands and time interval between two consecutive demands were the most important parameters affecting the designed mathematical model. The impact of the mentioned parameters are such that, for example, minor changes in parameters such as demand at the source node, demand at the destination node and the number of means of transport across the network can cause a significant amount (increase in time and decrease in profitability).

Studies can be developed in several areas, which are briefly described. Travel requests are considered randomly, while travel request values are definitive in most studies. Considering distribution functions for demand quantities can cover errors in estimating demand quantities as well as reflect the nature of their uncertainty.

The use of random user balance allocation is suggested for the low-level problem. Random user equilibrium travel allocation has been proposed in a number of studies that allow more realistic modeling of traffic flow behavior. However, the complexity of the problem increases. By considering distinct and contrasting functions together, multi-objective problem-solving techniques can be used to solve such problems. Demand matrix coefficient is one of the indicators of system capacity. Other indicators of system storage capacity can be used for these problems and a comparative analysis can be provided for these indicators.

Conflict of interest

The authors have no conflict of interest to declare.

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