# INVENTORY MANAGEMENT FOR UNCERTAIN DEMAND OF WHOLESALE AGRICULTURE SPARE PARTS

By

NARATIP PANICHPONGPAN

A Proposal of the Six-Credit Course
SCM 7203 Graduate Project

Submitted in Partial Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE IN SUPPLY CHAIN MANAGEMENT

Martin de Tours School of Management
Assumption University
Bangkok, Thailand

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I, Naratip Panichpongpan ______________________________

declare that this thesis/project and the work presented in it are my own and has been generated by me as the result of my own original research.

Inventory management for uncertain demand of wholesale agriculture spare parts

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I confirm that this thesis/project has been carried out under my supervision and it represents the original work of the candidate.

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Date ______________________________

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Naratip Panichpongpan

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# ABSTRACT

In a competitive business environment, companies would like to be profitable by minimizing the total costs of the company. Inventory management has become one of important functions which can be used to reduce the costs of companies. Therefore the research question of this study is "How can ABC Company improve their inventory management to reduce total inventory cost?" has been established. This study proposes the (Q, r) model of inventory management for use with imported spare parts. One such spare part was selected as the case for this research.

Imported spare parts were classified based on the annual cost of usage. They were separated into three groups by using the ABC classification method forming group A, group B and group C. The ASSY SEAL OIL (TC010-99600) part was selected for this pilot study because it had the highest cost of annual usage of all ABC Company imported spare parts (about 9.3 Million Baht in 2014). Then, the demand pattern of the selected part was analyzed by use of the variability coefficient (VC), and was found to equal 0.30 which indicates high variability. This means that the demand was not constant during the considered period. Therefore the (Q, r) model could be appropriately applied for use with this selected part. Then the inventory related costs of this selected part were estimated (e.g., ordering cost, carrying cost, and stock out cost). The appropriate quantity and reorder point of the (Q, r) model was determined by using all of inventory related cost of the selected part. When the (Q, r) ordering model was applied with the selected part, the total inventory cost was reduced as much as 29,972.63 Baht/year or 4.39 percent. Finally, a sensitive analysis was performed to analyze the model under changing demand. Demand was increased or decreased by minus 100% to plus 200%. The result was that the (Q, r) ordering model still reduced the total inventory costs, if the demand does not change by more than 40% of actual 2014 demand.

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INVENTORY MANAGEMENT FOR UNCERTAIN DEMAND OF WHOLESALE AGRICULTURE SPARE PARTS

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# CHAPTER I

# GENERALITIES OF THE STUDY

In global business all of companies attempt to maximize profitability. There is profit computational formula which is acknowledged in general business. It is: "Profit = Sales – Costs". As indicated in the formula, Profit can be maximized by "Sales" increasing and "Costs" reducing together. However cost reduction is a priority choice for many businesses because it is less affected by external factors. Therefore it will be easier to increase profit by cost reduction.

Inventory is one of most expensive and important assets for many companies because inventory can either be productive or wasteful for the company. In fact, many companies will try to reduce inventory levels for expected cost reduction (Render, Stair, & Hanna, 2008). But customers' expectations will not be satisfied if inventory is out of stock. Therefore inventory management has become one of the methodologies to balance inventory and customer satisfaction to minimize total cost (Render et al., 2008) and successfully maximize profitability.

This chapter will describe the current market situation and the current company situation. Then, the research objectives were proposed to give the expected benefit of the research. Then the process of research is presented. In conclusion, the significance of the study is given at the end of this chapter.

## 1.1 Background of the Research

Agriculture is one important industry of the South-East Asia region. Because the weather is appropriate to support cultivation and almost all of area is lowland. The countries in this region they are developing countries such as Cambodia, Myanmar, Laos, Vietnam, Indonesia, the Philippines and Thailand. All of them are agricultural countries. Therefore this region has become big market for agricultural machinery because this machinery can help them to increase the productivity of their agriculture and better compete with other regions. In addition, agricultural machinery can provide cost reductions for the farmer and there is a lack of workers in this region.

Accordingly demand for agricultural machinery has been increasing continuously in this region. It is made sales of agricultural machinery a highly competitive business in this region. The agricultural products are a seasonal product. Therefore the agricultural machinery cannot be broken down when the farmer needs to be working. Therefore quality and service have become key strengths of firms in the market. Therefore all competitors have attempted to improve their operations to satisfy this requirement.

ABC Company is an agricultural manufacturer and trader in Thailand. Their products can be separated into assembly products in Thailand and import products from Japan. They have two factories located in Pathumthani and Chonburi provinces. They have 82 dealers to distribute their product and provide service in Thailand. Neighboring countries have 34 dealers around the South-East Asian region. Their products are used in all of the processes of agriculture, from tilling the soil process until harvesting the crops.

