

# Design of An Agent-Based Simulation Model of Service Supply Chain

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## Abstract

The present research aimed to design an agent-based simulation model of the service supply chain. Suppliers were divided into suppliers of fast-moving consumer goods and slow-moving consumer goods, repairmen, and medicine suppliers, while services were divided into general, emergency, specialized, and nursing services, and patients were divided into people with insurance and those without insurance. Also, conditions of the service supply chain in this hospital were investigated and analyzed from different aspects. Next, this supply chain was implemented using NetLogo software, and the amount of unfulfilled demand and other cases were checked, and various weaknesses and gaps were shown. In the following, it was tried to decrease the existing gaps by developing different scenarios. Although the results of all the scenarios showed improved conditions, apparently, fast-moving consumer goods are the least affected by the decreased demand gap compared to the developed scenarios. In the maintenance section, the cost of preventive and in fact its increase can have the greatest effect. In nursing services, it is seen that there is not much difference between the two scenarios, i.e., the number of nurses and the increase in the costs of the nursing department, and that both strategies could lead to a 25% increase in the people covered by nursing services.

**Keywords:** Supply Chain, Simulation, Service Supply Chain

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## 1. Introduction

Like product supply chains, service supply chains have their own hierarchies and components, with the difference that the products offered in a service supply chain are intangible and customers receive intangible products. The nodes in a service supply chain are somewhat different from a product supply chain so that in service supply chains there are no materials supplied by suppliers; therefore, suppliers in service supply chains play the role of a service producer. Service supply chains can be extended to many sectors, such as medical services, banking services, insurance, tourism, and all industries with service-based characteristics instead of product-based ones. In a service supply chain, there are generally agents constituting the concept of a service supply chain. These agents need to be formed in an orderly and structured whole, and in order to simulate that, the agent-based approach can play a role as an important approach and an effective methodology (Salahi et al. 2023; Iraj et al. 2024).

Service supply chains can also be considered as a structured whole in which agents work together to form the supply chain (Delshad et al. 2024; Movahed et al., 2024). Of course, the nature of service supply chains is largely different from that of product chains due to the service-oriented situation, which should be taken into consideration. The healthcare supply chain is an important supply chain worth investigating because the issue of achieving the satisfaction of customers that are in fact patients is serious in this chain (Jahangiri et al. 2023; Mehrani et al. 2019; Nozari et al., 2024). The main problem in this research is designing a model of service-based supply chain or healthcare services supply chain, the main objective of which is to identify bottlenecks and investigate different scenarios to improve the performance of this chain. In fact, based on the studies conducted, the subject under study has defects and problems in service delivery, and the design of a service-based supply chain and its simulation can contribute to discovering the gaps and problems or bottleneck in this chain.

In previous studies, this approach has rarely been employed in the field of healthcare supply chain, while this approach has a special application in the supply chain of services, especially healthcare services. From this viewpoint, this research seeks to fill the gap in existing studies in this regard (Nozari & Aliahmadi, 2022). Based on the case study, which is Kowsar Hospital in Ilam, Iran, it is tried to simulate the relationship of agents in the healthcare supply chain using agent-based simulation. The agents are divided into two parts: suppliers and patients, and the relationship between them is explained in agent-based simulation.

The necessity of the present research is explained by the fact that healthcare is an important sector in the country. On the other hand, the subject of study has many problems in terms of taking care of patients and serving them, requiring the discovery of existing bottlenecks and problems using a quantitative simulation-based approach. Therefore, in this study, the researcher sought to identify bottlenecks in the studied hospital by proposing an agent-based simulation model as well as a generalized model for other medical centers with regard to the lack of comprehensive research in this field. This paper is organized as follows. The literature review is presented in the next section, and then the research methodology is explained. In the following, the analysis resulted from the simulation implementation is presented, and finally the conclusion is presented.

## 2. Literature Review

In this section, the research literature in the field of service supply chain is reviewed, and also the agent-based simulation approach is discussed. First, some domestic research and then foreign research are introduced.

Mansoori et al. (2017) addressed the agent-based simulation of the supply chain of banking services based on the service-dominant logic. Mohaghar and Abbasi (2021) designed and explained the sustainability

model of the supply chain of banking services. Mansoori (2013) developed a demand chain management model in the insurance industry using causal mapping. Chobar et al. (2022) planned capacity for production and reproduction in a closed-loop supply chain according to customer behavior using the system dynamics approach.

Utomo et al. (2017) reviewed research on food supply chains using agent-based simulation. Utomo et al. (2017) reviewed the literature of agricultural supply chains using agent-based simulation. Bok and Tavasi (2018) sought to develop a comprehensive simulation framework that could describe logistic decision-making in the context of urban transportation planning. Ravandi and Jovanovic (2019) sought to identify potential strategies to optimize food consumption in food service operation from the perspective of minimizing food waste while guaranteeing the quality of service. Faragan et al. (2019) pointed out the limitations associated with automated guided vehicles in dynamic environments such as environments in hospitals. Tahmasebifard et al. (2018), have investigated the effect of competitive intelligence on marketing capabilities and organizational performance. In this study, they investigated the effect of CI categories including market intelligence, competitor intelligence and technology intelligence on marketing capabilities (i.e. market measurement capability and customer connection capability), as well as organizational performance. The results showed that CI categories have a direct and significant effect on the organization's marketing capabilities and performance.

Backs et al. (2020) used agent-based market simulation to investigate two supply chain strategies by changing communication and product strategies in several market scenarios. Lohmer et al. (2020) discussed the effect of blockchain technology on supply chain risk management and supply chain resilience. The researchers identified blockchain allocation scenarios related to risk and investigated their effect on the existing resilience strategies. Backs et al. (2020) investigated the capacity of the agent-based market simulation by evaluating two supply chain strategies, i.e. traditional style and fast-fashion style, with changing communication and product strategies in several market scenarios.

Rahman et al. (2021) sought to evaluate a set of strategies and recovery plans to minimize cost and maximize access to essential items to respond to supply chain disruptions. Marmolejo-Saucedo et al. (2021) presented a supply chain design that considered disruption scenarios and improved the service effect compared to the current situation. Rahal et al. (2021) addressed the economic analysis of the Internet of Things system using the agent-based simulation approach. Hajian Heidari (2021) developed a new simulation optimization approach to find the best behavior of a risk-sensitive retailer against other risk-averse retailers over multiple contract periods.

