Managing Drug Shortages in Healthcare A Proposed Mathematical Response Strategies Model for Critical Supply Chain

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Abstract

Drug shortages are a global issue that every country has suffered from. It appears when a specific product is not meeting the demand of a hospital. It has many causes and effects that can intensely harm the patient's health.
This study aims to introduce a management strategy for controlling and handling the inventory of drugs in Kuwait's healthcare facilities in case of any drug shortages. The linear Programming mathematical model method is used to minimize the occurrence of drug shortages among healthcare facilities, manage the drug inventory in the hospitals, and control drug shortages in healthcare facilities. The proposed solution method's results show that the drug shortage problem can be solved optimally by distributing drugs between health centers. In addition, the solution methodology can shed light on health sector managers about the solution to the drug shortage problem.
Keywords: Drug shortages; hospitals; LP modeling; optimization in the health sector.

1.Introduction

Drugs are an essential part of healthcare since they improve the health and well-being of patients (Phuong J.M. et al. 2019). Drug shortages are a global issue that every country has been through. The shortages appear in the system when a specific product is unavailable to meet the demand. This shortage in healthcare is an important problem due to health consequences that impact patient treatment, medication errors, and quality-of-care services. Even though a large budget is allocated to healthcare facilities every year, specifically for costly hospital development programs, many hospitals have undeveloped systems for information technology and inappropriate transport facilities. Drug shortages in healthcare institutions and emergency units increase the cost of medication and reduce patient recovery rates. Some hospitals face drug shortages because of hospital size, number of patients, and graphical location. In addition, they are dealing with solving this problem and forming new strategies to get things under control. Hospitals deal with drug shortages by purchasing off-contract with their vendor, dealing with another vendor, purchasing pharmaceutical replacements, and using the pharmaceutical in stock.

Official healthcare administrators and other supply chain partners struggle to ensure that medicine is available to patients at healthcare centers. Numerous factors influence drug availability, including inventory management, supply chain constraints, demand from healthcare facilities, and supply from pharmaceutical industries. Many leading causes increase drug shortages problem. The first main cause of drug shortages is the drug manufacturers' response according to their earning profits and mitigating losses. The drugs manufacturing may face some quality problems, which can lead to a reduction in producing the drugs and restricted distribution. Moreover, the drug manufacturers' economic situation is also related to the number of products produced. These issues are related to the drug manufacturers' earned profit. For example, the number of products produced depends on the company's profits. If the earned manufacturers' profit remains stable, then the number of products being produced will remain constant, directly affecting the drug shortages in the healthcare facility. Moreover, the bad management of the supply chain and the inaccuracy in the workflow plan exacerbated the problem of drug shortages. Also, lead to delays in healthcare supplies. In addition, natural disasters can also affect drug shortages by impacting the availability of raw materials.

Drug shortages not only affect the patient's health but also it has financial and clinical effects. In the economic effect, there is a cost limitation constraint that the company cannot ignore, which leads to less production. The clinical effect means there will be an increment in medication errors even using other brands of a specific drug. Furthermore, drugs shortages affect the patient's health because of the treatment delay, so they will be forced to use other treatments that may be inappropriate and unsuitable for the patient's body. Consequently, increasing health care support use and spending. In addition, shortages lead to longer treatment times for patients or cancellation of procedures, such as surgery. Therefore, inefficient practices on drugs can also lead to drug shortages.

Furthermore, this topic has been chosen to have a better healthcare system and service, to serve the patients, and cover the issue of drug shortages in Kuwait by focusing on how to have a higher-level service with stabilizing or minimizing the cost. Avoiding drug shortages needs a very accurate study and some mathematical calculations. It is so, figuring out the most required drug in the hospitals and asking the manufacturers to produce more. Moreover, to solve this problem, using LP modeling method between hospitals must be used. So, the hospitals will collaborate using a unified system shared with all the collaborated hospitals and send the products to the hospitals that have shortages to meet their demand.

1.1 Objectives

The objective is to minimize the occurrence of drug shortages among healthcare facilities in Kuwait. Also, to manage the hospital drug shortage inventory by proposing a mathematical response strategies model for the critical supply chain. So, a high service with lower cost and meeting the hospitals' demand will be provided. Therefore, to have a sound system that can keep the hospitals updated date to date about the number of drugs available in their storage. Moreover, identify the critical issues in managing medical supplies to reduce drug shortages in Kuwait hospitals. The findings will inform the recommendations to healthcare stakeholders by helping hospitals build an optimized inventory management system, a streamlined hospital supply chain, and lateral transshipment programs.

