The Parameters Affecting the Mathematical Programming Model of the Appropriate Transportation System

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Abstract   **Due to the importance of public transportation, which has become today an important urban problem with special conditions, this study was conducted aimed at determining the parameters affecting the mathematical programming model of the appropriate transportation system. The study was performed by modeling method, and the problem was solved in three different sizes (small, medium and large) to show the efficiency of the model and the proposed solution methods. Some common test problems in the literature were selected and the required characteristics of the problem under study were defined for them as needed, since there are no sample test problems in the literature to examine the performance of the developed algorithms. The results indicated that some of the most important parameters affecting the designed mathematical model were movement risks, fatigue and drowsiness while driving, demands at the source node, demands at the destination node, number of vehicles across the network, the time interval between requests, and the time interval between two consecutive requests. The mentioned parameters were so effective that little changes in parameters such as demands at the source node, demands at the destination node, and the number of vehicles across the network significantly increased time and decreased profitability. the company has a significant effect on the debt cost rate and capital cost rate and does not have a**

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Introduction

One of the most important types of urban services is public transportation, which is recognized as one of the challenges in the world today. Transportation affects the development of regional roles, economic existence, environmental impacts, and quality of life of the middle class (Amanpour et al., 2016). As a socio-political phenomenon, transportation, which today 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 movements. Therefore, the development of the transportation system must have a detailed plan in the process of urban development, because the situation of citizens in different areas will be affected by the use of incorrect methods and decisions and neglect in using the principles of urban planning and traffic (Amanpour et al., 2016). The transportation infrastructure of a city is of special importance in terms of the quality of roads, the rate of access to public transportation, and the points to access them that determine the rate of access of people to buildings, places and spaces (Yazdan Panahi and Maleki, 2011). Another aspect is the essential role of the urban transportation sector in creating jobs and economic development of the city. Jobs in the public transportation sector account for 1 to 2% of the total employment rate in many countries. Transportation is an essential element for economic performance and also a key part in job creation, from manufacturing vehicles in factories to fuel refining, management of transportation services, and development and maintenance of infrastructure (Aghdas Vatankhah and Gharib, 2009). Moreover, the current transportation systems, which are mainly based on private vehicles, are inherently unjust and an obstacle to reducing poverty and creating justice for the benefit of all sections of society from

displacement and mobility in cities. There is a large gap between different income groups in terms of access to asphalt roads, as well as safe and affordable transportation in many developing countries. As a result, poverty can be reduced by investing in transportation, such as public networks that are accessible, reliable, and affordable for all, by providing job opportunities for individuals and facilitating access to services. Travel costs and time can be reduced by creating a local economic stimulus, which in turn will lead to cheaper services. These networks also protect people in the community against the harmful effects of transportation such as traffic accidents and air pollution (Chang et al., 2018). The goal of the first Five-Year Economic, Social and Cultural Development Plan of the Islamic Republic of Iran has been an annual growth of 12.3% in freight transportation and 8% in passenger transportation. However, in the first year of the plan (1989), freight transportation decreased by 4% and passenger transportation increased by 5%. Achieving the goals definitely requires a program of change and transformation in technical and administrative systems and the use of modern technologies (Mahdizadeh et al., 2010). One of the major physical factors of economic development and social progress is the appropriate transportation system. Rapid population growth on the one hand and economic growth on the other hand will increase the demand for freight and passenger transportation, and neglecting freight and passenger public transportation will cause many problems in the near future (Sharifi et al., 2014). The transportation system in the current situation faces challenges, some of the most important of which are as follows (Wey & Huang, 2018; Tajdar & Akbari, 2008):

- Improve safety (high rate of deaths and injuries resulting from transportation accidents)
- Congestion management (demand exceeds the capacity of the systems)

- Providing equal access (convenient access to transportation systems for all groups of people)
- Environmental protection (impact of transportation systems on the environment)
- Application of modern technologies (intelligent systems - ITS, IoT)
- Financing (lack of government financial resources)
- Developing an appropriate organizational structure (using the private sector and improving government structures)