### 1.2 Statement of the Problem

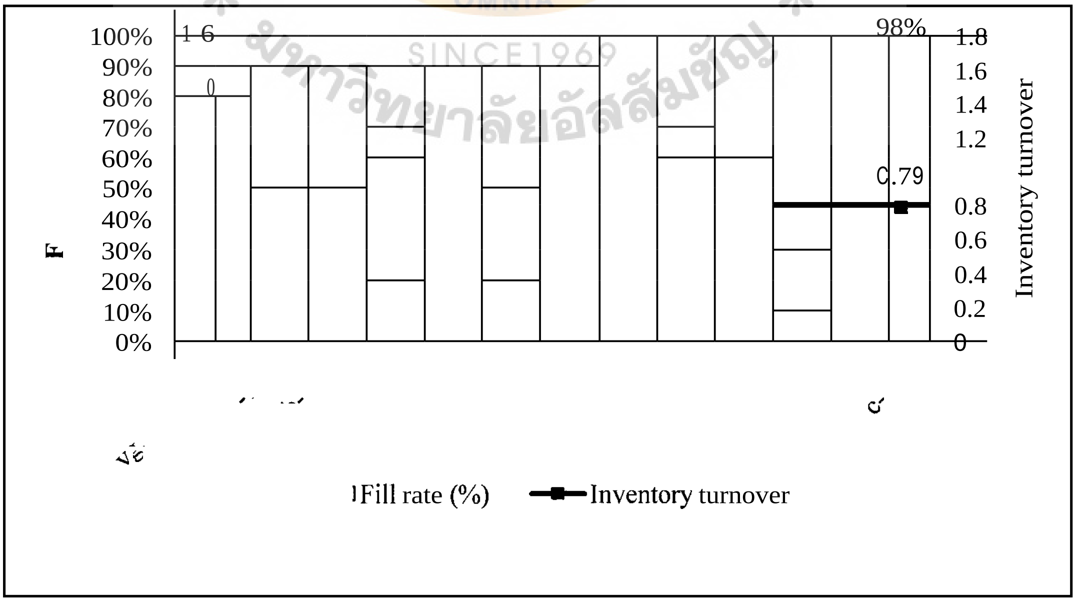
In a competitive situation businesses will be successful if they provide good customer service. The key to customer service is the speed of the service process. They must design their process to meet the customers' requirements. One of the customer service processes is spare parts availability. This process affects the speed of the customer service process directly. The market situation has led ABC Company to keep a high inventory of spare parts to serve the market situation. The past performance of spare parts availability of ABC Company is shown as Table 1.1.

**Table 1.1: Past Performance of Tractor Spare Parts of ABC Company**

| | Fill rate (%) | Back order (Item) | Loss opportunity cost | Inventory value | Inventory turnover |
|---|---|---|---|---|---|
| Avg 2012 | 72.0% | 777 | 12.25 | 1,726.26 | 1.63 |
| Jan-13 | 85.0% | 736 | 11.20 | 1,770.63 | 1.63 |
| Feb-13 | 85.0% | 663 | 8.12 | 1,777.09 | 1.61 |
| Mar-13 | 86.5% | 552 | 8.61 | 1,833.50 | 1.53 |
| Apr-13 | 88.0% | 590 | 9.00 | 1,535.34 | 1.59 |
| May-13 | 86.0% | 636 | 14.74 | 1,650.49 | 1.57 |
| Jun-13 | 88.0% | 517 | 10.98 | 1,712.74 | 1.48 |
| Jul-13 | 92.0% | 436 | 2.45 | 1,811.08 | 1.42 |
| Aug-13 | 95.0% | 232 | 0.86 | 1,880.78 | 1.07 |
| Sep-13 | 97.0% | 153 | 0.86 | 1,942.12 | 0.88 |
| Oct-13 | 98.0% | 134 | 0.52 | 1,965.88 | 0.80 |
| Nov-13 | 97.0% | 100 | 0.53 | 1,976.09 | 0.80 |
| Dec-13 | 98.0% | 124 | 0.99 | 1,963.52 | 0.79 |

Source: Data from ABC Company Unit: Million Baht

**Figure 1.1: Past performance of spare part availability of ABC Company**




Source: Data from ABC Company

According the Table 1.1 and Figure 1.1, ABC Company can increase their fill rate of orders to decrease lost opportunity cost. In contrast, the inventory holding cost has been increasing continuously. The company has to pay high expenses for inventory management such as storage cost, handling cost, and also scrap cost. These costs affect the company's operations costs and reduce the company's profit. The main reason for their high operations costs is inappropriate inventory management policies that cannot deal with fluctuating demand. The demand for agricultural machinery's spare parts fluctuates very highly because there are many unexpected events that affect demand such as the weather, agriculture's market price, seasonal products and pestilence.

The current inventory management policy is based on a minimum and maximum stock policy. The minimum and maximum stock levels are calculated by the use of the historical demand. Orders will be issued when the inventory approaches the minimum level. Then the quantity of the new order will be issued to fill to the maximum stock level. However, sometimes the actual demand fluctuates greatly from historical data. This can affect the inventory of ABC Company positively and negatively because the current ordering policy is calculated based on historical data. This means that if the fluctuation is higher than historical data, the inventory will be out of stock. So ABC Company must issue a short lead time purchase order (PO) to support the actual demand. As a result, ordering cost will be increased by air-freight costs and operational costs for emergency operations. On the other hand, if the fluctuation is lower than historical data inventory will be held in the warehouse. The effect of this is to increase of storage costs and handling costs.

Regarding to above problem, the research question is "How can ABC Company improve their inventory management to reduce total inventory cost?"

### 1.3 Research Objectives

The main purpose of this study is to establish an appropriate ordering model to reduce total inventory costs of ABC Company. The three objectives of the study are:

1. To analyze the usage of spare parts by using the ABC inventory classification system.
2. To compare the total inventory cost of the current model with a joint calculation of order quantity and reorder level model by using the actual demand data of a selected item from 2014.
3. To perform sensitivity analysis when actual customer demand increases and decreases within minus 100% to plus 200%.

### 1.4 Scope of the Research

There are many items of spare parts in the inventory of ABC Company. Therefore this project was focused on the most important imported part which is as determined by the cost of air-freight and the use of the ABC inventory classification method. Because imported parts have a long lead time to resupply, there will be more cost when there is a stock out situation.

The appropriate ordering model was selected after comparing the total inventory costs between current and new ordering policies using Microsoft Excel 2007. The related data came from actual 2014 records and includes such information as actual sales volume data and forecast values.