2. Literature Review

Adkins, C. (2012). proposed a mathematical model and analysis for hospital collaboration through an inventory pooling strategy using LP modeling. One of the solutions for identifying possible levels of service improvements is via a collaborative hospital inventory pooling strategy and exploring the impact of such sharing on transportation costs is hospital cooperation through inventory pooling. The objective of this study is to have the best service level and to reduce unmet demand. Furthermore, to increase drug production capacity with optimum profits and costs. In addition, it unites all the hospitals' systems and decision-makers so the issue can be solved. Sharing hospital inventory and making it seen by other hospitals will allow getting benefits from drug availability. The equitable distribution of inventory expenses and needs in cooperating health approval leads to a significant reduction in the shortage. This study ended with many results. First, the decentralized systems will not achieve any improvements on their system. Secondly, the progress of the service level will increase if the number of shared inventories between hospitals increases.

Moreover, individual hospitals will not face any negative impact on their service level by entering a centralized system. Finally, some transportation might be increased; to raise the fill rate. This article discussed two leading inventories: healthcare and blood inventory with lateral Transshipments. Saedi S. et al. (2015) proposed an inventory management approach using the stochastic model. This study aims to minimize drug shortages in healthcare facilities in uncertain distributions and demand conditions and maximize quality service. The proposed model also calculates the best stock levels that positively affect the shortages and substitution costs by minimizing them. That can be done by modifying inventory parameters in a hospital. The main concepts are zero ordering cost and zero lead time.

Moreover, the study focused on long-term uncertainties for demand and supply. The are many results at the end of this study. First, the holding cost should be considered since the current conditions have low utilization space. Secondly, some available alternative drugs can be used, but substitutes will cost more and be less effective than the primary drug. Finally, having the same stochastic model among hospitals by inventory pooling will benefit the healthcare system.

Zwaida A. et al. (2021) revealed that optimizing inventory management and streamlining hospital supply chains will improve healthcare outcomes locally and internationally using an LP model for maximizing inventory and minimizing cost. Inefficient inventory management is the most significant contributor to drug shortages and high medical expenses in the healthcare industry. Proper inventory management enables sufficient control of the drugs and satisfies usage requirements, especially when done on time (Zwaida A. et al. 2021). Unfortunately, it is practically and economically impossible to build a system immune to a drug shortage. However, the frequency and impacts of such scenarios should be reduced by planning how drugs should be distributed from the manufacturers to the hospitals. Such high-level optimization requires developing systems that use complex mathematical models to map the routes through the supply chain and establish critical paths that may cause delays. These issues can be addressed by applying mathematical programming methods that evaluate the multiple forms of medication, ordered drug sizes, inventory processing time, expiration dates, holding and storage costs, and customer service and satisfaction level to generate the most reliable supply chain. Most importantly, healthcare institutions should turn from manual processes and workflows, which are inefficient, slow, and troublesome at collecting intelligent information necessary for inventory and supply chain optimization. Therefore, constant monitoring of drug demand and supply situations can help mitigate the drug shortage problem in the healthcare industry.

3. Methodology

This study primarily focuses on increasing the service level rather than the financial incentives. First, Kuwait's healthcare system will be explained. Kuwait has two types of sectors: the public sector and the private sector. In the public healthcare sector, the centralized system is being followed. On the other hand, a decentralized system is being tracked in the private sector. Then, the total number of hospitals should be identified. After that, data will be collected from certain Kuwait hospitals by creating a survey for healthcare staff. Finally, the data will be collected and analyzed through LP modeling; to determine the finding and the result of LP modeling. Linear programming (LP, also known as linear optimization) is a technique for achieving the optimal outcome (such as the highest profit or lowest cost) in a mathematical model with linear criteria. Mathematical programming is a subset of linear programming (mathematical optimization). Linear programming is the most extensively used decision-making approach in the industry, business, and other sectors. Linear programming belongs to the field of mathematics known as the optimization method since it is used to discover the best optimum solution to a problem. The three components of LP modeling are variables, objective functions, and constraints (Martinich, 1997). This project uses the Xpress-MP to solve the Linear program and apply the methodology.

