



# Improvement of Medical Consumables Inventory Management by Simulation and Optimization in Hospitals

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**Abstract.** In order to ensure the uninterrupted continuity of their activities, businesses have to keep certain levels of inventory in market conditions that cannot be precisely measured and easily predicted, such as uncertainty in demands and lead times, fluctuations in prices. Inventory for health businesses that produce health service output as a result of business activities; means materials that must be kept for examination, treatment and diagnosis and that directly affect human health. For this reason, the management of medical inventory is very important both for human health and for the financial continuity of hospitals. In this study, which explains the inadequacy of the current medical consumable inventory control method used in the operating room unit of the hospital, which is the subject of the study, by using simulation and optimization techniques, and saving inventory costs by designing alternative inventory control models to the current situation; first of all, the current medical consumable inventory of the operating room were examined by ABC-VED analysis. Then, the new inventory control model, which was created using the (s,S) inventory control policy, in order to be an alternative to the existing inventory control management and current inventory control management of the operating room, was modeled using the stochastic modeling approach in the Arena Simulation package program, using real life data from the hospital. The simulation model is run for both inventory control models and the inventory costs of the materials are calculated for both inventory control models. In the last part of the application, the (s,S) inventory control model, which was designed as an alternative to the current situation, was optimized for the selected materials using the OptQuest optimization tool in the Arena Simulation program. As a result of the optimization, the minimum, maximum and reorder point parameters of the materials used in the study were re-determined to optimize the inventory cost of the materials. By using the optimized inventory parameters (s,S), the inventory control model was run again and the inventory costs of the selected materials were calculated for the third and final time. Finally, the outputs of the three inventory control models were analyzed and it was concluded that the lowest inventory cost value with a confidence level of 95% was achieved by using the optimized (s,S) inventory control model and the current inventory control method of the operating room was insufficient in terms of cost.

**Keywords:** Healthcare inventory management · Inventory control · (s,S) inventory policy · Simulation · Optimization

## 1 Introduction

As the competition between businesses increases day by day, businesses have to take various measures in order to survive and maintain their activities and financial continuity. One of these measures is inventories, which are kept in order to adapt to uncertain and unexpected market conditions and to maintain the continuity of operations. Almost every business that produces a product or service as a result of an activity, especially production businesses, has certain levels of inventory. One of these enterprises is the health enterprises that produce health service output as a result of the activities they carry out. All healthcare businesses, especially hospitals, make use of medical consumables as well as healthcare personnel while producing healthcare services. Medical consumables are mandatory materials that enable health personnel to carry out examinations, diagnoses and treatments. Since medical consumables are materials that directly affect patient health, inventory management processes applied to these materials are processes that must be carried out very sensitively by hospital management. Medical consumables, which are indispensable materials for human health and therefore for the uninterrupted functioning of health care, must be kept ready for use in hospitals at all times. However, due to the high costs of these materials, hospitals have to keep only certain levels of medical consumables in line with financial concerns and interests. In addition to maintaining a balance as best as possible between holding more inventory than necessary or keeping underinventory, another reason that makes it difficult to manage medical consumable inventory is that the demand in hospitals is unpredictable due to the fact that it is completely dependent on the human factor. Health institutions should design new inventory control and management models or replace the existing inventory control and management models they use, taking into account the uncertain demand conditions for medical consumables, in order to achieve a good balance between incurring unnecessary costs by holding more inventory than they need, or having insufficient inventory to stop health care. Must be updated according to the conditions. Only in this way will the ever-changing demand for healthcare services, depending on the patients, be met uninterruptedly with minimum costs. In this study, which aims to bring the control method of medical consumable inventory managed under variable demand and high cost conditions to a better point than the current situation and to show the inadequacy of the current inventory control method, the current situation inventory control method and stochastic inventory control models which reflecting the real life uncertainty conditions of the hospitals are designed by using Arena Simulation Software. The designed inventory control simulation models were run, then the total inventory costs of the models were calculated and finally comparisons were made between the simulation models.