Bae et al. (2022) investigated the collective planning capacity of empowerment through a physical Internet logistics system in an urban area acting as a freight transportation hub with e-commerce depots. Ogura et al. (2022) developed a Bayesian and penalty-based optimization method based on agent-based supply chain simulation as a new Monte Carlo optimization approach for multi-echelon inventory management in order to improve key performance indicators such as inventory cost and sales opportunity loss. McGarraghy et al. (2022) conducted a study in line with the case study of the food value chain with different governance states and market organization, the food supply chain in question includes salmon fillets, dairy products, and raw potatoes to processed potatoes.

As can be seen, the above studies have all addressed the issue of agent-based simulation in supply chains, but most of them have not focused on service supply chains, and also very few of them have considered health services in supply chains. The closest research to this research area is that of Ravandi and Jovanovic (2018) and Bok and Tavasi (2018), which are, of course, focused on the service supply chain, and they addressed the agent-based simulation, but healthcare services are not included in their research. On the other hand, among the above studies, only the research by Faragan et al. (2019) are focused on healthcare services and the use of agent-based simulation in them. This is despite the fact that these two studies have not paid attention to the supply chain of healthcare services and their simulation is generally on medical

services, while they have been completely neglected in the simulation of the service supply chain. Based on the above research gap, the present research seeks to solve the mentioned issues and tries to simulate the supply chain of healthcare services with the case study of Kowsar Hospital, Ilam, Iran using agent-based simulation and to solve the existing gaps based on the bottlenecks formed in the current model. In fact, considering that previous studies have not paid attention to the supply chain of healthcare services, the current research could be innovative, and the use of agent-based simulation can contribute to solving the gaps in the supply chain of healthcare services to a great extent.

### **3. Methodology**

This research is developmental in terms of purpose, and it is descriptive-simulation in terms of information collection and analysis. In order to collect information, library methods were used, and agent-based simulation (using Netlogo software) was used for data analysis and model development. Kowsar Hospital, Ilam, Iran is the case studied. Based on the case study, a three-level supply chain is considered, in which suppliers are at the first level, the hospital at the second level, and the patients at the third level. Full details about the method are provided in the model description.

Information collection in the current research was done in the field and in the library. In the library part, it was tried to find the gap of the research, and the theoretical foundations and background of the research are obtained using this method. In the field part, information was extracted from the database of Kowsar Hospital. It should be noted that this information included the demand for fast-moving consumer goods, the demand for slow-moving consumer goods, the demand of patients with social security insurance, the demand of patients without social security insurance, the demand for emergency services based on the entry of patients, and finally the rate of failure of hospital equipment such as ultrasound machines, radiography machines, CT scan machines, etc., all these items were extracted from the hospital database. The research was carried out in the field of healthcare services; thus, it is based on the case study. The case study of the current research is Kowsar Hospital, Ilam, Iran.

In this research, the agent-based simulation method was used for analyzing the data. The software used in the data analysis section was NetLogo. Using this software, the relationships determined in the model are entered into the software, and its output, including the decision variables introduced in the model, is obtained. Decision variables are often predictive in nature. Furthermore, parametric sensitivity analysis was performed on the variables to determine what effect the changes in the parameters would have on the prediction or the results of the variables.

#### **3-1. Model**

In this research, the agent-based simulation method was used to investigate the agents' behaviors. And Netlogo was used to run the simulation. In order to collect data for the research model, the hospital information was used. The proposed model is a three-level supply chain model, in which hospital suppliers are at the first level. These suppliers are divided into four general categories.

1. Suppliers of medicinal items
2. Suppliers of fast-moving consumer items such as masks, gloves, etc.
3. Suppliers of slow-moving consumer items such as surgical equipment
4. Hospital equipment service workers (research findings)

However, it should be noted that fast-moving consumer items do not necessarily mean disposable items, but include disposable items as well.

At the second level, the hospital is considered as a service producer or service provider, which produces services in different levels, these levels are divided into four major categories in this research.

1. Provider of specialized medical services
2. Provider of general medical services
3. Provider of emergency medical services
4. Provider of nursing services (research findings)

It is worth mentioning that general and emergency medical services overlap, but emergency medical services are separated due to their emergency and urgent nature.

At the third level, there are customers or patients who, in terms of receiving services, are in two situations: those who are covered by insurance and those who are not.

The figure below displays the schematic of the service supply chain.