### 1.5 Significance of the Research

ABC Company would like to be a leader in the agriculture machinery business. For this study it is important for the company to increase the profitability by reduce the total inventory cost. The $(Q,r)$ model is studied to apply the new inventory management model to ABC Company. This solution will be a benefit to ABC for cost savings of spare parts inventory cost. More significantly, this study can apply the same technique to other spare parts which currently use the minimum stock and maximum stock level model.

### 1.6 Limitations of the Research

This study is focused on the imported parts which use the information about actual demand from January 2014 through December 2014. There are other factors which can affect demand such as government policy, pestilence, weather situations, competitive market situations etc.

### 1.7 Definition of Terms

| | |
|---|---|
| Fill rate | The key performance index that measures the responsiveness to customer by the average line item requests shipped prior to the customer due date (Lee, & Billington, 1992). |
| Inventory | Raw materials, work-in process and finished products, which are kept to support the difference between demand and supply (Tersine, 1994). |
| Inventory management | It is the management of the flow of inventory to balance inventory supply and demand (Coyle, Bardi, & Langley, 2003). |
| Inventory turnover | A widely used measure of inventory performance defined as the ratio of the cost of units sold to average stock (Waters, 1992). |
| (Q, r) model | Joint calculation of order quantity and reorder level for uncertainty of demand (Waters, 1992). |

# CHAPTER II

# REVIEW OF RELATED LITERATURE

There are details which are described in the related literature review such as the function of inventory, the basic categories of inventory, inventory related costs, ABC inventory control, reorder point, service level, safety stock, uncertain demand and (Q, r) model methodology. The theories and concepts that are explained are based on academic source including study books, journals and published research.

## 2.1 Functions of Inventory

Inventory exists because it is impossible to synchronize the supply and demand perfectly. There are many a variety of reasons why supply and demand are usually different. However, inventory can be explained by the four functional factors of inventory as follows:

### *2.1.1 The Time Factor*

There is processing time during manufacturing and distribution before the goods reach the customer. The production schedule, transportation of raw material from suppliers, inspection process of the raw material, the manufacturing process and distribution of the products to customers all required time. There are very few customers who are willing to wait for the lead time on all that processing. Therefore the inventory will enable a company to reduce the lead time to meet the customers' requirement. The profitability of company will be increased if the product is available immediately or within a suitable time.

### *2.1.2 The Discontinuity Factor*

The inventory allows for a variety of dependent operations such as purchasing process, production process, warehousing, distribution and selling to be managed independently and economically. Inventory ensures that there is no need to vary the production process because the consumption rate is changed. For example, raw materials of inventory will be sent to separate suppliers from the trade companies. The discontinuity factor will allow companies to conduct many operations at desired performance levels. This would not be possible if each operation was dependently integrated.

### *2.1.3 The Uncertainty Factor*

There are many factors that are unpredictable events. Many of these can changed the original policy of an organization such as an error in demand forecasting, maintenance breakdown, labor strikes, and disasters. In that case, the inventory will be available to provide the company with some protection from unpredicted events.

### *2.1.4 The Economy Factor*

This factor allows a company to take advantage of cost savings. For example, the company can pay for items in economic quantities. The company will get a discount from the supplier. Also the economic purchasing will protect the company from facing price increase situations.

## 2.2 The Basic Categories of Inventory

The inventory can be separated into four categories. First, raw materials are unprocessed materials purchased before the production process and used to produce the finish product. Second is work-in process (WIP) which is incompletely processed inventory which is not ready to sell. The third type of inventory is products that are finished goods which are ready to sell to the ultimate customer. Finally, Maintenance, Repairing and Operating supplies (MRO) are materials which are used to facilitate the production process of the products. They do not become a part of the finished goods (Wisner, Keong, & Tan, 2008).

Inventory can also be classified into five categories based on the function of the inventory as follows:

### *2.2.1 Cycle Stock*

This category of inventory will be kept for company requirements. This is when a company orders a product size lots as opposed to an as required basis. However, the company can minimize ordering costs by ordering in lot sizes.

### *2.2.2 Buffer or Safety Stock*

This category of inventory is intended to be held in order to handle uncertainty of supply and demand. It will protect against shortage situations during the lead time required to replenish stock.

### *2.2.3 Seasonal Stock or Anticipation Stock*

This inventory category is made up of products that are kept in low supply during off seasons and in larger quantities during the high season (e.g., seasonal period of product).

### *2.2.4 Work in Process or Pipe Line Stock*

This category of inventory is in the beginning of being processed, which may be waiting for processing, or shipping by a mode of transportation (e.g., work in process stock).

### *2.2.5 Decoupling Stock*

This inventory will be held by each dependent operation to allow each stage of operation to work in an independent manner.

## **2.3 Inventory-Related Cost**

The inventory cost is composed of four important inventory costs when companies make an inventory management. They include:

### *2.3.1 Purchase Costs*

The purchase cost can be the unit price per unit when it is sourced from a supplier (e.g., supplier or processing cost per unit when it is processed by company process). The purchase cost will be the purchasing price. Processing cost will include the cost of material, labor cost and factory overhead cost (Vollmann, Berry, Whybark, & Jacobs, 2005).

### *2.3.2 Ordering costs or setup cost*

Ordering costs will be occurred when the new orders have been issued by the company. This cost includes variable administrative cost which is composed with the formalities (e.g., purchase order (PO)), or any cost which is one time (e.g., transportation cost). Moreover, it will be included in the cost of the purchasing process such as supplier selection, quality inspection cost and follow-up order cost. From a manufacturing perspective, there is a machine set-up cost for the production of a product.