## 2 Literature Review

Most of the studies in the literature that analyze and focus on the control and management of medical inventory in health institutions consist of studies using ABC, VED or ABC-VED matrix or based on these methods. Some of these studies; Reference [1], as a result of the Covid epidemic, the demand for medical consumables in hospitals became much more uncertain than in normal conditions, and under the effect of this increasing

uncertainty, medical consumable inventory in a public hospital were classified according to each method by using ABC, VED and ABC-VED Matrix methods. Suggested that the ABC-VED matrix method, which allows classification among three methods according to both cost and vitality, should be used in hospitals. Reference [2], based on the 958 drug data in the pharmacy department of the hospital, which is the subject of the research, firstly was classified the inventory in question according to their cost and vital importance with the ABC-VED matrix, then added the supplier reliability criterion among other criteria and classified the inventory this time using AHP and TOPSIS methods and thus designed a new inventory control method that can be used in healthcare businesses. Reference [3], as a result of their study with the aim of improving the inventory control process of surgical consumables in a hospital in New Delhi, the capital of India, using the ABC-VED matrix, by examining the past supply times of the most important materials belonging to the AV group, the minimum, maximum, average and calculated the median lead times and found out how many days the materials should be ordered in order not to run out of inventory.

Studies in the literature on the control and management of medical consumables and drug inventory are not limited to ABC, VED and ABC-VED matrix. There are also studies in the literature that try to reduce the inventory costs caused by medical consumables compared to the current situation and develop new inventory control models and techniques for this purpose. Some of these studies are as follows; Reference [4], the optimum reorder point and order quantity, which minimizes the inventory cost of medical consumables in a neonatal unit of a hospital, were determined by using simulation-meta modeling using  $(Q,r)$  inventory control policy and integer nonlinear mathematical modeling techniques together. Reference [5], for the drug inventory of a 100-bed hospital, four different inventory policies were designed as an alternative to the current situation, designed using the simulation modeling approach, and these inventory policies were compared according to the total inventory cost and the number of inventory outs performance criteria and decided which policy should be used according to the outputs of the simulation model. It has been concluded that the 3rd and 4th inventory policy, which decides when and how much drugs will be ordered, based on availability, vitality criticality and expiration dates, gives better results than other inventory policies as a result of the simulation model's outputs. Reference [6], in this study, if the  $(s,S)$  inventory control policy is used instead of the current inventory control method used by a pharmacy, how much savings will be achieved in the costs of drug inventory, was calculated by using simulation modelling. Results has been shown that if the  $(s,S)$  inventory control policy is used, a saving of 1.489.651 Turkish Lira (₺) will be achieved. Reference [7], in the study carried out in the medical consumables warehouse of a hospital in Taiwan, whichever of the  $(R,S)$ ,  $(s,S)$  and  $(R,Q)$  inventory control policies is used when inventory control of the materials determined for the pilot application is used, the rate of shortage inventory of the materials will be minimum. The answer to the question was sought and explained using the simulation modeling technique. And finally, by optimizing the simulation model representing the relevant materials, the reorder point  $(s)$ , fixed order quantity  $(Q)$ , order period  $(R)$  and maximum inventory amount  $(S)$  were re-determined by minimizing the rate of shortage inventory of the materials.

When the above-mentioned studies evaluated within the scope of the study are examined, it is seen that the ABC-VED matrix and simulation modeling techniques are applied separately in studies that examine and develop the inventory management and control processes of medical supplies in health enterprises. Therefore, in this study, firstly, the inventory were classified by applying ABC, VED and ABC-VED analysis, and then the medical consumables to be used in the simulation and optimization application were determined according to the ABC-VED matrix, taking into account the cost of inventory and surgical importance. In addition, when the application areas of the simulation modeling studies are examined within the scope of the study, no studies have been found on a simulation modeling and optimization-based inventory control and management carried out in the operating room unit, which is one of the most important health service units of hospitals. With this study, which was carried out in the operating room unit of a public hospital, this deficiency was tried to be eliminated. In addition, this study, which proves the inadequacy of the current inventory control method of the operating room, which is the subject of the study, in today's uncertain conditions, with alternative inventory control methods, has the mission of informing the hospital managers responsible for medical inventory on this issue. As a result of the literature research conducted in Reference [8], in which they comprehensively discussed many different modeling and solution methods used in medical product inventory management in hospitals, it is recommended to use a simulation-based approach for inventory problems in healthcare services due to its superior features in representing complexities and uncertainties. For this reason, simulation modeling approach was preferred in the study.

