IMPROVEMENT OF INVENTORY POLICY IN A STATE HOSPITAL FOR CONSUMABLE MEDICAL SUPPLIES

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IMPROVEMENT OF INVENTORY POLICY IN A STATE HOSPITAL
FOR
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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for degree of Master of Arts.

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ABSTRACT

IMPROVEMENT OF INVENTORY POLICY IN A STATE HOSPITAL
FOR
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Under the pressure of rising healthcare costs, most hospitals are urged to use more efficient methods for inventory management of consumable medical supplies. This is a very challenging problem because it requires the satisfaction of many conflicting objectives such as reducing overstock, stock out and procurement costs and in the meantime improving patient safety and avoiding any life-threatening incidents. This study is conducted at a public hospital, İzmir Katip Celebi University Atatürk Training and Research Hospital which is the second largest public hospital in Turkey. First, we identify problems in current inventory system with the help of cause and effect diagram. The diagram shows poor inventory management with the root causes in the current inventory policies.Second, we use ABC analysis to identify a few items which require more attention. Third, we use coefficient of variation to differentiate the few “A” class (the most important items) items by quantifying demand variabilities. The past demand data for these items are then analyzed to find more cost-effective inventory policies for items with low, moderate, and high demand variabilities. In this study, we propose a framework for obtaining the optimal ordering policy in a continuous review inventory system with a fixed lead time. We study the impact of order amount Q and re-order point R on total cost. This study is the first scientific examination regarding the consumable medical supplies of the (Q, R) continuous inventory policy in a state hospital in Turkey. Our contribution to the literature is to apply (Q, R) policy under different non-normal distributions instead of the commonly assumed normal distributions. This method is easy to use in the healthcare context. The purpose of this study is to explore policies to minimize the total annual inventory costs without affecting the patient service level. To minimize the total cost, the (Q, R) and (Q, R) type II service level are used to compare with the current inventory system. It is found that (Q, R) type II service level inventory policy can result in significant cost savings compared to the exisiting inventory system. The cost saving is the greatest for fast moving, and low or medium price items.

Keywords: (Q, R) policy, Inventory Management, Uncertain Demand

ÖZET

SARF MEDİKAL MALZEMELER İÇİN BİR DEVLET HASTANESİNDE STOK POLİTİKASI GELİŞTİRİLMESİ

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Ağustos, 2016

Sağlık maliyetlerinin yükselmesi baskısı altında birçok hastane tıbbi sarf malzemelerin envanter yönetimi için daha etkili yöntemler kullanmaya mecbur kalıyorlar. Bu çok zorlu bir problem çünkü stok fazlası, stokta bulunmayan malzeme oranı ve tedarik maliyetlerini düşürürken aynı zamanda hasta güvenliğini artırmak ve hayati tehlike yaratacak herhangi bir durumdan kaçınmak gibi birbiriyle çelişen birçok hedefin gerçekleştirilmesini gerekmektedir. Bu Türkiye'nin en büyük ikinci devlet hastanesi olan İzmir Katip Çelebi Üniversitesi Atatürk Eğitim ve Araştırma Hastanesi'nde yürütüldü. Öncelikle, sebep ve sonuç analizi yardımıyla envanter sistemindeki mevcut problemler tanımlanmıştır. Diyagram yöntemi mevcut envanter politikaları ve envanter yönetiminde bazı temel zayıflıkları göstermiştir. İkinci olarak, daha fazla dikkat gerektiren birkaç öğeyi tanımlamak için ABC analizi kullanılmıştır. Üçüncü olarak, talebin değişkenliği ölçmek için ABC analizinde "A" sınıfı (en önemli öğe) ürünleri ayırt etmek için varyasyon katsayısı uygulanmıştır. Daha sonra düşük, orta ve yüksek talep değişkenliğine sahip ürünler için daha düşük maliyetli stok politikalarını bulmak için bu ürünlerin geçmiş talep verileri incelenmiştir. Bu çalışmada, sabit teslim süresi ile birlikte sürekli gözden geçirmeli stok kontrol politikaları uygulayarak optimal sipariş politikası elde etmek için bir görüş sunulmaktadır.

Sipariş miktarı olan Q'nun ve tekrar sipariş noktası olan R'nin toplam maliyet üzerindeki etkileri araştırılmıştır. Bu çalışma Türkiye'de bir devlet hastanesinde (Q, R) sürekli envanter politikasının tıbbi sarf malzeme ile ilgili ilk bilimsel araştırmasısıdır. Literatüre katkımız (Q, R) politikasını genel olarak normal varsayılan dağılımlar yerine birçok normal olmayan dağılımlar altında uygulanmasıdır. Bu yöntemin sağlık bağlamında kullanımı kolaydır. Bu çalışmanın amacı, hasta hizmet seviyesini etkilemeden yıllık toplam stok maliyetlerini en aza indirmek için politikalar keşfetmektir. Toplam maliyeti en aza indirmek için, (Q, R) ve (Q, R) tip II hizmet seviyesi mevcut envanter sistemi ile karşılaştırmak için kullanılmıştır. (Q, R) tip II hizmet seviyesi envanter politikası var olan envanter sistemi ile karşılaştırıldığında önemli ölçüde maliyet tasarrufu sağlanabileceği bulunmuştur. Bu sistemde en yüksek maliyet tasarrufunun, hızlı tüketilen, düşük ve orta fiyatlı öğelerde olduğu saptanmıştır.

Anahtar Kelimeler: Envanter Yönetimi, Sürekli Kontrol Yöntemi, Belirsiz Talep

To my Family

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Aslı Kocamanlar Akçay

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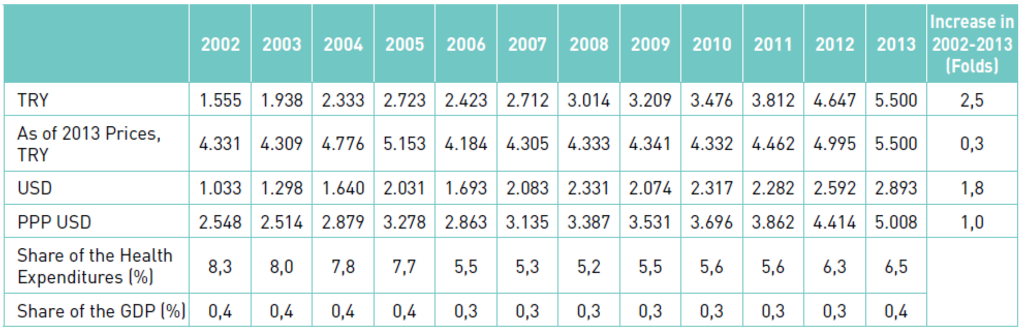
C & E	Cause and Effect Analyses
CV	Coefficient of Variation
IRA	Inventory record accuracy

1. Introduction

Improvement of Inventory Policy in a State Hospital for Consumable Medical Supplies

The healthcare supply chain costs are constituted of 25 to 30% percentage of hospital expenses. Moreover, the holding, ordering, and processing costs of medical items constitute of 35 to 40% of the total supply chain costs in hospitals while that ratio in many other industries is less than 10 percent (Gebici, et al., 2014). It shows that supply chain optimization in health care can significantly reduce the health care costs. Moreover, pharmaceutical and consumable medical supplies are important parts in the healthcare supply chain because of the high cost of such items (Priyan & Uthayakumar, 2014). In Turkey, the expenditures on medical equipment and supplies increased from 1.555 TRY million in 2002 to 5.500 TRY million in 2013, which increased 2.5 fold in twelve years as shown in Table 1. As inventory cost is a key part of the increase in health care expenditure, improving the consumable medical inventory management may reduce the cost of health care significantly. Our aim in inventory management is to reduce total cost without sacrificing a targeted patient service level, by ensuring item availability.



	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Increase in 2002-2013 (Folds)
TRY	1.555	1.938	2.333	2.723	2.423	2.712	3.014	3.209	3.476	3.812	4.647	5.500	2,5
As of 2013 Prices, TRY	4.331	4.309	4.776	5.153	4.184	4.305	4.333	4.341	4.332	4.462	4.995	5.500	0,3
USD	1.033	1.298	1.640	2.031	1.693	2.083	2.331	2.074	2.317	2.282	2.592	2.893	1,8
PPP USD	2.548	2.514	2.879	3.278	2.863	3.135	3.387	3.531	3.696	3.862	4.414	5.008	1,0
Share of the Health Expenditures (%)	8,3	8,0	7,8	7,7	5,5	5,3	5,2	5,5	5,6	5,6	6,3	6,5	
Share of the GDP (%)	0,4	0,4	0,4	0,4	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,4	

Table 1.Expenditures on Medical Equipment and Supplies (2012-2013), (million TRY/USD)

Source: Financing of Health Care Services and Analysis of Health Expenditures in Turkey between 2002 and 2013 (2014)

A key issue in inventory management is to deal with the uncertainty in demand and supply lead time. The demand for an item in hospital is random and the speed of consumption is also varied. The stochastic demand makes it challenging to find an optimal inventory policy. Hospital inventory management faces an additional difficulty because its primary aim is to ensure high patient service level, with cost minimization as a secondary objective. In this environment, the main issues in managing the inventory system is to determine the timing and amount of supplies ordered (when to order and how many to order) so that the desired service level can be reached, and the total cost of the system to be minimized.

Demand variability is one challenge for inventory management in hospital as each clinic requires different items. One clinic may need simple, inexpensive, easily accessible and consumable items, while another may need complex, specialized high-tech items, and others may require both types of items. Neurosurgery departments, orthopedics, plastic surgery, and cardiovascular surgery need a wide range of complex and high- tech items (There are a large variety of items at these departments). A general surgery clinic also uses technological items to shorten the operation time. Each clinic’s organizational structure is different, and it may not be practical for a hospital to stock every item due to many variations. In the health care industry, the single largest cost item after labor is material (Ross & Jayaraman, 2009). Therefore, it is important to improve hospital inventory management. In healthcare industry, however inventory management is difficult for many reasons. Hospitals may have different process within its operation management, and each clinic's operation management may also vary within the same institution (DeScioli, 2005).

This study is conducted in İzmir Kâtip Çelebi University Atatürk Training and Research Hospital, which is the second largest public hospital in Izmir. With limited budgets, public hospitals have to provide high quality service to their patients. The inventory management of the central medical supply warehouse is examined. Cause and Effect Analysis is used to determine the main problems related inventory management, as well as the roots of the problems. The ABC analysis is then implemented to prioritize items according to their usages, and we identify the vital few. DeScioli (2005) suggested that the hospital supply chain should be managed based on item’s unit cost, demand variability, physical size and criticality. At İzmir Kâtip Çelebi University Atatürk Training and Research Hospital, the demand is changeable and uncertain. The uncertainty in demands for consumable medical items is caused by the random and unpredictable consumer behavior. Each variable must be examined using historical data and measured by probability distributions, which are important for finding the most cost-effective inventory policy. After determined probability distribution, we perform the "Coefficient of Variation" CV analysis to assess the demand variability in consumable medical warehouse. The items in 'A' class from ABC analysis are then further categorized into three types, low, medium, and high variability.

After these preparations, we then apply management theory to find most efficient inventory policy. To minimize the cost, the most suitable inventory policy in the context of hospital is (Q, R) policy as well as (Q, R) type II service level. The process of proposed inventory system is shown in Figure 1.

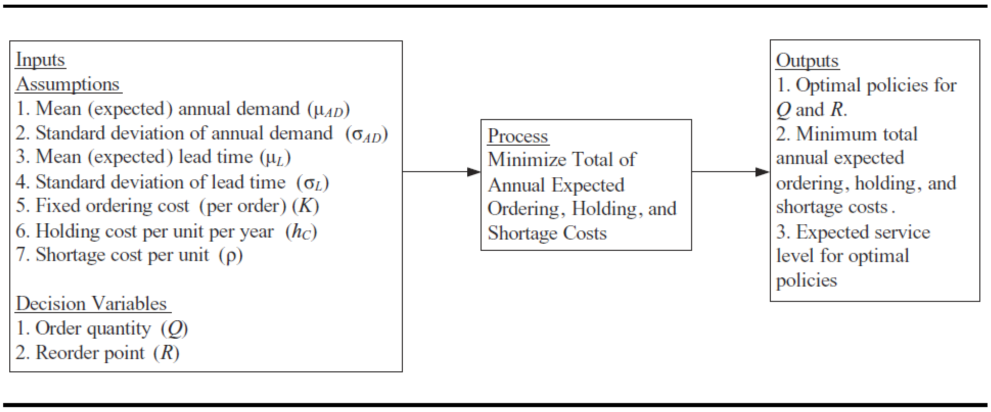


Figure 1.The proposed inventory policies are inputs, process and outputs

Source: Spreadsheet Modeling of (Q, R) Inventory Policies (2013)

Performances metrics in (Q, R) approach are

- Find optimal Q and R value.
- Reduce total ordering, holding, and shortage costs, and minimize total annual expected cost.
- Achieve desired service level
- Maximize product availability

The aim of this thesis is to find a balance between the ordering, holding and shortage costs in the face of uncertain demand in order to achieve the desired service level. The proposed inventory management policy is to reduce the total costs, while maintaining patient service levels under uncertain demands. The new inventory management policy should maintain high patient service level, high product availability, reduce excess inventory, and avoid obsolete inventory. Finally, as some key parameters such as holding cost, setup cost, and penalty cost are difficult to estimate, sensitivity analyses are performed on the proposed inventory policy to identify the impacts of these parameters changes.

The remainder of the thesis is as follows: In Section 2, the literature review is presented. The proposed inventory policies are then given with details in Section 3. In Section 4, the current system is analyzed with C& E diagram. Methodology is then discussed in Section 5 as well as the data analysis. In Section 6, the (Q, R) policy and (Q, R) type II service level are implemented with results. The sensitivity analysis is then performed in Section 7. Finally, we present the conclusions in Section 8.

2. Literature Review

Inventory management is an important component of the supply chain management. Recently, the industrial experts has used many different methods to solve complicated inventory control problems to provide best possible service level and find the optimal total cost within their budget. The most commonly used methods are periodic and continuous review policies. Comparing between periodic and continuous review policies, continuous review policy is better to dampen fluctuations in demand and is very responsive when there is a stok out of items (Amran & Lesmono, 2012). Our contribution to the literature is to apply (Q, R) policy under different distributions instead of the commonly assumed normal distributions. This method is easy use for the real operations. One of the primary challenging in inventory control is to decide when to order and how much to order.

The lot size decision determines the amount of order of (Q), and the reorder point (R) decision determines when to order. These two decisions affect the levels of inventory components, namely, turnover cycle stock and safety stock. The optimal value of these two variables would minimize total cost and satisfy the fill rate constraints. There are many different studies on the inventory policy in the literature. First, we give a detailed literature review relating general study on inventory management then explain healthcare inventory management in (Q, R) Policy literature review.

2.1. General Study on Inventory Management

Nahmias and Demmy (1981) develops an inventory control policy to meet both high and low priority demands for military depots. To determine the effects of rationing and no rationing on the fill rate, Nahmias and Demmy (1981) compared an inventory policy according to a periodic (s,S) policy with exponential demand and continuous review policy under a stationary Poisson process with arrival rate λ. Raitioning is introduced in the model by defining a support level K. When the inventory level hits K, all low urgency demands are backordered as shown in Figure 2.

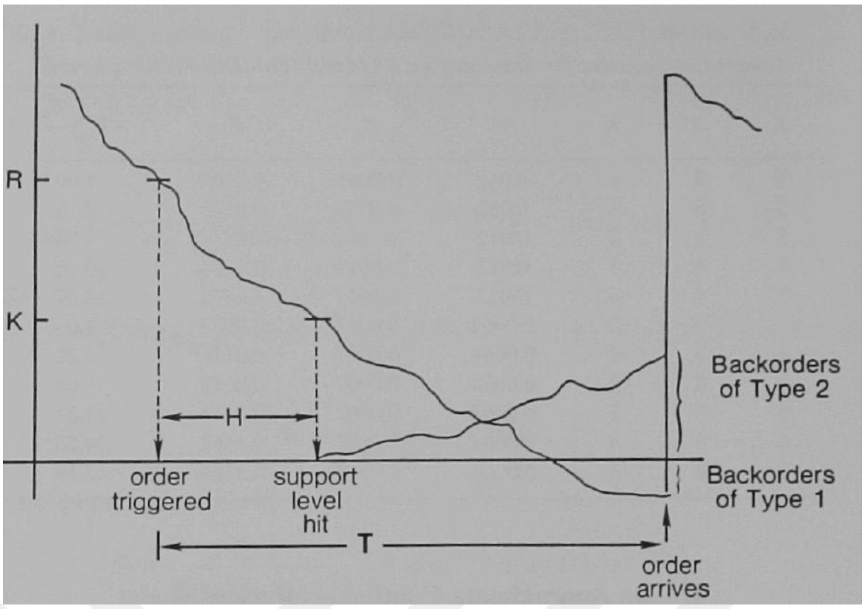


Figure 2. The Continuous Review Inventory with Rationing (Nahmias and Demmy, 1981)

When compared both inventory policies, periodic review inventory policy gives better result and provides better estimates on the fill rates. Another important finding in the continuous review policy is that it gives better result on the system fill rate without rationing (Nahmias and Demmy, 1981).

In another major study on the (Q, R) policy, Moinzadeh and Nahmias(1988) have examined a approximate model of inventory control policy with two options for resupply and one having a shorter lead time. In their optimal inventory policy, there are two different lot sizes Q_1 and Q_2, and two different reorder levels R_1 and R_2. R_1 is to be greater than R_2 with the condition, when the inventory level hits R_1, it places an order Q_1 to arrive at time τ_1. When the inventory level hits R_2, an order Q_2 is to be placed which will arrive at time τ_2 as shown in below Figure 3. Moinzadeh and Nahmias(1988) showed that when the stockout costs were extremely costly, the emergency ordering can be used. In addition, their model may generate considerable amount of cost saving than a simple (Q, R) model under high stockout cost and small setup cost.

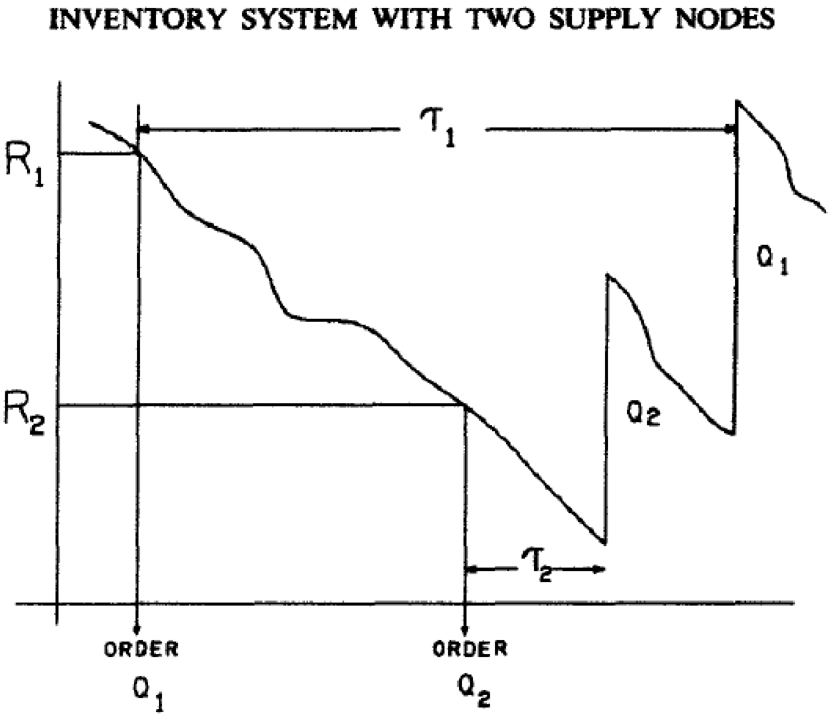


Figure 3.Inventory Process with an Emergency Order (Moinzadeh & Nahmias,1988)

Kim & Benton (1995) have suggested that important cost reduction can occur considering the interrelationships between the lot size and safety stok desicions in the (O, R) system. The authors study the relationship between lot size and lead time and show an iterative algorithm to find lot size and safety stock.

Forsberg (1996) studied the inventory holding cost and shortage costs using an exact solution method for a two-level inventory system with one warehouse and multiple retailers. The lead time is constant and the retailers face different independent Poisson demands under continuous review (R, Q) - policies. Forsberg (1996) extended the original model developed by Axsäter (1990) from two retailers to multiple retailers.

Fujiwara and Sedarage (1997) developed a mathematical model to find optimal order quantity and assembly lot size based on (Q, r) model to minimize the average total cost per unit time for a simple production system under the random procurement lead times, constant demand rate, and backorder for unsatisfied demand. The authors aim to determine reorder point, r_i , for each part and the production lot size by minimizing total costs. To ensure smooth production processes, the authors applied a nonlinear programming model to find the reoder point r_i for each part i and suggest a common order quantity Q.

Bookbinder and Çakanyildirim, (1999) developed two probabilistic models with on lead time as a random variable and a constant demand rate. In the first model, the lead time is exogenously random. In the second model, the lead time is affected by an expediting factor. For each model, the expected cost per unit is jointly convex to the decision variables Q and r to minimize objective function. They carry out a sensitivity analysis relating to cost parameters.

Similarly Çakanyıldırım et al., (2000) developed a model with random lead time related to the lot size and production capacity. They examined the cases of lead time linear and concave to the lot size.

Vasconcelos and Marques (2000) finding a new quasi-optimal solution using simple (Q, R) inventory models at Gamma distribution demands. They described the demand with a ratio $g = \left(\frac{d}{\sigma}\right)^2$, which is the modulus of gamma demand.The optimal Q is bigger than the EOQ all the time. These differences are due to the higher ratio of expected shortage per cycle to the probability of stockout. The authors derived the new formula for the optimal Q when the demand variability is high.

2.2. Healthcare Inventory Management in (Q, R) Policy

In the healthcare context, management of the purchasing, storage, and distribution of pharmaceutical, and other consumable medical supplies are crucial for hospitals and medical companies. Medical supply management is vital to ensure the safety, availability, and affordability of health care services (Rossetti, et al., 2012). Procurement personnel in hospital faces challenges in inventory policy in light of changing demand, limited suppliers, manufacturing issues, and regulatory constraints that affect the drug supply (Choudhary, et al., 2011). The medical items tend to be more costly than other products to purchase, distribute, and storage. Special method should be used in consumable medical inventory management to provide high item availability at the right time, at the right cost, and in good condition to the right patient. The good quality of healthcare industries depends on the availability of consumable medical supply on the time. If a shortage happens at a consumable medical supplies in a hospital, an urgent order is required, which is incredibly costly and might affect the patient health. The improper inventory management may lead to financial losses for hospital and a considerable adverse impact on patient health. Therefore, inventory management in healthcare is critical and requires a suitable model to control the consumable medical inventory, protect patient lives, and decrease inventory costs.