The Sets are:

Hospitals (i, j): any two hospitals in the system
Drugs (k): number of drugs

The variables of the model are:

X_{ij}: number of drug units transported from *Hospital i* to *Hospital j*

$$Y_{ij}\begin{cases}0, & if\ there\ is\ no\ transaction\ of\ drugs\ between\ Hospital\ i\ to\ Hospital\ j\\ 1, & if\ there\ is\ a\ transaction\ of\ drugs\ between\ Hospital\ i\ to\ Hospital\ j\end{cases}$$

$$Z_{ij}\begin{cases}0, & if\ there\ is\ no\ 2\ transaction\ lines\ of\ drugs\ between\ Hospital\ i\ to\ Hospital\ j\\ 1, & if\ there\ is\ a\ 2\ transaction\ line\ of\ drugs\ between\ Hospital\ i\ to\ Hospital\ j\end{cases}$$

The parameters of the model are:

Demand: demand of k in *Hospital i*
Exceed: excess of k in *Hospital i*
Available inventory (a): available inventory of k in *Hospital i*
Needed inventory (n): needed inventory of k in *Hospital i*

- The model objective function is:

$$Minimize \sum_{i,j\in HOSPITAL|j\neq i} Z_{i,j}$$

The objective of this study is to minimize the summation of Z_{ij} values. By applying it, the model will be sure to minimize the number of transactions to reduce the occurrence of traffic between the line's transactions. So, if a certain number of drugs need to be transferred from *Hospital i* to *Hospital j*, the required number of drugs will be done in one transportation.

The model constraints are:

$$\sum_{j \in HOSPITAL \mid j \neq i} x_{i,j,k} \leq Exceed_{i,k} \qquad \forall \quad i \in HOSPITAL\,, k \in DRUG \tag{1}$$

$$r_{j,k} = Demand_{j,k} + \sum_{i \in HOSPITAL \mid j \neq i} x_{i,j,k} \qquad \forall \quad j \in HOSPITAL\,, k \ \in DRUG \tag{2}$$

$$\sum_{k \in DRUG} x_{i,j,k} \leq y_{i,j} * 100 \qquad \forall \quad i,j \in HOSPITAL\,, \qquad j \neq i \tag{3}$$

$$y_{i,j} + y_{j,i} \leq z_{i,j} * 2 \qquad \forall \quad i,j \in HOSPITAL\,, \qquad j > i \tag{4}$$

$$y_{i,j} \in \{0,1\} \qquad \forall \quad i,j \in HOSPITAL\,, \qquad j \neq i \tag{5}$$

$$z_{i,j} \in \{0,1\} \qquad \forall \quad i,j \in HOSPITAL\,, \qquad j \neq i \tag{6}$$

The model has six constraints; each constraint has a different role in the model. The first constraint (1) determines whether the number of drugs sent from *Hospital i* to *Hospital j* is less than or equal to the exceeded values. The second constraint imposes that the drugs sent from *Hospital i* to *Hospital j* are the exact amount needed without any addition or subtraction. For example, if any hospital needs a certain number of drugs, they cannot order more than the required demand. The third constraint (3) determines that the number of drugs sent from *Hospital i* to *Hospital j* does not exceed the needed demand. For example, if a hospital needs 10 drugs, only 10 will be sent to this Hospital. The fourth constraint (4) ensures that the transportation between two hospitals does not exceed two transactions. For instance, if *Hospital i* needs 5 units of drugs from *Hospital j* it will indeed be sent in one trip. The fifth and sixth constraints (5) (6) identify that variable Y and variable Z as binary variables. This means that each variable has two values, 0 or 1, and each value refers to a different solution.

3. Data

In this study, the number of hospitals and drugs is generated randomly. Thus, the model consists of 10 hospitals and 20 different drugs. The selected hospital's available and needed number of drugs are determined and used in the proposed model. The needed number of drugs by hospitals and exceeded the number of drugs in the hospital's inventory data are given in Table 1 and Table 2, respectively.

