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醫材存貨管理最適訂購策略探討

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Optimization of Medical Material Warehouse Management Policy: A Case Study of Taiwan T Hospital

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醫材管理最適策略： 以台中某醫院為例

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摘　　要

由於近年來醫療保健材料價格不斷上漲，庫存管理比以往醫院人員管理更加重要，根據過去的研究，醫院倉庫中總是出現物料短缺問題。本研究以台灣某醫院倉庫為案例研究，試圖降低少數特定材料的短缺率。本研究使用系統模擬，分析應該應用於每種材料的不同訂購策略。我們開發一些仿真模型，其中一個是基於案例研究醫院的實際情況進行驗證，其他的通過應用不同的訂購策略來開發。最後，將試誤法和最佳化技術應用於這些模型，並找出所選的物料最適合之訂購策略。然後將向案例研究醫院倉庫提供建議

關鍵字詞：物料短缺、醫院倉庫、案例研究、訂購策略、系統模擬

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ABSTRACT

Since the healthcare material price has been increasing in recent years, the inventory management is much more important than before for hospital manager, and according to the past research, shortage problems are always happening in hospital warehouse. This research takes a hospital warehouse in Taiwan as a case study, trying to reduce the shortage rate of a few specific materials. The simulation approach is used in this research, and we focus on the ordering policy that should be applied for each material. We develop several simulation models, one of them is based on real situation in the case study hospital for validation purpose, and the others are developed by applying different ordering policies. Finally, trial and error technique and optimization technique are applied to these models in order to determine the best setting values of all decision variables. Suggestion is then provided to the case study hospital warehouse.

Keywords：Shortage, Hospital Warehouse, Case Study, Ordering Policy, Simulation

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Chapter 1 Introduction

1.1 Background

The implementation of universal health insurance in the Republic of China in 1984 not only provided a more convenient medical environment for the people, but also expanded the medical system in Taiwan. In this environment, the competition of hospitals is becoming increasingly fierce (Wang et al., 2005). Hospitals must face the reduction of operating costs, the improvement of medical service quality and service efficiency, and the pressure of compression of profit margins. For effective management, hospital administrators must systematically assess their core competencies, structure appropriate business strategies, and reinterpret hospital values and competitiveness. As a result, how to adopt appropriate management and control systems to improve operational efficiency has become a critical issue (Bill Binglong, et al., 1999).

In recent years, the healthcare industry has faced increasing prices of materials, which has increased the pressure on inventory management unit. Furthermore, the management of inventory is an important factor in ensuring the quality and safety of medical care, and it is also the key to whether the hospital can operate normally (Hu Zhi, 2002). Also, Jeffrey et al. (2015) shows that how hospital supply chain operation would affect the performance of warehouse. Therefore, managers must find an appropriate healthcare supply chain management approach to enhance the operational efficiency of hospitals.

The research of hospital inventory and logistics problems has been proposed for years. A supply chain model of drug logistics in hospital was proposed by Baffo & Kaihara (2016). In order to optimize the inventory cost of hospital drug logistics, the various levels of the supply chain are integrated and a mathematical model is built. Lapierre and Ruiz (2007) try to deal with the logistic activity in hospital supply system, they used Tabu search to solve two OR models that are minimizing inventory cost and balancing delivery schedules, respectively. Danas et al. (2002) suggested a solution that based on just-in-time concept, try to improve the logistics activities of hospital

Some of the researchers, have conducted a case study in order to verify their methodology practically. Potter et al. (2009) evaluate the inventory management performance in the private healthcare sector in Malaysia, and find that the vendor managed inventory (VMI) would be the best solution for them. Wu et al. (2015)

compares two different kinds of supply modes in the hospital in China. In this research, the possibility of applying the inventory pool theory to the supply chain in hospital is discussed. As a result, inventory pools will be an effective way to improve the performance of supply chain and procurement in this hospital. Kumar et al. (2008) aims to investigate cost reduction in logistics and supply chain management of medical supplies in healthcare industry of Singapore. This research redesigns a supply chain conceptual model and this reengineering model provides a more efficient solution with fewer staff, and reducing about 60% of the cost.

The study presented in this thesis will use the warehouse of a hospital in Taiwan as a case study. The next section will describe the problem of the hospital warehouse.

1.2 Statement of the problems

According to Lee (2006), the average shortage rate in Taiwan hospital for the past few years is about 3%. After visiting the case study hospital, we notice that it has some specific materials in the warehouse that have a more serious shortage problem than Taiwan average are, and it will affect the hospital unit's operation a lot.

According to the staff in warehouse, there are two types of order from each unit, normal order and abnormal order, normal order is the regular need of each unit in a week, and will be delivered by warehouse staff every week. The abnormal order will happen in case that resource from normal type is not enough, caused by the patients are more than usual or show up some rare condition patient that need specific materials. As a result, if there have the same abnormal needs from several different units at the same time, or if some mistakes of inventory control occur, then shortage problem will probably happen.

In addition, cost is the major matter for every industry even in hospital in which reduction of the cost is able to improve the social and economic benefits of it (Zhang et al., 2003), and every decision made without considering cost is unpractical.

Therefore, this research intends to use simulation approach to improve the shortage problem, and try to reduce or control the cost factor to make the decision reasonable, giving hospital warehouse a better inventory strategy.

1.3 Objectives of the Research

This research aims to propose an inventory strategy for a case study hospital to deal with the medical material shortage problem. So, this research tries to achieve optimization of two functions to reach this objective, the first is to minimize the shortage rate, and the second is to minimize the cost.

To develop an inventory strategy, we consider to determine an ordering policy first because it is highly related to stock out problem. As Jonas et al. (2017) mentioned, generally there have two kinds of policy which is periodic review, e.g., (T, S) and continuous review, e.g., (s, Q), (s, S). After that, the simulation model that is based on practical situations of the hospital warehouse operation process will be developed to analyze our objective functions. We input the real data and compare the output with hospital situations for having a verification of the model. Finally, the optimization function in simulation software determine the best values of decision variables.

1.4 Scope

- There have thousand kinds of inventory in the case study warehouse. Due to time limitation, We will consider only the inventories that face serious shortage problem for the study
- Research only got the data from hospital for 6 months, maybe can't reflect the seasonal factor and show the real distribution of demand.
- The simulation software that this research use is not for hospital only.
- This research will consider the shortage rate that combine both normal order and abnormal order into consideration.
- Input data (normal and abnormal orders) is transformed to statistic distribution forms.
- The research approach only fit to the case study hospital or the facilities that have similar situations.

Chapter 2 Literature Review

This study aims to give an inventory strategy recommendation for hospital warehouse by the approach that combine ordering policy with simulation model, Therefore, this chapter focus on the related literature review about ordering policy and simulation. Moreover, there are a lot of research using mathematical optimization approach, so we also have a literature review of this field because it has lot of importance knowledge and will help our research a lot.

2.1 Ordering policy

2.1.1 Definition of ordering policy

Chen et al. (2017) summarize the ordering policy knowledge, the ordering policy has two types: regular ordering and quantitative ordering. Regular ordering policy is also known as periodic review policy, and the quantitative ordering policy is known as continuous review policy.