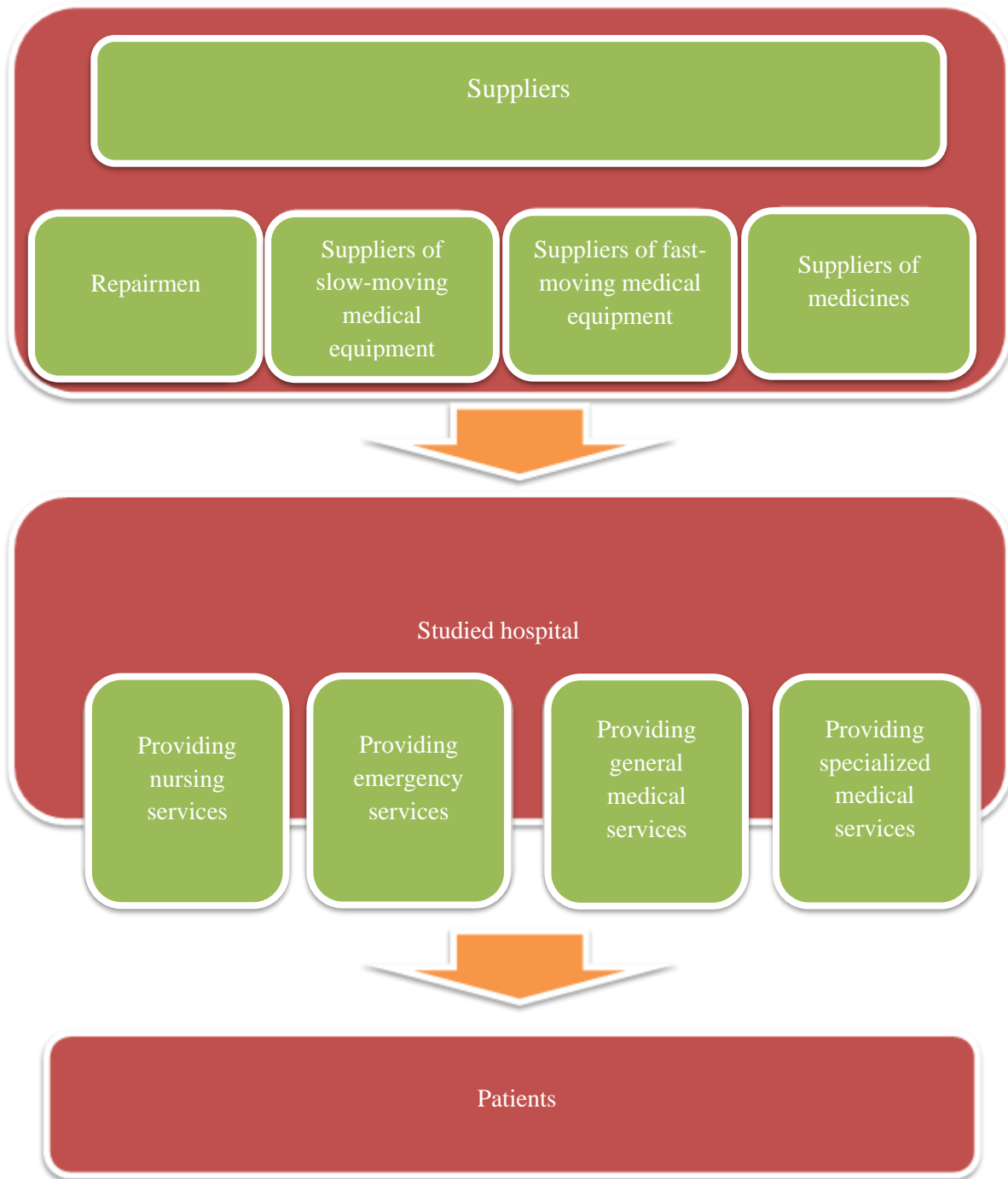


Figure 1. Schematic of the service supply chain (research findings)

If we want to present the assumptions of the supply chain in summary, these assumptions can be explained as follows.

1. It is a multi-product model.
2. The supply chain has three levels.
3. There are two types of customers: with insurance coverage and without one
4. The services provided by the hospital are divided into four levels of general, specialized, emergency, and nursing.
5. The goods provided by the suppliers are divided into three levels of fast-moving consumer goods, slow-moving consumer goods, and medicinal goods.
6. Repair and maintenance services are also provided by the suppliers (research findings).

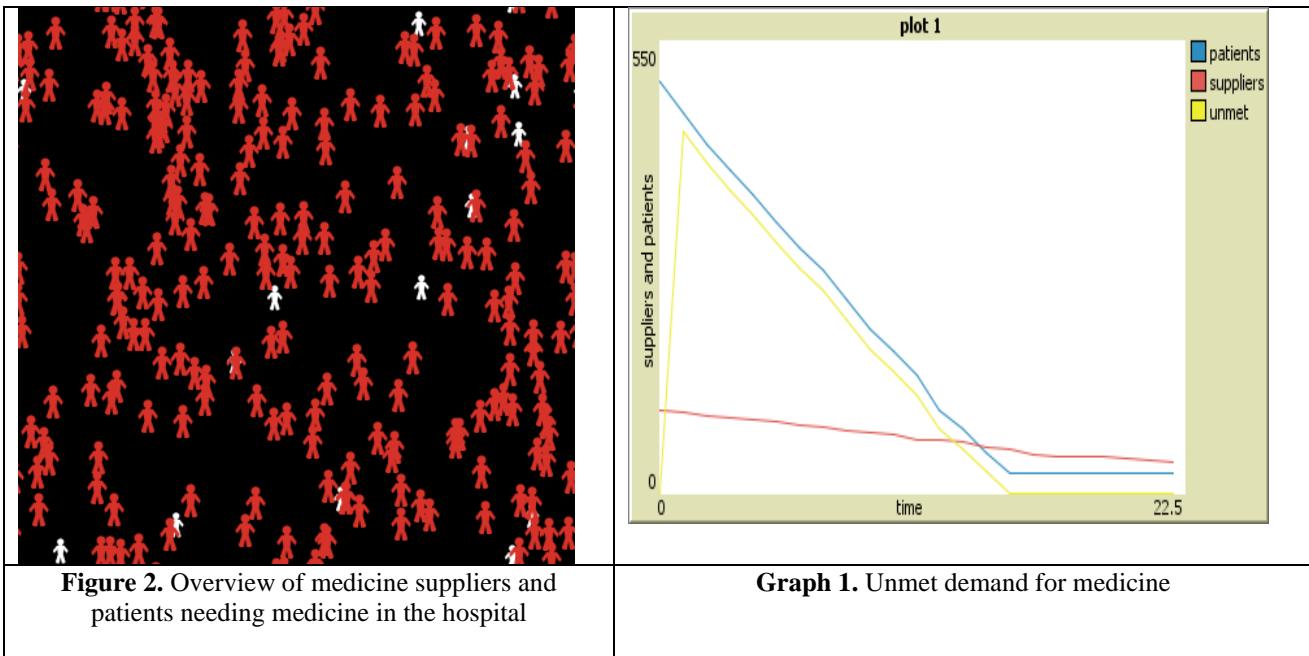
#### 4. Analysis

In this section, the agent-based simulation described in the third chapter is presented using the NetLogo software. At first, the model is implemented using NetLogo, and the existing weaknesses and bottlenecks are introduced. Then, suggestions are provided to improve the conditions and remove the existing bottlenecks by developing various scenarios. It should be noted that the numbers are related to the year 1401 according to Persian calendar (2022). In order to validate the model, the results obtained from the perspective of experts, which include the managers and senior staff of Kowsar Hospital, were examined. Considering that simulation was performed in this research, the results of the simulation were compared with the probable results, and the opinions of the experts were unanimous in favor of the obtained results.

The agent-based simulation in the present research is carried out in the order of the following steps: Identification of agents, domain definition, simulation plan, interaction plan, validation, and virtual testing