One of the main goals of national development and in fact one of the main prerequisites for the realization of development is to provide suitable facilities for freight and passenger public transportation. Emphasis on the use of passenger public transportation vehicles is one of the issues mentioned in these goals. In short, the design of transportation systems includes the planning, design, improvement and implementation of systems consisting of the deployment plan and transportation system in order to maximize efficiency and place utility. Since the economic condition is to have a proper transportation flow plan, the establishment of vehicles and a proper transportation system, the proper deployment will increase efficiency, reduce costs, and increase demand for public transportation systems, which can reduce traffic volume and environmental consequences (Dobson, 2015). Urban transport networks can be defined as a set of urban road networks and public transportation networks active in it. A transportation system can be considered as a set of fixed facilities, flow entities and a control system that allows passengers and freight to overcome geographical constraints and participate in the desired activities in a timely manner. Due to the efficiency required by both passengers and urban management, the importance of the problem, its impact on other sectors and also the lack of sufficient research in this area that would significantly reduce traffic

and transportation problems if done, this study provided the parameters affecting the mathematical programming model of the appropriate transportation system.

Background

Papageorgiou et al. (2009) claim that building more roads alone will not solve the problem of traffic congestion. So efforts should be made to find new ways to increase the level of public transport services, especially with the use of modern and efficient technologies such as computers and information technology for transport systems, rather than increasing the capacity of roads. In a study by Hayat (2010), traffic operations disruptions were modeled for public transportation networks, and time, space, passenger volume, and travel iteration were cited as disruptive factors using a descriptive analysis. The source of these factors was stated as follows: accidents, route breakdowns, maintenance time, inability to replace the service, inability to provide the necessary equipment for the disabled, driver delays, planning mistakes, lack of passenger control, reduced safety, and passenger problems such as congestion. Tierney et al. (2014) analyzed inter-terminal transportation (ITT) for the expansion of seaports using the integer programming model. ITT considers the movement of containers between terminals (sea, rail, etc.). This model is used to analyze the effect of the new structure, the location of terminals and investments in vehicles and considers various aspects of ITT such as traffic congestion, container delay penalties, multiple ITT transport models, and port infrastructure reform. The researchers designed an objective function to minimize container delays that results in optimal vehicle route and container flow. Modeling of trip forecasting process in intercity transportation planning based on a hybrid fuzzy inference approach was introduced in a study by Jasbi and Makvandi (2011). One of the most important decisions in the field of urban planning in metropolitan areas has recently been the planning of urban transportation. The key to success in proper

transportation planning is to forecast the volume of future trips between the two metropolitan areas. A key issue in the development of these models is the complexity of the problems that arises from the nature of human behavior in choice. This complexity always causes a lot of computational and operational problems to develop a model that has an acceptable forecast error. This is more important in developing or underdeveloped countries where historical data and computer computational capabilities are not sufficiently available. In this study, a fuzzy three-stage model is proposed to model the travel process between two hypothetical areas of a metropolis and finally a framework for forecasting the future of this quantity so that a function can be approximated to map the volume of trips made between two areas as output variables and demographic and social variables as input variables that can model the trip process. In this model, the base of fuzzy rules is actually formed to transfer the mental pattern of transportation experts to the mathematical model. Kucken and Sivri (2016) proposed the problem of fuzzy transportation including fuzzy cost coefficients, fuzzy supply, fuzzy demand, and fuzzy transportation, and used mathematical programming to solve the transportation problem with the aim of minimizing costs. Kelle et al. (2018) developed a multipurpose modular simulation model including highways, railways, and waterways because all three of these play a key role in transportation. They examined the performance of the Louisiana transportation network under different scenarios. The results indicated that a shift in the mode of transportation from highway to railway greatly affects the local highway transportation, increases speed, and reduces congestion, delays, and pollution. In addition, changing the mode of transportation rarely solves the problem of speed on medium highways and their congestion in a densely populated area with relatively small vehicles. One of the problems that human beings are struggling with today is overcrowding and the inability of urban infrastructure to meet their needs (Hayat, 2010). One of the important infrastructures that is affected by this issue is the transportation