In general, a periodic-review inventory policy is not applicable for healthcare inventory management because customer demands and patient arrivals are random with high expection on service quality. An efficient healthcare inventory management needs a method different from periodic-review reorder point models (Uthayakumar & Priyan, 2013). A continuous-review inventory policy is more proper than a periodic review inventory policy in the context of healthcare industry (Woosley, 2009). According to Hani et al., (2013), the continuous inventory policy is appropriate with the property of fast moving in the consumable medical supplies. The below part is showed published some literature with continous inventory policy.

Hani et al., (2013) chooses a case-study aproach to oberseve inventory management and distribution of consumable medical supplies and provide solutions for optimal inventory policy that can reduce inventory cost, and improve distribution system at a public hospital in Indonesia. To evaluate the effectiveness of periodic and continuous review policy comparing with the current inventory system, the developed model conducted disposable syringes and reduce the cost significantly through continuous inventory policy.

Akcan & Kokangul (2013) showed reducing inventory total cost by devoloping approximation and OptQuest. Their study have a pivotal role in determining the optimal reorder point (r) and the order quantity (Q) required and minimize the expected annual inventory total cost. A case-study approach was adopted a simulation meta-model and a single-item continuous review (r, Q) policy for a hospital. The study is conducted Neonatal Intensive Care Unit (NICU) in a university hospital. Assumed that stochastic lead-time is related to the number of patients in the hospital.

Saracoglu et al., (2014) developed a novel approach for multi-product, multi-period (Q, r) inventory models, with the objective of maximizing the profit under constraints such as storage area, budget, shelf life, and various promotions. Their aim is to find the optimal order quantity and optimal reorder point under the constraints of shelf life, budget, storage capacity, and ‘‘extra number of products’’ promotions according to the ordered quantity. Nine products were chosen to represent the deterministic, seasonal and high variability items as a case on pharmaceutical distributor.

Varghese (et al., 2012) examines the relationship between holding cost and ordering cost at the inventory management. An objective of their study was to investigate by (r, Q) inventory policy to model the current inventory system at each echelon and a multi-echelon inventory control system. Their method is particularly useful in studying actual usage inventory management. Moreover, they showed that the forecasting is an important component in the inventory management, and plays a key role in identifying seasonal demand variation. They analysed the data of 34 out of 927 in the hospital location 1 and 36 out of 1920 items in the hospital location 2. Their proposed inventory policy plays a critical role in the maintenance of cost saving the two main costs of inventory, which are holding costs and ordering costs and improve the forecasting.

Rachmania and Basri (2013) have been modeled three major issues in inventory management such as overstock, unjustified forecasting technique and lack of IT support. (R,S) periodic inventory policy and (s, Q) continuous review policy conducted on the basis of six items from oncology medication drugs in the Indonesian public hospital. One major criticism of Rachmania and Basri 's work is that Holt’s model appears to be the best adapted for oncology medication. Second importand finding is that the continuous review method is one of the more practical ways of reducing high holding cost.

Uthayakumar and Priyan (2013), developed a procedure for determining optimal solutions for inventory lot size, lead time, and the number of deliveries to achieve the service level targets with a minimum total cost for the supply chain. The main goal of their research is to reduce health care costs without sacrificing customer service in a single pharmaceutical company and a single hospital . The (Q, R) model considers multiple pharmaceutical products, variable lead time, permissible payment delays, constraints on space availability, and the service level.

3. (Q, R) Policy

This section presents an overview of (Q, R) inventory policy, and then explains the relevant costs such as holding costs, ordering cost, shortage cost, and imputed shortage cost.

3.1 Back Ground Information for Inventory Models

Inventory control models have been developed to optimize the whole inventory system. Their objectives are to find the optimal inventory policy on stock levels and the best replenishment policy in each department. Axsäter (2006) argued that "*The aim of an inventory control system is to determine when and how much to order. This decision should be based on the stock situation, the anticipated demand, and different cost factors*." A key issue in hospital is the demand uncertainty. For any hospitals, the number of patients varies widely and is largely unpredictable (Boutsioli, 2010). Demand for medication is normally predicted based on the size of population around the hospital and seasonal variations such as the flu season (Denton, 2013).

In inventory control models, there are three main models to deal with uncertain demand, News vendor, (Q, R) and (s, S). Since the News-vendor model does not allow shortages, it is not suitable to be implemented in the hospital setting; in which stock out is a major problem in a hospital. In the periodic (s, S) model, you place an order up to S whenever the inventory level is below s. It is not a continuous order policy, which does not fit with a hospital. In the hospital, there is an established continuous review system in which fixed order amount and certain reorder points are used. Therefore, the most suitable model is the (Q, R) model. According to (Q, R) policy, whenever inventory level reaches the reorder point R, an order is placed for Q units. The (Q, R) model allows shortages, and all its assumptions are consistent with current inventory system in the hospital. Classification of inventory models is shown in Figure 4.

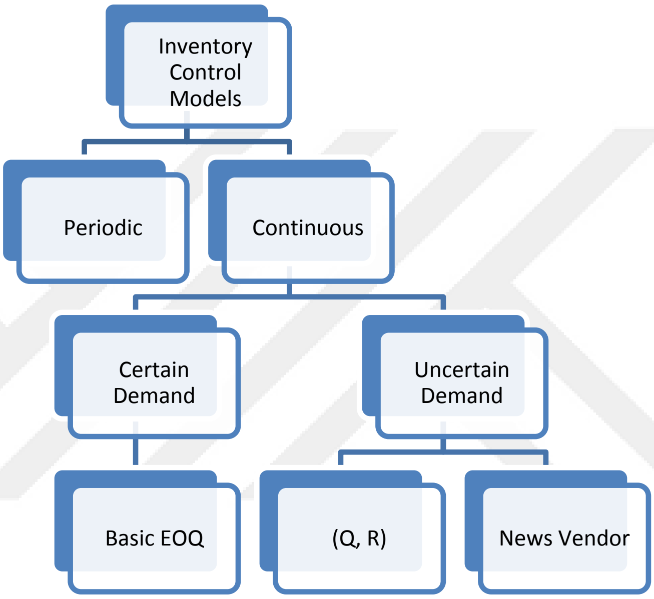


Figure 4. Classification of Inventory Models

In addition, Carrillo (2004) suggested a continuous review policy for critical items with costly stock-outs. This method determines the order frequency to find the optimal value of the order quantity Q, as well as the reorder point R. In this model, the critical factors are the average demand, standard deviation of the demand, and the expected customer service level, as shown below Table 2.

INVENTORY MODEL	DETERMINES	APPROPRIATE FOR	CRITICAL FACTORS
Continuous review	Order quantity (inventory level) and reorder point	Critical items with costly stock-outs Uncertain demand	Average demand Standard deviation

			demand Customer service level Fixed order cost Lead time
Periodic review	Order frequency	General purpose items	
Economic order quantity	Order quantity (inventory level)	Stable demand	Monthly demand Holding cost Fixed order cost Lead time

Table 2.Inventory Models (Carrillo, Carrillo, & Paul, 2006)

Considering trade-off in the continuous inventory policy, there are three major trade-offs on Q and R values in the policy (Hopp & Spearman, 2008), namely, the trade-off between setups (replenishment frequency) and inventory holding, the trade-off between customer service and inventory holding, and the trade-off between demand variability and inventory holding.

3.2. Relevant Cost

In this part, brief information is given about the cost involved in the continuous inventory policy.

3.2.1. Holding Cost

The holding cost can be defined as the cost of storage and retention, and is also called carrying cost. The holding cost is a considerable part of the inventory cost when inventory is stored for uncertain situation. Uncertain demand exists in healthcare, so it is important to decide the level of inventories to meet uncertain demands. This issue is related to the inventory management and the holding cost.

In addition, the holding cost is related to the maximum quantity held, the average amount held, and the amount of inventory at the end of the period (Lieberman, 2005). The holding cost in the literature ranges from twenty to thirty-five percent of a product's unit price. Because of the high stocking rates in hospital, in this thesis, the holding cost rate is estimated as thirty percent of the unit cost.

3.2.2. Ordering Cost

The cost of ordering a certain amount z, c(z) is often proportional to the quantity ordered, where c is the unit price. Another common assumption is that c (z) consists of two components, one directly proportional to the quantity ordered, and the other constant K for the positive value of z. If z is zero, then c(z) is zero. Thus,

$$c(z) = \begin{cases} 0, & \text{if } z = 0 \\ K + cz, & \text{if } z > 0 \end{cases}$$

Where K is the setup cost and c the unit cost

K is a constant to cover the administrative cost of ordering or setup cost of production preparation. In this thesis, K is the administrative cost of ordering (Lieberman, 2005).

In the health care context, the ordering cost is the cost of purchasing and ordering goods. It covers order preparation cost, cost of procurement processes, communication costs, stationery costs, costs of purchasing officers, invoice and delivery charges.

3.2.3. Penalty Cost

Penalty cost has also been known as shortage cost or the stock out cost. This cost occurs, when there is insufficient stock to meet the demand. According to Nahmias (2009), when the demand of amount exceeds the re-order point, the shortages will occur.

3.2.4. Imputed Shortage Cost

The imputed shortage cost, a method of calculating penalty cost, is a useful way to estimate a value appropriated to the service level. In the (Q, R) policy, we might also use the "optimal" calculation $1 - F(R) = \frac{Q\,h}{p\,\lambda}$ to solve p. i.e., $p = \frac{Q\,h}{[(1-F(R))\lambda]}$,to obtain an assessment of the shortage cost that is imputed by the service level. This permits us to evaluate whether our desired service levels are reasonable/proper or not.

If the imputed cost appears to be too high, we may wish to reduce the service level less demanding, on the contrary, if the imputed cost appears to be too low, we may wish to increase the service level.

3.3. The Cost Function

Nahmias (2009) shows that the expected cost function is composed of total average holding cost, order setup cost and stock out cost, represented by Equation 1. These expressions derived gives G (Q, R) equation. The minimum total cost is achieved by equation to zero its Q and R derivations. We then find the optimal Q and R in order to minimize the cost function G (Q, R), and this is assumed to be the objective function (Nahmias, 2009).

$$G(Q,R) = h\left({}^{Q}\!/_{2} + R - \boldsymbol{\lambda\tau} \right) + {}^{K\lambda}\!/_{Q} + {}^{p\lambda n(R)}\!/_{Q} \qquad (1)$$

where λ is defined the expected demand rate and μ is the defined the expected demand during lead time. The expected number of stock outs per cycle is denoted

$$n(R) = \int_{R}^{\infty} (x - R)\ f(x)dx \tag{2}$$

G (Q, R) is a parabolic convex function. This function is minimized by two independent decision variables $Q\ and\ R$. There is a necessary condition for optimality.

$$\partial G \big/ \partial Q = \partial G \big/ \partial R = 0 \tag{3}$$

$$\frac{\partial G}{\partial Q} = \frac{h}{2} - \frac{K\lambda}{Q^2} - \frac{p\lambda n(R)}{Q^2} = 0 \tag{4}$$

This model is minimized firstly with respect to variable Q using equation (4).

$$Q = \sqrt{\frac{2\lambda[K + pn(R)\ ]}{h}} \tag{5}$$

In order to derive the optimal value of R, we take the first derivation of the G (Q, R) with R provided that G (Q, R)

$$\frac{\partial G}{\partial Q} = h - \frac{p\lambda n'^{(R)}}{Q} = 0 \tag{6}$$

$$1 - F(R) = \frac{Qh}{p\lambda} \tag{7}$$

As shown above, Equations 4 and 6 under stochastic inventory control models are to be calculated iteratively until the optimal values of Q and R are found. Another approach starts at setting $EOQ = \sqrt{\frac{2K\lambda}{h}}$ to Equation (5). From this calculation we then go to find R values from Equation (7). Convergence is usually reached after the second or third iterations. Generally, continuous review policy reduces the level of safety stock which is used to guard against the demand fluctuation during the lead time. All variables in above equations are defined in the table below.

Notations:

EOQ =Economic Order Quantity

$f(t) =$ Probability density function of demand
$G(Q,R) =$ Expected average annual cost for the (Q,R) model
$h =$ Holding cost per unit
$I =$ Annual interest rate used to compute holding cost
$K =$ Setup cost
$\lambda =$ Expected demand per year
$n(R) =$ Expected number of stock − outs in the lead time for (Q,R) model
$p =$ Penalty cost per unit for not satisfying demand.
$Q =$ Lot size or size of the order

$R =$ Re order point

3.4. (Q, R) Model for Continuous Review Policy

The inventory levels are assessed continuously, and demand to appear on a time basis, the optimal policy is named a lot size reorder point policy or (Q, R) policy. This policy is based on the assumption that inventory on hand should be reviewed continually rather than periodically, so that the level of inventory is known at all times. However, here is a problem because *"The uncertainty enters the analysis in the form of demand during procurement lead time, which is assumed to be a random variable* (Balakrishnan, 2010)."

The continuous review (Q, R) policy allows random demand. There are two independent decision variables, order quantity Q, and re-order point R. In the circumstance of stochastic demand, R mostly comprises a safety stock (S.S) and the expected demand during the lead time. Thus, R=μ+S.S, and Safety Stock, S.S=R-μ. In the occurrence of random demand, the demand may exceed the inventory during lead time, and resulting in a shortage. R is selected to protect against the uncertainty of demand during the lead time, and the Q is selected to balance the holding and set up costs as, shown in Figure 5 (Nahmias, 2009).

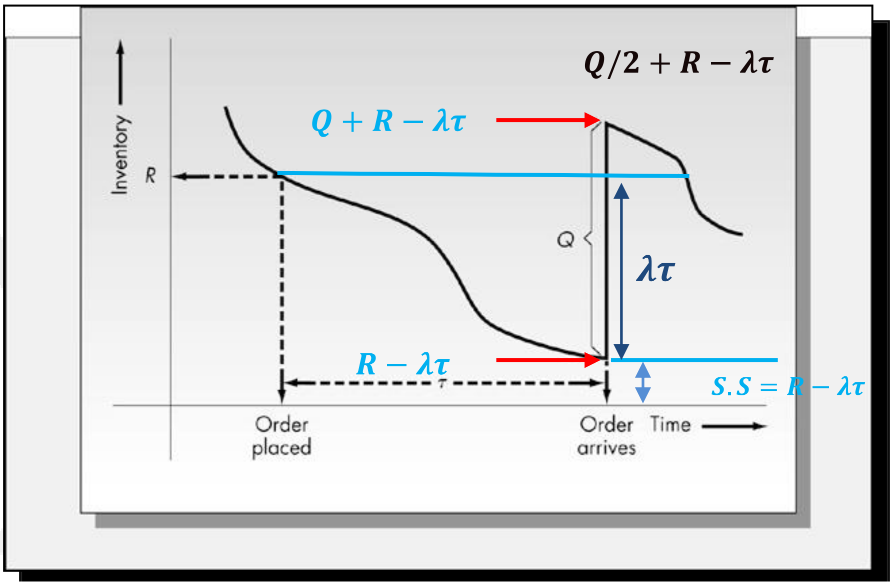


Figure 5.Changes in inventory over time for continuous-review (Q, R) system (Nahmias, 2009)

3.5. Type II Service Levels in (Q, R) Systems

In many cases, the penalty cost is difficult to estimate, therefore, we may instead set a specific service level, as the target of our inventory policy. This method is often preferred for its convenience. According to Nahmias (2009), the stock-out cost includes intangible components, such as unsatisfied patients, life-threatening and loss of goodwill. In real life, it 's hard to calculate the penalty cost hence. Because of this,we selected SQL model policy in this thesis. The service level is defined as the probability of meeting demand, and is divided into Type 1 and Type 2. In the study, we only considered Type 2 service with (Q, R) policy.

Type 2 service uses a predetermined specific value to measure the proportion of satisfied demands from warehouse. This pre-selected value is normally called β, or the fill rate. To meet the fill rate in this model, the R and Q should follow equations below (Nahmias, 2009).

$$\frac{Average\ Stockouts\ per\ Cycle}{Average\ Demand\ per\ Cycle} = \frac{n(R)}{\lambda T} = \frac{N(R)}{Q}$$

$$\frac{n(R)}{Q} = 1 - \beta$$

$$n(R) = (1 - \beta)Q \qquad (8)$$

EOQ value is used as an approximation for optimal lot size. This approach usually gives good results. We then use equation below to calculate p-value.

$$p = Qh\ /\ [(1 - F(R))\lambda]$$

We use the above formula (p) in the equation 5, and get an equation for Q

$$Q = \sqrt{\frac{2\lambda\{K + Qhn(R)/[(1 - F(R))\lambda]\ \}}{h}}$$

When we solve the above equation to find the Q,

with the solution as

$$Q = \frac{n(R)}{(1 - F(R)} + \sqrt{\frac{2K\lambda}{h} + \left(\frac{n(R)}{(1 - F(R))}\right)^2} \qquad (9)$$

To find R, the above equation 7 is used.

4. Current System Analysis

4.1. Current Inventory Policy

The central consumable medical supply warehouse in the hospital uses a specific Probel software program to track items. In this system, actual inventory level is tracked easily throughout the day. The hospital's inventory management is carried out by an automated continuous review system in which constant order quantity and certain reorder points are used. The inventory level is reviewed continuously by the warehouse clerk. In addition, the inventory management policy manages the inventory levels by setting the maximum amount of inventory at the standard stock policy legally required by the state. There are four standard stock levels, namely, maximum stock level, critical stock level, safety stock level, and minimum stock level. As shown in Figure 6., the standard maximum stock level of an item equals the amount of 60 days consumption in the year, the standard critical one equals the amount of 45 days consumption, the standard safety one equals the amount of 30 days consumption, and the standard minimum one equals the amount of 15 days consumption.

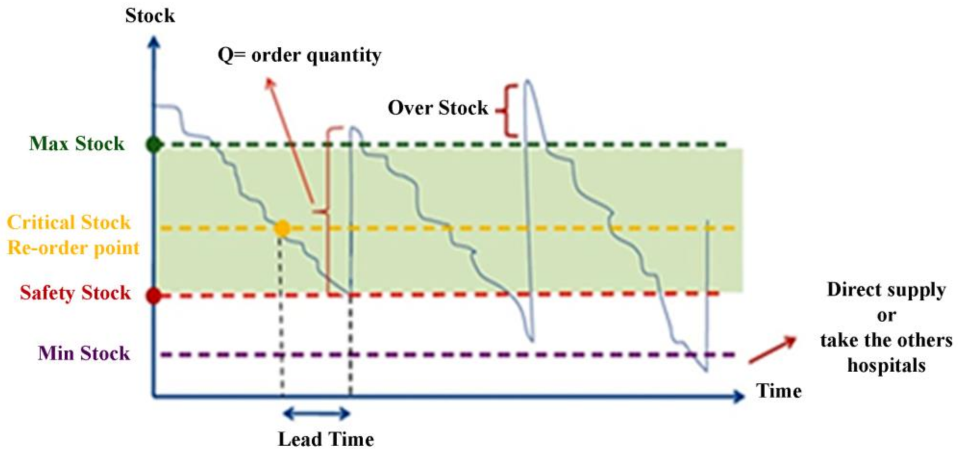


Figure 6.The standard inventory stock policy

Their standard inventory stock policies are defined as follows;

Max (Maximum) Stock Quantity: (60-day consumption amount) is the upper limit for the amount of on hand stocks items in the consumable medical supply warehouse.

Critical Stock Quantity: (45-day consumption amount) is the reorder point. The demand management has to give an order at this level.Otherwise, a shortage or urgent order could occur.

Safety Stock Quantity: (30-day consumption amount) is an additional amount to guarantee no stock out.The aim here is to stock additional items in the storage and reduce the risk of stockouts during the replenished lead time.

Minimum (Minimum) Stock Quantity: (15-day consumption amount) is the last warning point. This level is dangerous for the hospital due to the long purchasing process. In this case, the demand manager gives an urgent order, or the item is provided by other public hospitals by transfer as an urgent need. It is undesirable in both cases due to the increasing purchasing cost and the risk of shortage. The hospital's inventory management principle is to give an order at the critical stock level as the reorder point.

The inventory levels are determined based on the total consumption of the previous year.

$$\text{Standard stock level} = \frac{(\text{Annual demand quantity} * \text{Corresponding day level})}{360}$$

For example, the annual demand quantity of protected from light chemotherapy duplex pump set (the article number is 146777) was calculated as 12.055 units in 2012. The inventory manager computed the maximum standard stock level for this product as follows.

$$Standard\ maximum\ stock\ level = \frac{(12055 * 60)}{360} = 2009\ \text{pcs}$$

For the others stock levels, we can calculate similarly as shown in Table 3.

Stock Level	**Corresponding Day Level**	**Stock Level**
Standard maximum stock level (Initial inventory on hand)	60-day consumption amount	2009 pcs
Standard critical stock level (Re-Order point)	45-day consumption amount	1506 pcs
Standard safety stock level	30-day consumption amount	1004 pcs
Standard minimum stock level	15-day consumption amount	502 pcs

Table 3.The stock level for Item 146777

These standard stock levels are entered into Probel software system for each item. The current stock of items is followed by the software system. The initial stock level of an item is set at the 60-day consumption level. When the inventory level falls to the 45-day consumption level, Probel software system will give a warning. The warehouse clerk then gives an order of the 30 daily consumption level. In the example of Item 146777, the initial stock level is 2009 pcs. When the stock level falls below the standard critical stock level, or 1506 pcs, an order of places 1004 pcs will be placed to bring up the stock level back to the predetermined maximum inventory level. Unless the lead time is exact 15 days, the real stock level can be either higher or lower than the standard maximum stock level. Within this inventory policy, given demand and lead time are constant and known in advance, the order will be placed in the same quantity every time at the same re-order (R) point. Moreover, R is set at the size of 3/2 order (Q), or

$$R = \frac{3}{2}Q$$

4.2. The distribution of the items

In order to understand the process of the consumable medical inventory management in the hospital, we need to understand the consumable medical items flow in the hospital from the warehouse to end user (patients) illustrated in Figure 7. The consumable medical items flow and information requirement from clinics are summarized, and goods are then delivered to either a specific warehouse or a small clinic warehouse for consumption.