In reality, the ordering cost or setup cost will be related to order lot size. Therefore, if company places an order for larger quantities of a product the ordering cost per unit will decrease.

### *2.3.3 Inventory holding costs*

Inventory holding costs are composed of two cost components: opportunity costs and physical inventory holding costs.

When company keeps inventory, the costs come from the quantity of inventory, inventory value and the time period for which the inventory will be held. . By tying up funds in inventory the company will lose the opportunity to use these funds for another purpose (e.g., purchasing a new facility, developing new products, or a short-term investment to get a larger return). The cost of funds can be based on the interest rate of the inventory investment or may be based on the loan bank interest rate needed to purchase the inventory. This kind of cost is defined as opportunity cost or the cost of capital (Vollman et al., 2005).

Usually the opportunity inventory holding cost is defined as “rC”, where "r" is the company's rate of return which is usually considered as percentage, and "C" is the purchase cost of inventory (Anupindi, Chopra, Deshmukh, Mieghem, & Zemel, 2004).



The cost of capital is only a part of inventory holding cost. There are other costs that are related with the holding inventory such as taxes, fees, insurance, fees for inventory, obsolescence cost of inventory, operational costs for warehousing inventory that is included the expenses of warehouse rental and overhead cost of warehouse such as facilities expenses. These kinds of costs are defined as physical holding cost (Vollman et al., 2005).

Regularly physical holding cost of inventory is expressed as “hC”, where "h" is the total storing cost of inventory and "C" is the purchase cost of inventory

Finally, the total inventory holding cost was calculated by summing the opportunity costs and physical holding costs of inventory. This gives the total inventory holding cost per unit of inventory per period of time (e.g., year or month). The total inventory holding costs can be expressed as Equation 2.1:

Total inventory holding cost = the physical holding cost + the opportunity cost

$$H = (h+r)C \tag{2.1}$$

On the other hand with ordering cost, inventory holding cost will be dependent upon the size of inventory (Render et al., 2008).

### *2.3.4 Shortage Costs*

Shortage costs will occur when the actual customer demand exceeds the available inventory. It is more complicated to measure than other costs. Some companies estimate that it is equal to the margin of a shortage product, or it will be only cost of stock out follow up from supplier for a product until it will becomes to available inventory. However, stock out cost will be a very high penalty cost, if the customer's goodwill is lost (Vollmann et al., 2005).

## 2.4 ABC Inventory control

Efficient inventory control requires a considerable effort. Most control systems will be computerized, however they need manual effort to input data, check costs, update supplier information, perform order confirmation, make judgments, monitor process of operations, etc. For some items, especially inexpensive ones, this effort is not valuable (for example, routine stationery items tracked in a computerized inventory system). Finally the inventory expenditures are very expensive items which are required individual responsibility more than the routine calculation. An ABC analysis is one way of categorizing items to get this classification.

ABC inventory control uses the 80-20 rule or Pareto analysis. The 80-20 rule suggests that 80 percent of total inventory expenditures will be represented by only 20 percent of the total inventory items. The 80-20 analysis suggests that any inventory item that falls into the 20% category should be controlled as first priority and be managed individually.

The ABC inventory control method classifies the items of inventory into A group, B group and C group by using the annual cost of inventory usage. The annual cost of inventory usage for any inventory item can be calculated by using Equation 2.2

Annual cost of inventory usage = inventory unit cost x Annual usage (2.2)
Inventory that has a high annual cost of inventory usage will be assigned to group A. The intermediate annual cost of inventory usage will be assigned to group B and the low annual cost of inventory usage will be assigned to group C. When inventory is classified by annual cost of inventory usage, the ABC inventory control method will suggest the following:

Group A is made up of about 80 percent of the total annual cost of inventory usage, and it will represent about 20 percent of total items of inventory.

Group B is made up of about 15 percent of the total annual cost of inventory usage, and it will represent about 40 percent of total items of inventory.

Group C is made up of about 5 percent of the total annual cost of inventory usage, and it will represent about 40 percent of total items of inventory.

In reality, the percentage of total annual cost of inventory usage may differ for each company. It is dependent on management's judgment (Vollman et al., 2005). In addition, the ABC inventory classification can be determined using product shelf life and sales volume of inventory also.

## 2.5 Reorder Point: Determining When to Order

The reorder point (ROP) is the minimum inventory level at which a new order must be placed to avoid a shortage situation. The reorder point will be composed of two factors which are the average demand per unit of time and the average replenishment lead time of the product (Anupindi et al., 2004). The reorder point can be explained by Equation 2.3:

$$ROP = d \times LT \quad \text{or}$$
$$ROP = LTD \tag{2.3}$$

Where:

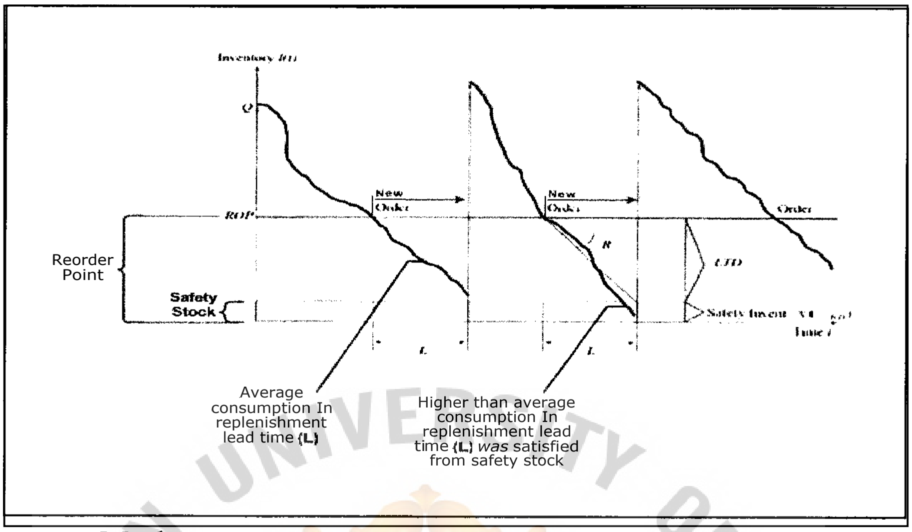
d = Average of demand per unit time

LT = Average replenishment lead time

LTD = Demand during replenishment lead time

Therefore, a new order will be placed when the inventory level falls to the ROP. The new order of inventory will arrive at the same time that companies' inventory level reaches its minimum level as shown in Figure 2.1