infrastructure. However, increasing transportation facilities through conventional methods cannot be considered as a suitable and basic solution due to the need for large investment and a lot of time to implement. So the tendency to use mechanisms to use modern technologies, optimal use of available historical resources and data, initiative and use of urban traffic management techniques in most countries have been considered by metropolitan traffic managers as the best solutions in recent years (Irtema et al., 2018). Economic development in any country basically requires investment in various economic sectors and activities, and the expansion of employment, production and economic prosperity cannot be expected without investment in infrastructure and superstructure projects. One of the important factors for social and economic development in the world is transportation, so that the economic development of any country is directly related to the efficiency of its transportation system, and today the development of any country or region is not possible without sufficient transportation facilities. Transportation is one of the basic needs of human societies that has forced people to use the most modern technologies due to its importance and significant role throughout the ages. Knowledge, analysis, and optimal use of existing factors and facilities are the conditions of proper planning in the field of transportation, whether at the strategic level such as major investments in development or change of technology, at the tactical level such as street widening, or at the functional level such as traffic light design and traffic management (Liu et al., 2016). Human access to places where services or goods are provided is essential, and the transportation network plays an important role in providing this access. Each form of transportation network development leads to a specific distribution of outcomes for different geographical regions. In recent years, researchers' attention has been drawn to how the benefits of transportation decisions are distributed among different groups. They see social justice as one of the goals of transportation. Accordingly, determining the parameters affecting the

development of the optimal model in this field is a fundamental issue. In this study, these parameters were determined with the aim of obtaining the optimal solution to determine the optimal route to reach the next station. The factors required to present and determine the parameters in this field are given in the next section.

Method

Decision making under uncertainty is required in many problems including production planning, scheduling, placement, transportation, finance and so on. Optimization under uncertainty has developed rapidly in both theory and algorithm and has been the subject of many studies. Uncertainty is an integral part of production planning problems. Approaches to optimization under uncertainty follow various modeling philosophies, including minimum expected cost (mathematical expectation) and mini-max cost (Barikani et al., 2011). In the standard two-stage stochastic programming model, the problem variables are divided into two groups. The first stage variables are those that must be decided before realizing the stochastic parameters. Subsequently, after realizing the uncertain parameters and determining their true values, other decisions are made based on these values, to improve the performance of the system by selecting the values of the second stage variables (recourse). Traditionally, the first stage variables are related to basic decisions before realizing uncertainties (scenarios). In production planning problem, for example, pre-production decisions such as determining the time and amount of raw material procurement from suppliers must be made before demand. However, the variables of the second stage are basically operational and recursive decisions and act after the realization of the scenarios to compensate and correct the decisions made in the previous stage regarding the realization of certain scenarios. For example, in the production planning problem, decisions about sending and distributing products to customers, as well as decisions about inventory and lagged orders are made after realizing the actual