Table 2. Exceeded number of drugs in the hospital's inventory

	H-1	**H-2**	**H-3**	**H-4**	**H-5**	**H-6**	**H-7**	**H-8**	**H-9**	**H-10**
Drug-1	0	0	0	6	0	6	2	1	1	0
Drug-2	1	0	2	0	0	0	1	0	0	6
Drug-3	3	1	9	0	0	0	0	0	0	0
Drug-4	4	0	0	0	5	0	0	10	1	5

Drug-5	0	7	3	0	0	2	0	0	0	3
Drug-6	0	0	0	0	4	0	0	0	0	0
Drug-7	1	3	5	3	5	0	2	3	0	4
Drug-8	0	4	0	0	0	3	0	0	0	2
Drug-9	10	0	1	0	0	0	5	0	2	0
Drug-10	0	0	6	2	0	0	0	8	0	0
Drug-11	8	0	0	1	3	0	3	0	2	3
Drug-12	7	0	1	2	7	1	0	3	3	0
Drug-13	0	2	0	0	0	0	0	0	0	8
Drug-14	0	3	9	0	0	0	0	0	0	0
Drug-15	0	0	7	2	0	7	5	1	4	0
Drug-16	0	1	4	0	0	3	1	0	4	0
Drug-17	7	3	3	3	3	5	0	4	0	0
Drug-18	0	0	5	0	1	0	0	2	6	0
Drug-19	0	2	2	0	0	0	3	2	0	0
Drug-20	4	1	4	0	0	0	0	0	0	0

Table 2. Needed number of drugs by hospitals

	H-1	**H-2**	**H-3**	**H-4**	**H-5**	**H-6**	**H-7**	**H-8**	**H-9**	**H-10**
Drug-1	2	2	1	0	5	0	0	0	0	1
Drug-2	0	4	0	4	4	1	0	5	4	0
Drug-3	0	0	0	0	2	7	4	5	1	4
Drug-4	0	4	4	2	0	4	0	0	0	0
Drug-5	0	0	0	4	0	0	0	1	3	0
Drug-6	1	3	1	4	0	0	3	1	0	0
Drug-7	0	0	0	0	0	3	0	0	6	0
Drug-8	1	0	0	0	1	0	4	2	0	0
Drug-9	0	2	0	3	10	5	0	3	0	4
Drug-10	4	7	0	0	8	2	3	0	0	1
Drug-11	0	2	2	0	0	5	0	2	0	0
Drug-12	0	3	0	0	0	0	4	0	0	0
Drug-13	3	0	5	4	7	4	2	8	0	0
Drug-14	2	0	0	0	1	5	1	5	0	4
Drug-15	3	7	0	0	7	0	0	0	0	3
Drug-16	4	0	0	1	7	0	0	3	0	2
Drug-17	0	0	0	0	0	0	4	0	5	1
Drug-18	5	0	0	5	0	3	10	0	0	0
Drug-19	6	0	0	2	5	2	0	0	4	1
Drug-20	0	0	0	7	5	7	0	1	2	3

4. Results and Discussion

In this section, the numerical and graphical results are discussed in detail.

4.1 Analysis Results

Each contributed hospital in the system will have an available inventory and needed inventory data for each drug. So, the model will recognize the difference in the drug's demand and exceed. The results of this study are shown in Table A1 in the appendix.

Table A1 in the appendix part shows the resultant of X values. X values show the number of drugs transported between two hospitals. The X_{ijk} means the number of *Drug k* sent from *Hospital i* to *Hospital j*. For example, *Drug 1* is sent from *Hospital 1* to *Hospital 6* by 2 units., *Drug 11* is sent from *Hospital 2* to *Hospital 4* by 1 unit. The rest of the drugs will follow the strategy shown below in Table A1. Figure 1 also shows the number of drugs transported between hospitals. Therefore, Figure 1 shows only the sent units of drugs between hospitals, other than the transactions shown in Figure 1, which means there is no transaction between these hospitals.