### 3 Methodology

In this study, it is aimed to improve the management of medical consumable inventory in the operating room, which is managed under variable demand and high cost conditions, and to show the inadequacy of the current inventory control method at the cost point by comparing it with alternative inventory control methods. The application steps within the scope of the study are briefly stated as follows:

- Since the importance level of each medical consumable that makes up the inventory is different for the operating room inventory management, the inventory are grouped on the basis of cost criteria with the ABC analysis, which is frequently used in the literature to determine the important and less important materials. However, since the said materials are medical supplies, the inventory were regrouped as V, E and D, respectively, according to their surgical importance by the users in the operating room using the classification technique called VED analysis in the literature. The groups formed as a result of these two analyzes were crossed and ABC-VED matrix was obtained, so medical consumables were classified considering both cost and surgical importance.
- Some materials have been selected to be used in simulation and optimization applications, which show the inadequacy of the current inventory control method and alternative inventory control models are designed. For the material selection, initially the materials constituting the AV group, which is the cost and surgically important

inventory group, were selected from the intersection groups formed as a result of the ABC-VED matrix, then it was reduced to fourteen materials by adding and removing some materials after taking expert opinion, and finally the three with the highest consumption value material was chosen for simulation and optimization application.

- The inventory control model representing the current inventory management process of the operating room was decided to be designed using the simulation modeling approach, and in Arena Simulation application, the simulation model representing the current inventory control method of the operating room, the real-life data of the operating room in 2021 and the expert opinion in the processes, it is designed using probability distributions in a way that reflects the uncertainty of real life. The current inventory control model designed was run in Arena Simulation program to calculate the inventory costs of the selected materials. As a result of the simulation outputs, the total inventory cost of the materials in the current inventory control model has been calculated. Then, in order to be an alternative to the existing inventory control model and provide cost-based improvement to the current situation, the (s,S) inventory control model, which is one of the stochastic inventory control models, was designed in Arena Simulation application and the model was run for selected materials and the total inventory cost of the materials was recalculated.
- The optimization process within the scope of the study was carried out with the OptQuest optimization tool, which is one of the tools of the Arena Simulation program. During the optimization application, the (s,S) inventory control model, which was designed to be an alternative to the current situation, was used and OptQuest was run to optimize the inventory cost of the materials. As a result of OptQuest's work, the outputs of the optimized (s,S) inventory control model were examined and the reorder point, minimum and maximum inventory level parameters that minimize the inventory cost of the materials were determined. Finally, the three inventory control models created and used throughout the study were compared with each other. In order to compare, the outputs of the inventory cost values calculated by the current inventory control model, (s,S) inventory control model and optimized (s,S) inventory control model for the selected materials were analyzed using statistical tests and graphics.

### 3.1 Applications

- 1) *ABC-VED Analysis*: By contacting the information technology unit of the hospital, the Microsoft Excel data set, which includes the information about the medical consumables used by the operating room unit, their consumption amounts and unit prices between 01.01.2021 and 31.12.2021, was reached. The materials were first listed in order from largest to smallest according to their annual total consumption values, then ABC (Always, Better, Control) analysis was performed to determine the ratios of groups A, B and C consisting of medical consumables in the annual total consumption value and the materials in the groups. Since VED (Vital, Essential, Desirable) analysis is applied based on expert opinion, unlike ABC analysis, after obtaining permission as a result of interviews with the nurse in charge of the operating room unit, the medical consumables consumed by the operating room in 2021, grouped as V, E, and D. By crossing the A, B and C inventory groups obtained as a result of ABC analysis of the medical consumable inventory consumed by the

operating room in 2021 and the V, E and D inventory groups obtained as a result of the VED analysis using Microsoft Excel, the inventory were divided into 9 subgroups as seen in Table 1.