amount of demand, and the risk of infeasible solution to the stage variables, and the risk of the infeasible solution resulting from the first stage variables regarding some of the revealed uncertainties is practically eliminated in some way by using the second stage variables. The cost of the second stage is a stochastic variable due to the presence of uncertainty. So the main purpose of stochastic programming is to determine the variables of the first stage in such a way that the sum of the costs of the first stage and the mathematical expectation of the costs of the second stage are minimized. The term recourse is also used for linear, integer and nonlinear programming. Robust optimization is a solution to the uncertainty in the input data and gives decision makers the opportunity to act in accordance with their level of risk taking and risk aversion in their decisions on the problem of risk. Ultimately, it will lead to the creation of a series of solutions that are increasingly less sensitive to uncertainty in the input data and the full realization of the scenario set. The optimal solution provided by the robust optimization model is called robust if the proposed solution remains as feasible as possible and close to the optimal solution if the input data is changed. This is commonly referred to as solution robustness in the literature. A feasible solution is called robust if this response remains feasible with small changes in the input data. This is commonly referred to as model robustness in the literature. For further explanation, a bivariate linear programming solution space is considered as shown in Figure 1. If, like the technical coefficients, the parameters of the problem are assumed to be certain, the solution space will be something like a green rectangle, which is called the nominal boundary in the figure. In this case, if the coefficients of the objective function are assumed to be certain, the optimal solution will be obtained somewhere where the levels of this function collide with the solution space. This solution will be the certain optimal solution to the problem under discussion.

Figure 1.

Feasible Solution Space of Linear Programming Problem with Uncertain Technical Coefficients
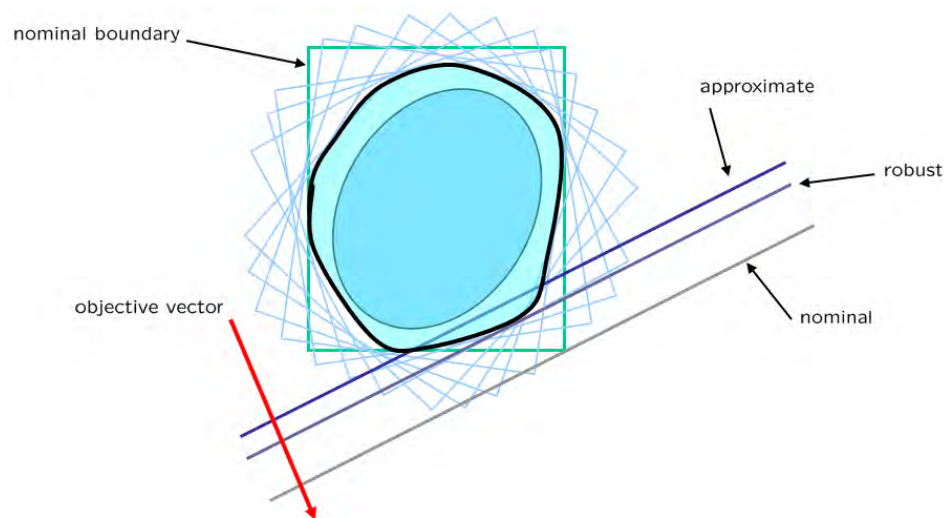
Now, it is assumed that the technical coefficients of the above problem are uncertain. This assumption means that any of the constraints of the problem that previously acted as a fixed boundary and linearly with a constant slope will no longer be so. However, this constraint fluctuates like a line with an unknown slope around its nominal slope due to the uncertainty in the assumed line slope. Such an assumption for all constraints leads to the creation of a space similar to the blue rectangles in Figure 1 due to the uncertainty in their slope, which is equivalent to the technical coefficients of the constraints. Therefore, the feasible space of the problem, which was a fixed rectangle in the previous case, will become an irregular shape under this assumption, which is indicated by a bold black line in the figure above. This new feasible space is known as the feasible space counterpart of the uncertain problem. The first and simplest approach is to approximate a solution space with completely risk-averse approximations to ensure that the proposed solution space will not be disturbed under any circumstances and with the simultaneous