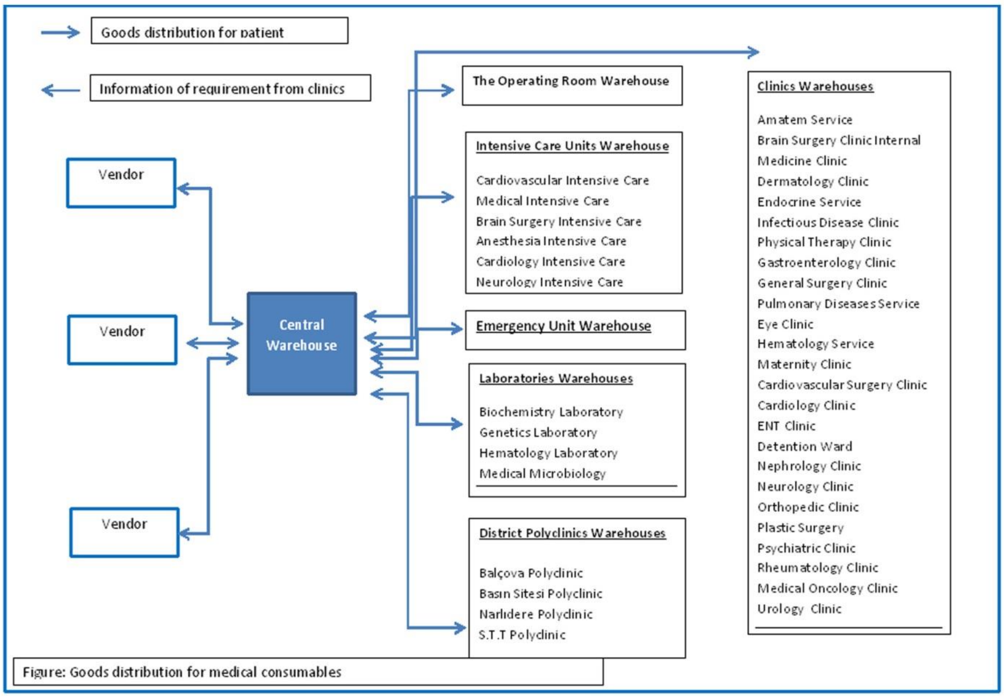


Figure 7.Goods distribution for consumable medical supply

4.3. Root Cause Analysis

Root cause analysis is used to identify the root causes of problems or events and sort out these causes to improve the performance. As there are many problems in the current system, we conduct a root cause analysis to select for causes and possible solutions. The most commonly-used types of the root cause analyses are a cause-and-effect (C&E) diagram, Current Reality Tree, and ANOVA (Arsyid, et al., 2013). ANOVA is a statistical method tool to examine the difference between the averages or the “means” of two or more population. The aim of this analysis is to measure the cause-effect relationship through statistics (Nykiel, 2009). Current Reality Tree is a method to identify the cause of problems by the undesirable effect of the core problems in an organization (Sesiovira & Adhiutama, 2014). If an error is identified in this analysis, the Current Reality Tree does not explore the prevention or recovery (Arsyid, et al., 2013). Due to the limitation of these two methods, C&E diagram is the best method to find the consumable medical inventory problems with solutions. In this method, first, underlying causes for inventory management problems are identified. Second, to prevent future a recurrence, the method helps managers to know why the fail occurs in the inventory system and how to control and fix it with effective recommendations (Rooney & Heuvel, 2004). When everything is considered, using the C& E diagram can help to identify the root of the problems for the high total inventory cost in the hospital.

4.4. Cause and Effect Analysis

C&E diagram is a graphical tool used to identify possible causes for an effect by describing the relationship between an effect and its causes (Besterfield & Besterfield, 2003). It is a valuable problem-solving tool (Li & Lee, 2011), created by Kaoru Ishikawa in 1943 and sometimes called Ishikawa diagram as well.

As illustrated in Figure 8, C&E diagram is generated with the effect on the right and causes on the left. The effect side is the quality characteristics that needing improvement. The main causes are placed on the diagram’s left side and each major cause is further dived into minor causes. Each major cause is then specified and categorized according to its impact on the problem. Then, rank causes in the order of the significance level of the problems. The findings of C&E diagram provide insights for further correcting actions and developing solutions (Besterfield & Besterfield, 2003).

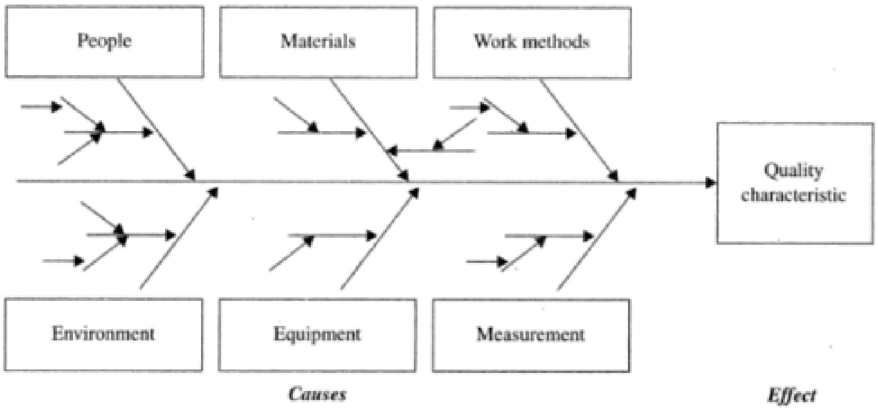


Figure 8. C&E Diagram Example

Source: Quality Control Dale H.Besterfield (2009)

To begin with a C&E diagram, the symptom of the problem is observed in the consumable medical inventory management. In this stage, the question ‘what is the problem related to the consumable medical inventory management’, is asked to help us to define the problems properly. It is placed on the right side of the box at the “head” of the C&E diagram. In the second stage, the causes are then analyzed by asking ‘why did it happen.' Six major causes are identified with this question, namely, poor inventory management, poor purchasing management, poor demand management, poor storage management, unexpected situations, and poor hospital information systems. In the third stage, the aim is to find out solutions to our problems by asking the question ‘what will be done to prevent the problems?’ Every major and minor causes are analyzed and evaluated in the current inventory management system to improve the effectiveness of the inventory management. The C&E diagram on the hospital is shown in Figure 9 with both effects and causes.

Figure 9. The C&E Diagram for consumable medical supply warehouse

4.4.1. Cause 1: Poor Inventory Management

The consumable medical supply is a critical section in the healthcare service of the hospital. The consumable medical supply's availability or shortage has either positive or negative impact on the healthcare service (Sarda & Gharpure, 2010). Difficulties in inventory management are usually caused by poor inventory control management (Kokilam, et al., 2015). The current study would investigate the effects of the poor inventory control management. There are four main reasons for the poor inventory control management: poor inventory control method, inventory record inaccuracy, stock out, and excess stock.

Poor Inventory Control Method

The first cause is poor inventory control method. Inventory control method is the tools used to manage inventory (Bose, 2012). As mentioned before, the hospital uses standard continuous inventory level policy for all items that ignores considerable differences among various items. More scientific methods should be used for items, especially for high volume ones.

Inventory record inaccuracy

The second cause of poor inventory management is inventory record inaccuracy. Inventory record accuracy (IRA) is a measure on how closely the official inventory records match the physical inventory (Lee, 2006). IRA has an adverse impact on the inventory managements. Moreover, safety stock is not regularly checked and generally held as an additional stock since procurement department does not trust the IRA in the hospital.

Further C&E diagram shows that Inventory record inaccuracy is mainly associated to both process and volume related errors in the hospital. For example, the inventory levels sometimes do not reflect the actual stock of the items. In the clinical side, the nurse may not update a number of used items on time to the system. The amount of used items should be deducted from the inventory at the end of the day by the medical secretary. The medical secretary sometimes does not update the information or do it inaccurately. Due to the manual data entry, mixing of the item codes can lead to discrepancies between recording and actual data quantity and locations. Each error in transaction process steps may result in incorrect data record, leading to in inaccurate demand forecast, stock out, excess inventory, or unsatisfied patient services. To avoid such situation, all inventory transactions should be updated accurately and on time in the software system. In addition, the hospital should motivate all staff to maintain right data tracking (Bose, 2012). Another observed problem is the lack of good data systems such as automation barcode monitoring system which affects the track of the item usage, location and inventory levels in the hospital.

Volume related errors are similar to process related errors, as every transaction is prone to mistakes. Both process improvement and transaction minimization can be used to reduce new errors. At the same time, cycle counting and physical inventory checking should be used to remove existing errors (Lee, 2006).

Stock out & excess stock

Inventory management is the key to provide smooth service and maximize the efficiency and effectiveness of inventory usage. The C&E diagram shows the weakness that occurs in the poor inventory management and inventory record inaccuracy at the hospital. Any failures in inventory control method and inventory record inaccuracy may cause either excess inventory or shortage inventory. Both excess stock and stock out adversely effect on inventory management. Having looked at the causes of excess stock and stock out, which may cause unsatisfied patient services, high holding cost, high purchasing cost because of urgent orders, negative impact on the cash flow, occupying of excess space in the hospital, and obsolete and damaged inventory.

4.4.2. Cause 2: Poor Demand Management

In this stage, the C& E diagram would analyze the root causes of poor demand management and to reveal its effects. This analysis is to better understand problems associated with the poor demand management and provides a practical approach to solving these problems as well.

The demand forecasting is a key component in the demand management. According to Heroman, et al., (2012), many weak data result to bad forecasting outcomes in prediction. Therefore, the data accuracy plays a vital role in creating reasonable prediction. Good prediction is usually associated with quantitative method that needs accurate data, looking backward and forward in addition to some common sense. Besides, good prediction helps to find the right balance among inventory, purchasing, and demand management. Forecasting future demand accurately is a key factor for effective inventory, purchasing, and demand planning since it leads to higher patient satisfaction and reduction of costs. When considering the demand forecasts, the main idea is to make the possible estimate closer to real data. In general, the forecast is rarely correct; there are continually some errors. The whole procedure is to create prediction for the unknowing future. The demand forecast may be accomplished with a minor difference data when comparing with the actual data.

Inaccurate Forecasting Method

Robison (2003) claimed that all rooted causes of demand problems relate to the inappropriate forecast method usage and the data in accuracy. The hospital uses the combination of both quantitative and qualitative method. The order quantity of any item is based on an annual consumption ratio. When an officer starts to generate forecast on a consumable medical item, he checks the total consumption of the item from the historical data, especially the last year, and then reviews the total consumption of the item in the same year. After that, a report on the item is prepared in the stock utilization rate of the previous year with a report by the officer. This report is submitted to the needs assessment commission. This report is evaluated by the combination of both qualitative and quantitative techniques. To estimate demand with qualitative techniques, management perception is captured in this report by checking at the trends on the stock utilization rate report, upcoming events, and personal experiences. It is mainly generated with the jury of executive opinion in terms of their experience, comments, and judgment. But, it sometimes leads to the inaccurate demand forecast due to the using of simple mathematical demand estimation. Using this demand forecast method could result in either overstock or stock out. According to the feedback, the hospitals require a more accurate method of forecasting. The mean absolute deviation may be useful to measure the forecast errors, and some quantitative demand forecasting method can be used. The goal of forecasting is to obtain closer estimation. From this perspective, it is important to decide what factors are to be considered and how to weight the forecast errors. According to Arsyid, et al., (2013), the weight of error on demand forecast would have a big impact to reduce the occurrence of stock outs.

Data Inaccuracy

The accuracy of a demand forecasting method does not only depend on the selection of appropriate forecasting method, but also the data accuracy (Robison, 2003). The most obvious errors observed in the hospital are caused by incorrect coding, i.e., user-generating either incorrect coding or lack of coding. To amend this problem, a long-term action is to implement a system to ensure the right data entry. Because of the incorrect coding, the annual consumption amount sometimes does not match the reality. Thus, incorrect coding is a risk factor for demand forecasts and inventory control. Any errors related to incorrect codes will cause the wrong forecasting.

Incorrect Re order Point and Order Quantity

A major cause of the poor demand management is the calculation of the reorder point by the hospital's methods. It is not a scientific method. It requires the two-month consumption unit to be in storage. When the stock level drops to 45-day consumption amount as the reorder point, the system places an order to replace the one-month consumption amount. The impacts of this re-order point and order quantity in the current demand forecasting method may result in either excess stock or stock out. According to Arsyid, et al., (2013), all the anticipating demands must be fulfilled. Unavailability of needed materials at required times may lead to high cost of supplies. Therefore, the effective stock level controls are crucial and needed.

Obsolete Inventory

Another important factor in the demand forecasting is that there are many obsolete items in the warehouse, especially, for slow moving. As a public hospital, it has to the guarantee the availability of most items because of the demand uncertainty from patient and disease variety. The uncertain demand of the item sometimes causes an incorrect request. If demand planning and control procedures are managed efficiently and effectively, they would limit the amount of obsolete inventory in the hospital. These obsolete items become useless over time. While the hospital may transfer some partially useless items to another public hospital, it would face another budget problem, called transform cost.

4.4.3. Cause 3: Poor Purchasing Management

In the health care environments, purchase contracting policy plays a key role in reducing purchasing cost and has faced major challenges. A good purchase contracting policy improves health systems performance and reduces purchasing cost. There are a range of processes in the management of purchase contracting policy in the healthcare. The processes of purchase contracting include, (i) writing of contracts; (ii) tendering, (iii) bid evaluation, award and negotiation and (iv) monitoring and support for contract implementation. Moreover, contracting of health services is growing as a new mode of governance in purchasing of services (Zaidi, et al., 2011). In addition, the purchase contracting has increased focusing on the ability to write and monitor well-specified contracts (Siddiqi, et al., 2006). Petrou (2015) provides an in-depth analysis on the long-term effect of tendering on prices of branded pharmaceutical products, which shows tendering is relevant to a statistically significant price reduction and provides a cost advantage. Tendering can be viewed as a potent pricing and reimbursement method in the long-term. To be successful in the tender process, it should be done in accordance with country's operational health policy framework (Petrou, 2015). On the other hand, Zaidi et al., (2011) have suggested that the purchase contracting process is complex and the purchasers who work with legal process still have to make an effort to manage the contracting process well in addition to the provision of well-designed contracts and guidelines. The results of their study indicate that weaknesses are found in three areas (i) poor capacity for managing tendering; (ii) weak public sector governance resulting in slow processes, low interest and rent-seeking pressures; and (iii) mistrust between the government and the private sector. Poor purchasing management in hospitals may have some critical consequences, such as the lack of inventory control, poor contract compliance, excess inventory levels, frequent stock-outs, costly emergency deliveries, frequent workflow interruptions and expensive rework, and increasing emergency labor requirements (Kumru & Kumru, 2013).

Long Bidding & Buying Process

It is known that the purchasing management is managed inefficiently because of some problems in the current purchasing policy. A main part of the hospital purchasing policy is determined by the public procurement legislation. Because of these legal processes, the purchasing process can vary between 3 and 8 months, which normally take at least 3 months. We then examine the factors that may cause failures in the purchasing process. The competitions among suppliers may cause a long duration of the buying process. The suppliers participating in the bidding would closely follow the technical specifications and pricing at the tender. The objection to the tender resulting from any supplier may further extend the procurement duration. Sometimes the purchasing process has to start again and all legal documents are prepared again. It can then lead to a longer buying process and an emergency purchasing. The clinic side may then experience stock out and serve patients poorly.

Technical Specification Problems

The other major problem in purchasing management is that the item on tender cannot have any specific trademark in the technical specification document. Because of supplier competition, when a doctor draws up a technical specification document, it should be fair, objective, and each property of the item must be defined clearly. If the technical specification has any specific trade mark, the suppliers would object to the tender, which may cause the extension of the bidding process and the stock out might occur. The demand management would have to urgent order to meet the demand.

The technical specification is normally prepared by one doctor for general-use items. In such a process, there may be a problem either with other clinics or with other doctors in the same clinic. Different doctors may want to use different treatments with different consumable medical supplies, especially for the surgical patients. In this aspect, it is important to prepare a technical specification report according to the request of multiple doctors. The preparation of the technical specification by multiple doctors can lead to better outcomes for the general-use items.

Price Objection

Another major problem is the price objection from suppliers to tender due to the competition among them. As a result, the competition can prolong of the procurement period. In the same time, the clinic side has to give urgent order to prevent the stock out. To avoid the price objections, the price of an item should be determined by considering MKYS system, a software system where the purchasing staff of public hospitals in Turkey can check and show the price of any item. The aim of this software system is to control the price differences for the same item throughout Turkey. The system prevents public hospital from paying different price from suppliers for the same item.

To sum up, the public hospital is an organization with limited resources like limited budget, but facing many challenges such as increasing cost and severe competition, which requires more effective planning and supervising activities (Kumru & Kumru, 2013). Due to the tough economic conditions in recent years, public hospitals place a greater emphasis on the tender to cut costs, but there are also many disadvantages for tenders. The extension of the purchasing time and termination of the contract are two most commonly effects of poor purchasing management. The causes of poor purchasing management include employee related errors and problems in purchasing management process. Process improvement plays a key role in healthcare service to correct these failures (Kumru & Kumru, 2013). Keeping up with fast changes in technology is beneficial to improve the purchasing process. To maintain a strong relationship with suppliers would also help hospitals to cut purchasing costs (Bose, 2012).

4.4.4. Cause 4: Poor Storage Management

Availability of consumable medical supply is one of the most visible and obvious indicators that a health system is functional (Muyinda & Mugisha, 2015). The most significant component of the health system is a storage management. In this stage, we are to analyse the storage management with cause and effect analysis. From healthcare perspective, storing is an activity where unused inventory, stored in various storages depending upon the types of inventory (Arsyid, et al., 2013). In the hospital, a large amount of consumable medical supplies from the warehouse come in and out every day. This activity requires good data and storage management that synchronizes the existent stock with new data every day. Poor storage management mainly comes from non-standardized storing activity in the hospital.The storage management may experience problems from errors such as keeping expired product and obsolete inventory, first in first out (FIFO), stolen, miscount, and paperwork errors. The main cause of these problems is manual processes and data inaccurarcy.

Manually Processes

One cause for the poor storage management is manual processes. The on-hand stock is controlled manually by the demand management staff in the warehouse, who counts the consumable medical supplies to create a replenishment order to avoid stock out. In addition to a counting or visual scans, giving a rough estimate of inventory levels according to experience or best guess by demand management staff, the staff should check inventory level with the software system at same time. To complete accounting or visual scanning on a daily basis requires a large labor force for all items. Moreover, the storage staff has no time and energy to monitor

FIFO and expired items daily due to the heavy workload. In order to prevent of expired stock, items should be issued on a FIFO. The main reason for expired items is because of insufficient checking of stocks, not practicing FIFO and no time for evaluating. Aziz et al., (2013) implemented a new system with regular checking storage and improved further the process of supply by taking corrective actions. The value of drugs disposed reduced by applied the new system. Stock controlling is done by pharmacy staff on expired drugs once a month, and monthly report will be given to all unit managers. There was 94% reduction in term of drug wastage.

Furthermore, miscounting or paperwork errors would affect the inventory balance. Any deviation from the data due to miscounting or paperwork errors can result in problems such as stock-out, over stock, inaccurate forecast, unsatisfied patient service, and high cost. In order to avoid the errors, storage clerks should be trained and systematic monitoring method should be developed. To reduce the data inaccuracy, the product usage data should be reviewed at least every 1 months visually to identify any seasonal or cyclical patterns. This system helps to balance inventory and prevent data usage errors. To make the system functioning properly, the clinic side and the consumable medical supply side needs to focus their efforts on synchronization to balance the inventory. In addition, they have to consider supply lead time, service level expectations and their purchasing policy for a smoothly systematic process. If the system is well supported by automation and information technology, it may produce good results.

Data Inaccuracy

Data inaccuracy is a matter affecting to the quality of data. Accurate data can improve the efficiency of storage management in the hospital. A wrong entry in the storage can lead to the loss of profits, reduction of patient service level and item damage or obsoleting due to the item expiry. The FIFO and expired problem is critical since the lack of awareness or knowledge is the store staff’s most error in inventory management. The hospital information systems are useful for monitoring the FIFO and expired item. In order to prevent expiry and FIFO issues, the store staffs should identify the FIFO and expired items in the software system. To have more reliable and accurate data, the barcode scanner systems can be used to replace manual data entry systems and eliminate human error.

4.4.5. Cause 5: Unexpected Situation

It was observed that the hospital was struggling to meet demand in unexpected situations, including urgent demand and irregular demand for stationary items.

Unexpected Additional Demand

One of common event is the emergence of an unfamiliar disease during surgery, which extends the operating time and increases the amount of medical supplies consumed. The degradation of the item quality at the surgery or treatment leads to over-consumption and create additional demand. These situations may cause forecast deviations, and result in stock-out and emergency purchases. Consequently, total cost increases in the hospital. To prevent the occurrence of unexpected additional demands, scientific forecasting methods should be applied and tested. In addition, it is found that emergency surgeries tend to consume huge amount of consumable medical supplies. For instance, in the case of traffic accidents, the consumable medical items are consumed in larger quantity than in normal operations. Changing the demand forecasting method can solve these problems.

Irregular Demands of Stationary Items

Another important issue is that there are multiple stationary items in the warehouse. These items are chosen by surgeons, according to the ease of use and operation needs. Sometimes the consumable medical supplies used in a same operation may be different due to the preference of doctors. The demand may suddenly change significantly due to such preferences. When a doctor moves to another hospital, products ordered by him may not be used by other doctors. Same times, the item may be upgraded with the technological advances in medical treatment. These advances may reduce the operation time or help the patient to recover more quickly. As the effectiveness of doctors' treatment is more important than the item cost, high-tech items are chosen to improve the effectiveness of a treatment. Some old items are then not used and remain in the shelf and called stationary products.

4.4.6. Cause 6: Poor Information System

In broad terms, hospital information systems can be defined as a health program that use to collect, process, and transmit health data to support the monitor, evaluate, and control of the healthcare system. According to a definition provided by Lippeveld, et al., (2000), hospital information system is as an integrating mechanism for data collection, processing, reporting, and usage with the purpose to improve the healthcare service effectiveness and efficiency. Moreover, hospital information system has been seen as a key factor in ensuring that reliable and timely health information is available for operational and strategic decision-making and resulting in better healthcare services and enhancing public health (Hunter, 2011). In contrast, due to the poor implementation of information technology, medical storages in hospital have experienced the increasing inventory and escalating budgets for procurement of drugs (Kumar, et al., 2016). Here we examine the impacts of poor hospital information management system as a cause for high inventory cost.