**Table 1.** ABC-VED matrix

Categories	Number	Amount (₺)	Rate (%)	Amount Rate (₺)
I. (AV + AE + AD + BV + CV)	270	5.268.547,43 ₺	48,39%	87,75%
II. (BE + CE + BD)	273	729.831,33 ₺	48,92%	12,16%
III. (CD)	15	5.796,18 ₺	2,69%	0,10%
Total	558	6.004.174,94 ₺	100,00%	100,00%

2) *Simulation and Optimization:* The operating room medical consumable warehouse has 558 different types of medical consumables. Making simulation applications for each recorded material is difficult in terms of both time and cost. For this reason, firstly, 21 materials belonging to the AV group, which is one of the material groups obtained as a result of ABC-VED analysis, and which have the highest importance both in terms of cost and surgery, were selected. After the interviews with the medical consumable office supervisor and the HIMS (Hospital Information Management System) were examined, the materials that are no longer used or preferred by the users as of 2022 were removed from the list and the number of materials was reduced to 14. The consumption values determined as a result of ABC analysis of 14 materials were examined and the first three materials with the highest consumption value were selected for simulation and optimization application. Selected materials; General Surgery Drape Set Disposable, Spinal Epidural Combi Set, Anesthesia Circuit (Adult). Data of consumption amounts, purchase quantities, current inventory parameters, procurement times of purchasing methods, and the dates of demand for materials between 01.01.2021 and 31.12.2021 in the operating room medical consumable warehouse to be used in simulation and optimization applications of three medical consumables, it was obtained with a Microsoft Excel file by contacting the information processing unit of the hospital. By using the Input Analyzer tool in Arena Simulation program, the probability distribution formulas of the data were determined for all three materials as follows (Tables 2, 3, and 4).

After the basic input parameters were determined, the model representing the current inventory management process of the operating room was created in the Arena simulation program as in Figure 1, by ensuring the active participation of the medical consumable office supervisor of the hospital, during the establishment of the model and at every stage. Assumptions of the simulation model:

**Table 2.** Probability distribution formulas of consumption amounts

Materials	Probability distribution formulas of consumption amounts
Anesthesia Circuit (Adult)	TRIA (40, 123, 240)
Spinal Epidural Combi Set	DISC (0.05, 3, 0.6, 30, 0.95, 60, 1.0, 90)
General Surgery Drape Set	25 + 665 * BETA (0.81, 1.21)

**Table 3.** Probability distribution formulas of purchased quantities

Materials	Probability distribution formulas of purchased quantities
Anesthesia Circuit (Adult)	5 + 235 * BETA (1.86, 1.94)
Spinal Epidural Combi Set	DISC (0.042, 3, 0.083, 10, 0.125, 20, 0.583, 30, 0.625, 40, 0.917, 60, 0.958, 90, 1.0, 120)
General Surgery Drape Set	3 + 687 * BETA (0.561, 0.95)

**Table 4.** Probability of time (days) between two demand distribution formulas

Materials	Probability of time (days) between two demand distribution formulas
Anesthesia Circuit (Adult)	DISC (0.0256, 1, 0.0769, 5, 0.2821, 6, 0.5385, 7, 0.6667, 8, 0.7692, 9, 0.7949, 11, 0.8205, 12, 0.8718, 13, 0.8974, 14, 0.9231, 15, 0.9744, 16, 1.0, 34)
Spinal Epidural Combi Set	DISC (0.11, 7, 0.21, 8, 0.26, 13, 0.58, 14, 0.79, 20, 0.95, 24, 1.0, 28)
General Surgery Drape Set	-0.5 + 32 * BETA (0.944, 1.33)

**Table 5.** Lead times probability distribution formulas

Supply methods	Lead times (day) probability distribution functions
Direct Supply (DS)	TRIA (7, 14, 21)
GMO (Government Materials Office) Supply	TRIA (15, 45, 60)