occurrence of the most unlikely events in the values of technical coefficients. This approximate feasible space is shown in Figure 1 with a blue ellipse inside the previous rectangle. The first best alignment of the objective function with the above ellipse is definitely the optimal solution to the problem (intersection of the approximate line with the ellipse). Where the first optimal level of the objective function intersects with the above ellipse is definitely the optimal solution to the problem (intersection of the approximate line with the ellipse). However, a few important points are made about this optimal solution. First, the value of the solution obtained is far from the actual value of the optimal solution. This is due to the risk aversion approach of the solution and reduces its optimality for the actual situation of the problem. Second, this approach does not report any possibilities for a solution. There may be better solutions with a lesser possibility of feasibility that the decision maker, in the face of a better solution, accepts the low risk of its feasibility. The purpose of the robust optimization approach is to provide a model of uncertainty that incorporates both the decision maker's risk-taking and risk-aversion as parameters and to provide solutions that are the result of a tradeoff between the solution optimality and its infeasibility (Mehregan, 2008). Stochastic robust optimization is one of the most common methods in the field of optimization and control science after 1990, which examines the problem of optimization with uncertain parameters. A stochastic optimization model includes two types of robustness: solution robustness (the solution is almost optimal in all scenarios) and model robustness (the solution is feasible in almost all scenarios). The phrase "almost" is affiliated to the modeler. The objective function of the model has general penalty functions for both the model robustness and the solution robustness and is weighted using two parameters in order to achieve the modeler preference between the above two modes. This optimization method actually develops stochastic programming by substituting the minimum expected cost objective function with a function that explicitly indicates cost variability (Madani, 2010). In a study by Ben-Tal and Nemirovski (2000) on several case

studies from the Net Library linear optimization problems, it was found that in real-world linear programming applications, the possibility that small uncertainties in the data can make the usual optimal solution completely meaningless from a practical point of view cannot be ignored. So the tendency to develop models that can secure solutions to data uncertainty as much as possible has naturally increased. Soyster (1973) made the first attempts in this direction. He proposed a linear optimization model in which the resulting solution remains feasible for all values belonging to a convex set. The model proposed by him produces solutions that are very conservative. This means that much of the optimality of the nominal problem is sacrificed to ensure its robustness. He considered the following linear programming model:

P_1: maximize $c'x$

subject to
$$\sum_{j=1}^{n} a_{ij}x_j \leq bi, \qquad i = 1, ..., m \qquad \qquad 1$$

$$x_j \geq 0,$$

He hypothesized that the uncertainty would affect the parameter a_{ij}. In the robust optimization method, it is assumed that in line i of Equation 1, only some parameters are bound by the condition of uncertainty, and this set of parameters is represented by J_i. Each parameter a_{ij} models $j \in J_i$ as a finite and symmetric stochastic variable that can only take interval values $[\bar{a}_{ij} - \hat{a}_{ij}, \bar{a}_{ij} + \hat{a}_{ij}]$ with center $\bar{a}_{ij}$, called the nominal value, and $\bar{a}_{ij}$ measures the accuracy of the estimate. He showed that the above problem is equivalent to the following problem:

P_2: maximize $c'x$

s.t.
$$\sum_{j=1}^{n} \bar{a}_{ij}x_j \leq bi, \quad i = 1,...,m \qquad \qquad 2$$

$$x_j \geq 0,$$

Where $\bar{a}_{ij} = \sup_{j \in Ji}(a_{ij})$.

Soyster (1973) is very conservative in practice because the solution he offers as a robust optimal solution is in practice much worse than the optimal solution to the nominal problem (Mehregan, 2008).

Findings

Due to the efficiency required by both passengers and urban management, the importance of the problem, its impact on other sectors and also the lack of sufficient research in this area that would significantly reduce traffic and transportation problems if done, in this study, and intra-city transportation system was designed. The programming was conducted with the aim of determining the location of public transport stations as well as determining the optimal route to reach the next station in order to obtain the optimal solution. The study was mainly performed to identify the parameters affecting the above items. The problem was solved in three different sizes (small, medium and large) to show the efficiency of the proposed model. Some common test problems in the literature were selected and the required characteristics of the problem under study were defined for them as needed, since there are no sample test problems in the literature to examine the performance of the developed algorithms. These characteristics included the number of lanes per edge, free travel times and capacities based on the travel time function, lane increase projects, and budget levels. Three groups of test problems were prepared based on the size of the problem, which are given in Table 1.