Poor Data Quality & Inaccurate Identification Codes

To stay in a business in fierce competition, suppliers closely follow the latest technology and develop new items continuously. A new item takes a different barcode number in the hospital. This difference sometimes causes confusion with the old item. There are numerous items in the hospital facing such a problem. This results in poor data quality in some items that is frequently inaccurate, stationary, or obsolete. Incorrect data can lead to increased cost due to pricing error, wrong barcode number, and incorrect consumed amount, which cause time wasted and extra works for managers to deal with rebate return and credit issues with suppliers. The data quality problem has negative impact on the patient service level (Pinna, et al., 2015). Another major impact of the poor data quality is that unreliable data generate inaccurate forecast, excess stock, and stock out in the hospital. Better information management will lead to greater coordination in the hospital supply chain.

Good information system can help users to spend less time in inventory planning, forecast, purchasing planning, and control. The hospital information management system is the backbone of a hospital. The biggest problem in the hospital is that data do not match among departments. Data transformation is needed to ensure they are compatible with each other and the data should be integrated with other departments. If the data are not consistent across departments, the system may experience failure. Therefore, inconsistent data cause problems such as huge buffer stock or stock out. Pinna, et al., (2015) suggest that the movement of inventories should be properly synchronized as shown in Figure 10. Items are delivered quickly to the right location at the right time. This improvement is undertaken with the following steps:

- At every level, the storage and movement of items are tracked along the hospital supply chain, which provides reliable data.
- Enable smooth stock rotation to prevent obsolete, stationary, and expiry items.
- Support managers to make decisions with information on the total amounts of inventories and their locations (Pinna, et al., 2015).

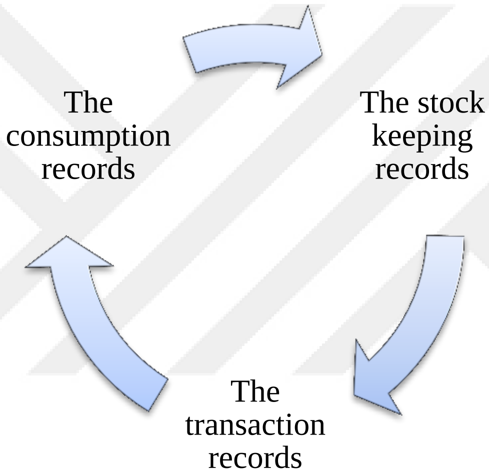


Figure 10.The data recording system

Lack of IT Equipment

The hospital is not able to update equipment easily because of that high cost of technological equipment. It is also not able to change the comprehensive software program which tracks all product usage in the hospital by a centralized information system. An upgrading at the hospital can provide huge benefits and reduce wastage. To tackle the problems of in the purchasing transactions, it may be useful to operate an electronic ordering system. The problems of the faulty ordering process, overstocking and stock out are solved by a comprehensive software program. It is found that hospital staffs often do not have adequate IT capacity to maintain the equipment, and also lack technical supports (Bose, 2012).

4.5. Problem Identification

We have examined the inventory management in the hospital with various problems. To understand the real causes behind the symptoms, we have performed the cause and effect analysis at the hospital. The high total inventory cost, the stock out and excess inventory arise from the poor inventory management and inaccurate inventory method. It means that the biggest problem is related to traditional inventory management the hospital. Many problems are found in the medical supply warehouse because of the item variety and huge amount of items. Inventory policy in healthcare has to manage all combinations of items in the warehouse. In this context, creating an effective inventory management is a strategic decision in the hospital. The uncertainty of demand, the item variety and the huge amount of items are difficult for the inventory managers in the consumable medical supply warehouse. For these reasons, the hospital needs a more effective method to manage inventory so that it can meet demand and reduce their inventory cost at the same time. This study is thus initiated to reduce the total costs without reducing patient service levels under the demand uncertainty.

5. Developing Better Inventory Policy

5.1. The Research Methodology

In general rule, a research can be divided into five stages, as illustrated in Figure 11 (Stuart, et al., 2002). In this thesis, the research is similar conducted according to this framework. There are two stages in the conceptual framework. First, we select a few items for this study, and the second stage is the implementation of our inventory system as shown in Figure 12 and Figure 13. The first stage is related to analyse the hospital inventory system.

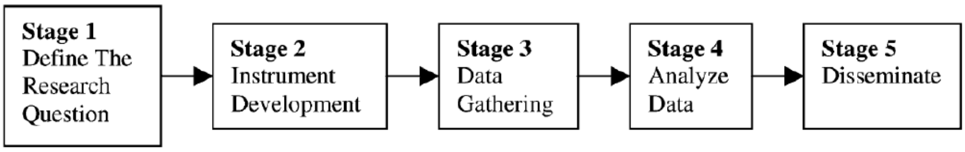


Figure 11.The five stage research process model (Stuart et al., 2002)

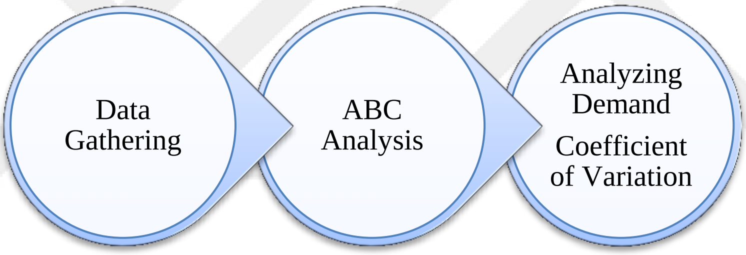


Figure 12.Data Selection

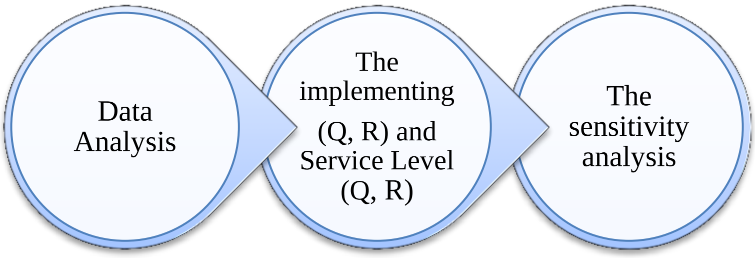


Figure 13.Implementation of Proposed Inventory System

In the first stage, we gather the data using the 2013 actual item usage. The next step is ABC analysis which is used to divide items into three categories. The ABC analysis provides a method for identifying items which result in a substantial impact on overall inventory cost, as well as providing a method for identifying different categories of stock that will need to different management and controls (Vollmann, et al., 2005). The ABC analysis has helped us to choose a few critical items for the study. In order to enhance an appropriate inventory policy for an item, one must first characterize the demand for that item should be determined in terms of volume and variability (DeScioli, 2005). For this purpose, for each item the coefficient of variation is applied, then the daily demand is classfied as low, moderate or high variability.

The second stage is to propose (Q, R) and Type II Service Level for the hospital inventory management system. The total cost for the current system is calculated, and compared with the proposed inventory system. According to Hopp & Spearman (2008), the (Q, R) continuous policy is easier to implement in practice when compared to other inventory policies.

The final step is to perform the sensitivity analysis to show the robustness of our results.

5.2. ABC Analysis

In this section, we introduce the method for managing multiple items in inventory and prioritizing the items for improvement, called ABC analysis. It is an effective cost analysis tool by classifying the items in a list and prioritizing them according to usage. The most common used method is to split the inventory items into three groups, called single-criterion ABC analysis. Group A is vital, and Group B is quite significant, while Group C is not important. This method is also called the eighty/twenty rule. 20 percent of the items are in "A" in the inventory, which account 80 percent of the annual cost volume usage. There are six stages in an ABC analysis:

1. Designate the method of sorting the data: by a problem, cause, type of nonconformity, etc.
2. Determine whether the dollars or the weighted frequency, or frequency can be used to classify.
3. Gather the data for a proper time interval.
4. The data are ranked according to categories descending order.
5. Calculate the cumulative percentage.
6. Build the diagram and find a way to identify the vital few.

A considerable amount of literature has been published on ABC analysis. In brief, the experience has revealed that it is easier to make a 50% quality improvement in the vital few items (Besterfiel, 2009). One of the primary features is that ABC analysis helps the inventory management. The central consumable medical supply warehouse is responsible for managing a total of 2961 items in the consumable medical supply. It takes too much time for controlling each item in the inventory. ABC analysis is a method for categorizing items since the most (important items should receive) more management attention (Vollmann, et al., 2005). Considering the criticality of items, a manager needs to focus on the 'vital few' and spends less time on the' trivial many'. Therefore, this analysis is first implemented to categorize items into three groups according to their annual cost-volume usage. In this thesis, we implemented the ABC analysis in the hospital based on follows criteria.

$$Criteria = Unit\ cost * Annual\ usage$$

In the ABC analysis, the annual consumption and expenditure are examined by considering annual cost volume usage on each item in consumable medical supply for one year (January 1, 2013 – December 31, 2013). As seen in Table 4 and Figure

14, the ABC analysis reported the total percentage by value, the number of items, total value and total percentage by number of items. The annual total consumable medicals' expenditure was 30.857.363, 28 TL in 2013. According to this classification, an "A" item forms 19% of total number of items in the stock. However, the percentage of their total value is 80% in one year, while B item comprises 26% of the total number of items in stock, and the proportion of their total value is 15 %. Besides, although the C items comprise 55% of the entire items in number, their percentage by the total value is only 5%.

Category	Total percentage by value	Number of items	Total value	Total percentage by number of items
A	80	576	24.686.711,48 TL	19%
B	15	762	4.629.867,044 TL	26%
C	5	1620	1.540.784,751 TL	55%

Table 4. ABC Analysis of Consumable Medical Supply

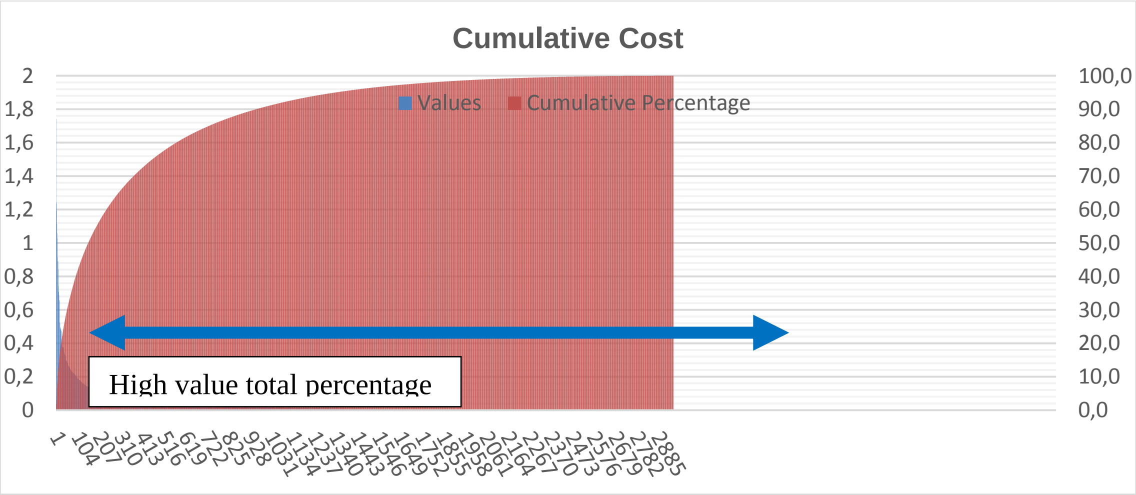


Figure 14.ABC analysis of the medical supply in central warehouse

Class “A” items are fast-moving, often featuring, professional items which are expensive. For example, the surgery related specific items at the orthopedics, cardiovascular surgery, or the neurosurgery cases. These consumable medical items are fast-moving products, and are experiencing continuous self-improvement and renewal. The older products are no longer preferred by doctors and become obsolete in stock. It means that older items stay still in the stock. Due to more sustainable or innovative, doctors may prefer new items to reduce the operation time or get better results from the treatment. Therefore, the hospital may encounter obsolete items in the orthopedics, plastic surgery, and neurosurgery department. At the same time, A group also includes standard low price products but with huge consumption volumes such as gloves, cotton, and syringe.

An interesting result from the data is that “B” items tend to take lots of stock against unexpected situations. Character of B group is still fast - moving, some of which may have more consummation by volume compared to some expensive “A” group items.

“C” items were noted to be slow moving products with excess stock. We can see much more obsolete products in C group than that in other groups. The price of items is lower than the other two groups.

5.3. CV Analysis

In this section, the method of coefficient of variation (CV) analysis is explained. The normal distribution is usually utilized in the literature to measure customer demand (Strijbosch & Moors, 2003). To determine the variability of different demands, the CV is used. Then, the A class items are divided into three subclasses based on average demand variety, including, highly, moderate and low.

In order to develop an inventory policy for an item, one should first know the demand of the item by the volume and variability to choose the suitable stocking levels (DeScioli, 2005). We calculated the CV first, and then defined the items on variability based on the classification as shown in Table 5 (Hopp & Spearman, 2008).

Demand Level	CV
Low	CV<0,75
Moderate	0,75<=CV<1,33
High	CV>=1,33

Table 5.Classification of Demand

The CV presents the variability as a percentage of the mean, therefore, providing a measure on its relative variability. We classified that a stochastic variable into low variability if CV is fewer than 0, 75, moderate variability if CV is between 0, 75 and 1, 33, and a high variability If CV is bigger than 1, 33 (Hopp & Spearman, 2008). In this thesis, each “A class” item’s CV is calculated according to the following formula.

Where σ is the standard deviation and μ is the mean.

$$CV = \frac{\sigma}{\mu}$$

The most important factor in the hospital inventory management is controllability. The CV fluctuation is the major cause for the lack of controllability, and it can be said that the CV is an indicator of controllability. If the CV of an item is more than 1.33, the item is almost uncontrollable according to Hopp & Sperman (2008). This uncontrollability is visible at the actual patient service level. That is why CV is vital to control stock levels and service level. Hopp and Sperman (2008) compared the three types of variability in details. As seen from Figure 15 and Figure 16 below, the low variability distributions are reported more bell-shaped or normal in probability density than the other two groups.

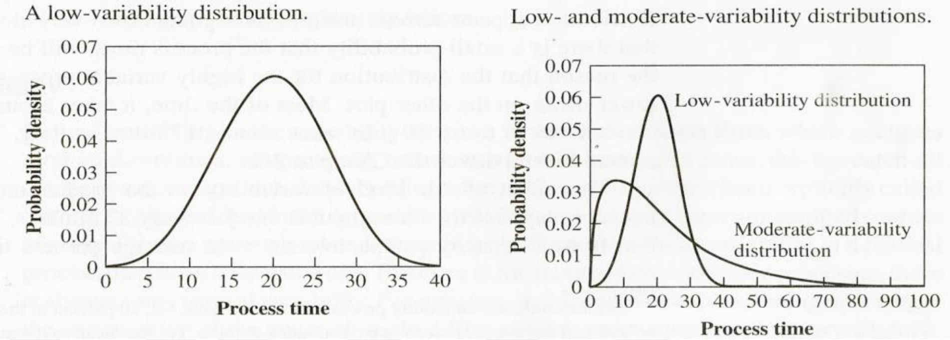


Figure 15.Comparison of moderate and low variability distribution (Hopp&Spearman, 2008)

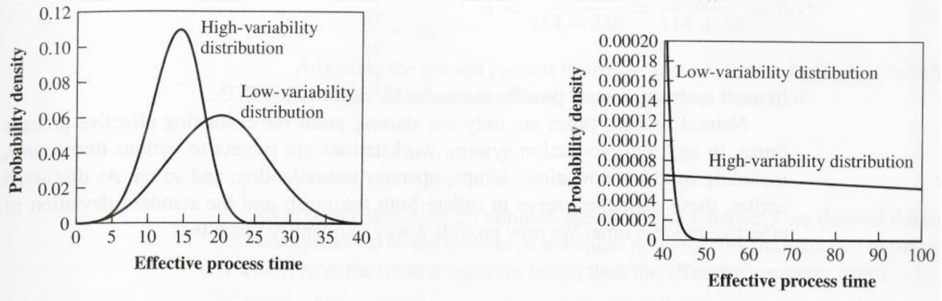


Figure 16.Comparison of high and low variability distribution (Hopp&Spearman, 2008)

Table 6 shows “A” class items according to the variability. The low variability group includes 418 items with a percentage of 72%. The moderate variability group has 316 items with 23% in percentage. The high variability group has 30 pcs and accounts for 5% in percentage.

Demand Level	CV	Number of items	Percentage
Low	CV<0,75	418	72%

Moderate	0,75<=CV<1,33	316	23%
High	CV>=1,33	30	5%

Table 6.Classification of variability by daily demand in hospital for A Group items

5.4. The Selection of Items

We select nine items from “A” class according to demand variability, such that we have three high variability items, three moderate variability items that three low variability items. The effect of demand variability on optimal Q and R can thus be investigated. Furthermore, the items are chosen from both expensive and inexpensive categories, and both specific usage and general usage ones. In this manner, the effect on the item characteristics of optimal Q and R can also be studied. The selected items are presented in Table 7.

Items	Clinic	Demand Variability	Usage	Price
109835	Hemodialysis Day Service & Nephrology Dialysis Services	Low	Specific	15.5 TL
110532	cardiovascular surgery & Angiography Laboratory	Low	Specific	1695 TL
146777	Medical oncology & Hematology unit	Low	Specific	38 TL
110917	All clinics	Moderate	General usage	6 TL
102214	All clinics	Moderate	General usage	0.5 TL
110804	All clinics	Moderate	General usage	2.2 TL
100264	All clinics	High	General usage	0.4 TL
145625	Neurosurgery department	High	Specific	132 TL
147257	All clinics	High	General Usage	1.8 TL

Table 7.General information for the selected items

5.5. Data Analysis

The demand for consumable medical supplies can occur at any moment in the hospital. These requirements generate diverse forms of data. The consumable medical inventory system collects these data in various forms, on a daily, weekly and monthly basis. These data come in different formats and forms to the consumable medical inventory system. The data size, data quality, and distribution type would affect inventory's model selection, and inventory model life cycle (Mulugeta, et al., 2014).

To select a proper inventory model, data analyzing is of vital importance. The idea behind data analysis is to understand data characteristics and choose appropriate inventory policy for the hospital. Therefore, the descriptive statistics is an important part for data analysis.

As mentioned before, the items for consideration is extremely diversified. Therefore, the demand data for each item have to be analyzed individually for appropriated inventory models. When the demand is continuous, the most commonly used distribution is the normal distribution (Ghassami & Ghandehary, 2014). Firstly, we checked whether items follow normal distribution or not. If the item does not follow normal distribution, we will identify the suitable distribution by histogram plots and estimate the shortage costs. The steps of data analysis are shown in following Figure 2.17.

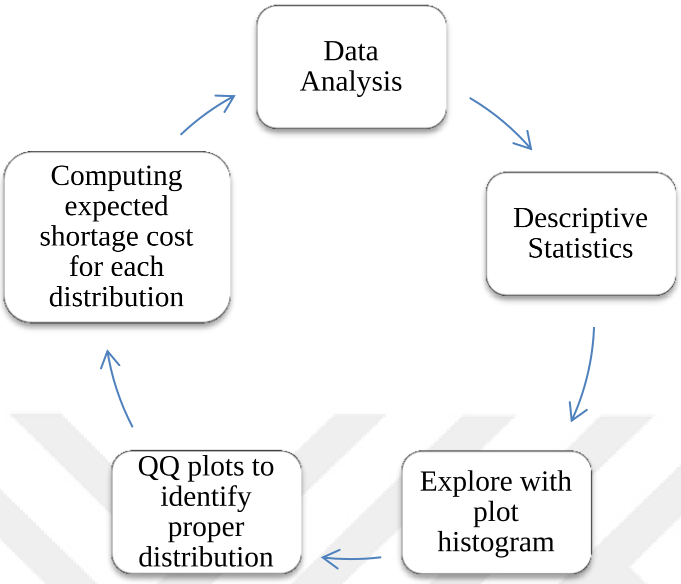


Figure 17. Data Analysis Process

5.5.1. Descriptive Statistics

The demand character of the consumable medical items is vastly diverse. Thus, in this section, the demand data for selected items will be analyzed individually in order to produce more accurate information to implement proposed inventory model. First, we need to specify the distribution type, and the daily demand data are thus analyzed. The daily demand is measured by two variables, the number of demands and the amount of each demand. To find the distribution type, the Easy Fit 5.6 Professional tool is used. The histograms of nine selected items are shown in below figures. We can see that some items are used in large quantities and some are used seldom in the hospital.