- For each material, the probability distributions of the Direct and GMO lead times in Table 5 are considered the same
- According to Reference [4], the order cost has been determined as 4000 Turkish Lira (₺) as a fixed
- The unit holding cost is taken as 20% of the unit price of the material
- Inventory levels of materials are checked instantly

- The model allows for holding and accumulated demand

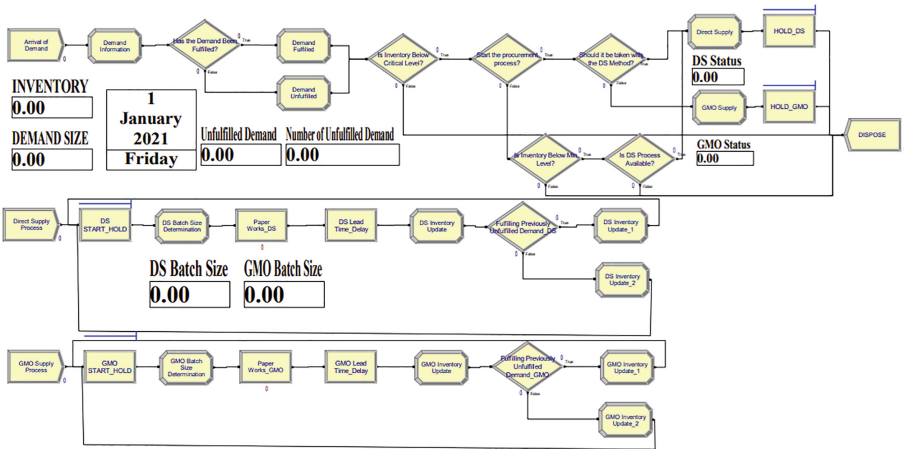


Fig. 1. Arena simulation model

- For each material, the probability distribution formulas of purchase quantities are considered equal for Direct and GMO supply methods
- The starting inventory of each material is as much as the reorder point of the material
- The inventory, which is renewed with each incoming order, must first meet the accumulated demand. Only any the remaining amount is used for future requests
- Unit holding cost is taken as twice the unit holding cost. The reason for the high cost of retention here is that the system subject to the study is an environment such as the operating room that affects human health significantly

Before running the simulation model, the replication numbers of the selected materials, the Fixed Sample Size Method and the Relative Error ( $\gamma$ ) Formula were used for the General Surgery Drape Set; 33 replication, Spinal Epidural Combi Set; 10 replication, Anesthesia Circuit (Adult); 10 replication. The simulation length is set to 24 h 365 days a year for all three materials.

## 4 Results

Using the simulation model, the inventory cost of the three materials was calculated for each replication, first according to the current inventory control method of the operating room, and then the inventory cost of the three materials was recalculated by running the simulation model again using the (s,S) inventory control policy. Finally, by using the optimization tool OptQuest in the Arena Simulation program, the minimum, maximum and reorder points that optimize the inventory cost of the three materials were determined,



and the simulation model using the inventory policy (s,S) according to the new inventory parameters was run again, and the inventory cost of the three materials was determined as the third and last time. Thus, the outputs of three different inventory control methods were obtained for the selected materials.

#### 4.1 Outputs of Models

The averages of the total inventory cost values calculated by the three inventory models created within the scope of the study for each replication result for all three materials are summarized in the table below (Table 6).

**Table 6.** Average inventory costs of models

Material	Current model	(s, S) Model	Opt. (s, S) Model
General Surgery Drape Set (33 rep)	₺ 2,021,850.57	₺ 1,255,092.87	₺ 899,706.11
Spinal Epidural Combi (10 rep.)	₺ 217,791.83	₺ 188,307.41	₺ 161,183.29
Anesthesia Circuit (Adult) (10 rep.)	₺ 798,603.21	₺ 284,953.79	₺ 255,918.30