**Figure 2.1 : The Reorder Point**




Source: Maslov (2008)

## 2.6 Service Level

The service level can be explained by assuming that the replenishment lead time will be constant and the demand during the lead time of replenishment will be unidentified, but it can be considered as a normal distribution around the mean. If the average demand during replenishment lead time (LTD) is represented by $\mu$ and the reorder point (ROP) is represented by x, then the safety stock is $(x - \mu)$, that is calculated by the standard deviation formula Z = (x - / a. Then, if the probability of stock out is represented by a, then the probability that the inventory is enough to cover the demand during replenishment lead time is (1 – a). Therefore (1 – a), is defined as the service level. Then, the Z-value can be computed by use of the standard normal curve. For any Z-value, the service level can be found from the standard normal curve table.

Finally, if companies indicate the safety stock for a particular level, then the service level is calculated by using Equation 2.4 as:

(ROP – LTD) / ad or

SS / 6d (2.4)

Where:

| | | |
|---|---|---|
| 6d | = | Standard deviation of demand during replenishment lead time |
| SS | = | Safety stock |
| Z | = | Service level factor |

## 2.7 Safety Stock

Unexpected events and risk are always associated with inventory management because there are many variables in reality. However, most of variation will be in demand and lead time. Therefore the company should manage these variations by using a safety stock that will be defined as an additional inventory. The company will keep on hand an amount of inventory as a cushion against a shortage situation. Safety stock will cover the fluctuation of demand during replenishment lead time when the actual demand is higher than expected demand or lead time is longer than the expected lead time of replenishment. Safety stocks will have two effects on the costs of the company. First, safety stocks will reduce the shortage costs of the company. Second, they will increase the company's inventory carrying cost.

Render et al. (2008) suggested that the best method to determine safety stock is to adjust the reorder point. This can be accomplished by adding the quantity of safety stock to the reorder point. In the previous section, when demand during replenishment lead time and lead time are constant the reorder point is expressed as Equation 2.3

On the other hand, when demand during replenishment lead time varies and safety stock will be required, the reorder point will be:

$$ROP = (d \times LT) + SS \text{ or}$$

$$ROP = LTD + SS \qquad (2.5)$$

Where;

SS = Safety stock

In fact, most of companies usually need to determine a safety stock to provide a desired service level. In this case, companies have to reform Equation 2.4 to get the new formula below:

$$Z = (ROP - LTD) / 6d \quad \textbf{or}$$
$$Z = SS / \sigma_d \quad \text{or}$$
$$SS = Z\ \sigma_d \tag{2.6}$$

In reality, when a company has been providing a service level, that company is simply making a tradeoff of stock outs costs and inventory carrying costs (Freeland, & Landel, 2009). Safety stock levels will be determined as high or low. There are three factors which are used to decide the safety stock level as described below:

*2.7.1 Service Level Policy*

If Company needs to reduce the possibility of shortage, then the company must set the service level policy at the highest level. This will result in larger quantities of safety stock that company will keep in reserve.

*2.7.2 Variations of Demand during Replenishment Lead Time*

If the variation of demand during replenishment lead time is high, there will be high shortage probability which might occur during replenishment lead time. Therefore, the company must carry more safety stock in order to avoid shortage situation.

*2.7.3 Variations of replenishment lead time*

If the variation of replenishment lead time is high, there will be high shortage probability which might occur before the replenishment order arrived. Therefore, the company will keep more safety stock if they would like to minimize the effect of a shortage situation.

When considering the effect from those factors, the safety stock amount can be calculated by applying Equation 2.7 as:

$$SS = Z\sqrt{\overline{LT}\sigma_d^2 + d\ \sigma_{LT}} \qquad (2.7)$$

Where;

| | | |
|---|---|---|
| SS | = | Safety stock |
| **LT** | = | Average lead time of replenishment of product |
| d | = | Average demand per unit time for the product |
| $\sigma_d$ | | Standard deviation of demand |
| $\sigma_{LT}$ | = | Standard deviation of replenishment lead time |
| Z | = | Service level factor |

## 2.8 Uncertain Demand

Waters (1992) stated that uncertain demand is very common in inventory systems. Probabilistic models for dealing with significant uncertainty assume demand follows a known probability distribution.

Independent demand inventory systems rely on forecasts of demand. Unfortunately, these forecasts are likely to contain some uncertainty, and when this uncertainty is sufficiently large, we must use models based on probabilistic demand. Many such models have been developed and this section will describe some of the more useful ones.

Aggregate demand for an item is often made up of small demands from a large number of customers. In these circumstances it is reasonable to assume that overall demand is normally distributed. Then we can easily show why deterministic models can give unsatisfactory results. Deterministic models would use mean values, so that reorder level is calculated as in Equation 2.3.

Then three things can be happen:

Actual demand during the lead time exactly matches expected demand. This gives the ideal pattern of stock.