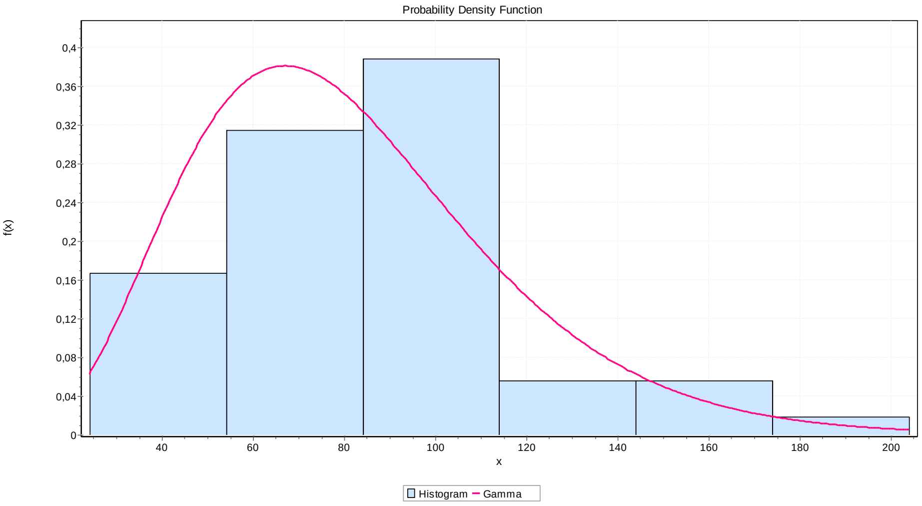


Figure 18.Histogram based on daily demand for Low Item 109835

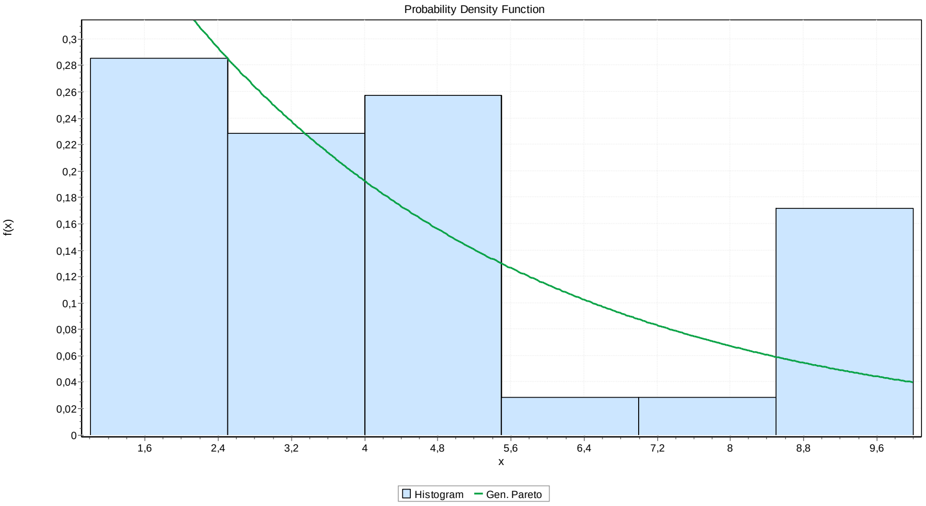


Figure 19.Histogram based on daily demand for Low Item 110532

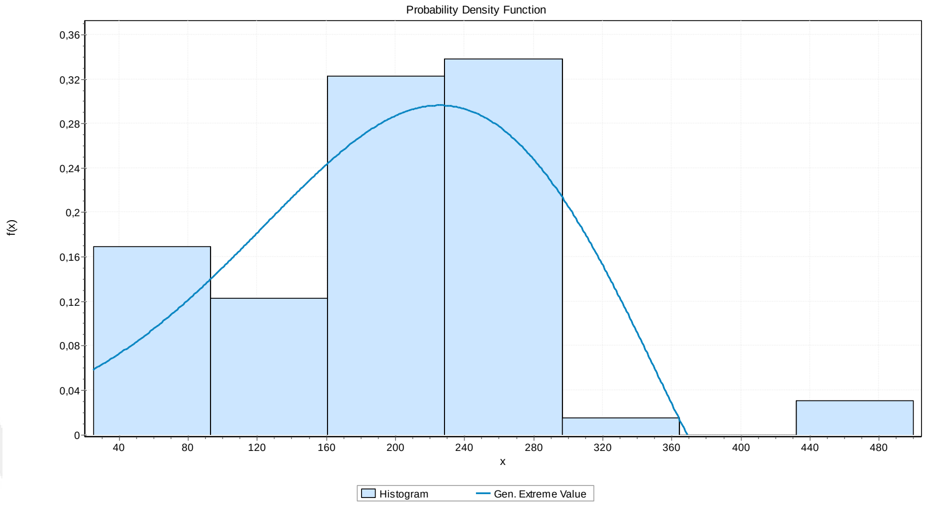


Figure 20.Histogram based on daily demand for Low Item 146777

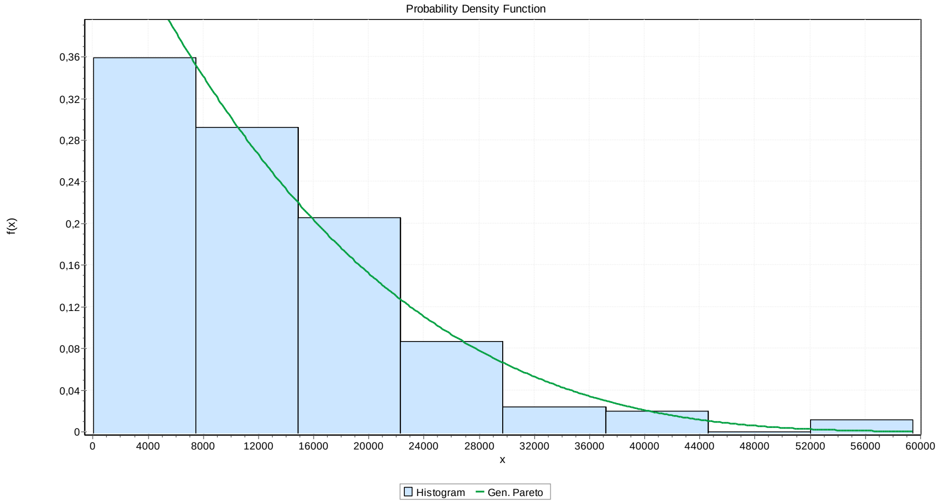


Figure 21.Histogram based on daily demand for Moderate Item 102214

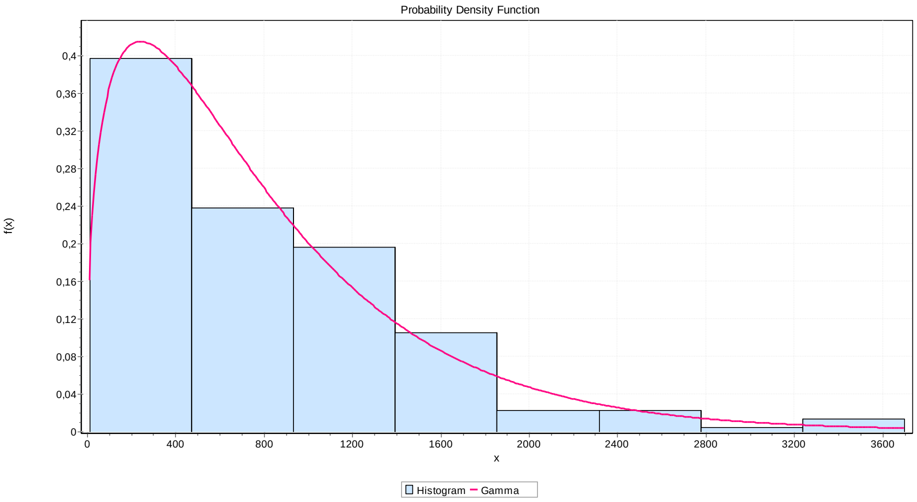


Figure 22.Histogram based on daily demand for Moderate Item 110804

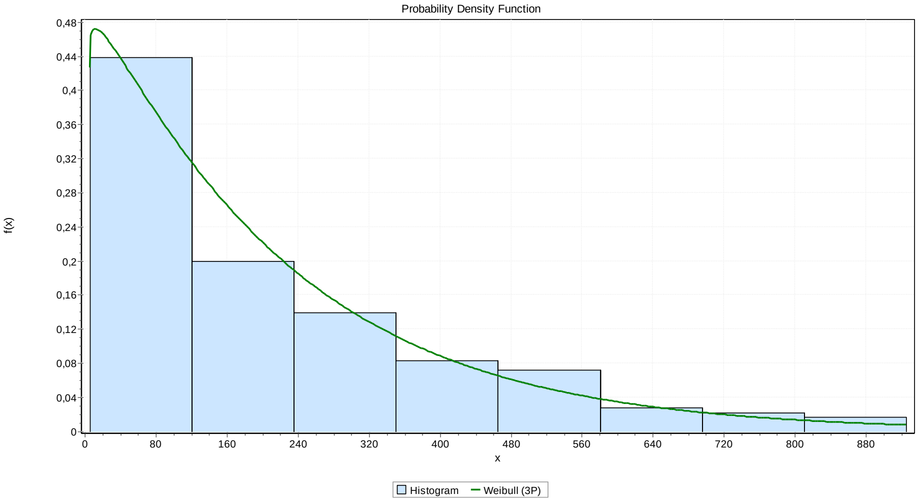


Figure 23.Histogram based on daily demand for Moderate Item 110917

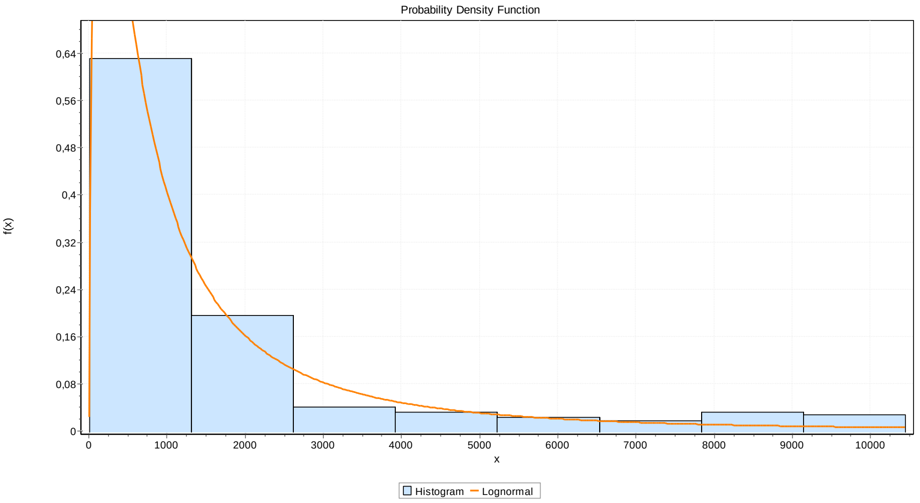


Figure 24.Histogram based on daily demand for High Item 100264

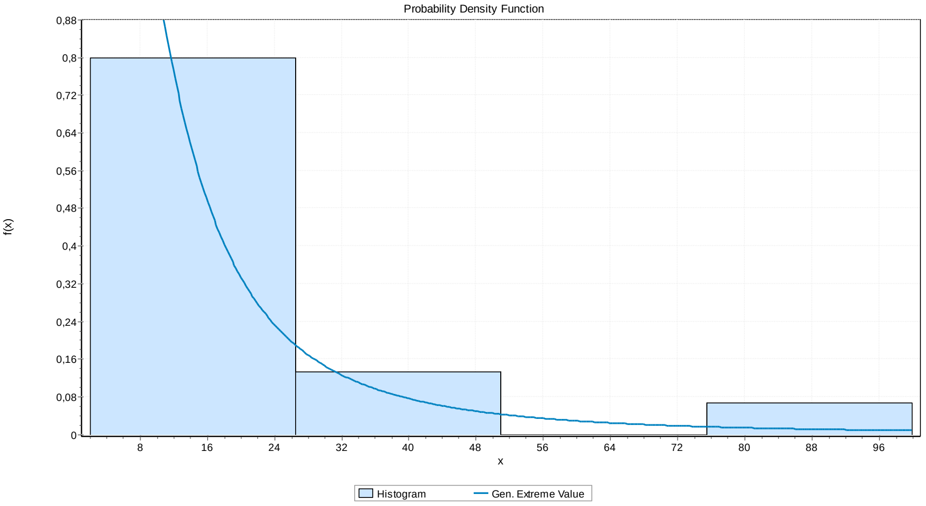


Figure 25.Histogram based on daily demand for High Item 145625

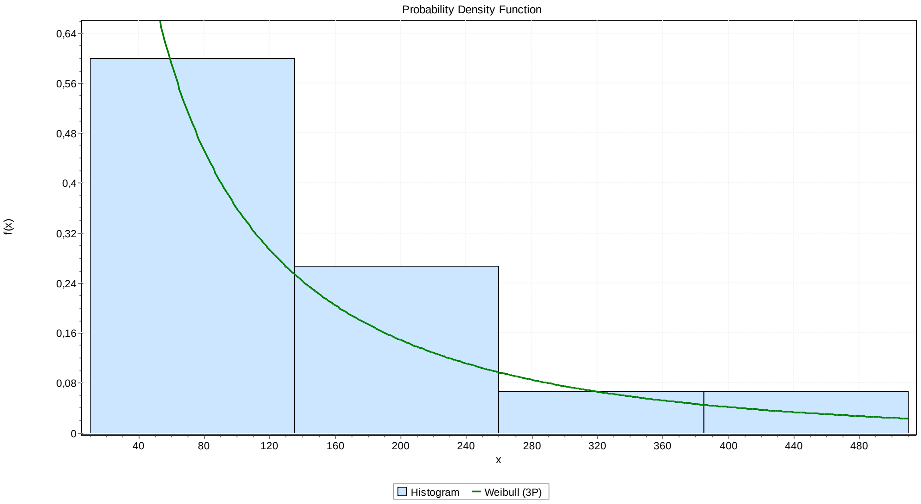


Figure 26.Histogram based on daily demand for High Item 145625

A probability plot is a graphical display tool to evaluate the data fit to certain distribution. The q-q plot of the residuals can be used to evaluate the presumption of normal distribution. If the data are normally distributed, the plotted data will be fit to a straight line. The residual diagnostic checks the normality with p-value or Shapiro-Wilk test (Cabrera & McDougall, 2002). Figure 27 shows the probability plots of some selected items. They check the distribution fit to the normal distribution. When we check the item 109835 on The Figure 27, some points does not fit well with the reference line. It means that the distribution does not follow normal distribution.

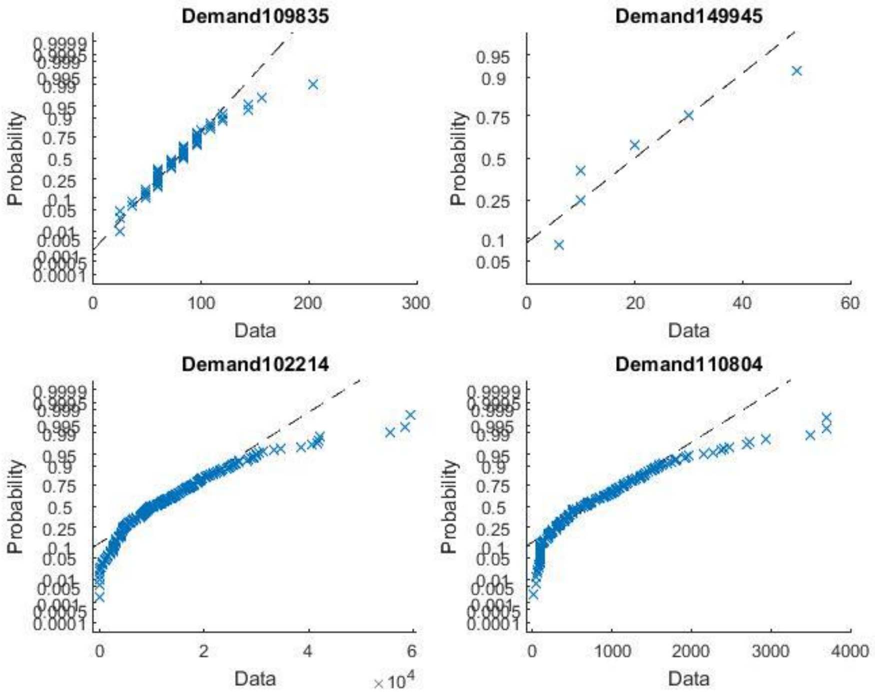


Figure 27. Probability plot of four items selected

The descriptive data analysis is based on three factors, the central tendency (mean, median, minimum, and maximum), the dispersion (standard deviation and coefficient of variation), and the data distribution (skewness, kurtosis, Shapiro-Wilk test) (Mulugeta, et al., 2014). The descriptive statics of some item’s daily demand are shown in Table 8.

After the descriptive analysis, the selected items are found to be to non-normal distribution. In the inventory management process, most items assume the normal distribution of the demand data. In this thesis, we observed that no items follow normal distribution. The transformation data of normality may not be effective either. In the literature, the issue of non-normal distribution has received considerable critical attention. A major problem with this kind of application is the computation of expected shortage cost .In this thesis, we decided to compute expected shortage cost instead of transformation to normality for finding optimal Q and R value.

Descriptive Statistics

	N	Range	Minimum	Maximum	Sum	Mean	Median	Std. Deviation	CV	Variance	Skewness		Kurtosis		Distribution Type
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error	
109835	54	180	24	204	4384	81	84	34	0,418	1154	1,015	,325	2,317	,639	Gamma
110532	35	9	1	10	161	5	3	3	0,629	8	,966	,398	-,339	,778	Gen. Pareto
146777	65	475	25	500	12520	193	200	98	0,507	9533	,283	,297	1,732	,586	Gen.Extr.Value
110917	180	921	5	926	40175	223	150	201	0,900	40365	1,303	,181	1,351	,360	Weibull 3P
102214	253	59460	10	59470	3212775	12699	10406	10168	0,801	103382366	1,587	,153	3,862	,305	Gen.Pareto
110804	219	3690	10	3700	178133	813	650	681	0,838	464175	1,561	,164	3,348	,327	Gamma
100264	220	10445	5	10450	381706	1735	795	2329	1,342	5424886	2,194	-,164	4,110	,327	Log Normal
145625	15	98	2	100	266	18	8	25	1,398	615	2,941	,580	9,647	1,121	Gen.Extr.Value
147257	170	3285	5	3290	62219	366	161	513	1,402	263244	2,783	,186	10,281	,370	Weibull 3P

Table 8.Descriptive Statistic Information for selected items

5.6. Parameter Estimation

In the inventory management literature, the cost parameters are difficult to estimate. The hospital has not defined or calculated these costs yet. We then explain the cost estimation methods to decide cost parameters for the (Q, R) and SQL policy.

Holding Cost

The annual holding cost is assumed to be 30 % of the unit cost for all items.

Ordering Cost

The ordering cost is the fixed cost related to the placing of an order regardless of the order quantity. In this study, the ordering cost is calculated based upon the purchasing policies and procedures within the hospital. As a result of this calculation, the ordering cost is estimated as 150 TL. Here we assume that everything goes regularly without disruption in the procurement process.

Stock out cost

Stock out cost is the financial outcomes of not having the capacity to meet demand for the stock. From the hospital’s perspective, the stock out may affect the patient's health or treatment, and can cause severe problems at the hospital. For this reason, the stock out cost is set at 50% of the unit price for all items.

6. Results

In this chapter, the proposed methodology will be implemented for selected items to find optimal Q and R value by (Q, R) and SQL models. Secondly, the proposed inventory policies are compared with current inventory policy to evaluate their effectiveness.

6.1. Applying (Q, R) Model

The expected shortage cost is calculated first for selected nine items. Firstly, the distribution and distribution parameters are determined by Easy Fit 5.6 Professional Program for each distribution as shown in Table 9. The parameters are derived according to the distribution formula. For example, Weibull 3P Distribution where α is the continuous shape parameter $(\alpha > 0)$, β is the continuous scale parameter $(\beta > 0)$, γ is the continuous location parameter $(\gamma \equiv 0)$. The common formulation for the probability density function of the Weibull 3P Distribution is

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x-\gamma}{\beta}\right)\ exp\left(-\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right) \qquad (10)$$

The Equation 10 and Weibull 3P parameters are derived. The aim of this is to determine f(x) function. The probability of daily item constructs one delimiter tool by Easy Fit 5.6 Professional Program to find X point. Finding the expected shortage cost is generally difficult. The main problem is to calculate indefinite integral and mostly result in divergent results. To evaluate on the demand property, we need to set a limit if the endpoint of the demand interval is infinite to make to the equation simple. The integral is computed by Wolfram Mathematica 9 in this study.

Data	Parameter	Distribution
109835	α=5.76 β=14.1	Gamma
110532	k=0 μ=1 $\sigma = 4$	General Pareto
146777	k=-0.48988 μ=169.89 $\sigma = 97.61$	General Extreme Value
110917	α=1.0289 β=220.73 γ=4.9226	Weibull 3P
102214	k=-0.22457 μ=844.75 $\sigma = 14516$	General Pareto
110804	α=1.4253 β=570.67	Gamma
100264	α=1.3 μ=6.7	Lognormal
145625	k=0.55987 μ=6.2918 $\sigma = 6.3538$	General Extreme Value
147257	α=0.70666 β=273.88 γ=5	Weibull 3P

Table 9.Parameters information for selected items

To calculate 146777 item, the parameters are given in Table 10.

K-set up cost	**150 TL**
The price of the item	38
Annual demand	12520
Holding cost	11,4
penalty cost	19
General Extreme Value mean	192,62

Table 10.The parameters of 146777 item for calculation Total Cost

Step 1

EOQ $=\sqrt{\frac{2*150*12520}{11.4}}$=574

F(R0)=$1-\frac{EOQ*h}{p*\lambda}=1-\frac{574*11.4}{19*12520}=0.97249$

The x point with pdf f(x) determined by Easy Fit 5.6 as shown in Figure 28.

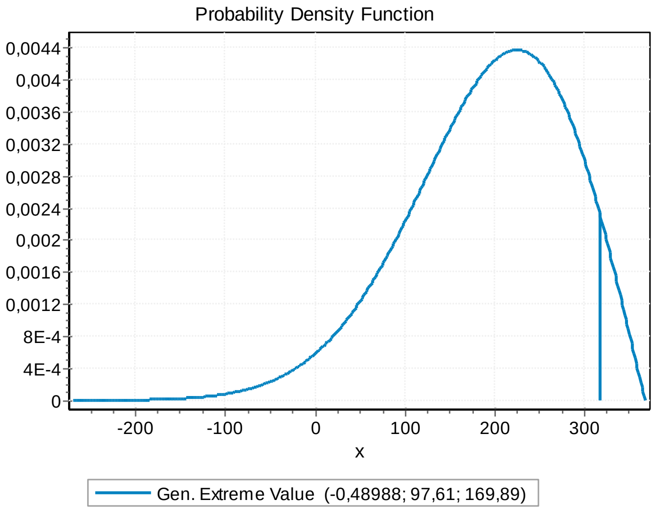


Figure 28.The x point is placement with pdf f(x) at first iteration

x has a value of 334.63

R=0.94*334.63=325.425

$$E(\max(D-R,0))=\int_{rR}^{\infty}(x-R)*f(x)\,dx,$$

$$E(\max(D-R,0))=\int_{R}^{\text{inf}}(x-R)*\frac{1}{98}*\exp(-(1-0.5*\frac{x-170}{98})^{2})*(1-0.5*\frac{x-170}{98})\,dx,$$

Which is defined as n(R).

$$n(R) = -0.000052(2.7183^{(0.01905-0.000026\mathrm{inf})\mathrm{inf}}(-587.63002\mathrm{inf} + 587.63002R - 333648.8\,\mathrm{Erf}[1.86735 - 0.0051\mathrm{inf}] + 3336438.8\mathrm{Erf}[1.867 - 0.0051R])$$

When n(R) computed above equation, the result is too small. In addition, the Q and R value do not converge due to the too small n(R) value. In the second and third iteration, the Q and R value is taken same value in terms of having too small n(R) value. Therefore, we want to make simple in the equation to see the differences each iteration and find the optimal Q and R value. In addition, the n(R) value should be small and reasonable to find the optimal total cost. To find the shortage cost, the equation takes second part which does not include infinite parts as shown in Equation 10. In the literature, when computing the shortage function, the logarithm is limited with an upper bound and lower bound. Instead of this method, the logarithm function calculated with lower bound as R-value and with upper bound as infinite.

$$n(R) = 3336438.8\mathrm{Erf}[1.867 - 0.0051R]) \qquad (11)$$

When computed the shortage cost by Equation 11, the results in 179074, 2 for Q value. We need to do more to simplify the Equation 11 to optimal Q and R value and efficient service level F(R). In The Equation 11, n(R) modulus is reduced step by step as a decimal. The difference in modulus is shown in Table 11.