Periodic review policy normally in the form of (t, S), using time to decide the reorder point. This kind of policy will need larger safety stock amount and order quantity, but variety of items can be ordered together and maybe receive some discount, also, transportation of multiple items together become large-scale transportation and it can reduce transportation costs.

Continuous review policy normally in the form of (R, Q) and (s, S), using quantity to decide the reorder point. This kind of policy will lead to shortened order cycle, and need to spend more time to monitor the inventory level, but can control inventory more accurately

2.1.2 Ordering policy application in the healthcare industry

Bijvank and vis (2012) compared the performance of fixed order quantity replenishment policy with (R, s, S), and found that fixed order quantity is able manager to have more insight of replenishment process, (R, s, S) policy will be better to apply in case the inventory levels are monitored automatically. Dellaert and van de Poel (1996) develop (R, s, c, S) policy that can easily apply to hospital warehouse. However, Uthayakumar and Priyan (2013) had an argument that periodic inventory review policy is not suitable to hospital due to the demand uncertainty problem. Saedi et al. (2016) use (Q, r) policy combined with stochastic model to manage the inventory of healthcare facility. Kelle et al. (2012) developed few types of (s, S) model in corporate with different constraint to deal with Pharmaceutical supply chain problems. As a conclusion, using which kinds of policy with which approach is depends on what is more suit to the problems and situations.

2.2 Mathematical optimization

Saedi et al. (2016) developed a continuous time Markov chain model to help minimizing the total cost of healthcare facility and also minimize the impact of drug shortage in the situation of uncertain disruptions and demand. Baboli et al. (2011) presented a model that not to find optimal solution, but tend to compare the total cost within two types of replenishment case base on heuristic methods. Lawrence et al. (2004) develop two optimization model to compare three-echelon distribution network with two-echelon distribution network, and find that outsourcing the non-critical medical can not only save the cost but also not to affect service level. Guerrero et al. (2013) use heuristic model based on Markov decision process to minimize the stock on hand of the system, and according to the practical situation of research hospital, the stock on hand will reduce about 45%. And a Fuzzy model be applied to minimize total cost, and deal with the significant uncertainty (Priyan and Uthayakumar, 2014), as a result the cost is reduced a lot as a whole, but may cause some disadvantages at some part. Kelle et al. (2012) develop three models with different constraints to searching the best solution of three various objective function, and the result show that 70% to 80% of medicine expenditure can be reduced.

2.3 Simulation

2.3.1 Definition of simulation

System is a group of individuals who are related or interacted with each other and operate according to certain rules, and it can perform the work that individual components cannot. Wu (2011) mention that simulations can provide the information needed for managers to make decisions. The main functions are as follows: (1) evaluation (2) prediction (3) comparison (4) sensitivity analysis (5) bottleneck analysis (6) optimization

The objective of using simulation is to create a model that is close to the real situation, and make some improvements and adjustments in this model in order to solve the practical problems. Law and Kelton (1991) pointed out that the simulation is to imitate the real worlds operating system. In order to conform to the real implementation situation, there is a standard system simulation construction sequence (Fig. 2.1), which is: problem definition, develop the model, collect the data, input the model, confirm the model, and the results analysis.

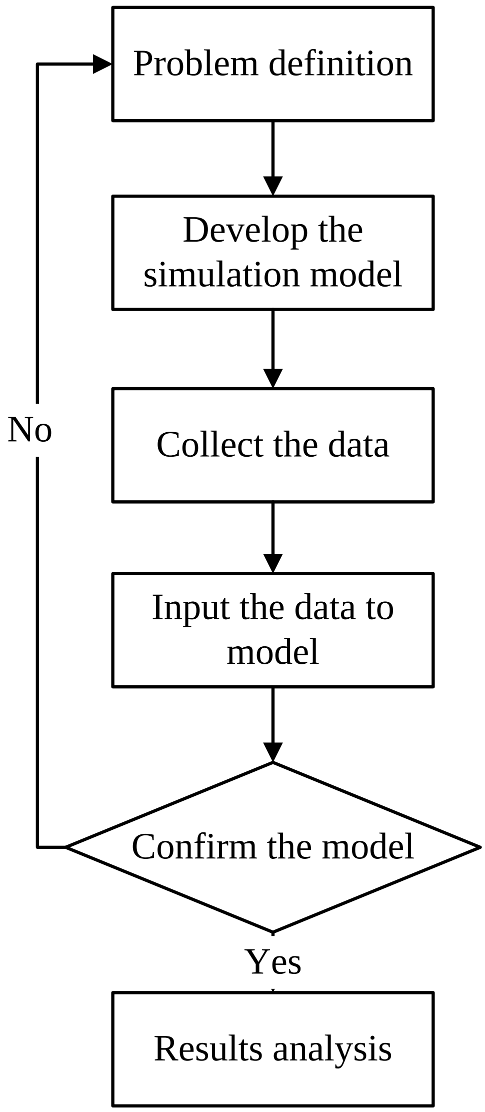

Figure 2. 1 System simulation construction flowchart

2.3.2 System simulation application in the supply chain

Jack (2005)'s research shows that discrete dynamic system simulation is an important method for supply chain management. A discrete event simulation model was proposed by Zhou & De Souza (2016) to improve supply chain performance. Start by collecting data, building simulation models, generating scenarios, running simulations, comparing results, and making recommendations, the indicators they use are service level, delivery period and utilization. Zhao et al. (2010) base on three different types of indicators, established a multi-objective fuzzy decision model. Which makes it easy for supply chain managers to assess system performance. Lin et al. (2008) studied key factors affecting the retail supply chain and analyze policies that result in out-of-stock or loss, and simulate current supply processes and comparisons after RFID (Radio Frequency

Identification).

2.3.3 System simulation application in the healthcare industry

Recently, more and more healthcare organizations using supply chain management to reducing the cost, in this case, they can't use trial and error approach because it is related to human's life, therefore, simulation and modeling become an alternative approach for supply chain managers in healthcare organizations (Eman AbuKhousa et al. 2014). According to the research by Naseer et al (2008), there are diverse simulation technique now, and each technique suit to different kinds of applications to healthcare, for instance the potential application of Contact Dynamic Simulation is modelling the robotic surgeries, Discrete-Event Simulation is using for analyze and designing clinical pathways, clinical workflow management. Ahmed and Alkhamis (2009) Use system simulation and optimization to determine the optimal number of physicians, technicians, and nurses to increase patients and reduce patients waiting time. Zhecheng Zhu et al. (2012) used simulation to assist healthcare providers in estimating the correct amount of ICU beds.