Table 1.

Test Problems and their Characteristics

The number of control nodes	The number of pairs of source and destination	The number of arcs	The number of nodes	Reference	The problem code	The problem size
2	2	14	6	Zeev and Yifan	ZY	Small
4	2	18	6	Taynz et al.	TX	Medium
8	6	32	11	Kaskta et al.	CG	
11	552	76	24	Lablank et al.	SF	Large

Lane increase costs are a linear function of the number of lanes added on both side of the edge. The travel time functions on the edges are listed in Appendix (a) in the BPR format, which are some of the most well-known functions in this field and have been used in most studies:

$$t_{ij}(x_{ij}) = t_{ij}^0 \left(1 + \alpha \left(\frac{x_{ij}}{c_{ij}} \right)^{\beta} \right) \qquad 3$$

The values of the parameters α and β are assumed to be 0.15 and 4, respectively, which are common values in the literature. Where t^0_{ij} is the travel time, in the free flow of the edge (i, j). The parameters of the Simulated Annealing (SA) and the Red Deer meta-heuristic hybrid algorithm were tuned by searching the developed algorithms for the same problems and experimentally solving one of the test problems for different values. The parameter values of the algorithms are presented in Table 2.

Table 2.

Factors and Levels of Candidate of Tunable Values in Simulated Annealing (SA) and Red Deer hybrid algorithm

Parameter	Level values		
	Level 1	**Level 2**	**Level 3**
Maximum iteration	100	150	200
Population size	100	100	300
Number of males	20	35	50
Percentage of commanders	0.5	0.6	0.8
Percentage of inside the harems	0.4	0.6	0.7
Percentage of outside the harems	0.3	0.5	0.5

The Simulated Annealing (SA) and the Red Deer hybrid algorithm was programmed by MATLAB software version R2015 without using the software toolbox. The algorithms were tested on a laptop computer with a 2.2 GHz Core2Duo T7500 processor and 2G RAM. Each algorithm was run 5 times for each test problem. In test problems, the maximum number of lines added to each edge was 2 and the minimum and maximum values for the effective rate in signal optimization were 0.05 and 0.95, respectively. In the optimization, it was assumed that the time period was predetermined and its value in these problems was considered to be 94 seconds. Intersections equipped with traffic lights are shown with gray circles in the problems. The counting method was used to evaluate the ability of the algorithm to find the optimal solution or the solution close to it. Since there was no model similar to the model presented in this study, there was no criterion for assessing its validity. Therefore, the counting method was used and the results were compared with those of the Simulated Annealing (SA) and the Red Deer hybrid algorithm. The counting method was used only to solve small test problems because it took a very long time to solve even small problems. All feasible scenarios for the problem were obtained and for them the objective function was calculated. The time spent solving small test problems was 2 hours and 25 minutes. Both the algorithms used and the

counting method obtained the optimal solution, the results of which are presented based on the time periods defined in Table 3 for three types of problems: small, medium and large.

Table 3.

Summary of Computational Rresults

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
Large 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

The results of the small, medium and large problem are presented in Figure 2.