#### Simulation of medicine supply

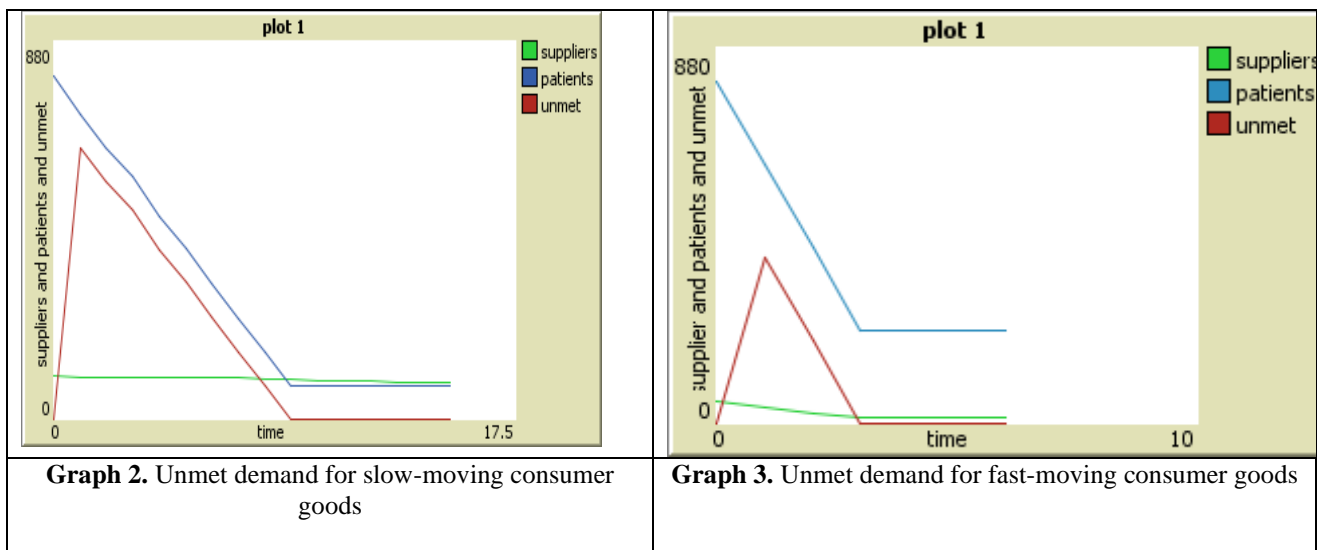
In this section, medicine supply for the studied hospital is simulated. First, the figure below illustrates a general outline of the population, consisting of suppliers and patients in need of medicine.



As can be seen in Graph 1, the blue line indicates demand, the red line indicates suppliers, and the yellow one represents unmet demand. The unmet demand was a little far from the total demand and it would take a long time for the unmet demand to reach zero; therefore, it can be said that the value of unmet demand is relatively high. This one of the main weaknesses of the supply system, and efforts should be made to minimize the unmet demand by developing proper scenarios.

### Demand for fast-moving and slow-moving consumer goods

Similar to the measures taken regarding the demand for medicine, the necessary investigations are also carried out regarding fast-moving consumer goods. Fast-moving consumer consuming goods usually include disposable health products such as gloves, masks, needles, syringes, etc. The result of the simulation analysis using NetLogo is as follows.

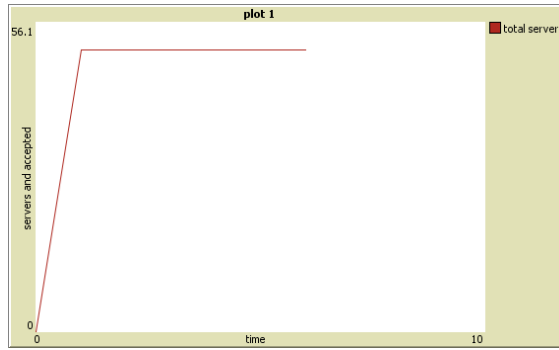


Graphs 2 and 3 show the high level of unmet demand, which indicates the relatively same conditions as medicine; hence, exactly the same action taken for medicine and developing the relevant scenarios for it should be taken for fast-moving consumer goods.

As it can be seen, the conditions regarding slow-moving consumer goods are slightly different, and it can be seen that after peaking, there is a relative decline in unmet demand, showing a slightly better situation than the two situations of medicine and fast-moving consumer goods. However, the required efforts to improve unmet demand could be made.

### Machine maintenance

In this section, the maintenance and repair of machines and the costs are examined. The important point is that in machine maintenance, efforts are made to minimize the cost by choosing the least expensive repairers who are actually suppliers of the hospital. The result can be seen in the graph below.

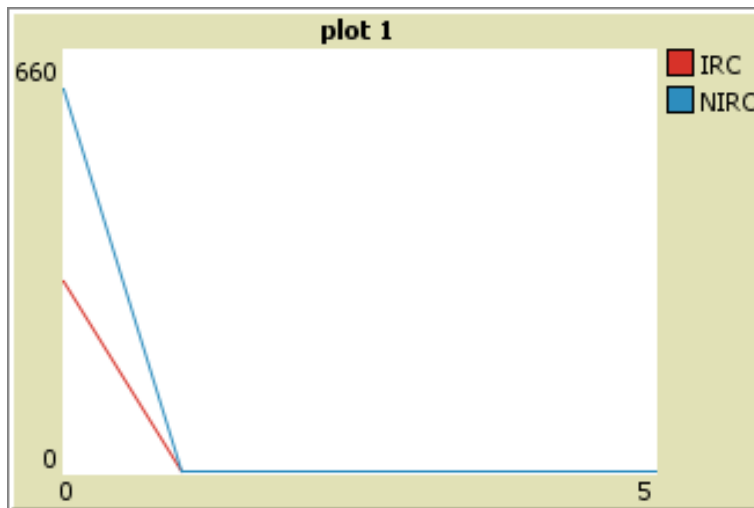


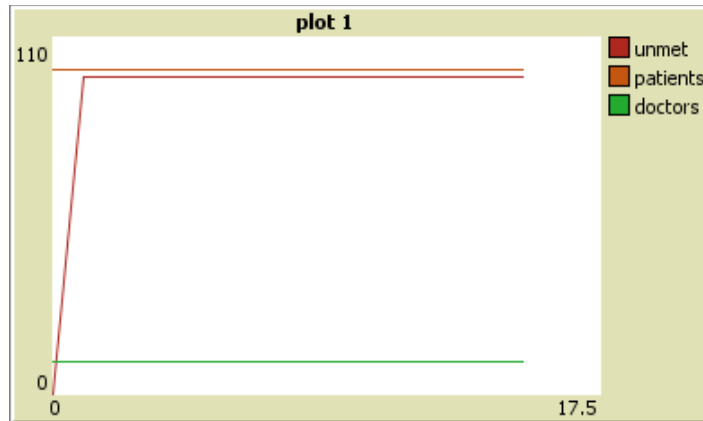
**Graph 4.** Minimizing cost by choosing the least expensive suppliers

As can be seen in Graph 4, it is possible to minimize the cost to some extent, and by reaching the number 56, it can be seen that it is not possible to choose a supplier more than this value; therefore, the maximum number of suitable suppliers for repairing medical equipment is this number. Moreover, it is possible to reduce the costs even more by developing proper scenarios.

### Emergency services

The item that is finally examined is receiving emergency services and examining the unmet demand in this section, which is displayed in the graph below.