#### 4.2 Output Analysis

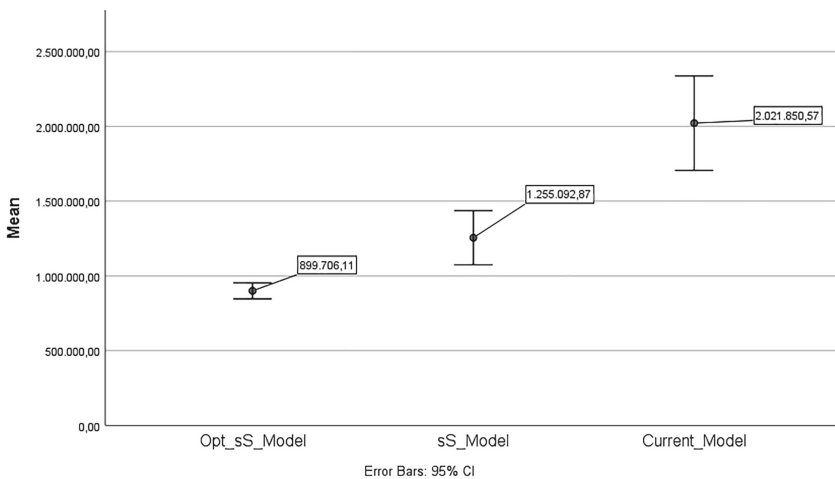
A stochastic simulation model emerges because all of the input parameters used in the three inventory control models that calculate the total inventory costs of materials are obtained by using probability distribution functions. Due to this situation, the total inventory cost output obtained from the models is a random value. The fact that the model outputs are a random value eliminates the possibility of deterministically comparing the total inventory costs of the related materials obtained from the models. For this reason, the t-test was applied to the outputs of the inventory costs calculated in the three inventory control models of the selected materials by using the SPSS package program and it was determined whether there were statistically significant differences between the three inventory control models.

- $H_0$ : There is no significant difference between the outputs of the inventory control models.
- $H_1$ : There is a significant difference between the outputs of the inventory control models.

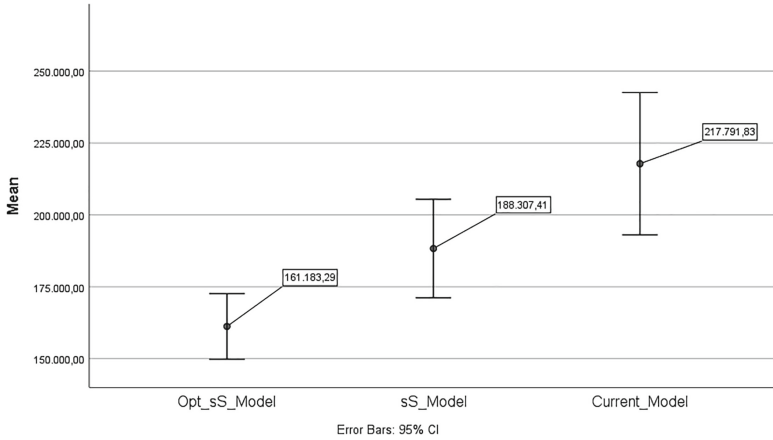
**Table 7.** General surgery drape set T-Test results

95% Confidence interval of the difference								
Pairs	Mean	Std. Dev.	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Current Model - (s,S) Model	766757,6955	751345,8004	130792,5157	500342,0591	1033173,332	5,862	32	,000
(s,S) Model - Opt. (s,S) Model	355386,7652	460892,9475	80231,16394	191961,2321	518812,2982	4,430	32	,000
Current Model - Opt. (s,S) Model	1122144,461	876713,8655	152616,2946	811275,2413	1433013,680	7,353	32	,000