Chapter 3 Methodology

3.1 Overview

The following flowchart presents the method that would be followed in order to achieve the research objectives. First, we will conduct a literature review to understand past research results. Then sort out the actual data obtained from the hospital and decide the type of ordering strategy to be tested. The next step is to build a system simulation model and define the internal parameters, then have a verification and validate to the model in order to confirm that the model is feat to the real situation. Finally perform system optimization to find the most appropriate value for the decision variable

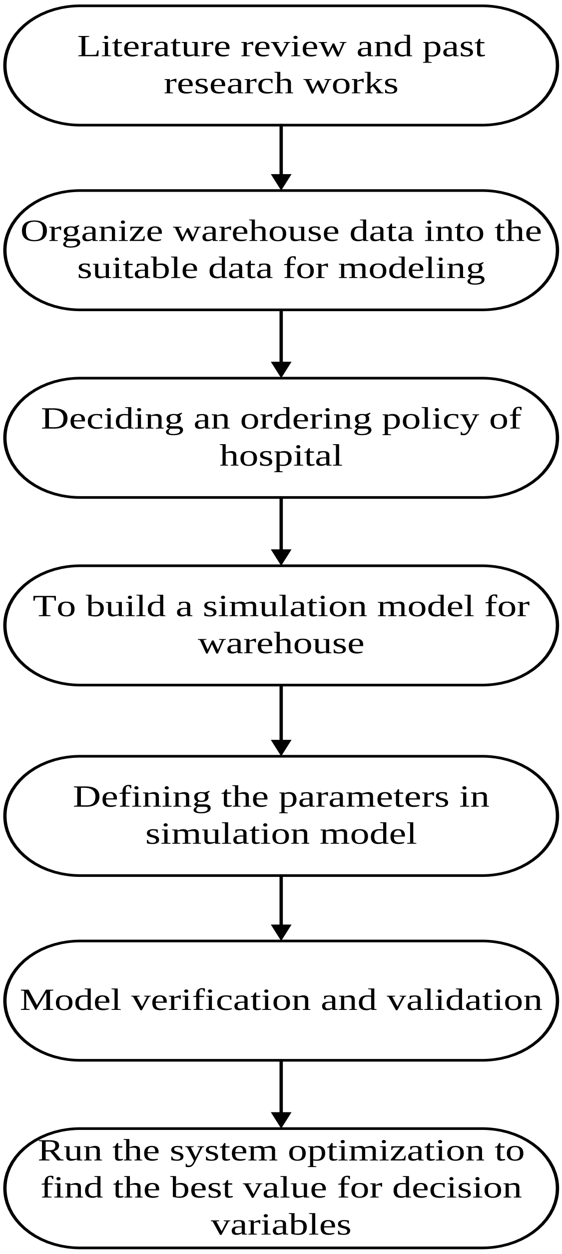

Figure 3. 1 Research framework

3.2 Introduction to the research object

This study is mainly based on a medical center in Taiwan, with more than one hundred in-hospital units. Among them, warehouse is the objective of this research. The working contents in the warehouse are management and accept, check, store, distribute, and inventory various types of equipment and items. The following Figure 3.2 shows the operation flow chart of the case study warehouse.

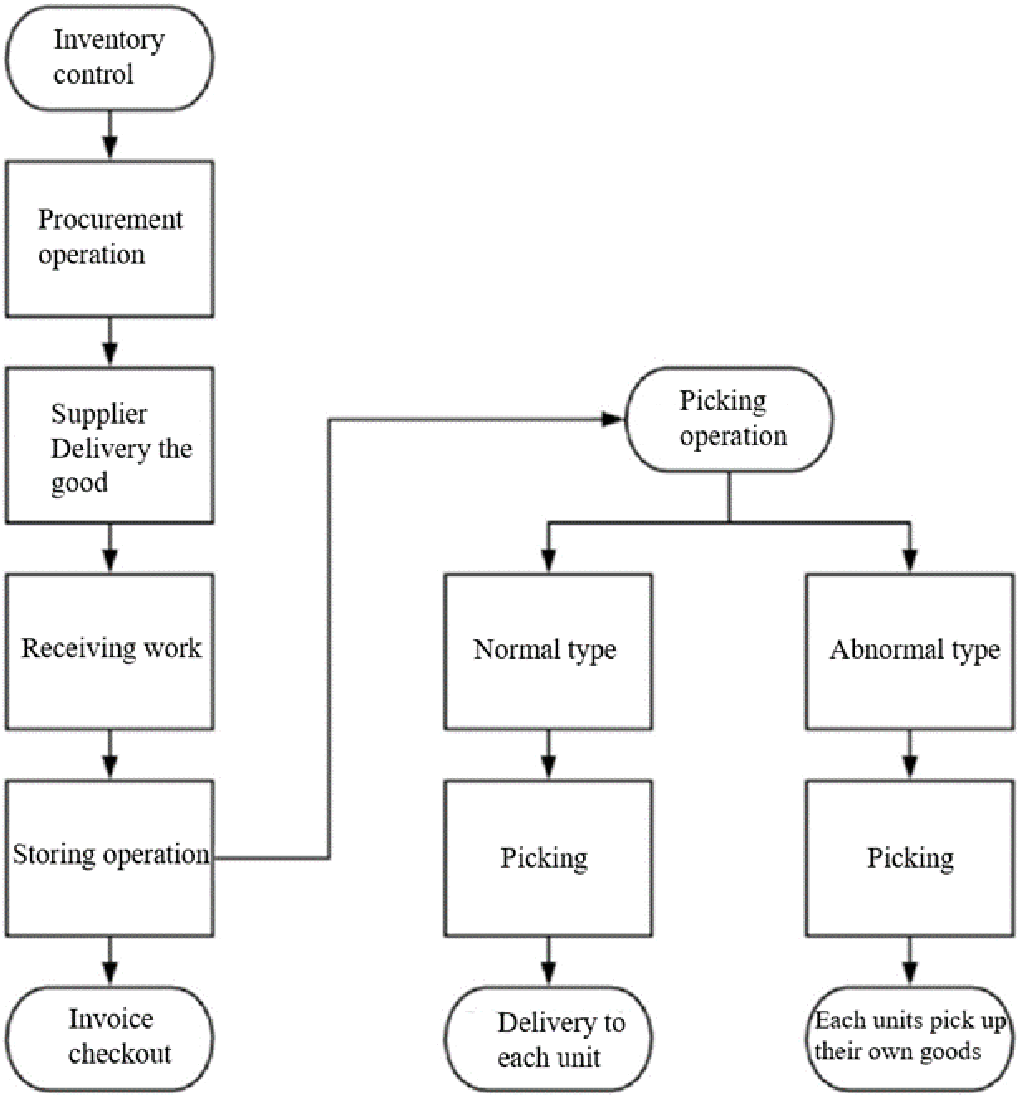

Figure 3. 2 Operation flow of warehouse

3.3 Ordering policy

The hospital uses both periodic review and continuous review ordering policies now, but using periodic review the most. Our research will apply two continuous review ordering policy which are (s, S) and (R, Q) policy, and compare to the periodic review ordering policy (T, S) and (T, s, S) that hospital normally use, because based on past research, continuous review ordering policy is more fit to the situation that has high uncertainty. The parameters used in the initial model will be the same as the case study hospital warehouse current setting, and after selecting the better policy for the case study hospital warehouse, these parameters will become decision variables and optimal values of these decision variable will be address.