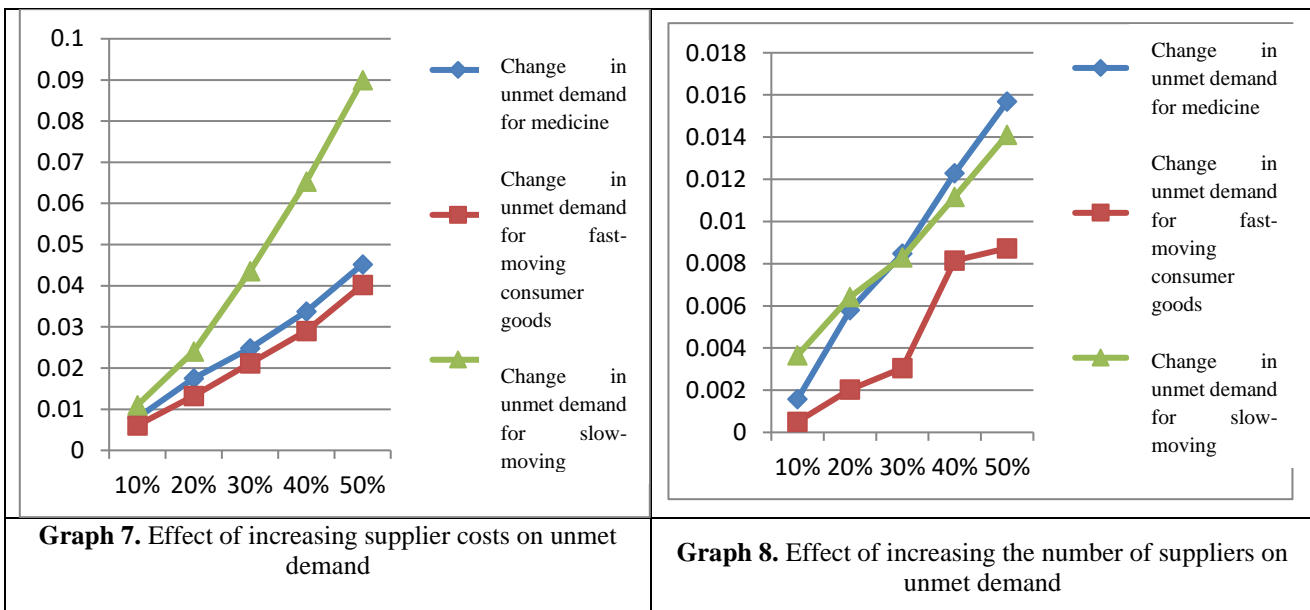


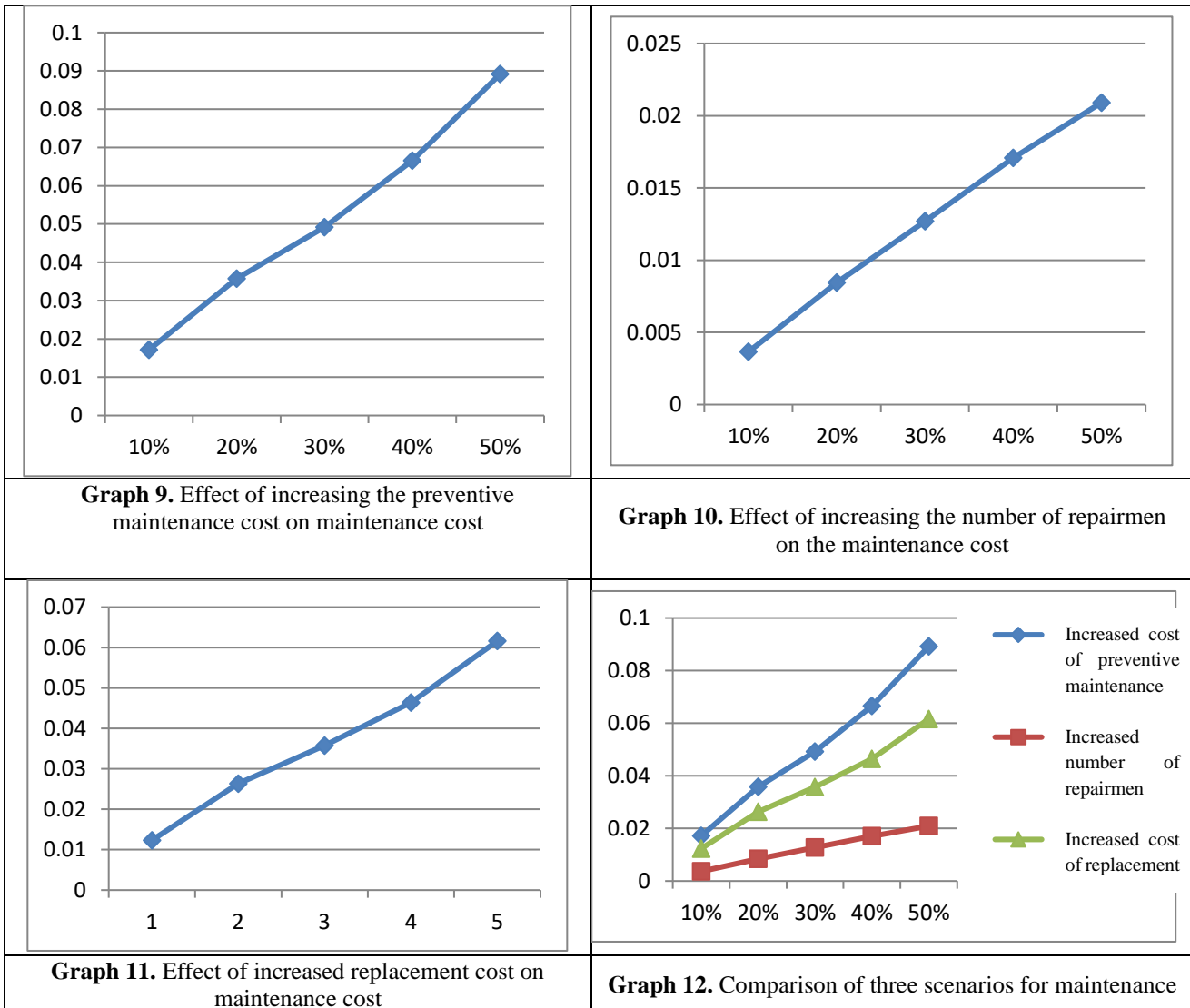
**Graph 6.** Analysis of the unmet demand of emergency services

As it can be seen, there is a possibility of increasing the unmet demand with the increase in the number of incoming patients; hence, this weakness is also seriously seen in the emergency department. In such a way that we can expect an increase in the unmet demand with the increase in the number of patients.

### Analysis of scenarios

Given the drawing of the current situation and the existence of various gaps and bottlenecks in various parts of the supply chain of the services provided in this department, efforts are made to take required actions by developing proper scenarios to improve the conditions. It should be noted that the results are provided in the form of figures and graphs, and the results of different scenarios are presented in an illustrative manner.