N(R) Modulus	**Q value**	**F(R) VALUE**
3336438,8	170974,2	-7,58183
333643,88	56630,85	-1,71394
33364,388	17916,53	0,14138

3336,4388	5691,811	0,72723
333,64388	1880,478	0,90988
33,364388	806,3164	0,96136
3,3364388	602,0568	0,97115

Table 11.The difference in modulus calculation shortage cost

According to the above results, the shortage cost modulus is given best result valued at 3, 3364388. Thus, the equation can be indicated as;

n(R)= $3.3364388\text{Erf}[1.867 - 0.0051R]$)

To start calculation

n(R0)=3.34*Erf(1.867-0.0051*325.425)= 0.7684

Step 2

$$Q = \sqrt{\frac{2\lambda[K + pn(R)]}{h}}$$

$$Q1 = \sqrt{\frac{2*12520[150+19*0.7684]}{11.4}}=601.3$$

$$1 - F(R) = Qh/p\lambda$$

F(R1)=0.97118 and the x value is 333.83 form Easy Fit 5.6 as shown in Figure 29.

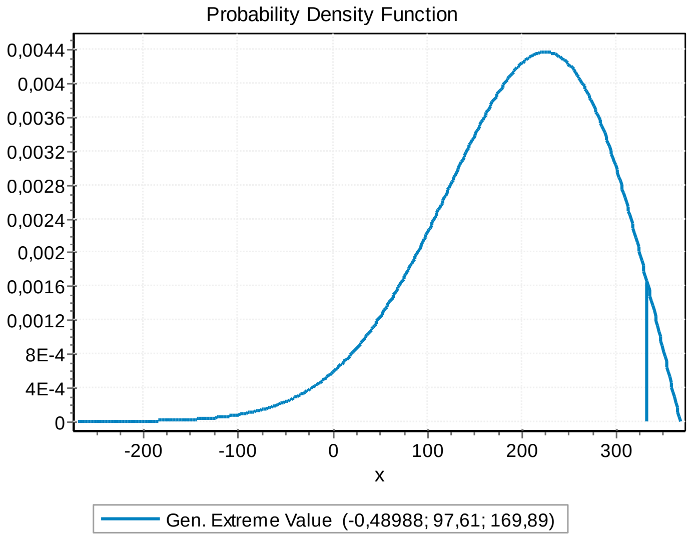


Figure 29. The x point is location with pdf f(x) at second iteration

R1=0.97118*333.83=324.2105

N(R1)= 0.791

Step 3

Q2=602.0568

F(R2)=0.97115 and the x value is 333.81 from Easy Fit 5.6 as shown in Figure 30.

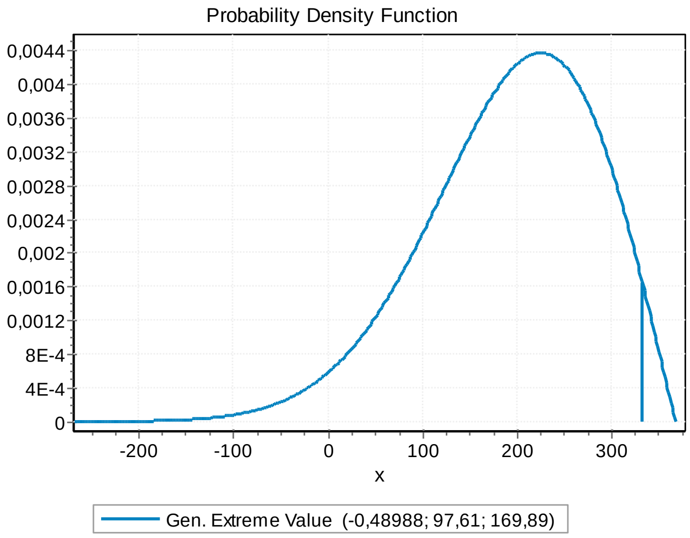


Figure 30.The x point is location with pdf f(x) at third iteration

R2=0.97115*333.81=324.1787

The R value is converging and the iteration is stopped. We apply the model to all the nine items with results shown in Table 9.

6.2. Applying Type II Service Level (Q, R) Policy

The type II service level is computed by Excel. The primary aim of this method is to fix the service level. The other advantage of this method is that the imputed shortage cost can be computed whereas, the stock out cost is assumed at the 50% percentage of original value in the (Q, R) policy. We similarly apply the model to all nine items, with results in Table 12.

6.3. Cost Comparisons and Analysis

The three inventory policies are compared and evaluated according to the total cost. The most noticeable trend on cost comparison is the lower cost of proposed inventory policy comparing with the existing system. In some items, the (Q, R) inventory policy has resulted in lower total cost, and in some other items, the (Q, R) type II service level inventory policy has resulted in a lower total cost. These differences are caused by the smaller Q or R value. Generally, both inventory policies gave better results comparing to the existing hospital policy.

The main cost component is the holding cost when comparing the result in Table 12. The reason for differences in holding cost is the different inventory levels of each policy. Moreover, demand during the lead time is the most significant factor in the total holding cost. On the other hand, the optimal Q and R value have the largest effect on the total holding cost. By balancing holding cost and the set up cost, these three values determine the right trade-off points. The hospital's existing system tends to hold more inventories due to their standard calculations on Q and R value. Their pre-set values on Q and R do not balance various inventory costs and may be faraway from the optimal Q and R value, which causes the poor performance in high holding cost. The other two policies provide much better Q and R value, and thus significantly improve the result in reducing the holding cost as shown in Table 12. To examine the effects of setup cost, the existing policy has a fixed set up cost for each item. It sets Q at the monthly demand, and so

K=150 TL, and $up\ cost = \frac{K*\lambda}{Q}$, since $Q = \frac{30}{360} * \lambda,$

$Set\ up\ cost = \frac{K*\lambda}{30/360*\lambda} = K * 12 = 150 * 12 = 1800$ TL

The (Q, R) and type II service level approaches are more realistic than the existing system at the set up cost calculation. As can be seen in Table 12, the differences in the set up cost are related to Q value. Both inventory policies reported significantly better performance than the existing system in set up cost calculation. In the existing system, fixed Q formula also affects the service level F(R). As shown in Table 12 , the service level of all items was 95 % due to the standard fixed Q value.

Table 12 shows the total cost reduction by percentage in proposed inventory policies. The total cost comparison shows our proposed inventory policies perform better than existing system. Applying proposed inventory system would generate more benefits in reducing the total cost. The performance improvement is not much if the item has slow demand, specific and expensive such as Items 145625 and 110532 (reduction by 27% and 16%). The performance improvement becomes even more effective and efficient if the item has fast and many consumed in demand such as Items 102214 and 110804 (reduction by 79% and 66%). The cost reduction percentages are observed between 16% and 79%.

Variability	Item	Inventory Policy	Q	R	Total Holding Cost	Total Set up Cost	Total Penalty Cost	Total Cost	Cost Saving	S.L
L	110532	EXISTING SYSTEM	13	20	11306	1800	615	13721		95%
L	110532	Q, R (GEN PARETO)	15	11	7292	1571	2611	11473	**16 %**	94%
L	110532	TYPE II SERVICE LEVEL (GEN PARETO)	16	11	7385	1492	2622	11499	**16 %**	94%
L	109835	EXISTING SYSTEM	365	548	3020	1800	66	4886		95%
L	109835	Q, R (GAMMA)	566	123	1510	1162	158	2830	**42 %**	92%
L	109835	TYPE II SERVICE LEVEL (GAMMA)	567	123	1510	1160	158	2829	**42 %**	92%
L	146777	EXISTING SYSTEM	1043	1565	21592	1800	432	23824		95%
L	146777	Q, R (GEN EXTREME VALUE)	602	325	4941	3120	313	8373	**65 %**	97%
L	146777	TYPE II SERVICE LEVEL (GEN. EXTREME VALUE)	602	324	4932	3119	313	8363	**65 %**	97%
M	110917	EXISTING SYSTEM	3348	5022	11651	1800	151	13602		95%
M	110917	Q, R (WEIBULL 3P)	2882	649	3360	2091	503	5955	**56 %**	96%
M	110917	TYPE II SERVICE LEVEL (WEIBULL 3P)	2882	648	3359	2091	504	5953	**56 %**	96%
M	110804	EXISTING SYSTEM	14844	22267	19058	1800	188	21046		95%
M	110804	Q, R (GAMMA)	9287	2373	4094	2877	187	7159	**66 %**	97%

M	110804	TYPE II SERVICE LEVEL (GAMMA)	9287	2372	4093	2877	58	7028	**67%**	97%
M	102214	EXISTING SYSTEM	267731	401597	78415	1800	510	80725		95%
M	102214	Q, R (GEN PARETO)	86432	39250	10465	5576	726	16766	**79 %**	98%
M	102214	TYPE II SERVICE LEVEL (GEN PARETO)	86428	39253	10465	5576	906	16947	**79 %**	98%
H	100264	EXISTING SYSTEM	31809	47713	7426	1800	117	9343		95%
H	100264	Q, R (LOGNORMAL)	30734	6664	2421	1863	-19	4265	**54 %**	95%
H	100264	TYPE II SERVICE LEVEL (LOGNORMAL)	30734	6665	2421	1863	-19	4265	**54 %**	95%
H	145625	EXISTING SYSTEM	22	33	988	1800	421	3209		95%
H	145625	Q, R (GEN.EXT.VALUE)	48	30	1436	819	119	2374	**26 %**	89%
H	145625	TYPE II SERVICE LEVEL (GEN.EXT.VALUE)	48	29	1396	824	120	2340	**27 %**	89%
H	147257	EXISTING SYSTEM	5185	7777	5402	1800	116	7318		95%
H	147257	Q, R (WEIBULL 3P)	5954	1146	2038	1567	40	3646	**50 %**	94%
H	147257	TYPE II SERVICE LEVEL (WEIBULL 3P)	5954	1145	2038	1567	40	3645	**50 %**	94%

Table 12.Cost comparison of inventory policy for low, moderate, and high variability items

7. Sensitivity Analysis

A sensitivity analysis was performed for the three key factors, holding cost, penalty cost and set up (fixed) cost because of the difficulty to decide these costs. The aim of the sensitivity analysis is to explore whether that Q and R are sensitive to changes in holding cost, setup cost, or shortage cost. In addition, the sensitivity analysis is conducted to investigate the outcome of model parameter to see the effect of the (Q, R) policy, (Q, R) type II service level, and existing system on the total cost. The sensitivity analysis is also done by increasing or decreasing inventory system parameters.

7.1. Holding Cost

With the aim of developing the (Q, R) solution, we have to make some assumptions. Especially, there is a problem of estimating holding cost. A sensitivity analysis can solve the problem of inaccurate estimates. This analysis is used to study the impact of uncertainty on the results. The impacts of holding cost fluctuation are evaluated on the total cost, and safety stock. The low holding cost is computed as 20% of the original value and the high as 40% of the original estimate. As mentioned before, the original holding cost is estimated as 30% of the original item price. The sensitivity analysis for holding cost is conducted for three types of items, namely, low, moderate and high variability items to assess the effects of the parameter for change.

We firstly have to consider the low variability items in the sensitivity analysis. The consumption of low variability items is highly stable in the hospital, and there are no severe fluctuations in the demand pattern, which does not cause inventory control difficulties for a hospital. As can be seen in Figure 31, existing system has to more safety stock to avoid stock out in terms of setting the inventory buffer levels. Both proposed inventory policies are choosing inventory levels by optimizing Q and R value. In this case, the holding cost is the most sensitive component of cost under both (Q, R) policy and type II service level approach as shown in Table 13. Both policies give nearly same results, therefore, Figure 31 shows only two lines. In addition, the greatest cost effectiveness and cost saving is provided at the holding cost range from 20% of the original value and reduce the total cost by 67% for item 146777. Increasing holding cast range from 40% of the original value, the cost saving is provided 62%. According to Table 13, when the holding cost increases, the total cost will also increase. Safety stock also decreases with the same and service level. Both proposed inventory policies are extremely suitable to reduce total cost for low variability items.

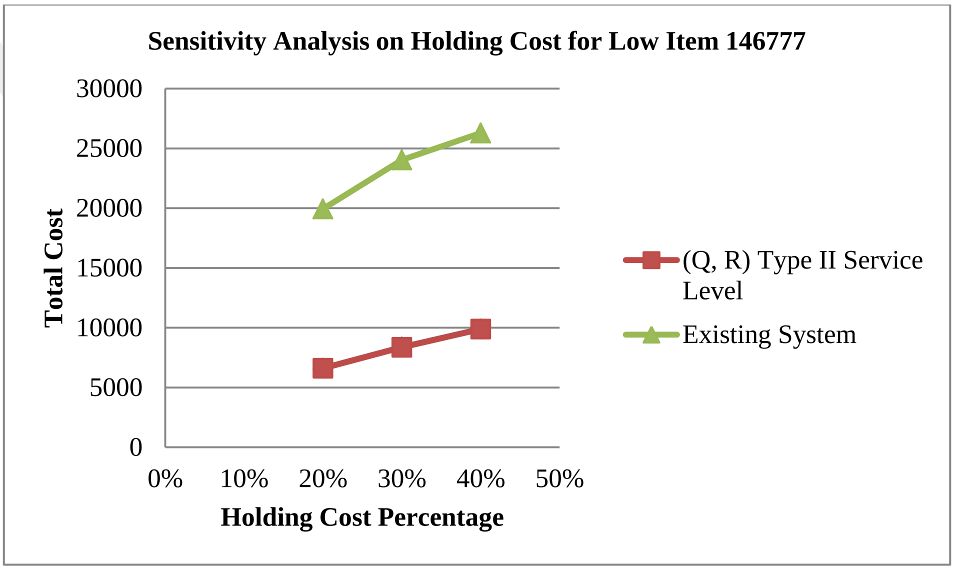


Figure 31.Sensitivity Analyses on Holding Cost for Low Variability Item 146777

In the case of a moderate variability item, there are strong seasonal fluctuations or trends. Monitoring the inventory according to its volume can provide important information to control inventory. The impact of moderate demand variability on the system was examined by sensitivity analysis on total holding cost, total setup cost, total penalty cost, and service level. The existing system is highly sensitive on holding cost. The existing inventory policy keeps more inventories and results in a lowest set up cost. Under this policy, the setup cost and the service level are fixed. On the other hand, the (Q, R) and (Q, R) type II service level are more flexible policy to balance between the holding cost and setup cost. Table 14 shows that the

(Q, R) and (Q, R) type II service level can reduce total cost by 80% at the cost of holding twenty percentage range. When the cost of holding forty percentage range, the cost saving is 78%.

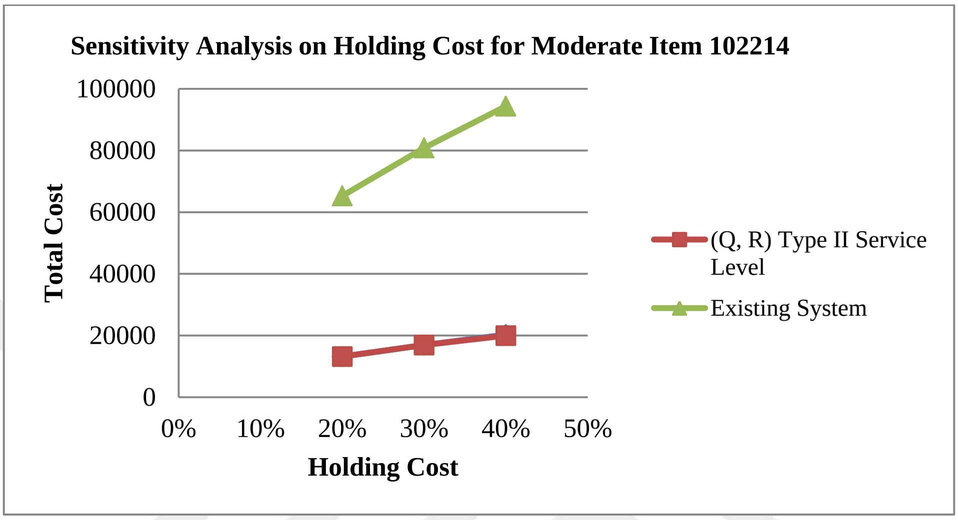


Figure 32. Sensitivity Analyses on Holding Cost for Moderate Variability Item 102214

The consumption of high variability items is the most irregular and heavily fluctuating at the inventory. Moreover, demands for high variability items are not always predictable. Within the large fluctuation in demand, the estimate of the future inventory consumption or determining the inventory levels are much more difficult. The most commonly used approach in the hospital is to create the adequate stock reserve against the risk of stock out. When we consider results presented in Table 15, the (Q, R) and type II service policies are lower in total cost. These both policies keep more inventories against stock out position whereas the setup cost decreases. The existing inventory policy is better with regard to the service level. In other words, while the total cost of the existing policy is about 50% more the other two policies, the service level of the existing system is better with 95%. The other two policies are under around 90%. Table 14 shows that the (Q, R) and (Q, R) type II service level can reduce total cost by about 23 % at the cost of holding twenty, thirty, and fourth percentage range.

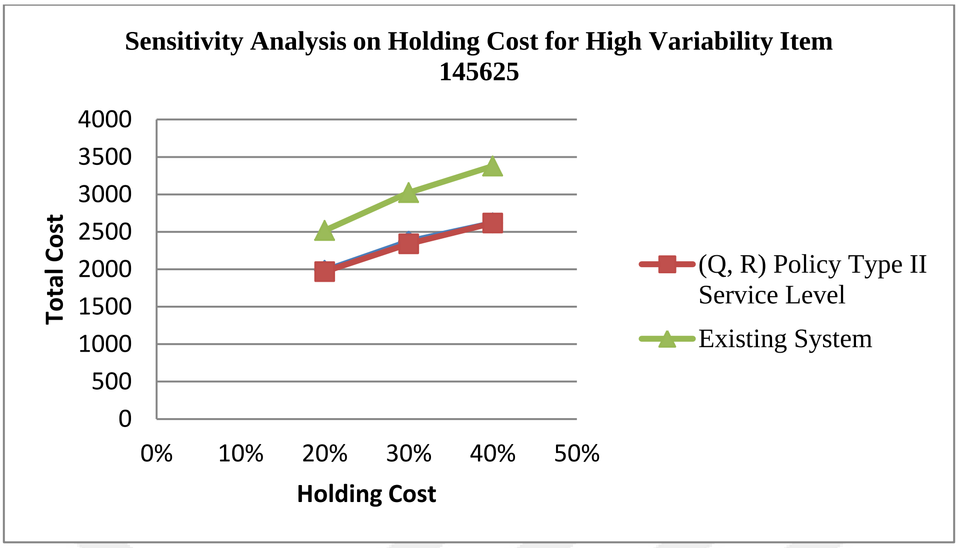


Figure 33. Sensitivity Analyses on Holding Cost for High Variability Item 145625

The sensitivity analysis was conducted with holding cost parameters as a 20%,30%, and 40% of the original value of item and shows how the results react to parameter changes. From Table 13 to 15, we find that with the increase of holding cost h,we would observe the decrease of Q and R as well as safety stock and service level, and the increase of total holding cost, total set up cost, total penalty cost as well as the total cost.

H%	Inventory Policy	Q	R	Total Holding Cost	Total Setup Cost	Total Penalty Cost	Total Cost	Cost Saving	S.S	F(R)
40%	QR (GEN EXTREME VALUE)	524	320	5916	3586	394	9897	62%	128	97%
30%	QR (GEN EXTREME VALUE)	602	325	4941	3120	313	8373	65%	132	97%
20%	QR (GEN EXTREME VALUE)	733	330	3829	2562	226	6617	67%	137	98%
40%	TYPE II SERVICE LEVEL (GEN EXTREME VALUE)	524	320	5917	3586	394	9897	62%	127	97%
30%	TYPE II SERVICE LEVEL (GEN EXTREME VALUE)	602	324	4932	3119	313	8363	65%	132	97%
20%	TYPE II SERVICE LEVEL (GEN EXTREME VALUE)	733	329	3826	2561	226	6612	67%	137	98%
40%	EXISTING SYSTEM	857	1284	23099	2192	989	26280		1091	95%
30%	EXISTING SYSTEM	1043	1565	21590	1801	650	24041		1372	95%
20%	EXISTING SYSTEM	1270	1904	17832	1479	626	19937		1711	94%

Table 13.Effect of the holding cost change on the total cost for low variability Item 146777

H %	Inventory Policy	Q	R	Total Holding Cost	Total Setup Cost	Total Penalty Cost	Total Cost	Cost Saving	S.S	F(R)
40%	QR(GEN PARETO)	76014	38224	12706	6340	1262	20308	78%	25525	98%
30%	QR(GEN PARETO)	86432	39250	10465	5576	907	16947	79%	26552	98%
20%	QR(GEN PARETO)	104060	40591	7992	4631	572	13195	80%	27893	99%
40%	QR TYPE II(GEN PARETO)	76014	38224	12706	6340	946	19992	79%	25525	98%
30%	QR TYPE II(GEN PARETO)	86432	39250	10465	5576	907	16947	79%	26551	98%
20%	QR TYPE II(GEN PARETO)	103947	40680	7995	4636	561	13193	80%	27981	99%
40%	EXISTING SYSTEM	235461	353192	91645	2047	658	94349		340493	95%

30%	EXISTING SYSTEM	267731	401597	78415	1800	638	80853		388898	95%
20%	EXISTING SYSTEM	322334	483501	63197	1495	625	65317		470803	94%

Table 14.Effect of the holding cost change on the total cost for moderate variability Item 102214

H %	**Inventory Policy**	**Q**	**R**	**Total Holding Cost**	**Total Setup Cost**	**Total Penalty Cost**	**Total Cost**	**Cost Saving**	**S.S**	**F(R)**
40%	QR(GEN.EXT.VALUE)	42	26	1521	946	152	2618	23%	8	87%
30%	QR(GEN.EXT.VALUE)	48	30	1436	819	119	2374	21%	12	89%
20%	QR(GEN.EXT.VALUE)	58	35	1221	678	86	1985	22%	17	91%
40%	TYPE II SL (GEN.EXT.VALUE)	42	26	1521	945	152	2618	23%	8	87%
30%	TYPE II SL (GEN.EXT.VALUE)	48	29	1396	824	120	2340	23%	11	89%
20%	TYPE II SL (GEN.EXT.VALUE)	58	34	1204	679	86	1968	23%	17	91%
40%	EXISTING SYSTEM	19	28	1008	2079	309	3396		10	95%
30%	EXISTING SYSTEM	22	33	988	1800	236	3024		14	95%
20%	EXISTING SYSTEM	26	39	884	1490	167	2541		21	94%

Table 15.Effect of the holding cost change on the total cost for high variability Item 145625

7.2. Penalty Cost

In this section, we analyze how the penalty cost factor affects the three inventory policies, namely, (Q, R) policy, type II service level, and existing system. Owing to the uncertainty related with the estimates of penalty cost, the cost was estimated in a range from 30% to 70% of the original item value. To measure the effects of these changes on the result, we perform sensitivity analysis based on low, moderate and high demand variability with results in Table 17 to 19. From the tables, we observe that total holding cost and set up cost increase whereas total penalty cost decreases due to the decreasing of order quantity and increasing re-order point.