Figure 2.
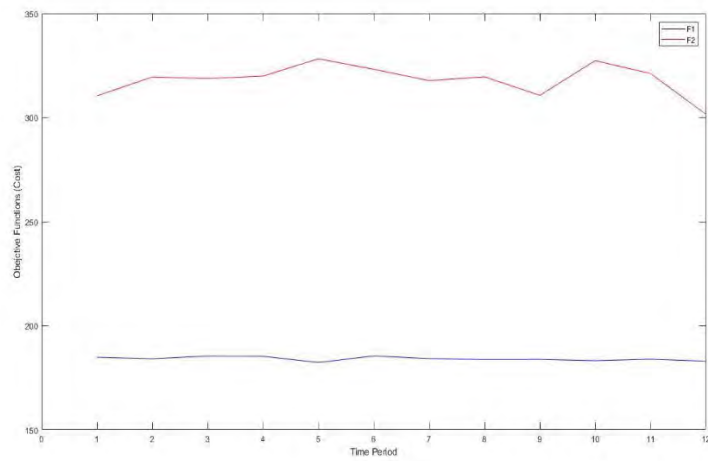
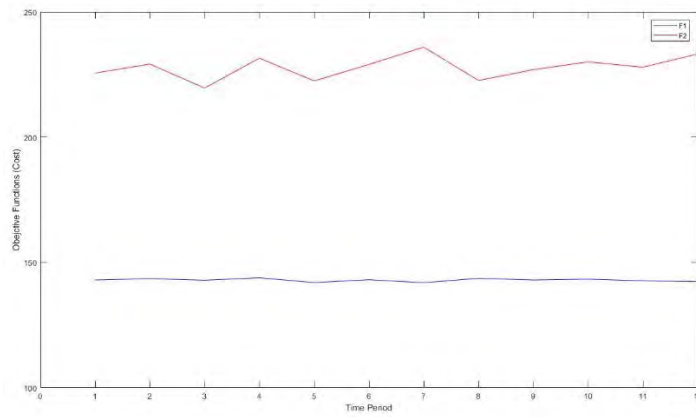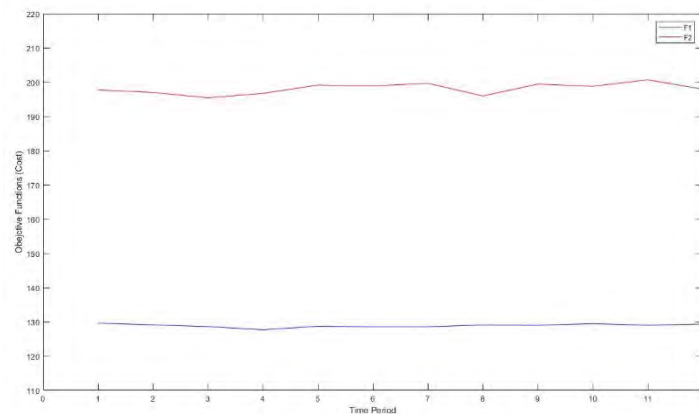*Small Problem Results*

Figure 3.

Medium Problem Results

Figure 4.

Large Problem Results

Conclusion

The design problems of urban transportation networks include a hierarchy of long-term, medium-term and short-term decisions to improve the performance of the urban road network and public transportation networks active in the network. In this study, a hybrid network design problem with two objectives was investigated. The first objective function consisted of three parts. The first was to minimize delays in the transportation system in which any vehicle that could not meet demand at two points would be fined. In other words, a specific price is assigned to each curve that enters a time-location node of a requested destination, 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 demands. The second represents the minimum risk of movement between two points in the transportation system. In addition, the third represents the human risks and factors in the transportation system. Demand is affected by various factors that can be calculated as accurately as possible using the Internet of Things. Installing an app that shows the traffic volume on mobile

phones, stations, as well as on public transportation vehicles helps passengers choose the route to reach the final destination. By better selecting the vehicle route by the passenger, this will create optimal changes in access time, satisfaction, and traffic reduction. In addition, if the passenger has multiple routes, in choosing his / her next service, he / she requests the use of a vehicle / route that will take him / her to the final destination with less delay. This leads to reduced traffic (thus reducing delays), reduced energy consumption, reduced pollution, as well as increased satisfaction. Therefore, dynamic demand rates should be estimated using the Internet of Things to achieve more reliable results. In a general conclusion, according to the designed model and the results, it was 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 across the network, the time interval between requests, and the time interval between two consecutive requests were the most important parameters affecting the mathematical model. The mentioned parameters were so effective that little changes in parameters such as demands at the source node, demands at the destination node, and the number of vehicles across the network significantly increased time and decreased profitability.

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