- (T, S) policy: Review time (T) and the maximum inventory (S) will be set in the simulation model. Review time (T) will be set to one week, which is the real review time in the case study hospital, order quantity will be the difference of maximum inventory(S) and the inventory quantity at the time of review.
- (T, s, S) policy: Review time (T), reorder point (s) and the maximum inventory (S) will be set in the simulation model. If inventory is higher than reorder point while reviewing, then do nothing, if inventory is lower than reorder point while reviewing, then will do the replenish action.
- (s, S) policy: Reorder point (s) and maximum inventory (S) will be set in the simulation model. Order quantity will be the difference between maximum inventory and reorder point.
- (R, Q) policy: Reorder point (R) and order quantity (Q) will be set in the simulation model. Both these parameters have fixed values.

3.4 Input data interpretation

3.4.1 Selected material

According to the problem statement, the materials that have long term shortage situation, or the average shortage rate is higher than standard will be chosen to be the examined items. Following are the materials that this research will study and, Table 3.1, Table 3.2 show information about shortage rate of each material.

- Nitrile medical exam glove (GLOVE)
- Pre-filled syringe (SYRINGE)
- Glucose tube (TUBE)
- Ice bath clamp bag (BAG)

Table 3. 1 Shortage rate of each material

Material \ Month	Order types	May	June	July	August	September	October	Average
Nitrile medical exam glove	Normal order	8%	7%	1%	2%	2%	3%	4%
	Abnormal order	0%	5%	0%	0%	7%	4%	3%
Pre-filled syringe	Normal order	1%	4%	1%	1%	0%	1%	1%
	Abnormal order	4%	37%	3%	1%	3%	3%	9%
Ice bath clamp bag	Normal order	25%	18%	18%	25%	34%	29%	25%
	Abnormal order	0%	0%	0%	0%	0%	0%	0%
Glucose tube	Normal order	8%	4%	17%	5%	4%	10%	8%
	Abnormal order	0%	0%	1%	0%	14%	0%	3%

Table 3. 2 Total average shortage rate of six months

Material	Six months average
Nitrile medical exam glove	2.9%
Pre-filled syringe	3.44%
Ice bath clamp bag	21.1%
Glucose tube	6.4%

3.4.2 Distribution selection

This research gets the normal and abnormal demand data from the case study hospital for six months, from May to October, 2018. In order to convert the raw data into a suitable form to input to the model, we converted the raw data to distribution form. The software EasyFit is using to get a distribution, and the domain will be discrete distribution. Each material’s data will have two parts to convert, first is arrival time and second is the amount per order.

The arrival time of GOLVE normal order has three types of distribution fitted (Table 3.3), as the result the D. Uniform distribution is the best fitted distribution, but due to simulation software can’t apply this kind of distribution, we will apply Geometric distribution which is the second fitted distribution in the simulation model.

Table 3. 3 GLOVE normal order arrival time distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.48687	1	602.47	1
2	Geometric	0.90961	2	4187.5	2
3	Poisson	0.92832	3	N/A	
4	Bernoulli	No fit (data max > 1)			
5	Binomial	No fit			
6	Hypergeometric	No fit			
7	Logarithmic	No fit (data min < 1)			
8	Neg. Binomial	No fit			

Appendix 1 is the distribution convert information of the remaining material's arrival time and amount per order, and due to the same consideration above, all distributions will be Geometric distribution.

3.5 Simulation model

3.5.1 Simulation software

Simul8 2009 professional version is the system simulation software for discrete event simulation. It can create a visual model for real systems and can import parameters that match real-world conditions. It can even use Visual Logic to create logic to express special behaviors that are more consistent with reality. Therefore, this study uses Simul8 to construct a hospital warehousing inventory model, import demand orders, and use the ordering policy to get initial results, and then use the system optimization function to find the best solution.

3.5.2 Simulation model development

We developed simulation models that based on operation flow of warehouse in Figure 3.2, and Figure 3.3 is the model of warehouse. It mainly simulates the four selected materials. The models that this research built are (T, S) policy model, (s, S) policy model and (R, Q) policy model, they all looked the same from surface but have different parameters and logic settings