Actual demand during the lead time is less than expected demand. The resulting stock level is higher than expected and this incurs unnecessary holding costs.

Actual demand during the lead time is greater than expected demand. This results in a shortage which may have very high costs.

However, a normally distributed demand will be above the mean value in 50% of the cycles. Then high costs from shortages and many unsatisfied customers are inevitable. This level of performance must be considered unacceptable, and we need to look for a model which will take the uncertainty into account. The following sections develop models based on uncertain demand.

## 2.9 Probabilistic Models for Inventory Control

There are three models for demand which are both uncertain and discrete. We will extend these analyses to cover continuous demand.

### *2.9.1 Marginal Analysis*

The first probabilistic model considers finding an optimal order quantity to satisfy demand for a single period. This kind of analysis is particularly useful for items which have a strong seasonal demand (Waters, 1992). For example, a baker may want to know how many Christmas cakes to make, knowing that any cakes left unsold will have much lower value immediately after Christmas.

This problem uses a marginal analysis which is based on the expected profit and cost of each unit that is shown as equations:

| | | |
|---|---|---|
| Expected profit | = | P (Selling unit) x Profit of selling unit |
| Expected loss | = | **P** (Not selling unit) x Cost of selling unit |

If a small order size is placed, the probability of selling all the units will be high and the expected profit is greater than the expected cost. If a large order is placed, the probability of selling all of the units will be low and the expected profit is less than the expected cost. Therefore based on suggests that the optimal order size is the largest quantity which gives a net expected profit per selling unit. Ordering less than the optimal order size will lose some potential profit, while ordering more will incur net cost.

*2.9.2 Newsboy Problem*

Waters (1992) stated that the marginal analysis for single periods can be extended to the general Newsboy problem. Then expected profit can be maximized by ordering the number of units.

The newsboy problem is phrased in terms of a newsboy selling papers on a street corner. The newsboy has to decide how many papers to buy from his suppliers when customer demand is uncertain. If he buys too many papers he is left with unsold stock which has no value at the end of the day. On other hand, if he buys too few papers he will have unsatisfied demand which could have given a higher profit. Because of this situation, single period problems are usually referred to as Newsboy problems.

*2.9.3 Joint Calculation of Order Quantity and Reorder Level [(Q, r) model]*

Water (1999) stated that since calculating the economic order quantity, we have assumed that this is the best order size in a variety of circumstances. However, the original derivation assumed that shortages were not allowed. It would seem reasonable to ask whether uncertain demand and the possibility of shortages affect the calculation. This section looks at an alternative derivation for an optimal order quantity when demand is uncertain.

Therefore, we will assume all shortages are met by back-orders and the number of stock outs is relatively small. Then, if the lead time is shorter than the stock cycle, the stock out situation is approached.

In this section, demand is assumed to be continuous random and stationary having a mean (pt) and a standard deviation (G). Each variable is shown below:

| | | |
|---|---|---|
| Q | = | Order quantity |
| d | = | Expected demand per unit time |
| C | = | Unit cost |
| K | = | Ordering cost per unit |
| h | = | Holding cost per unit per unit time |
| p | = | Shortage cost per unit |
| LT | = | Lead time of replenishment |
| s | = | Average inventory level before an order arrives |
| | = | $R-\mu$ |
| n(R) | = | Expected shortage per cycle |

$$= \int_{0}^{R} 0\, f(x)dx + \int_{0}^{\infty}(x-R)f(x)dx$$

$$= \int_{0}(x-R)f(x)dx$$

$$= \sigma L(z)$$

| | | |
|---|---|---|
| L(z) | = | Standard loss function |
| T | = | $\frac{Q}{d}$ |

Therefore the expected total cost per unit of time was calculated as follows:

C (Q) = Holding cost + Ordering cost + Shortage cost

$$= h\left(s+\frac{Q}{2}\right)+\frac{K}{T}+p\frac{n(R)}{T}$$

$$= h\left(\frac{Q}{2}+R-dLT\right)+\frac{Kd}{Q}+p\,dn(R)$$

Then find the minimum expected total cost by Q:

$$\frac{\partial C}{\partial Q} = \frac{h}{2}\quad\frac{Kd}{Q^2}\quad\frac{pdn(R)}{Q^2} \rightarrow 0$$

$$\frac{h}{2} \qquad \frac{d[K + pn(R)]}{Q^2}$$

$$\sqrt{2d[K + pn(R)]} \qquad (2.8)$$

Then find the minimum expected total cost by R:

$$\partial C = \frac{pd(1 - F(R))}{h} => 0$$

$$1 - F(R) = \frac{Qh}{pd}$$

$$F(R) = 1 - \frac{Qh}{pd} \qquad (2.9)$$

Therefore the optimal solution is equal to equation 2.8 and equation 2.9. The following points can be made for these results:

- First, the optimal order quantity is never less than the economic order quantity. The EOQ calculation underestimates the best order quantity as it balances only ordering and holding costs but makes no allowance for shortages. By increasing the amounts ordered the number of shortages, and hence costs, are reduced.

  Second, the equations are only valid if h x Q is less than p X d

However, the equations are not in a form which is easily solved. The best approach uses an iterative procedure with the following four steps:

1) Calculate the economic order quantity and use this as an initial estimate of Q.
2) Substitute this value for Q into the second equation and solve this to find a value for ROP.
3) Substitute this value for ROP into the first equation to give a revised value for Q.
4) Repeat steps 2 and 3 until the values converge to their optimal values.

## 2.10 Test the Assumption of (Q, r) Model

The (Q, r) model is the technique that should be applied when demand is uncertain and discrete. Therefore if demand is known or constant, the simple technique can be used easier to reduce the amount of time required.