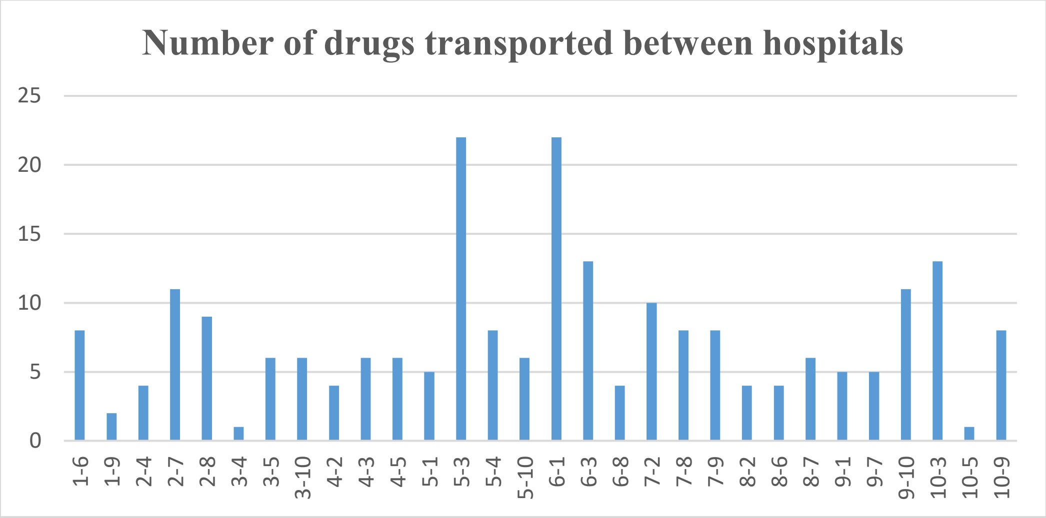

Figure 1. Number of drugs transported between hospitals.

If the demanded number of drugs by any hospital is unavailable in another hospital's inventory, demand cannot be met, so there will be no transaction. Figure 2 shows the number of drug demands of hospitals that could not be supplied.

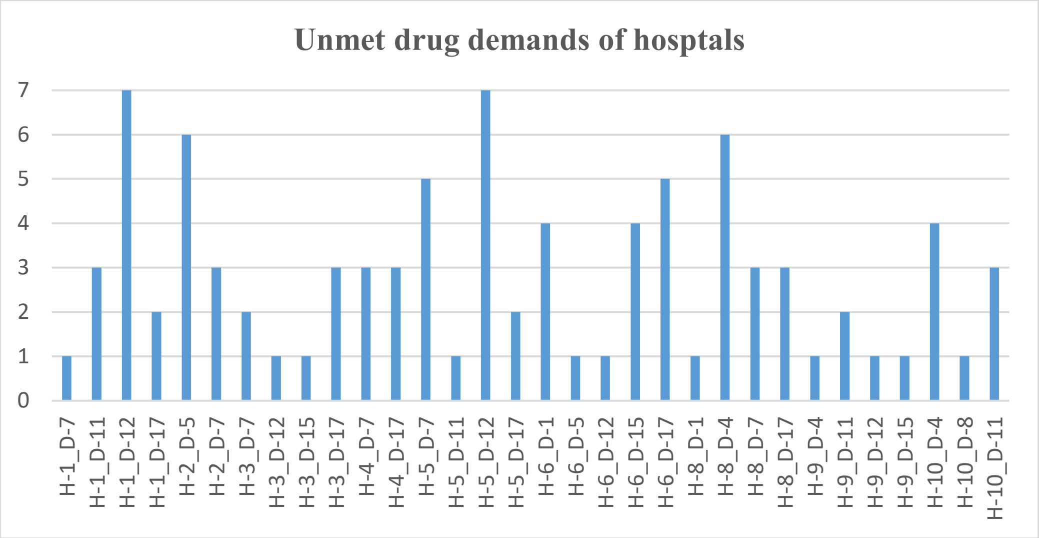

Figure 2. Number of drug demands of hospitals that could not be supplied.

Table 3 below shows the result of Y values. The transportation line between the two hospitals is Y_{ij} with a binary value (0 or 1). For example, if *Hospital i* shares its drugs with another *Hospital j*, Y_{ij} will get a value of 1. Otherwise, if there is no sharing, the value of Y_{ij} will be 0. Table 1 and Figure 3 show that *Hospital 1* shares its drugs with *Hospital 5*.

Furthermore, *Hospital 2* shares its drugs with *Hospital 4*. And the same concept for the rest of the transaction lines. Again, other resultant Y values with zero (not shown in the table) mean no transaction between these hospitals. Figure 2 illustrates the transportation lines between two hospitals.