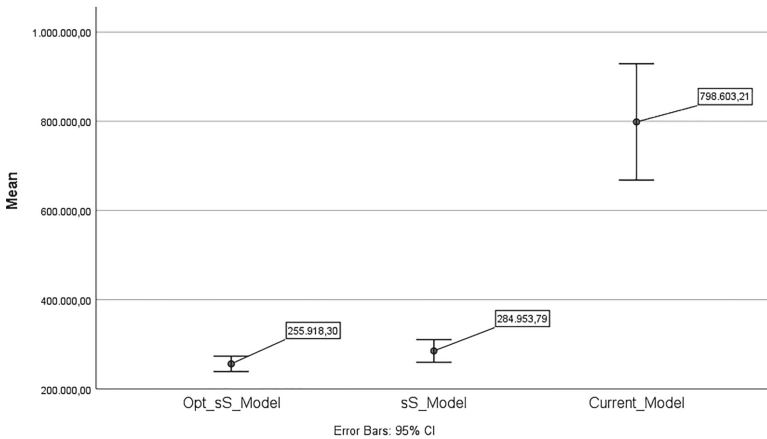
When Table 7 is examined, as a result of comparing the three models one by one, it is seen that the “significance” value is considerably lower than 0.05 in all three cases. In this case, the  $H_0$  hypothesis is rejected. In other words, this means that the outputs of the three inventory control models are statistically significantly different from each other at the 95% confidence level. T-test was also applied for the other two materials and the same results were obtained. After it was understood that the inventory costs of the selected materials, calculated as a result of each replication according to the three inventory control models, showed a significant difference, the charts of the outputs of the inventory models were created using the SPSS package program as follows. The lower, upper and average values of the total inventory cost values for each replication of the inventory control models are shown in the figures below.



**Fig. 2.** Output cost chart of inventory control models (general surgery drape set)



**Fig. 3.** Output cost chart of inventory control models (spinal epidural combi)



**Fig. 4.** Output cost chart of inventory control models (anesthesia circuit (adult))

## 5 Conclusions

In this study, which shows the inadequacy of the current medical consumable inventory control method in the operating room unit of Sakarya Training and Research Hospital, by using simulation and optimization methods, the current inventory control model, (s,S) inventory control model and optimize (s,S) inventory control model which optimized with OptQuest, has been calculated the total inventory costs of the selected medical consumables. Since the input parameters and output values of the inventory control models which design in this study are random values, the inferences obtained from the study are as follows when the graphs of the output values in Fig. 2, Fig. 3 and Fig. 4 are examined under the condition of 95% confidence level:

- The total inventory cost of the current inventory control method used in the operating room is higher than the costs of other inventory control models, and it has been proven with 95% confidence by the statistical tests conducted within the scope of the study
- It is seen in the output analyzes made within the scope of this study that using (s,S) or optimized (s,S) inventory control model instead of the current inventory control model of the operating room, will give better results
- By examining the output analyzes at the 95% confidence level, it is clearly seen that the optimized (s,S) inventory control model is superior to other inventory control models in terms of total inventory cost value

As a result of the findings obtained from the output analysis, it can be said that the applications made within the scope of the study reached their goal at the 95% confidence level. In short, the current medical consumable inventory control method of the operating room has been proven within the scope of the study with a 95% confidence level that it is quite inadequate compared to alternative inventory control models. Although the results of the simulation and optimization inventory control models, which are designed as an alternative to the current situation in the study, seem very inviting to use, the should not be forgotten point here that the simulation and optimization application is not easy to use in the field. The successful results of simulation and optimization in field applications are directly proportional to the knowledge of the personnel and upper management. When the programs and software used are added to this situation, it can bring a serious labor, cost and time burden to the companies. Suggestions for future work are given below.

- Although the holding cost is taken into account in the calculation of the inventory cost, this study ultimately compares the inventory control models by considering only the total inventory costs. In another study, the optimization process can be performed by considering the average missing inventory values and average inventory values of the models as well as the costs
- A more detailed comparison can be made by comparing the performance criteria of the two methods by using analytical techniques together with the simulation method. In addition to the (s,S) inventory control model, simulation models can be designed for other stochastic inventory control models, (s,Q), (R,s) and (R,s,S) and it can be determined which model gives better results
- Since the data obtained is one-year data, the simulation length is limited to one year. A simulation application using 5–6 years of data can give more effective results from a retrospective point of view

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