Peterson and Silver (1797) proposed a tool that can be used to determine the variability of a demand pattern by using a variability coefficient or VC. This statistic is denoted by a variability coefficient and is computed using formula given by equations 2.10 and 2.11 below:

1=1 d

$$\text{Est. var D} \quad \frac{1}{n}\sum_{i=1}^{n} d_i^2 - d^2 \qquad (2.10)$$

$$\text{VC} = \frac{\text{Est.var D}}{d2} \qquad (2.11)$$

Where;

$d_i$ = demand in period i

Number of period

Est. var D = Estimated variance of demand

In order to determine whether the demand pattern has high variability or not, we have to consider the value of VC. If VC is less than 0.25, then a simple technique can be applied (such as the EOQ model). If VC is higher than 0.25, it means that the demand has high variability. Therefore, the (Q, r) model should be applied.

**Figure 2.2 : Variability Coefficient Detemination**

$$VC = \frac{\text{Est.var } D}{d'} \begin{cases} < 0.25, \text{ Demand is low variability.} \\ \text{(Inventory management technique for constant demand should be applied)} \\ > 0.25, \text{ Demand is high variability.} \\ \text{(Inventory management technique for demand distribution should be applied)} \end{cases}$$

Source: Peterson & Silver (1979)

### 2.11 Key Criteria to Choose the Appropriate Inventory Management Approach

There are three key criteria for choosing the appropriate inventory control model. The characteristics of each model influence the approach adopted to manage the inventory.

#### *2.11.1 Is the Demand Independent or Dependent?*

Independent demand assumes that the demand for an item is independent of the demand for any other item. Then the aggregate demand for an item is made up of many independent approaches from separate customers.

Dependent demand assumes that the demand for an item is directly related to the demand for other items. This is particularly clear when the demand for material is related to the demand for finished products.

#### *2.11.2 Is the Demand Certain or Uncertain?*

Certain demand is the demand that is customer demand. Cost and lead time are all known exactly and are constant.

Uncertain demand is when the value of demand is not known exactly, but follows a known probability distribution.

### *2.11.3 Is the Inventory Decision Single Period or Multiple Periods?*

Single period inventory is a business scenario faced by companies that order seasonal or one-time items. There is only one chance to get the quantity right when ordering.

Multiple period inventories are designed to ensure that item is available on an ongoing basis throughout the year. Usually the item is ordered multiple times throughout the year where logic dictates the actual quantity ordered and the timing of the order.

For this study, the (Q, r) inventory control model was selected to manage a selected agriculture spare part characteristic of ABC Company because:

1. Agriculture spare part demand is independent demand because it is not related to other products. It occurred due to customer requirement.
2. Agriculture spare part demand is uncertain demand because there is high variability of demand as defined by the variability coefficient test shown in equation 2.10.
3. Agriculture spare part demand is based upon multiple period inventories because it results from orders placed several times during a year.

**Table 2.1: Comparison Table between Agriculture Spare Parts Characteristics and Each Model Required Characteristics**

| Inventory control model | Independent Demand | Uncertain Demand | Multiple Period Inventory |
|---|---|---|---|
| Agriculture Spare Parts Characteristics | Required | Required | Required |
| Marginal Model | ✓ | ✓ | x |
| Newsboy Model | ✓ | ✓ | X |
| (Q, r) Model | ✓ | ✓ | ✓ |

Source: Author

Where;

Required = A model requirement due to the characteristics of agriculture spare parts demand

Inventory control model can support the characteristic of agriculture spare parts

"x" = Inventory control model cannot support the characteristic of agriculture spare parts

According to Table 2.2, agriculture spare parts inventory management requires an inventory control model that can work function with independent demand, uncertain demand and a multiple period inventory. Therefore the (Q, r) model is the most suitable for the agriculture spare part characteristics of ABC Company. This is because the model can work with all of characteristics of agriculture spare parts.

## 2.12 Related Studies and Research

This section reviewed the research and studies related to the (Q, r) model in order to gain more knowledge in terms of (Q, r) model application in real business environments.

In terms of application, some researchers have applied the (Q, r) model as discussed below:

Mandal and Mahanty (1989) developed a discrete simulation for inventory systems to describe the effect of the decomposition of widely varying demand. They simulate the total inventory cost of the current situation and four possible scenarios as:

Current : Base on average demand

Si : a constant ROP

S2 : a variable ROP based on a three month moving average of a seasonality index

S3 : a variable ROP based on the present month's seasonality index

S4 : a variable ROP based on the following month's seasonality index

**Table 2.2: Comparison of Total Inventory Costs per Year Using Each Scenario**

| Scenarios | Total inventory cost (100,000 Rupees) |
|---|---|
| Current | 13.96 |
| 51 | 10.05 |
| S2 | 8.71 |
| S3 | 10.51 |
| S4 | 9.60 |

As shown in Table 2.3, total inventory costs can be reduced from 139,600,000 Rupee to 87,100,000 Rupees when scenario 2 is used.

Comez and Kiessling (2012) developed the (Q, r) policy system with a pricing strategy for a continuous inventory review system. They aim for the optimal price and inventory control variables simultaneously and then obtain the benefits of joint optimization of the inventory and pricing decisions over the sequential optimization policy.

Therefore, this study is focused on joint optimization of inventory replenishment and a constant selling price. By showing optimal conditions on the price and inventory decision variables, two algorithms on how to obtain optimal decision variables (one for an additive and another for a multiplicative demand-price model) are provided. Through extensive numerical analyses, the potential profit increases are reported if price and inventory problems are solved simultaneously instead of sequentially. In addition, the sensitivities of optimal decision variables to system parameters are revealed.