Table 3. One-way drug transactions between hospitals

Hospital (i)	Hospital (j)	y
1	5	1
1	6	1
1	9	1
2	4	1
2	7	1
2	8	1
3	4	1
3	5	1
3	6	1
3	10	1
4	2	1
4	3	1
4	5	1
5	1	1
5	3	1
5	4	1
5	10	1
6	1	1
6	3	1
6	8	1
7	2	1
7	8	1
7	9	1
8	2	1
8	6	1
8	7	1
9	1	1
9	7	1
9	10	1
10	3	1
10	5	1
10	9	1

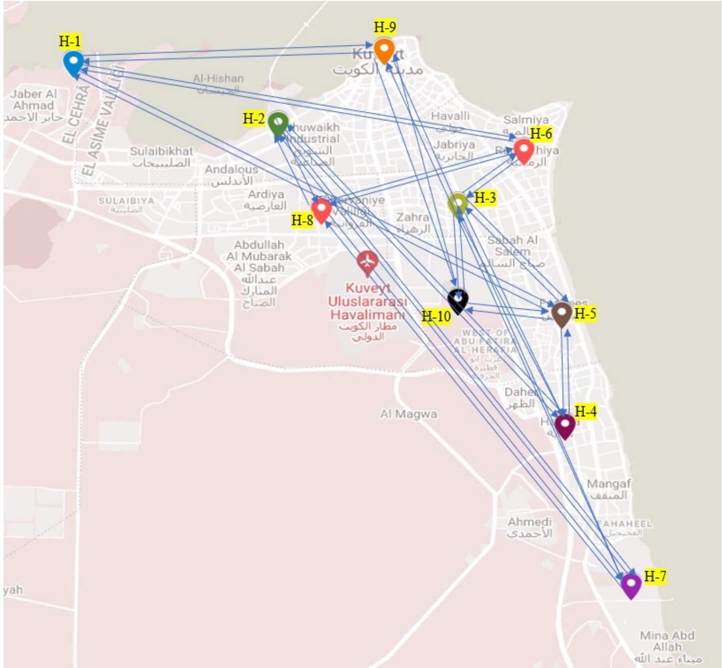

Figure 3. One-way drug transactions between hospitals

Table 4. Two-way drug transactions between hospitals

Hospital (i)	Hospital (j)	z

1	5	1
1	6	1
1	9	1
2	4	1
2	7	1
2	8	1
3	4	1
3	5	1
3	6	1
3	10	1
4	5	1
5	10	1
6	8	1
7	8	1
7	9	1
9	10	1

Table 4 below shows the resultant Z values. The Z_{ij} is also a binary variable that shows a transfer between *Hospital i* and *Hospital j*. However, Z_{ij} guarantees that there will be no more than two transfers between *Hospital i* to *Hospital j*. Therefore, the resultant Z_{ij} values with 1 mean that there is a transaction between these hospitals. For instance, there is a transaction between *Hospital 1* to *Hospital 3*, *Hospital 1* to *Hospital 5*, *Hospital 2* to *Hospital 3*, *Hospital 2* to *Hospital 5*, etc. Other than these results, Z values with zero mean that there is no transaction between these hospitals—the transactions between hospitals with a value of one are shown in Figure 3.

Figure 4. Two-way drug transactions between hospitals

By getting these feasible solutions, the result is that the transaction lines will be decreased. For example, if *Hospital i* need a specific drug unit from *Hospital j*, it will be transferred in one way. This will satisfy the objective function of minimizing the transaction lines between hospitals by making the Z_{ij} value minimized. Also, the service levels in hospitals will increase.

6. Conclusion

This project aims to introduce a management strategy for controlling and handling the inventory of drugs in Kuwait's healthcare facilities in case of drug shortages by proposing an LP model to minimize drug shortages among the healthcare facilities, manage the drug inventory in the hospitals, and control drug shortages in healthcare facilities. Then, an LP mathematical modeling approach was determined to find an optimum transaction of drugs between hospitals to decrease drug shortages.

Thus, a practical solution was found to solve the problem by creating an LP model to make one unified system that involves all the collaborated hospitals' data. The solution to the drugs shortages problem can be applied in real-life situations. For example, the Kuwait health ministry can adopt the project. To help them in solving the drug shortage problems. Trading off this project helps maintain patients' health, organize drug distribution between the hospitals, and have high-quality services. Furthermore, the transportation cost will decrease since the drugs will be transported between the hospitals with a maximum of two lines at one time.