The proposed inventory policies are a convex function whereas the existing system is not convex function. Therefore, the existing system shows different affects as seen in Table 16, 17 and 18. Moreover, the total holding cost, set up cost, and penalty cost nearly equals at the (Q, R) Policy and (Q, R) Policy type II service level which were nearly given equal accomplished in total cost as shown Figure 34, 35, 36, and 37 which also demonstrate that the proposed inventory policies are the best inventory policy measured by the total cost. Table 16, 17 and 18 show that the (Q, R) and (Q, R) type II service level can reduce total cost by 65% at low variability Item 146777, 79% at moderate variability Item 102214, and around 23% at high variability Item at the cost of penalty thirty, fifty, and seventy percentage range. The proposed inventory policies are more achievable cost saving and cost-effective for low, moderate and high variability items. The both proposed policies are most effective to control inventory level and prevent the stock out than existing inventory policy at the low, moderate and high variability items. Therefore, the proposed inventory policies can significantly reduce the total cost against the various demand variability items.

Interestingly, if the demand is low and variability is high as shown Table 18, the order quantity will not increase too much and re order amount will decrease as a portion. Therefore, the performance improvement can change at every point penalty cost percentage. The cost reduction is observed by 21% at 70% of original penalty cost value p, by 23% at 50% of original penalty cost value p, and by 27% at 30% of original penalty cost value p as shown in Figure 37.

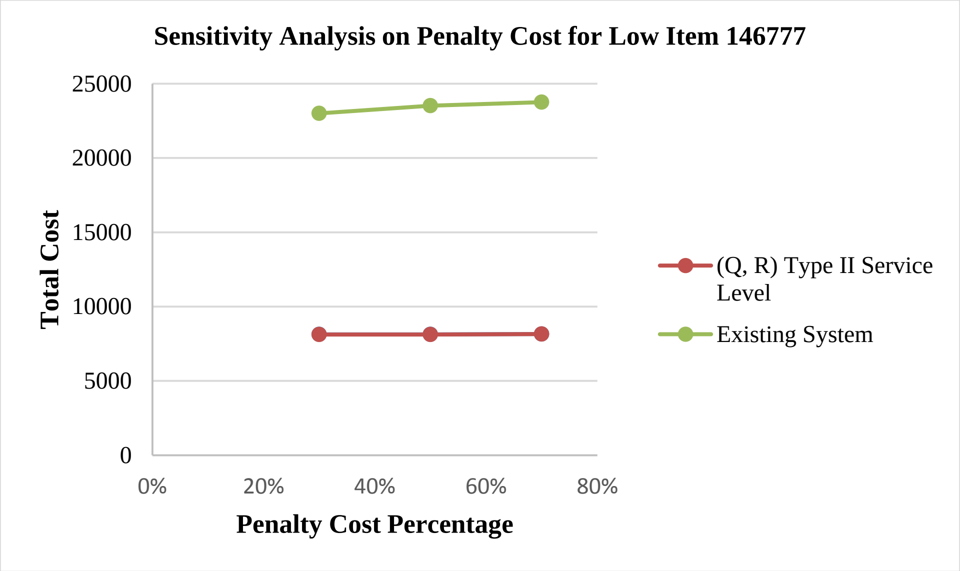


Figure 34. Sensitivity Analyses on Penalty Cost for Low Item 146777

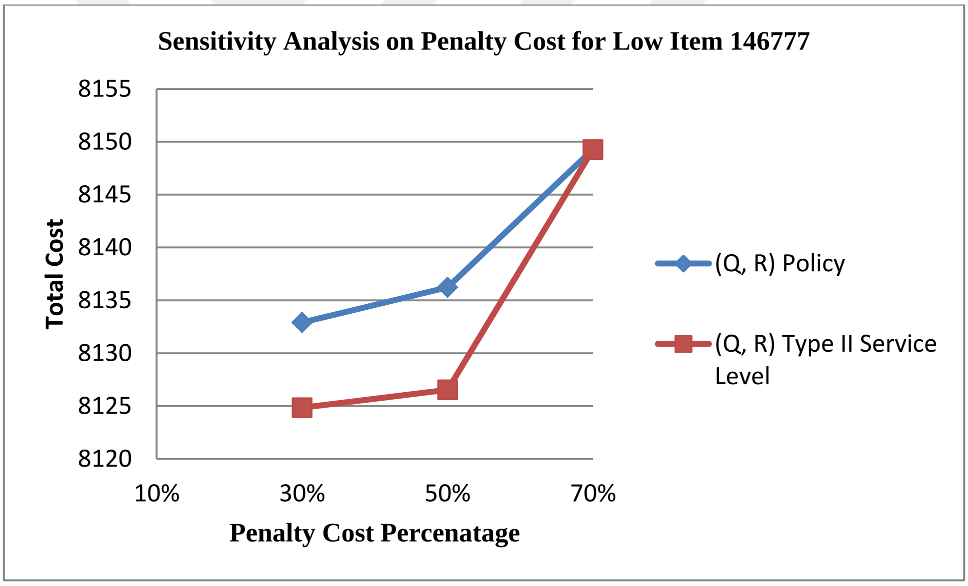


Figure 35. Sensitivity Analyses on Penalty Cost for Low Item 146777 with comparing (Q, R) and Type II Service Level

With the increase of penalty cost p, increase the total cost of the proposed inventory policies and existing inventory policy. Figure 34 is not shown increasingly line. This difference in between the proposed policies with the existing policy arises from the high total cost at existing system. Therefore, the line shows straight. Figure 35 shows a better way to indicate increasing total cost between (Q, R) Policy and Type II Service Level.

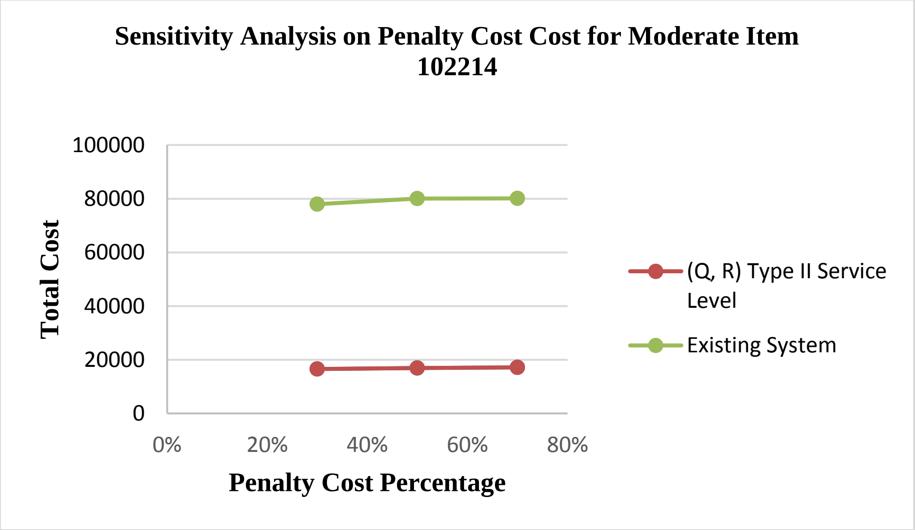


Figure 36.Sensitivity Analyses on Penalty Cost for Moderate Item 102214

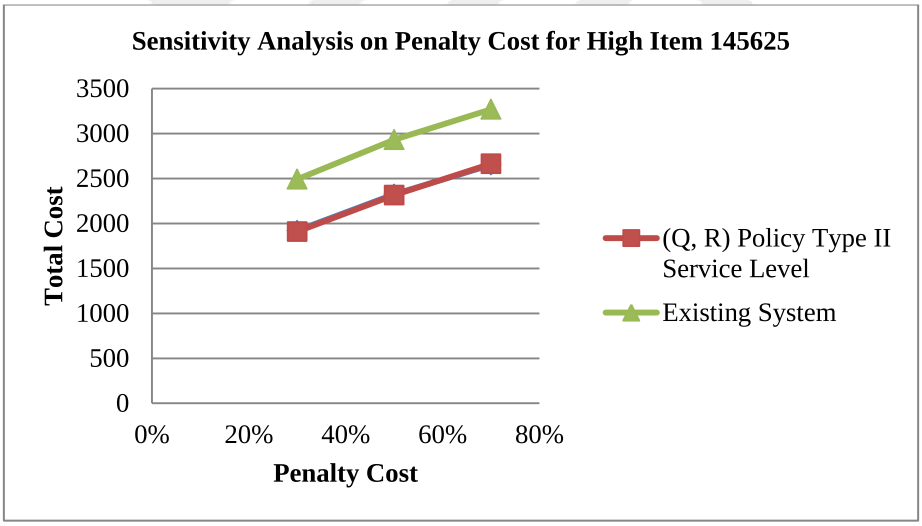


Figure 37.Sensitivity Analyses on Penalty Cost for High Item 145625

The sensitivity analysis on penalty shows that with the increase of penalty cost p, we would observe the decrease of Q and the increase of R, as well as the increase of total holding cost, set up cost, total cost, safety stock, as well as service level, but the total penalty cost will decrease.

P%	Inventory Policy	Q	R	Total Holding Cost	Total Setup Cost	Total Penalty Cost	Total Cost	Cost Saving	S.S	F(R)
70%	QR (GEN EXTREME VALUE)	574	333	4876	3270	3	8149	66%	141	98%
50%	QR (GEN EXTREME VALUE)	580	326	4827	3238	72	8136	65%	133	97%
30%	QR (GEN EXTREME VALUE)	597	309	4730	3146	258	8133	65%	116	95%
70%	TYPE II SERVICE LEVEL (GEN EXTREME VALUE)	574	333	4876	3270	3	8149	66%	141	97%
50%	TYPE II SERVICE LEVEL (GEN EXTREME VALUE)	580	325	4819	3236	72	8127	65%	133	97%
30%	TYPE II SERVICE LEVEL (GEN EXTREME VALUE)	597	308	4722	3146	258	8125	65%	116	95%
70%	EXISTING SYSTEM	1033	1598	21907	1819	30	23756		1405	95%
50%	EXISTING SYSTEM	1043	1565	21585	1801	135	23520		1372	95%
30%	EXISTING SYSTEM	1074	1497	20989	1749	260	22998		1304	93%

Table 16.Effect of the penalty cost change on the total cost for Low variability Item 146777

P%	Inventory Policy	Q	R	Total Holding Cost	Total Setup Cost	Total Penalty Cost	Total Cost	Cost Saving	S.S	F(R)
70%	QR(GEN PARETO)	85898	41309	10734	5610	832	17176	79%	28611	99%
50%	QR(GEN PARETO)	86427	39254	10465	5576	906	16948	79%	26555	98%
30%	QR(GEN PARETO)	87447	35711	10010	5511	1048	16569	79%	23012	97%
70%	QR TYPE II(GEN PARETO)	85898	41309	10734	5610	832	17176	79%	28610	99%
50%	QR TYPE II(GEN PARETO)	86432	39250	10465	5576	907	16947	79%	26551	98%
30%	QR TYPE II(GEN PARETO)	87449	35709	10010	5511	1048	16569	79%	23010	97%
70%	EXISTING SYSTEM	266091	399137	77923	1811	384	80118		386438	95%

50%	EXISTING SYSTEM	267731	396242	77611	1800	638	80049		383544	95%
30%	EXISTING SYSTEM	270891	379247	75299	1779	892	77970		366549	95%

Table 17.Effect of the penalty cost change on the total cost for moderate variability Item 102214

P%	**Inventory Policy**	**Q**	**R**	**Total Holding Cost**	**Total Setup Cost**	**Total Penalty Cost**	**Total Cost**	**Cost Saving**	**S.S**	**F(R)**
70%	QR(GEN.EXT.VALUE)	46	38	1735	849	68	2652	21%	21	92%
50%	QR(GEN.EXT.VALUE)	46	30	1405	847	73	2324	23%	12	89%
30%	QR(GEN.EXT.VALUE)	47	19	985	833	102	1920	27%	1	82%
70%	TYPE II SL (GEN.EXT.VALUE)	47	38	1741	842	81	2664	20%	21	92%
50%	TYPE II SL (GEN.EXT.VALUE)	46	30	1396	847	73	2315	23%	12	89%
30%	TYPE II SL (GEN.EXT.VALUE)	47	19	976	832	102	1910	27%	1	82%
70%	EXISTING SYSTEM	22	42	1350	1804	192	3346		23	95%
50%	EXISTING SYSTEM	22	33	988	1800	237	3025		14	95%
30%	EXISTING SYSTEM	22	27	779	1770	337	2627		2	95%

Table 18.Effect of the penalty cost change on the total cost for high variability Item 145625

7.3. Setup Cost

Similarly, to assess the effect of setup cost K changing on the solution, we perform the sensitivity analysis. We report that the performance of three policies after the set up cost change in Table 19, 20, and 21. The existing system generates better total set up cost due to the high order quantity. On the other hand, the high reorder point and order quantity tends to hold more inventory and increases total holding cost in the existing system. The existing inventory policy is more sensitive to the K change, having more safety stocks for the decrease of K so that the high total cost occurs mostly in the existing sytem. On he other hand, in the case of low variability items, it is seen that the total cost very sensitive in the (Q, R) and type II service level policies to reduce setup cost and increase service level when K reduces.

In the case of moderate and high variability items, we observe that the most suitable policy is still the proposed inventory policies as shown in Table 20 and Table 21. The significant cost saving is of the moderate and high-variability items. The proposed policy fill rates the high inventory levels and insurance against the problem of stock out. Moreover, the existing inventory system is the highest total cost in the case of bullwhip effect inventory levels.

The greatest cost effectiveness and cost saving is provided at the penalty cost range from 100 TL and reduced the total cost by 60% for low variability Item 146777. Increasing penalty cost range p, 200 TL, the cost saving is provided 65%. In moderate variability Item 102204, the cost saving performance is invenstigated at the penalty cost range p over 100 TL and reduced by 78%. When the penalty cost increased 200 TL, the cost saving performance is obtained 80%.

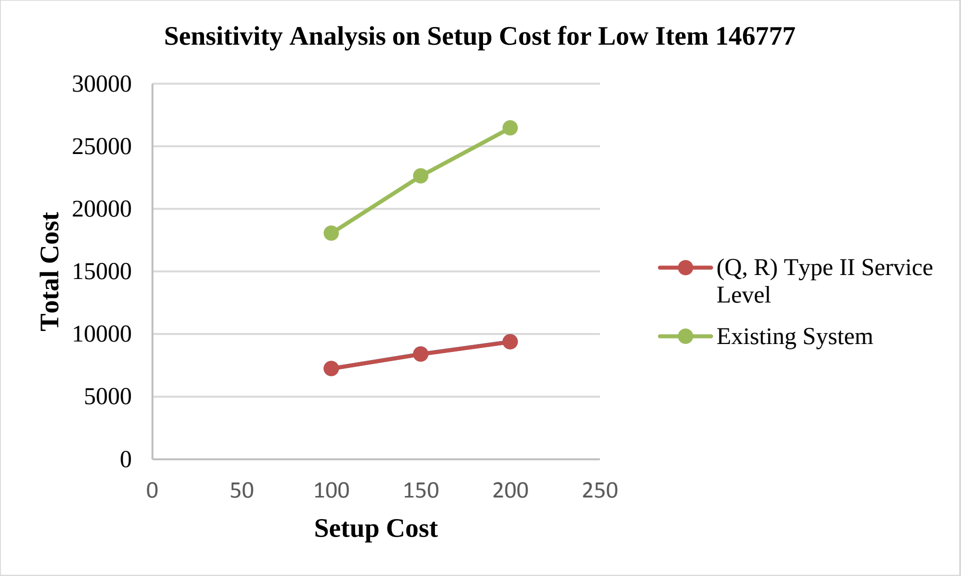


Figure 38. Sensitivity Analyses on Setup Cost for Low Variability Item 146777

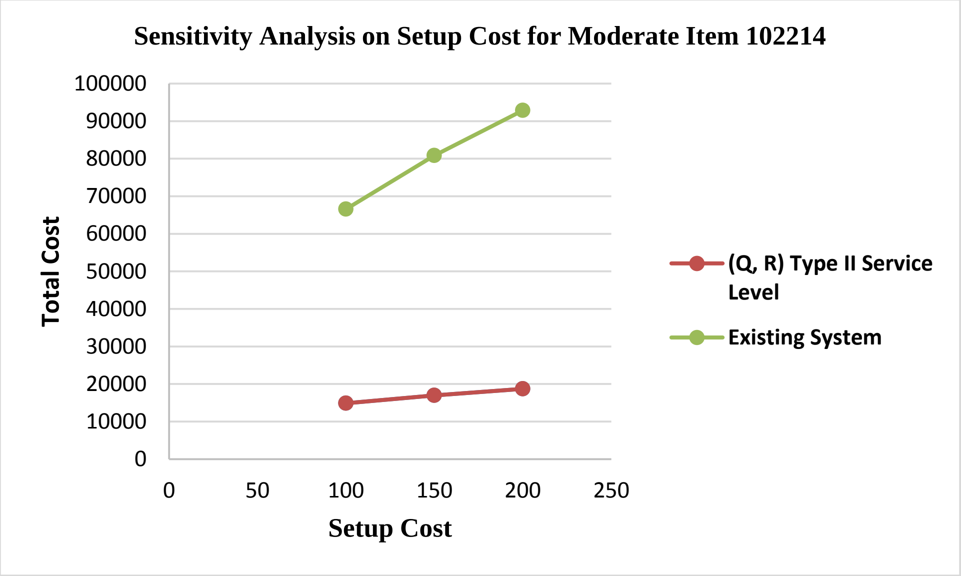


Figure 39.Sensitivity Analyses on Setup Cost for Moderate Item 102214

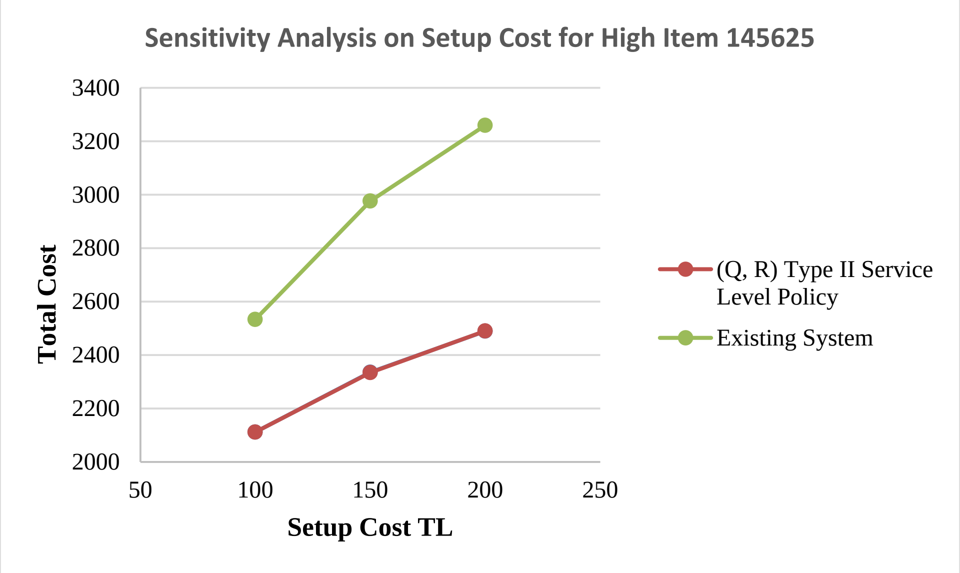


Figure 40.Sensitivity Analyses on High Cost for High Item 145625

We find that as the set up cost increases, the amount of order quantity Q increases whereas re order level R decreases, resulting in the increase of total holding cost, set up cost, and penalty cost. At the same time, the set up cost increase also reduces the safety stock and service level. In this analysis, to reduce the total setup cost cost, The (Q, R) policies would leat to a large Q.