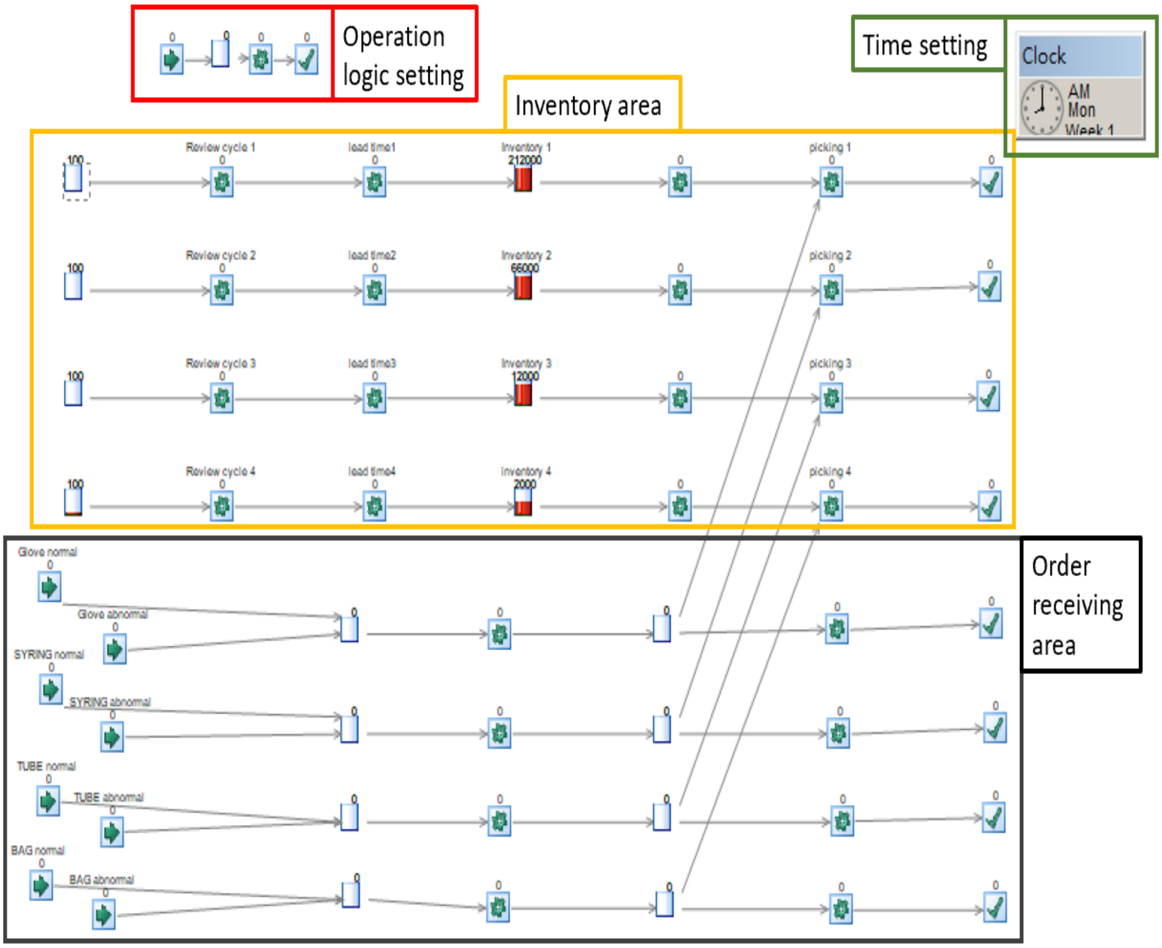

Figure 3. 3 Inventory model of major materials

3.5.3 Simulation model interpretation

The research model is built for simulating the demand and supply operation flow of four selected materials, so the model's appearance is not the layout of hospital warehouse. Due to ordering policy of the materials that this research selected are all belong to (T, S) policy, we develop (T, S) policy model to simulate the real situation first, then develop (s, S) policy model and (R, Q) policy model based on the original model. Following are the interpretation of each part of the simulation model.

The Inventory area is the part that simulate inventory status and picking operation, the parameters that relate to inventory will be set in this part, for instance lead time, order quantity, maximum inventory, etc. The Order receiving area is used for simulate the materials demand situation of the hospital, the arrival time and the amounts of order are converted to the distribution form by statistical software EasyFit, Table 3.4 and Table 3.5 show the distributions that are inputs to the model. The Operation logic setting part is the part that inputs the programming command, and is able to simulate every review type environment (periodic or continuous). The Time setting part is using for manage the time parameters, the time unit in this model is minutes, and there are seven days per week. Duration of a day is eight hours and the total simulation time is 184 days which is six months.

Table 3. 4 Materials order arrival time distribution

Material type	Normal order arrival time distribution	Abnormal order arrival time distribution
Nitrile medical exam glove	Geometric (0.0187)	Geometric (0.00663)
Pre-filled syringe	Geometric (0.01268)	Geometric (0.00313)
Glucose tube	Geometric (0.00452)	Geometric (7.1344E4)
Ice bath clamp bag	Geometric (0.00308)	Geometric (2.7956E4)

Table 3. 5 Materials ordering quantity distribution

Material type	Normal order ordering quantity distribution	Abnormal order ordering quantity distribution
Nitrile medical exam glove	Geometric (8.1551E4)	Geometric (8.1724E4)
Pre-filled syringe	Geometric (0.00153)	Geometric (0.00213)
Glucose tube	Geometric (0.00354)	Geometric (0.00116)
Ice bath clamp bag	Geometric (0.0064)	Geometric (0.00475)

3.6 Simulation model verification and validation

In order to make sure that the case study model is conform to real situation, we conduct a hypothesis testing for both the input data and the result.

3.6.1 Input data

In order to have a hypothesis testing. first, we assume that μ is the input data of simulation model, and μ_0 is the real data in case study hospital, then:

Null hypothesis H_0: $\mu = \mu_0$

Alternative hypothesis H_1: $\mu \neq \mu_0$

Next, we decide to apply T test to test our hypothesis, the t value and the range will be:

$$t = \frac{\overline{\chi} - \mu_0}{s/n}, \quad -t\alpha/_2, n-1 < t < t\alpha/_2, n-1$$

Set the significant level α = 0.05, and n =30, then the range of t value will be:

$$-1.6991 < t < 1.6991$$

If t value is in the range then H_0 is true, and if t value is outside the range then we will reject H_0, accept H_1. The result of t test will be arranged as in Table 3.6. According to the result, all simulation input data are match with the real data.

Table 3. 6 T test result of input data

Material	Average ($\bar{\chi}$)	Standard deviation (s)	T value	Result
Nitrile medical exam glove	2780791	85972.96	0.457499	Not significant
Pre-filled syringe	865332	36569.17	0.427779	Not significant
Glucose tube	163421	9870.358	-1.36817	Not significant
Ice bath clamp bag	47661	4193.326	1.321154	Not significant

3.6.2 Simulation result

The result of the simulation is shortage rate. In order to test if the shortage rate resulting from the simulation model is matched with the real shortage rate or not, we will also use hypothesis testing to confirm that. In this case, μ will be the shortage rate of simulation model, and μ_0 will be the shortage rate of real situation. T test is also be used for testing hypothesis, significant level α = 0.05, and n =30, the result of T test will be arranged as in Table 3.7. According to the result, all simulation shortage rates are matched with the real shortage rate.

Table 3. 7 T test result of shortage rate

Material	Average ($\bar{\chi}$)	Standard deviation (s)	T value	Result
Nitrile medical exam glove	0.028881	0.015388	-0.18482	Not significant
Pre-filled syringe	0.035579	0.015671	0.412144	Not significant
Glucose tube	0.072467	0.028097	1.533557	Not significant
Ice bath clamp bag	0.224996	0.053277	1.438846	Not significant

Chapter 4 Results and Discussions

The materials that this research selected from the case study hospital warehouse are all using (T, S) ordering policy in the real situation. In order to find a better ordering policy to reduce shortage problem, we will compare (s, S) ordering policy and (R, Q) ordering policy with the policy that the warehouse currently use for every single material that were selected. since each material may have different suitable ordering policy. The (T, s, S) ordering policy is not be considered in this part, because based on the features of it and the past research, the shortage rate of (T, s, S) ordering policy will normally higher then (T, S) ordering policy, and it is normally used for low service level materials. So, we will skip this ordering policy in this research.

4.1 Optimization implementation

The optimization function in SIMUL8 will be used in this stage. In this stage, this research is trying to derive a better inventory policy for each material. The core concept of the research is to find a solution that is realistic and can be achieved for the case study hospital. Therefore, we will not have a conclusion that the best outcome from simulation-optimization program is the optimal solution for the case study hospital, since there has cost consideration. Instead, we will provide a few solutions and recommend the one we prefer, but the case study hospital warehouse can select the appropriate solution that they can afford. For each material, we will try to find which policy is more suitable through comparing (T, S) ordering policy, (s, S) ordering policy or (R, Q) ordering policy.

The objective is to minimize the shortage rate, for each ordering policy model considering two decision variables. We will consider decision variables in a range of values during optimization process to find the best value of decision variables. However, not every decision variable can be found in optimization process since we need to consider some practical issues. What problem are we considering and how to overcome it is presented in the following paragraphs.