References

Abu Zwaida, T., Pham, C., & Beauregard, Y., Optimization of inventory management to prevent drug shortages in the hospital supply chain. Applied Sciences, 11(6), 2726,2021.

Adkins, C. , Response strategies for critical supply shortages in healthcare: Modeling variations,2012. Retrieved from https://scholarworks.uark.edu/ineguht/8/

Martinich, J. S.(1997). Production and Operations Management: An Applied Modern Approach. Retrieved from https://www.uky.edu/~dsianita/300/online/LP.pdf

Phuong, J. M., Penm, J., Chaar, B., Oldfield, L. D., & Moles, R. , The impacts of medication shortages on patient outcomes: A scoping review. PLOS ONE, 14(5), 2019. https://doi.org/10.1371/journal.pone.0215837

Saedi, S., Kundakcioglu, O. E., & Henry, A. C. , Mitigating the impact of drug shortages for a healthcare facility: An inventory management approach, 251(1), 2016. doi: 10.1016/j.ejor.2015.11.017

Biography

Lujain Al-Ameri, Munera Bokubar, Mariam Salem, Moudi Al-Ali, and Nour Al-Shami are graduate students in industrial engineering from the American University of the Middle East. The university is located in Kuwait. In addition, during their bachelor's in engineering, they got to experience many projects in the industrial engineering field and developed skills in many courses such as Safety, Control Systems, Six Sigma, Manufacturing, Production Management, Operation Research, Economics, Computing, Computer Science, Work Analysis, Quality Control, and Statistics. Moreover, they participated in their projects in the academic fair's activities. Furthermore, they have dealt with many software such as MATLAB, AutoCAD, Lingo, MP-Express, Python, Minitab, Microsoft Project, Arena, and visual studio. Moreover, they worked on their graduation project presented in this research paper, and their goal is to publish it.

Recep Kizilaslan received his Ph.D. in Industrial Engineering from Istanbul Technical University in 2012. He has worked at several universities as an Assist. Professor in Turkey and abroad. He is an Assistant Professor in the Department of Industrial Engineering of the American University of Middle East, Kuwait.
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APPENDIX

Table A.1 Transported number of drugs between hospitals.

HOSPITAL (i)	HOSPITAL (j)	DRUG	X
1	6	1	2
1	6	8	1
1	6	15	3
1	6	16	2
1	9	16	2
2	4	11	1
2	4	12	2
2	4	15	1
2	7	1	2
2	7	2	1
2	7	9	2
2	7	11	1
2	7	15	5
2	8	4	4
2	8	10	3
2	8	12	1
2	8	15	1
3	4	1	1
3	5	4	3
3	5	6	1
3	5	11	2
3	10	4	1
3	10	13	5
4	2	5	1
4	2	19	2
4	2	20	1
4	3	5	3
4	3	16	1
4	3	18	2
4	5	4	2
4	5	6	3
4	5	18	1

5	1	9	5
5	3	2	2
5	3	3	2
5	3	9	1
5	3	10	5
5	3	14	1
5	3	15	6
5	3	16	3
5	3	19	1
5	3	20	1
5	4	1	5
5	4	10	2
5	4	15	1
5	10	2	2
5	10	8	1
5	10	13	3
6	1	2	1
6	1	3	3
6	1	4	4
6	1	9	5
6	1	11	5
6	1	20	4
6	3	3	3
6	3	7	3
6	3	14	4
6	3	18	3
6	8	10	2
6	8	19	2
7	2	8	4
7	2	13	2
7	2	14	1
7	2	17	3
7	8	10	3
7	8	12	2
7	8	17	1
7	8	18	2
7	9	12	2
7	9	18	6
8	2	3	1
8	2	14	2
8	2	16	1
8	6	5	1
8	6	8	2
8	6	16	1
8	7	9	3
8	7	11	2
8	7	16	1
9	1	17	5
9	7	7	2
9	7	19	3
9	10	2	4

9	10	5	3
9	10	7	4
10	3	3	4
10	3	10	1
10	3	14	4
10	3	19	1
10	3	20	3
10	5	17	1
10	9	1	1
10	9	9	2
10	9	15	3
10	9	16	2