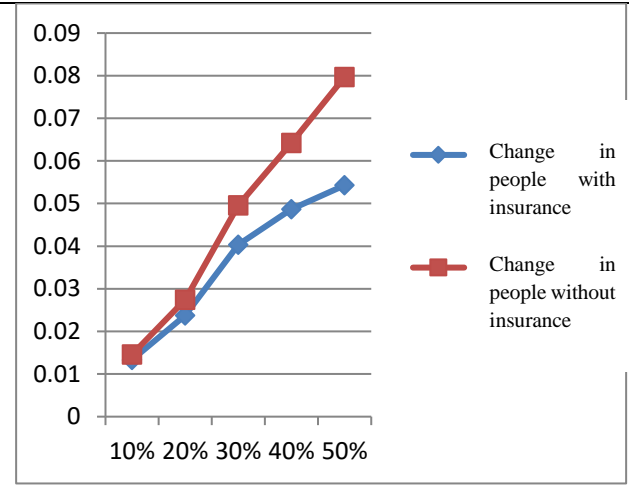




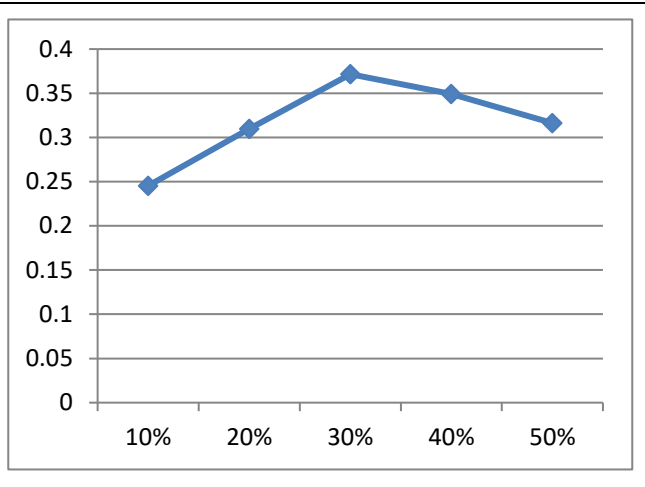
The results in Graphs 11 and 12 exhibit that the preventive maintenance strategy is the most effective, whose 50% increase leads to a 9% reduction in maintenance cost, then the replacement cost with 6%, and then the number of repairmen with an effect of 2%; thus, the best scenario would be an increase in the cost of preventive maintenance.

Scenario	Description
Scenario 1	In the first scenario, it is tried to decrease the demand for medicine by increasing the supplier cost, i.e. increasing the supplier salary or bonus. As it can be seen, a 50% increase in the supplier cost causes a 9% decrease in the unmet demand for fast-moving consumer goods, while it leads to a 4.5% decrease in the unmet demand for medicine and a 4% decrease in the unmet demand for fast-moving consumer goods. Therefore, fast-moving consumer goods are considered the most affected compared to other items.
Scenario 2	The result of this scenario shows the effect of the number of suppliers on the decrease in the unmet demand for medicine, which, of course, has a greater effect on the unmet demand for medicine and then on the unmet demand for slow-moving consumer goods in such a way that a 50% increase in the number of suppliers can reduce the unmet demand for medicine and

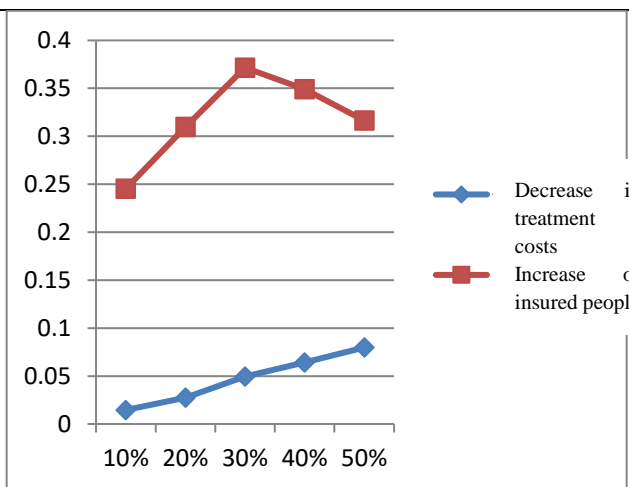
slow-moving consumer goods by up to 1.6% and 1.4%, respectively, while it can reduce the unmet demand for fast-moving consumer goods by over 8%.



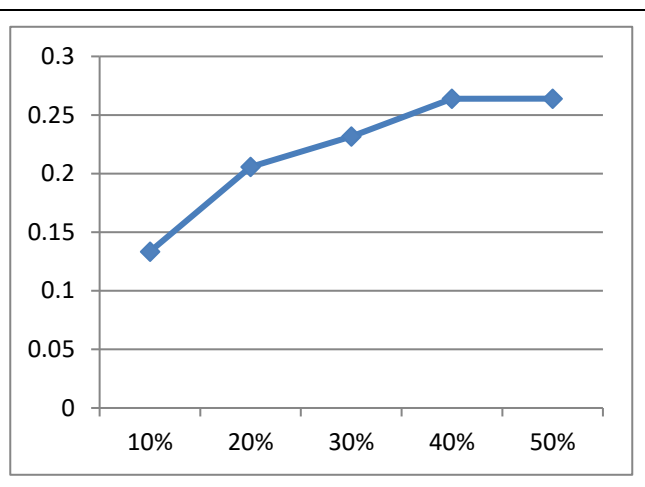
**Graph 13.** effect of reduction in treatment costs



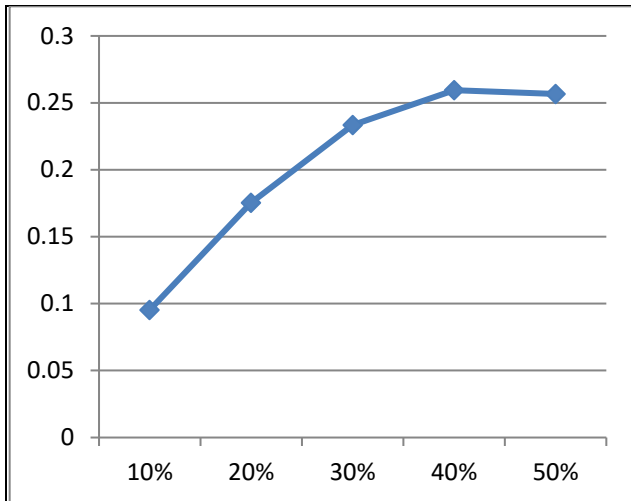
**Graph 14.** Effect of increasing insured people