K TL	Inventory Policy	Q	R	Total Holding Cost	Total Setup Cost	Total Penalty Cost	Total Cost	Cost Saving %	S.S	F(R)
200	QR (GEN EXTREME VALUE)	689	321	5391	3634	356	9382	65%	128	97%
150	QR (GEN EXTREME VALUE)	602	325	4941	3120	344	8404	63%	132	97%
100	QR (GEN EXTREME VALUE)	499	329	4399	2509	336	7244	60%	136	98%
200	TYPE II SERVICE LEVEL (GEN EXTREME VALUE)	689	320	5386	3632	356	9375	65%	128	97%
150	TYPE II SERVICE LEVEL (GEN EXTREME VALUE)	602	324	4932	3119	344	8395	63%	132	97%
100	TYPE II SERVICE LEVEL (GEN EXTREME VALUE)	499	329	4398	2509	336	7243	60%	136	98%
200	EXISTING SYSTEM	1194	1791	25030	2097	-657	26470		1599	95%
150	EXISTING SYSTEM	1043	1565	21592	1800	-759	22633		1372	95%
100	EXISTING SYSTEM	865	1297	17522	1448	-916	18054		1105	95%

Table 19.Effect of the setup cost change on the total cost for low variability Item 146777

K TL	Inventory Policy	Q	R	Total Holding Cost	Total Setup Cost	Total Penalty Cost	Total Cost	Cost Saving %	Safety Stock	F(R)
200	QR(GEN PARETO)	99039	38377	11280	6488	940	18708	80%	25678	98%
150	QR(GEN PARETO)	86428	39254	10465	5576	906	16948	79%	26555	98%
100	QR(GEN PARETO)	71454	40423	9518	4496	863	14877	78%	27724	99%
200	QR TYPE II(GEN PARETO)	99039	38377	11280	6488	940	18707	80%	25678	98%
150	QR TYPE II(GEN PARETO)	86432	39250	10465	5576	907	16947	79%	26551	98%
100	QR TYPE II(GEN PARETO)	71464	40414	9517	4496	864	14877	78%	27715	99%
200	EXISTING SYSTEM	306797	460195	90134	2094	652	92881		447497	95%

150	EXISTING SYSTEM	267731	401597	78415	1800	638	80853		388898	95%
100	EXISTING SYSTEM	221346	332019	64499	1451	620	66570		319320	96%

Table 20.Effect of the setup cost change on the total cost for moderate variability Item 102204

K TL	**Inventory Policy**	**Q**	**R**	**Total Holding Cost**	**Total Setup Cost**	**Total Penalty Cost**	**Total Cost**	**Cost Saving %**	**Safety Stock**	**F(R)**
200	QR(GEN.EXT.VALUE)	54	26	1412	964	115	2490	24%	9	88%
150	QR(GEN.EXT.VALUE)	48	29	1410	819	106	2336	22%	12	89%
100	QR(GEN.EXT.VALUE)	37	34	1378	707	27	2111	17%	18	92%
200	TYPE II SL (GEN.EXT.VALUE)	54	26	1412	964	115	2490	24%	8	88%
150	TYPE II SL (GEN.EXT.VALUE)	48	29	1409	819	107	2334	22%	12	89%
100	TYPE II SL (GEN.EXT.VALUE)	37	34	1378	707	26	2111	17%	17	92%
200	EXISTING SYSTEM	26	32	1041	2015	203	3260		13	94%
150	EXISTING SYSTEM	22	33	1001	1786	189	2976		14	95%
100	EXISTING SYSTEM	19	34	982	1379	173	2533		15	96%

Table 21.Effect of the setup cost change on the total cost for high variability Item 145625

7.4. Service Level

To quantify the uncertainty in service level, we study the effects of the parameters on the proposed inventory policies and evaluate the sensitivity of the total cost with regard to change the parameters. The service level is assessed in a range from 94% to 99, 9% and track its resulting at the total cost. Firstly, the sensitivity analysis for service level can be performed to see the effect on the safety stock. The existing system is the most sensitive policy to the service level change by holding more safety stock, especially for low and moderate variability items. If the item is high variability and expensive, the existing inventory policy will trend to hold less safety stock.

The optimal Q and R value in (Q, R) and type II service level policy would increase total set up cost and holding cost with the increase of service level because of lower Q value and higher R value. On the other hand, when service level increases, the total holding cost, set up cost, and safety stock increase, on the contrary, the stock out cost decreases. The most suitable method to the total cost is type II service level in the case of low and moderate variability items as shown in Table 22 and 23. In the case of high variability item, the most sensitive method is the existing system accordingly total cost as shown in Table 25.

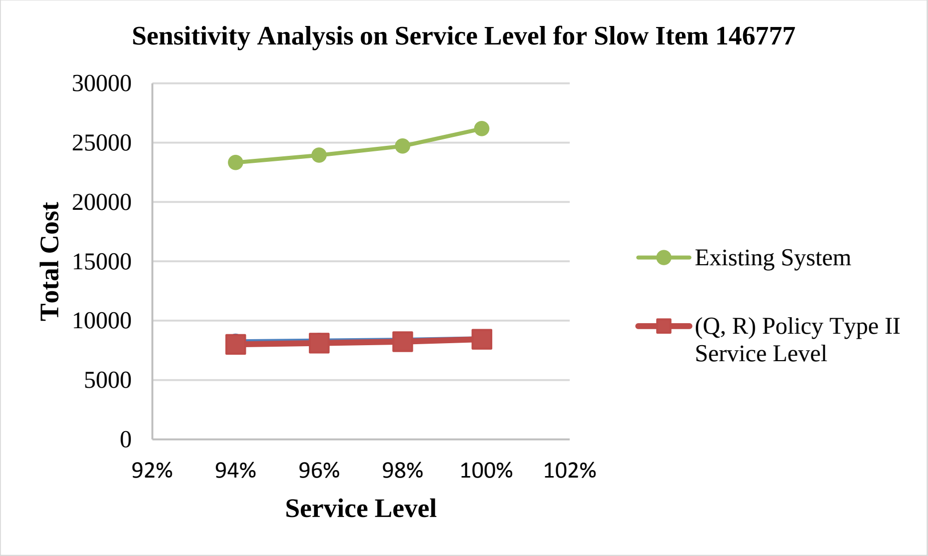


Figure 41.Sensitivity Analyses on Service Level for Low Item 146777

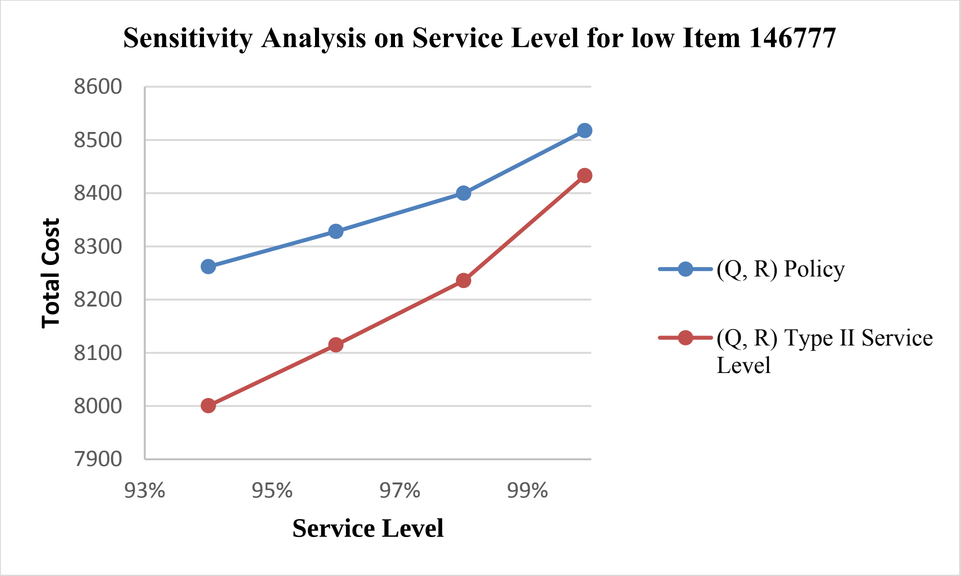


Figure 42.Sensitivity Analyses on Service Level for Low Item 146777 comparing with (Q, R) and Type II S.L

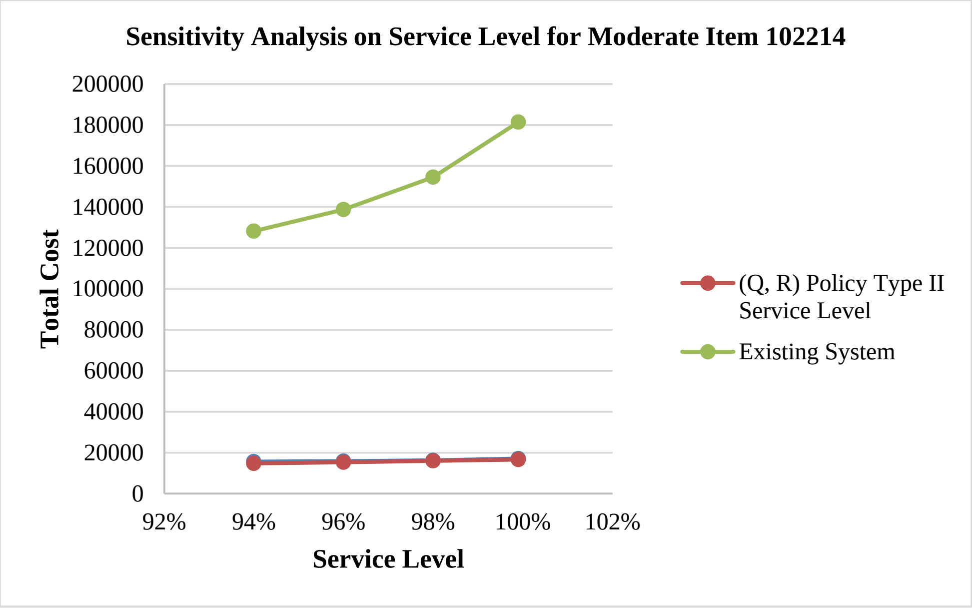


Figure 43.Sensitivity Analyses on Service Level for Moderate Item 102214

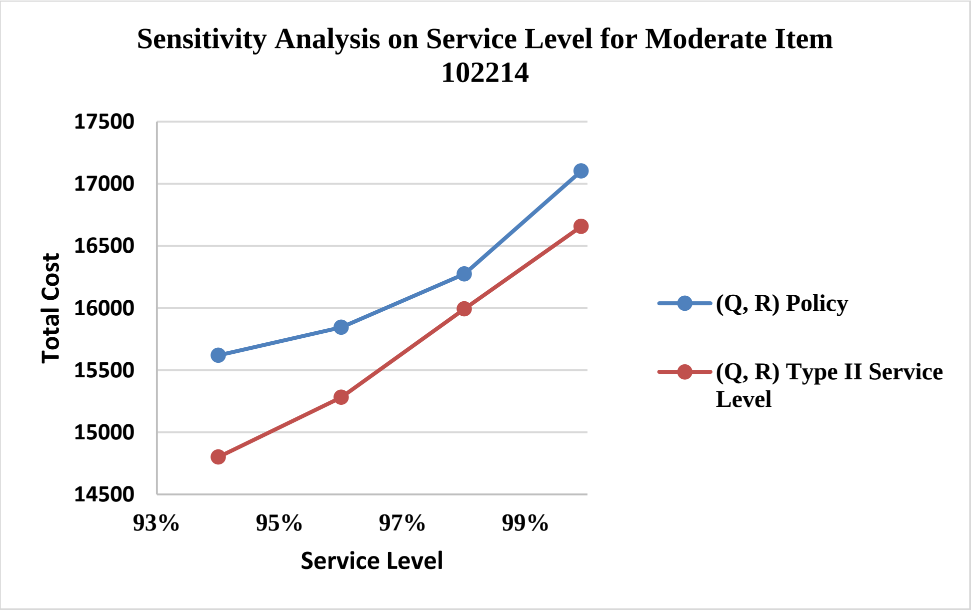


Figure 44.Sensitivity Analyses on Service Level for Moderate Item 102214 comparing with (Q, R) and Type II S.L

In the hospital, bullwhip effect results at a high variability in demand as shown in Table 24. This uncontrollability demand is visible at the actual patient service level. That is why high variability is key to control stock levels and service level. Large demand fluctuations result in a need for extra inventories to prevent stockouts. To reduce the impact of variability on the consumable medical supply warehouse, continuous replenishment policy can be used. To meet the peak demand, the continuous replenishment policy places the order by considering demand arrival rate. The existing system has just only considered their standard replenishment policy and ignored demand arrival rate. Therefore, the safety stock is less than both proposed inventory policies. In the existing system, if the service level is under a 94% percent, the stock out may occur at any moment. The existing system meets the peak demand after a 99% percent service level. Therefore, the existing system includes lower total cost, but It involves the risk of stock out. To minimize the risk at the consumable medical supply warehouse, the continuous replenishment policy takes measure to provide building up additional inventory for safety stock to account for the variability of the hospital. Both proposed inventory policies meet the peak demand after a 95% percent service level. Therefore, both proposed inventory policies are higher total cost.

Item 145625 Annual Demand														
22	4	8	100	12	4	32	2	2	16	8	32	8	12	4

Figure 45.The demand arrival for high variability at the consumable medical supply for Item 145625

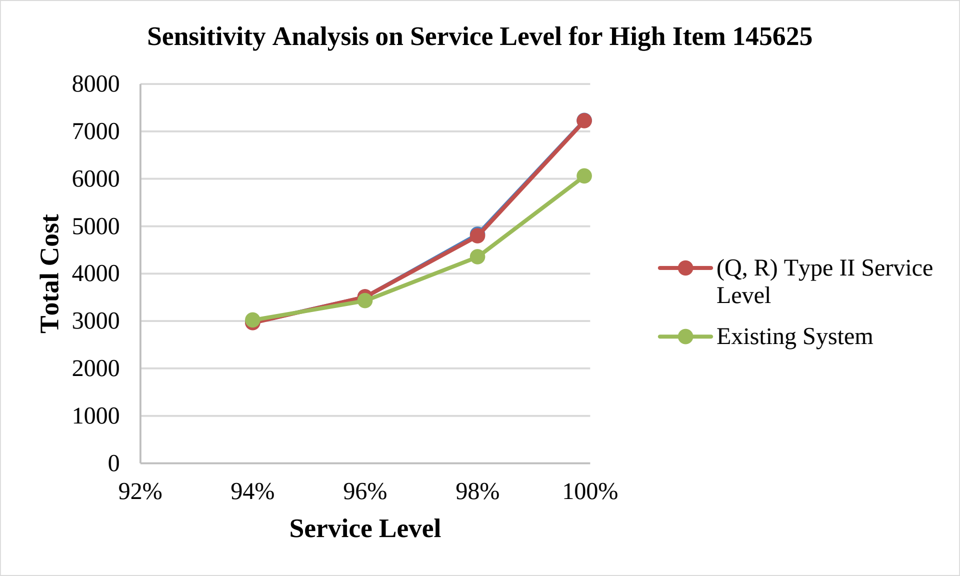


Figure 46.Sensitivity Analyses on Service Level for High Item 145625

The sensitivity analysis on service level shows that with the increase of the service level, we would observe the Q decrease and R increase of total holding cost, setup cost, total cost and safety stock but the decrease of the penalty cost.

Service Level	Inventory Policy	Q	R	Total Holding Cost	Total Setup Cost	Total Penalty Cost	Total Cost	Cost Saving	Safety Stock
94%	QR (GEN EXTREME VALUE)	617	300	4741	3044	477	8262	65%	107
96%	QR (GEN EXTREME VALUE)	608	315	4861	3089	379	8328	65%	122
98%	QR (GEN EXTREME VALUE)	596	333	4998	3151	251	8400	66%	140
99,9%	QR (GEN EXTREME VALUE)	577	363	5231	3255	32	8518	67%	170
94%	TYPE II SERVICE LEVEL (GEN EXTREME VALUE)	595	300	4610	3157	233	8001	66%	107
96%	TYPE II SERVICE LEVEL (GEN EXTREME VALUE)	590	314	4752	3183	180	8115	66%	122
98%	TYPE II SERVICE LEVEL (GEN EXTREME VALUE)	582	333	4917	3226	93	8236	67%	140
99,9%	TYPE II SERVICE LEVEL (GEN EXTREME VALUE)	570	362	5182	3293	-42	8433	**68%**	169
94%	EXISTING SYSTEM	1040	1514	20992	1806	531	23329		1322
96%	EXISTING SYSTEM	1025	1590	21769	1833	337	23938		1397
98%	EXISTING SYSTEM	1004	1681	22689	1870	154	24713		1488
99,9%	EXISTING SYSTEM	972	1832	24233	1931	10	26174		1640

Table 22.Effect of the service level change on the total cost for low variability Item 146777

Service Level	Inventory Policy	Q	R	Total Holding Cost	Total Setup Cost	Total Penalty Cost	Total Cost	Cost Saving	Safety Stock
94%	QR(GEN PARETO)	87571	29253	9051	5503	1065	15619	88%	16554

96%	QR(GEN PARETO)	85584	32746	9426	5631	788	15845	89%	20047
98%	QR(GEN PARETO)	83334	37860	10024	5783	467	16274	89%	25161
99,9%	QR(GEN PARETO)	80218	46500	11087	6008	9	17103	91%	39017
94%	TYPE II SERVICE LEVEL (GEN PARETO)	82118	29253	8642	5869	290	14801	88%	16554
96%	TYPE II SERVICE LEVEL (GEN PARETO)	81828	32746	9144	5889	248	15281	89%	20047
98%	TYPE II SERVICE LEVEL (GEN PARETO)	81460	37859	9884	5916	193	15993	90%	25160
99,9%	TYPE II SERVICE LEVEL (GEN PARETO)	81255	42980	10636	5931	89	16656	**91 %**	39016
94%	EXISTING SYSTEM	270699	380512	125790	1780	575	128146		367813
96%	EXISTING SYSTEM	264557	425947	136382	1822	559	138762		413248
98%	EXISTING SYSTEM	257601	492468	152142	1871	522	154535		479769
99,9%	EXISTING SYSTEM	247969	604854	179035	1943	463	181441		592155

Table 23. Effect of the service level change on the total cost for moderate variability Item 102214

Service Level	**Inventory Policy**	**Q**	**R**	**Total Holding Cost**	**Total Setup Cost**	**Total Penalty Cost**	**Total Cost**	**Cost Saving**	**Safety Stock**
94%	QR(GEN.EXT.VALUE)	46,70	46	2044	842	83	2969	2%	28
96%	QR(GEN.EXT.VALUE)	46,23	60	2589	850	65	3505	2%	42
98%	QR(GEN.EXT.VALUE)	45,67	94	3924	860	44	4829	11%	76

99,9%	QR(GEN.EXT.VALUE)	45,24	155	6332	869	27	7227	19%	137
94%	TYPE II SL (GEN.EXT.VALUE)	46,95	46	2032	837	93	2962	2%	28
96%	TYPE II SL (GEN.EXT.VALUE)	46,34	60	2590	848	69	3508	2%	42
98%	TYPE II SL (GEN.EXT.VALUE)	45,72	93	3889	859	46	4794	10%	75
99,9%	TYPE II SL (GEN.EXT.VALUE)	45,27	155	6326	868	28	7222	19%	137
94%	EXISTING SYSTEM	22,06	33,10	1006	1781	233	3020		14
96%	EXISTING SYSTEM	21,31	43,17	1390	1844	191	3426		24
98%	EXISTING SYSTEM	21,02	67,63	2353	1869	129	4352		49
99,9%	EXISTING SYSTEM	20,81	111,52	4087	1889	81	6057		93

Table 23.Effect of the service level change on the total cost for high variability Item 145625

8. Conclusion

This thesis concludes that the implementation of (Q, R) policy and (Q, R) Type II service level policy improves the current inventory management in the consumable medical warehouse. In addition to a summary of this study, we also explore the research implication as well as future studies.

8.1. Summary

The aim of this thesis is to assess the current inventory system in a public hospital and suggest improvements. To identify problems in current inventory system, the cause and effect diagram is used. C&E diagram method shows poor inventory management with the root causes in the consumable medical inventory management. The biggest problem was the high total cost and uncertain demand in the hospital. The most critical problem in the current inventory management is their standard calculation of Q and R value for all items. R value is equal to 1.5 Q in the current system. The standard Q and R value would result in sometimes excess stock and sometimes stock-out in the hospital. In the literature, demand variability is a key factor in determining the optimal re-order point. In addition, the average lead time and standard deviation of the lead time affect the optimal re-order point. On the other side, the standard deviation of lead time is an important factor in estimating order quantity (Q). The most obvious finding from this study is that current standard reorder point and order quantity can lead to poor inventory management in the hospital. Moreover, the tradeoff among holding cost, set up cost, and the stock-out cost is important, which affects the total cost. The purpose of this study was to explore policies to minimize the total of annual expected ordering, holding and shortage costs without affecting the patient service level. To minimize the total cost, the (Q, R) and (Q, R) type II service level are used to compare with the current inventory system. In this study, the performance metrics are used to explore the optimal policies for Q and R by minimizing total annual anticipated ordering, holding and shortage costs, while maintaing a reasonable service level to ensure the product availability.

The two proposed inventory policies reduce the total inventory cost when comparing to the current inventory policy at the consumable medical warehouse. This study has found that new policies generate better two results for the low and moderate variability items in total cost reduction but not so far high variability items. High variability items are better to ensure high fill rate service level, with cost minimization secondary objective.

There is no much difference on the total cost by the proposed two inventory policies when the service level is at the same rate. These findings suggest that in general it is better to use a type II service level inventory policy. Moreover, this approach ensures product availability, avoids the stock out and provides an expected service level for the hospital. The proposed (Q, R) type II policy was not only the most optimal solution but also the most stable solution at a desired service level. With the aim of reduced inventory at the consumable medical warehouse, one should apply (Q, R) type II service level.By fixing the service level, it ensures the accuracy of imputed shortage cost, and generate the most accurate estimation of the total cost. It also provides optimal re-order point to avoid stock out situation. The (Q, R) type II service level ensures item availability and achieves high patient satisfaction within the given service level.

The second finding was that the existing inventory policy generates a better cost reduction in the case of high-variability items. The reason for this finding is that the existing model does not compute order lead time and lead time demand.Their system is based on the consumption average to compute Q and R value, therefore this method generates lower total cost than both proposed policies. Conversely, both proposed inventory policies reduce the variability risk and provide higher service level. As a result of this, the total cost is high at both proposed policies. To achieving patient service level goals and objectives, type II service level can be used to prevent stock out especially in a case of high demand and moderate variability items. This uncontrollability demand is visible at the actual patient service level. That is why high variability is key to control stock levels and service level. Large demand fluctuations result in a need for extra inventories to prevent stockouts. To reduce bullwhip impact of high variability and moderate variability in demand on the consumable medical supply warehouse, continuous replenishment policy can be used. To meet the peak demand , the continuous replenishment policy places the order by considering demand arrival rate.

8.2. Discussion

Inventory policy and inventory control techniques are affected by demand, variability, unit cost, criticality, and physical size. These factors further affect various inventory management objectives in different scale. Nine items in ‘A’class, i.e., items with highest annual values, are selected in this study according to the low, moderate and highly demand variability. One of the more significant findings in this study is that (Q, R) inventory policy is most suitable for the low, moderate and high variability items in reducing total cost.

The second major finding was that the calculation of expected shortage cost is critical to find the optimal order quantity and reorder point. The real-world parameters is different the a literature settings. The current data highlight the importance of calculation expected shortage cost. We had set parameters to solve the problem by a continuous distribution f(x) pdf function and need to limit the integral due to the upper infinite bound. Thus the results may not be optimal in the real life setting.

This study is successful to deal with different distributions that generates in an easily applicable (Q, R) inventory policy which achieves significantly better results than the current inventory policy. The proposed inventory policies are enhancement over current practice by more flexiblility in choosing re order point, order quantity, and target service level. These methods make the hospital to better understand the tradeoffs in the inventory system and find better solutions.

Further research could also be conducted to determine the effectiveness of (Q, R) inventory policy with data in more variability. Future trials should assess the impact of expected shortage during the lead time calculation with real-world parameters. The challenge now is to determine expected shortage cost that contains complex pdf f(x) function. Continued efforts are needed to make expected shortage cost more accessible to compute the optimal Q and R value. In the real life, especially hospital environment, the demand is a random variable x and given distribution and parameters different each item is difficult to compute expected shortage cost.

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