In the case of (T, S) ordering policy, decision variables are review cycle and maximum inventory. Review cycle is considered in optimization process and the setting range is from one day to seven days. Lower bound is set to one day because the time unit of review cycle will be a day normally. For the upper bound, we consider that the maximum inventory in current situation is about two weeks demand, and lead time is one week, so the longest review time must not exceed one week, otherwise, shortage may happen. It is noted that maximum inventory will not be considered together with review cycle in optimization process. There have two reasons. First reason is that it is a parameter that the higher the better for optimization objective, so if we make it to be a decision variable in optimization process, the outcome of it will always be the upper bound. Then why can't we just accept the outcome in this case, for example, if the range of it is from 1000 to 10000, then outcome will tell that 10000 is the best, which means shortage rate is zero, but maybe the shortage rate is already become zero when it is 4000. Furthermore, why can't we say that 4000 is the best in this case? The following is the explanation and also the second reason of why we can't use maximum inventory to be the decision variable during optimization process. Our research tries to provide a practical solution for the case study hospital in which we tend to reduce the shortage rate of these materials but not through the method that will make a lot of change on the current practice of the hospital. So, we will derive a few solutions to let the hospital select. In this case, the maximum inventory level will not be considered as a decision variable, but it's value will be determined using trial and error procedure. For a fixed value of maximum inventory, the cycle time T will be determined by simulation and the shortage rate can be derived. If the shortage rate is still high, the maximum inventory will be increased by an amount equals to one day demand. This process will continue until the resulting shortage rate is acceptable.

In the case of (s, S) ordering policy, decision variable will be reorder point and maximum inventory, the maximum inventory will be dealt with in a similar way as in (T, S) ordering policy, and the reorder point will be the decision variable for optimization.

In the case of (R, Q) ordering policy, the situation of this ordering policy is different from the other two. This ordering policy will not use optimization to find the result since both of decision variables are not suitable for optimization consideration. It is noted that the shortage rate of (R, Q) ordering policy is dependent on reorder point, because it is used to cover the demand during lead time, if reorder point is not high enough then shortage will occur. Therefore, we will fix the order quantity value and try to find an appropriate reorder point. We fix the order quantity as average demand during one week as in the current practice, after that we use trial and error to find reorder point. The starting value of reorder point is one week demand, if the shortage rate is still high, reorder point will be increase by an amount equals to one day demand. This process will continue until the resulting shortage rate is acceptable.

4.1.1 Nitrile medical exam glove

The initial setting of Nitrile medical exam glove for each ordering policy is from the current practice and presented in Table 4.1. First, we already know the value of maximum inventory and review cycle since it is using (T, S) ordering policy now. After that, we can calculate the value of maximum inventory, reorder point and ordering quantity when it is using (s, S) and (R, Q) ordering policy. Next, we use the simulation model to simulate the average shortage and inventory holding time of each. Then we can see that the differences between the policies are not significant, so we will investigate all three ordering policies to find out which one is more suitable in this case.

Table 4. 1 Initial setting of Nitrile medical exam glove

Ordering policy	Maximum inventory (PC)	Review cycle (Days)	Reorder point (PC)	Ordering quantity (PC)	Average shortage rate	Inventory holding time (Days)
(T, S)	212000	7			2.8%	3.53
(s, S)	212000		106000		4.3%	3.68
(R, Q)			106000	106000	4%	3.9

The solutions of (T, S) ordering policy, (s, S) ordering policy and (R, Q) ordering policy for Nitrile medical exam glove are presented in Table 4.2. We will compare the inventory holding time of different ordering policy under the same average shortage rate. According to the results, the efficiency of (R, Q) ordering policy is worse than the other ordering policies, so we will select between (T, S) ordering policy and (s, S) ordering policy. After the comparison, we found that inventory holding times of both ordering policies are almost the same, and the order frequency of (T, S) ordering policy's solutions are about seven days which are also same as the order frequency of (s, S) ordering policy's solutions, since the material consumption per day is about 15000. Therefore, we suggest the solution 2 for Nitrile medical exam glove, since the inventory holding cost and order frequency is almost the same as in current situation, only the maximum inventory is higher than before.

Table 4. 2 Experiment results of Nitrile medical exam glove

Ordering policy	Solution number (PC)	Maximum inventory (PC)	Review cycle (Days)	Reorder point (PC)	Ordering quantity (PC)	Average shortage rate	Inventory holding time (Days)
(T, S)	1	217000	6			2%	3.96
(T, S)	2	222000	6			1%	4.27

Ordering policy	Solution number (PC)	Maximum inventory (PC)	Review cycle (Days)	Reorder point (PC)	Ordering quantity (PC)	Average shortage rate	Inventory holding time (Days)
(s, S)	3	217000		108000		2%	3.85
(s, S)	4	227000		109000		1%	4.13
(R, Q)	5			111000	106000	3%	3.79
(R, Q)	6			116000	106000	1%	5.25

4.1.2 Pre-filled syringe

The initial setting of Pre-filled syringe for each ordering policy model is from the current practice and presented in Table 4.3. According to the results, the shortage rate of (R, Q) ordering policy is much higher than the others and inventory holding time is also the highest. Therefore, we will consider (T, S) ordering policy and (s, S) ordering policy only for this material.

Table 4. 3 Initial setting of Pre- filled syringe

Ordering policy	Maximum inventory (SET)	Review cycle (Days)	Reorder point (SET)	Ordering quantity (SET)	Average shortage rate	Inventory holding time (Days)
(T, S)	66000	5			3%	3.34
(s, S)	66000		33000		3%	3.68
(R, Q)			33000	33000	6%	3.9

The results of (T, S) ordering policy and (s, S) ordering policy are presented in Table 4.4. Based on the results, we suggest solution 4 for material Pre-filled syringe, since the inventory holding time only increase for no more than one day but average shortage rate is reduced to 1%. Furthermore, the order frequency of (T, S) ordering policy is four days and (s, S) ordering policy is about ten days, so we will not select (T, S) ordering policy's solution.

Table 4. 4 Experiment results of Pre-filled syringe

Ordering policy	Solution number (SET)	Maximum inventory (SET)	Review cycle (Days)	Reorder point (SET)	Average shortage rate	Inventory holding time (Days)
(T, S)	1	70000	4		2%	4.22
(T, S)	2	72000	4		1%	4.58
(s, S)	3	69000		36000	2%	3.95
(s, S)	4	72000		38000	1%	4.52

4.1.3 Glucose tube

The initial setting of Glucose tube in each ordering policy model is from the current practice and presented in Table 4.5, According to the results, (T, S) ordering policy has the shortest shortage rate, and although (s, S) ordering policy has the higher shortage rate, inventory holding time is much shorter than the others. Therefore, we will consider (T, S) ordering policy and (s, S) ordering policy only.

Table 4. 5 Initial setting of Glucose tube

Ordering policy	Maximum inventory (EA)	Review cycle (Days)	Reorder point (EA)	Ordering quantity (EA)	Average shortage rate	Inventory holding time (Days)
(T, S)	13000	5			7%	5.41
(s, S)	13000		7000		10%	2.05
(R, Q)			7000	7000	11%	4.93

The results of (T, S) ordering policy and (s, S) ordering policy for Glucose tube are presented in Table 4.6. Based on the results, solution 1 and solution 2 need to have an order for every two days, and the holding time is about two more days in comparison to the current situation. The order frequency of solution 3 and solution 4 is about seven to ten days since the material needed per day is 1000, also, the inventory holding time is less than solution 1 and solution 2. Therefore, we suggest solution 4 if the case study hospital warehouse can afford additional holding cost.