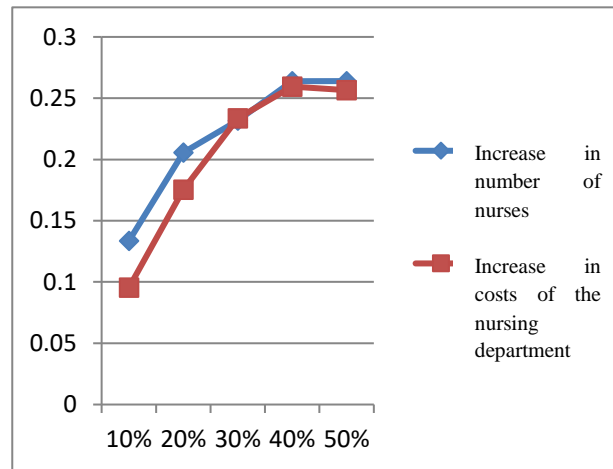
**Graph 15.** Comparison of two scenarios for the maximization of healthcare service coverage



**Graph 16.** Effect of increasing the number of nurses on the number of patients covered by nursing services



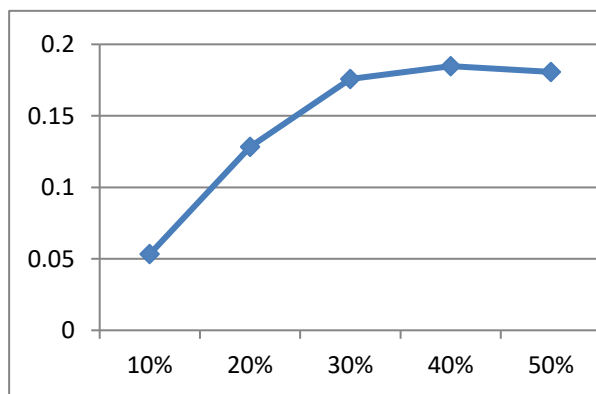
**Graph 17.** Effect of increased costs of the nursing department on the number of patients covered by nursing services



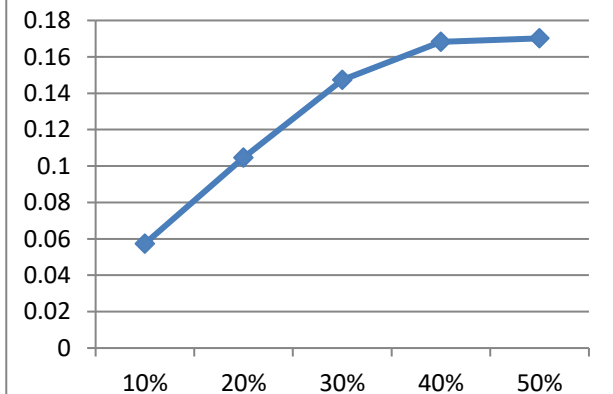
**Graph18.** Comparison of two scenarios for the nursing department

Scenario	Description
Scenario 3	In this scenario, it is tried to significantly decrease treatment costs for all people, regardless of whether they have insurance or not. With the reduction in treatment costs, it can be seen that people without insurance benefit from services more by 8%, while the figure for people with insurance is about 5.5%. Therefore, a reduction in treatment costs by 50% can attract more people who do not have insurance by 8%.
Scenario 4	In the next scenario regarding the nursing department, instead of increasing the number of nurses, the costs of the nursing department, such as salaries or beds and equipment, would be increased, which Graph 17 exhibits exactly the decreasing or constant nature like the previous scenario, therefore indicating the non-permanence of the effects of this department.

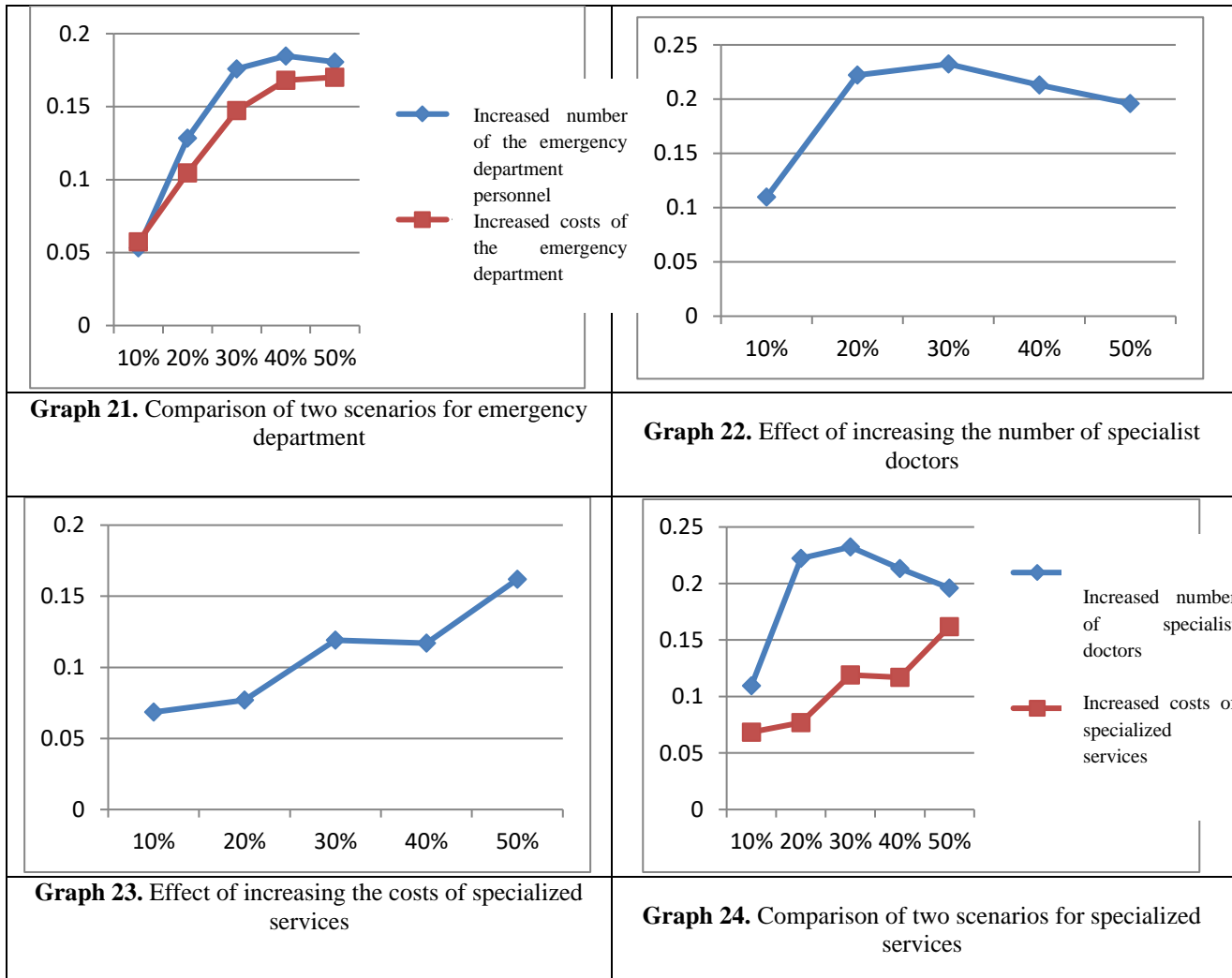
According to the above two scenarios, it can be seen that the effect of the two scenarios is the same and that both scenarios with an increase of 50% lead to an increase of over 25% in the insurance coverage of patients in this department, but both graphs have a decreasing or constant nature, meaning that the efficiency of the effect is lost after a certain period of time.