Table 4. 6 Experiment results of Glucose tube

Ordering policy	Solution number (EA)	Maximum inventory (EA)	Review cycle (Days)	Reorder point (EA)	Average shortage rate (EA)	Inventory holding time (Days)
(T, S)	1	15000	2		3%	6.41
(T, S)	2	17000	2		1%	8.37
(s, S)	3	17000		9250	3%	6.4
(s, S)	4	20000		9470	1%	7.58

4.1.4 Ice bath clamp bag

The initial setting of Ice bath clamp bag for each ordering policy model is from the current practice and presented in Table 4.7. We will compare all ordering policies since the shortage rate of all of them is very high, and it is hard to tell which one is really better.

Table 4. 7 Initial setting of Ice bath clamp bag

Ordering policy	Maximum inventory	Review cycle (Days)	Reorder point	Ordering quantity	Average shortage rate	Inventory holding time (Days)
(T, S)	3000	7			22%	3.66
(s, S)	3000		1500		20%	3.5
(R, Q)			1500	1500	26%	3.43

The solutions of (T, S) ordering policy, (s, S) ordering policy and (R, Q) ordering policy for Ice bath clamp bag are presented in Table 4.8. According to the results, it is obvious that (R, Q) ordering policy is not good as compared to the others because the holding time is too long. We can also observe that the inventory holding time of (s, S) ordering policy's solutions are all lower than (T, S) ordering policy's solutions, and (T, S) ordering policy's solutions suggest a very short reorder cycle. Therefore, we suggest to apply solution 4 for Ice bath clamp bag since it reduces the shortage rate for 19% but only increase the inventory holding time for about four days, and the reorder cycle is more acceptable. However, if the case study hospital can afford more inventory holding cost, then solution 6 will be the best solution.

Table 4. 8 Experiment results of Ice bath clamp bag

Ordering policy	Solution number	Maximum inventory	Review cycle (Days)	Reorder point	Ordering quantity	Average shortage rate	Inventory holding time (Days)
(T, S)	1	4750	1			3%	7.87
(T, S)	2	5000	1			2%	8.71
(T, S)	3	5250	1			1%	10.34
(s, S)	4	4750		2650		3%	7.85
(s, S)	5	5000		2700		2%	8.35
(s, S)	6	5500		3150		1%	10.05
(R, Q)	7			6500	1750	2%	13.43
(R, Q)	8			6750	1750	1%	16.42

Chapter 5 Conclusions and future works

In this research, three kinds of ordering policy are examined to help reduce the shortage rate of Nitrile medical exam glove, Pre-filled syringe, Glucose tube and Ice bath clamp bag. We try to find the solutions that can make the shortage rate lower than before, and also under 3% since it is the average shortage rate of Taiwan. The result shows that (s, S) ordering policy are normally been selected as suggest solution,

only one material is recommended for TS policy. We do not make a conclusion that (R, Q) ordering policy and (T, S) ordering policy is worse than others, but in this research, the results show that (s, S) ordering policy is more suitable for each material than other ordering policies.

In fact, we planned to control cost factors in this research but we can’t get the cost data from this case study hospital. So, in order to find an appropriate solution, we decide to consider inventory holding time and reorder cycle as the indicators. Due to the fact that the cost factors are not taken into consideration, we can’t find the optimal values of all variables simultaneously. In our approach, one decision variable of each ordering policy will be fixed and gradually updated by use of trial and error technique while the other variable will be determined through optimization function of the simulation software. For future research, the cost factor should be taken into consideration so that the optimal solution for all decision variables of the inventory policy can be determined precisely.

Furthermore, we recommend the hospital to find out the appropriate inventory policy for each material. The results of our analyses for the four materials show that different ordering policies will have different effects for various materials, and the ordering policy currently in use is probably not the suitable one for all materials. Simulation approach is also recommended because it will not affect regular operation of the hospital.

References

Chinese References

王敏容、王如萱、王佳惠、郭乃文(2005)。市場競爭程度對醫院開發自費醫療服務之影響。**北市醫學雜誌，2(10)**，895-906。

周成超、胡志(2002)。醫院藥品存貨管理存在問題思考。**中國醫學管理，2**。

張丹陽、傅蓉、藍毓濱。(2003)。淺談 HIS 系统在醫院管理中的成本控制作用 。**中國衛生經濟，3**。

English References

AbuKhousa, E., Al-Jaroodi, J., Lazarova-Molnar, S., & Mohamed, N. (2014). Simulation and modeling efforts to support decision making in healthcare supply chain management. *The Scientific World Journal*, *2014*.

Ahmed, M. A., & Alkhamis, T. M. (2009). Simulation optimization for an emergency department healthcare unit in Kuwait. *European journal of operational research*, *198*(3), 936-942.

Baboli, A., Fondrevelle, J., Tavakkoli-Moghaddam, R., & Mehrabi, A. (2011). A replenishment policy based on joint optimization in a downstream pharmaceutical supply chain: centralized vs. decentralized replenishment. *The International Journal of Advanced Manufacturing Technology*, *57*(1-4), 367-378.

Bijvank, M., & Vis, I. F. (2012). Inventory control for point-of-use locations in hospitals. *Journal of the Operational Research Society*, *63*(4), 497-510.

Danas, K., Ketikidis, P., & Roudsari, A. (2002). A virtual hospital pharmacy inventory: An approach to support unexpected demand. *Journal of Medical Marketing*, *2*(2), 125-129.

Dellaert, N., & van de Poel, E. (1996). Global inventory control in an academic hospital. *International Journal of Production Economics*, *46*, 277-284.

Guerrero, W. J., Yeung, T. G., & Guéret, C. (2013). Joint-optimization of inventory policies on a multi-product multi-echelon pharmaceutical system with batching and ordering constraints. *European Journal of Operational Research*, *231*(1), 98-108.

Haszlinna Mustaffa, Noorfa, and Andrew Potter. "Healthcare supply chain management in Malaysia: a case study." *Supply Chain Management: An International Journal* 14.3 (2009): 234-243.

Kumar, A., Ozdamar, L., & Ning Zhang, C. (2008). Supply chain redesign in the healthcare industry of Singapore. *Supply Chain Management: An International Journal*, *13*(2), 95-103.

Kelle, P., Woosley, J., & Schneider, H. (2012). Pharmaceutical supply chain specifics and inventory solutions for a hospital case. *Operations Research for Health Care*, *1*(2-3), 54-63.

Kleijnen, J. P. (2005). Supply chain simulation tools and techniques: a survey. *International Journal of Simulation and Process Modelling*, *1*(1-2), 82-89.

Law, A. M., Kelton, W. D., & Kelton, W. D. (2000). *Simulation modeling and analysis* (Vol. 3). New York: McGraw-Hill.

Lapierre, S. D., & Ruiz, A. B. (2007). Scheduling logistic activities to improve hospital supply systems. *Computers & Operations Research*, *34*(3), 624-641.