**Graph 19.** Effect of increasing the number of emergency department personnel



**Graph 20.** Effect of emergency department costs



Graphs 23 and 24 demonstrate the first upward and then constant effect of the increase in the number of emergency department personnel. In this scenario, it is planned that the number of emergency department personnel would be increased, and then its effect on the coverage of patients in this department would be checked. The results in the 50% situation indicates an 18% increase in the coverage of medical services or patients of this department. The second scenario would increase the costs of the emergency department instead of increasing the number of personnel. The results of the graph analysis show that a 50% increase in the cost could improve the services in the emergency department by over 16%.

Scenario	Description
Scenario 5	In the next scenario, the effect of increasing the number of specialist doctors is examined, which can be seen in Graph 23 that this effect has a decreasing nature and the effect tends to zero after some time. The peak effect of the increase in the number of specialist doctors is a 30% increase, and in a 50% increase, we see a 20% increase in covered patients, while in a 30% increase, there is a 23% increase in the covered patients.
Scenario 6	The scenario of increasing the number of specialist doctors completely outperforms the costs, and a 50% increase in the number of specialist doctors can lead to a 20% improvement in patient coverage, while this figure is 16% in terms of costs. However, the difference between the two scenarios' graph patterns indicates that the number of doctors followed a downward pattern, while the costs of specialized services followed an ascending and staggered pattern.

## **The optimal scenario**

In all the applied scenarios, there is a noticeable improvement in the studied variables. For example, in the first scenario, an increase in the cost of wages or bonuses leads to a 9% decrease in the unmet demand for fast-moving consumer goods, and a 4.5% decrease in the unmet demand for medicine, and a 4% decrease in the unmet demand for fast-moving consumer goods. This is seen in all scenarios; therefore, it can be said that all scenarios lead to an improvement and that there is no best scenario among the existing scenarios. Hence, in this research, all scenarios are considered optimal scenarios leading to the optimal solution.

## **5. Conclusion**

In this section, the results of developing the scenarios are analyzed and explained. Developing the scenarios for the unmet demand showed the effectiveness of all scenarios, with the increased supplier cost having the greatest effect on the demand for slow-moving consumer goods and reducing it significantly, while it has almost the same effect on the unmet demand for medicine and the unmet demand for fast-moving consumer goods. However, the increase in the number of suppliers can have the greatest effect on the unmet demand for medicine and the least effect on fast-moving consumer goods, so it can be said that fast-moving consumer goods are the least affected in terms of reducing the demand gap compared to the developed scenarios.

In the maintenance department, the cost of preventive maintenance and in fact its increase can have the most effect followed by cost of replacement; hence, increasing the cost of preventive maintenance is better than the cost of selectable replacement and is more preferable. Increasing the number of repairmen is not a very optimal scenario, thus having little effect, and it can be ignored.

Regarding the increase of insured people, the increase of insured people is a better scenario than reducing the cost of treatment, and in fact, reducing the cost of treatment cannot increase the number of people covered by healthcare services as it should, so it is better to put on the agenda the scenario of increasing the number of insured people who are insured in the hospital itself.

In nursing services, it can be seen that there is not much difference between the two scenarios of the number of nurses and the increased costs of the nursing department, and both strategies can lead to a 25% increase in the number of people covered by nursing services. In other words, it can be said that the two scenarios have a positive and significant performance from one aspect. However, in the emergency department, it should be said that the increased number of personnel in the emergency department has a better performance compared to the increased costs; therefore, the preferred strategy can be increasing the number of personnel. Although both strategies are subject to costs. Although both strategies are subject to costs, the scenario for the number of personnel is better in terms of increasing improvement and increasing patient coverage.

In specialized services, increasing the number of specialist doctors is more preferable than increasing the costs of specialized services, and exactly the same as in the emergency department, here, if the number of doctors is increased, better results would be obtained. Nonetheless, it could lead to the improvement in service coverage, and from a certain point onward, for example, we see a drop in the efficiency of effectiveness from a 30% increase onward.

Due to the fact that the present research is generally different from the conducted research and has an agent-based simulation approach in the supply chain of healthcare services, and none of the previous research have used the agent-based simulation approach in the field of the supply chain of healthcare services, it can be said that the current research is consistent with the previous research. However, it is worth mentioning that it has many similarities with the research by Backs et al. (2019) and Ravandi and Jovanovic (2018).

Nonetheless, it cannot be consistent with similar research in terms of results, because it is structurally different from similar research and is in fact innovative.

### **5-1. Suggestions**

In this section, practical recommendations and suggestions for future research are provided. Practical recommendations are about the supply chain of healthcare services.

- If hospitals can increase the cost of salaries and wages of suppliers, one could expect a decrease in the unmet demand for medicine, as well as fast- and slow-moving consumer goods.
- The policy of increasing the number of suppliers can also be included in the agenda of hospitals so as to reduce the unmet demand.
- If a hospital can increase the technical staff and specialist repairmen of the hospital equipment, they can expect a reduction in the cost, benefiting the hospitals. Although it should be taken into account that these people must have sufficient and necessary expertise.
- If hospitals replace the equipment when the failure is obvious, this can help reduce their maintenance costs.

In this section, future suggestions are as follows.

- Using other simulation approaches such as discrete event simulation and system dynamics
- Providing a mathematical model for the service supply chain
- Using a qualitative approach to identify agents in the reviewed study
- Using the current agent-based model in other service supply chains
- Developing the current service supply chain model into robust, agile or resilient models

Finding an appropriate study case was the most important limitation of the research. Kowsar Hospital, Ilam, Iran was selected due to its special conditions and the high level of deprivation in this province. On the other hand, due to confidentiality, obtaining proper data of the hospital is considered as another limitation in the present research.

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