Lee, B. K., Zhou, R., de Souza, R., & Park, J. (2016). Data-driven risk measurement of firm-to-firm relationships in a supply chain. *International Journal of Production Economics*, *180*, 148-157.

Lin, C. C., Shieh, S. C., Kao, Y. H., Chang, Y. T., & Chen, S. S. (2008, July). The simulation analysis of push and pull shelf replenishment policies for retail supply chain. In *2008 International Conference on Machine Learning and Cybernetics* (Vol. 7, pp. 3964-3969). IEEE.

McKone‐Sweet, K. E., Hamilton, P., & Willis, S. B. (2005). The ailing healthcare supply chain: a prescription for change. *Journal of Supply Chain Management*, *41*(1), 4-17.

Naseer, A., Eldabi, T., Jahangirian, M., & Stergioulas, L. (2008, May). Potential applications of simulation modelling techniques in healthcare: lessons learned from aerospace & military. In *Proceedings of the 5th European and Mediterranean Conference on Information Systems (EMCIS'08)*.

Nahmias, S., & Cheng, Y. (2005). *Production and operations analysis* (Vol. 6). New York: McGraw-hill.

Nicholson, L., Vakharia, A. J., & Erenguc, S. S. (2004). Outsourcing inventory management decisions in healthcare: Models and application. *European Journal of Operational Research*, *154*(1), 271-290.

Priyan, S., & Uthayakumar, R. (2014). Optimal inventory management strategies for pharmaceutical company and hospital supply chain in a fuzzy–stochastic environment. *Operations Research for Health Care*, *3*(4), 177-190.

Saedi, S., Kundakcioglu, O. E., & Henry, A. C. (2016). Mitigating the impact of drug shortages for a healthcare facility: an inventory management approach. *European Journal of Operational Research*, *251*(1), 107-123.

Stecca, G., Baffo, I., & Kaihara, T. (2016). Design and operation of strategic inventory control system for drug delivery in healthcare industry. *IFAC-PapersOnLine*, *49*(12), 904-909.

Uthayakumar, R., & Priyan, S. (2013). Pharmaceutical supply chain and inventory management strategies: Optimization for a pharmaceutical company and a hospital. *Operations Research for Health Care*, *2*(3), 52-64.

Volland, J., Fügener, A., Schoenfelder, J., & Brunner, J. O. (2017). Material logistics in hospitals: a literature review. *Omega*, *69*, 82-101.

Wang, B. B., Ozcan, Y. A., Wan, T. T., & Harrison, J. (1999). Trends in hospital efficiency among metropolitan markets. *Journal of medical systems*, *23*(2), 83-97.

Wu, D., Rossetti, M. D., & Tepper, J. E. (2015). Possibility of Inventory Pooling in China’s public hospital and appraisal about its performance. *Applied Mathematical Modelling*, *39*(23-24), 7277-7290.

Zhao, W., Wang, D., Guo, X., & Li, L. (2010, June). Performance measurement of supply chain based on computer simulation. In *2010 International Conference On Computer Design and Applications* (Vol. 4, pp. V4-183). IEEE.

Zhu, Z., Hoon Hen, B., & Liang Teow, K. (2012). Estimating ICU bed capacity using discrete event simulation. *International journal of health care quality assurance*, *25*(2), 134-144.

Appendices

Appendix 1: Material data distribution

Appendix 1. 1 GLOVE normal order amount per order distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.30509	2	412.63	2
2	Geometric	0.15594	1	27.102	1
3	Logarithmic	0.55351	3	729.48	3
4	Poisson	0.71747	4	21373.0	4

Appendix 1. 2 GLOVE abnormal order arrival time distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.40181	1	214.98	1
2	Geometric	0.7896	2	1383.2	2
3	Poisson	0.79626	3	N/A	

Appendix 1. 3 GLOVE abnormal order amount per order distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.29734	2	187.12	2
2	Geometric	0.1869	1	18.902	1
3	Logarithmic	0.56452	3	302.7	3
4	Poisson	0.74726	4	9193.2	4

Appendix 1. 4 SYRINGE normal order arrival time distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.47431	1	400.43	1
2	Geometric	0.87562	2	2868.7	2
3	Poisson	0.8883	3	N/A	

Appendix 1. 5 SYRINGE normal order amount per order distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.19825	3	329.04	3
2	Geometric	0.12714	1	10.385	1
3	Logarithmic	0.50176	4	466.91	4
4	Neg. Binomial	0.18661	2	32.88	2
5	Poisson	0.58193	5	5497.6	5

Appendix 1. 6 SYRINGE abnormal order arrival time distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.3247	1	122.62	1
2	Geometric	0.60942	2	416.02	2
3	Poisson	0.61255	3	N/A	

Appendix 1. 7 SYRINGE abnormal order amount per order distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.34983	2	58.69	2
2	Geometric	0.13348	1	6.1111	1
3	Logarithmic	0.55375	3	115.41	3
4	Poisson	0.57708	4	1846.5	4

Appendix 1. 8 BAG normal order arrival time distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.32765	1	123.54	2
2	Geometric	0.5984	2	400.68	3
3	Poisson	0.60148	3	-108.0	1

Appendix 1. 9 BAG normal order amount per order distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.33571	1	83.501	3
2	Geometric	0.47376	2	51.285	1
3	Logarithmic	0.72561	5	160.31	4
4	Neg. Binomial	0.49624	3	59.035	2
5	Poisson	0.67399	4	1851.3	5

Appendix 1. 10 BAG abnormal order arrival time distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.24103	2	8.6303	2
2	Geometric	0.13163	1	1.1722	1
3	Poisson	0.64986	3	38.428	3

Appendix 1. 11 BAG abnormal order amount per order distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.37015	1	6.8849	3
2	Geometric	0.37889	2	2.7628	1
3	Logarithmic	0.69689	5	11.259	4
4	Neg. Binomial	0.40911	3	3.056	2
5	Poisson	0.58724	4	16.27	5

Appendix 1. 12 TUBE normal order arrival time distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.34385	1	159.13	1
2	Geometric	0.67969	2	725.0	2
3	Poisson	0.68421	3	N/A	

Appendix 1. 13 TUBE normal order amount per order distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.40516	1	175.21	3
2	Geometric	0.44889	2	97.396	1
3	Logarithmic	0.55293	3	119.25	2
4	Poisson	0.8575	4	4221.1	4

Appendix 1. 14 TUBE abnormal order arrival time distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.19415	1	19.833	4
2	Geometric	0.19601	3	11.171	2
3	Neg. Binomial	0.19592	2	11.512	3
4	Poisson	0.55738	4	-24.904	1

Appendix 1. 15 TUBE abnormal order amount per order distribution

#	Distribution	Kolmogorov Smirnov		Anderson Darling	
		Statistic	Rank	Statistic	Rank
1	D. Uniform	0.33477	1	25.387	3
2	Geometric	0.45298	2	18.221	2
3	Logarithmic	0.45367	3	12.763	1
4	Poisson	0.69355	4	N/A	