The results mainly support the practical intuition that marketing wants to sell more with lower prices, while operations is more concerned about inventory levels such that if price and inventory decisions are made together, the optimal price is higher and stocking levels are lower than those in sequential decision making. Moreover, the benefits of joint decision making increase significantly as the fixed ordering or holding costs increase. This indicates the increasing importance of coordination for expensive to order and stock products.

### 2.13 Summary

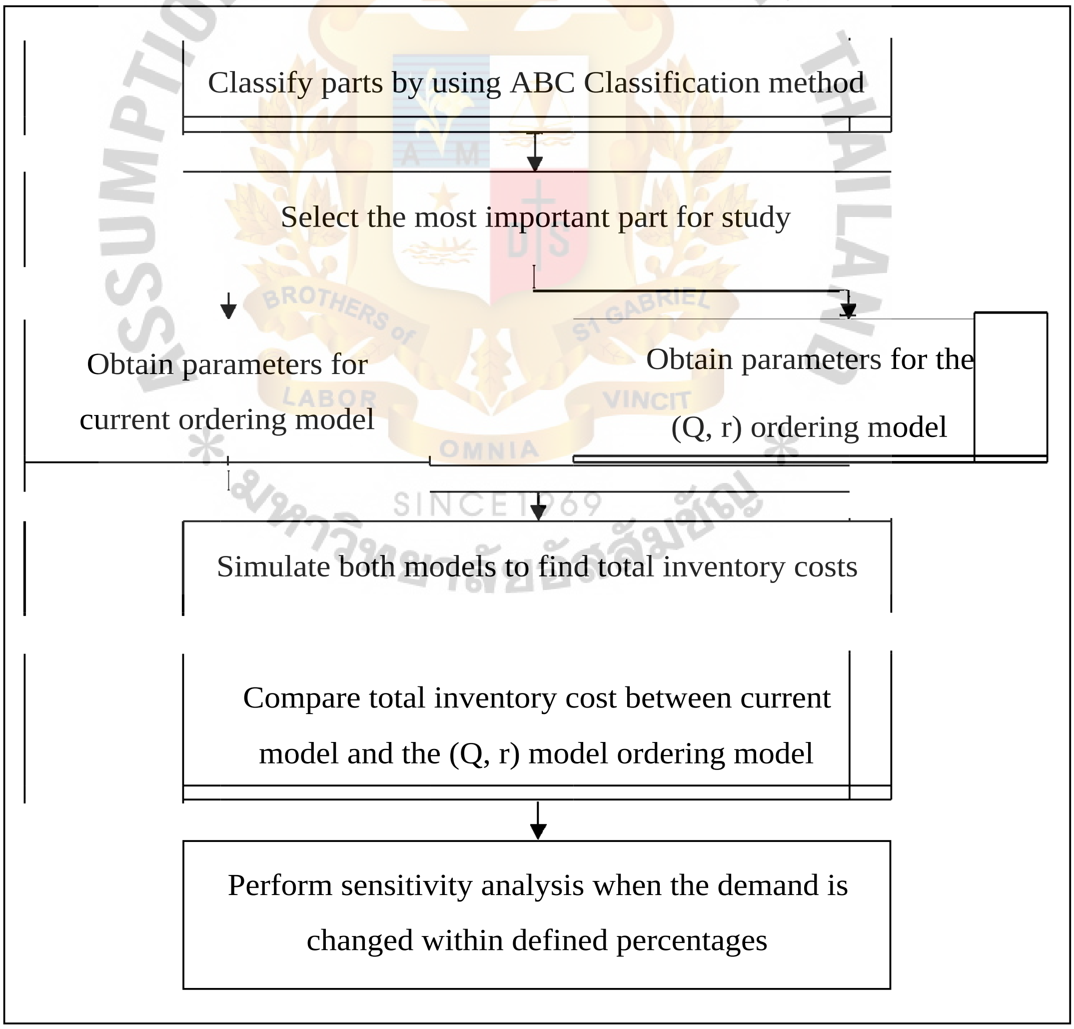
In this chapter, the theoretical background and literature concerning the study topic were reviewed. The relevant theories are used to address ABC Company's situation in order to answer the research question. This chapter reviewed topic areas in the literature including inventory management theory and probabilistic inventory control models for uncertain demand. In the next chapter, the research methodology is described and details of how this study was conducted to achieve the research objectives are provided.

# CHAPTER III

# RESEARCH METHODOLOGY

This research is an attempt to find the appropriate order quantity and timing required to reduce total inventory costs. To find the appropriate order quantity and timing for ABC Company, the analysis conducted was applied to the historical data of ABC Company for the year 2014. The stages of research process are shown step by step in Figure 3A

**Figure 3.1 : Stage of Research Conduction**




Source: Author

### 3.1 Classification of Parts Using ABC Classification Method

The sales quantity of each imported part in 2014 has been collected. There are many of varieties of imported parts which are used by ABC Company. It is beyond the scope of this study to attempt to improve inventory management model for all of ABC Company's imported parts because of the high cost excessive amount of time that would be required for this improvement. Therefore the researcher applied the ABC classification method to classify all imported parts based on annual cost of sales for each part. The imported parts with the highest cost of sales were placed in group A and the highest annual cost of sales tool was selected to develop the inventory management model. The steps used to classify the parts are shown as follows:

1. Determine the annual sales volume quantity of each imported part.
2. Multiply the annual sales volume quantity of each imported part by the purchase cost of each imported part to determine the annual cost of sales volume of each imported part.
3. Sum of the annual cost of sales volume for each imported part to get the annual cost of sales volume of all parts.
4. Divide the annual cost of sales volume of each imported part by the annual cost of sales volume of all imported parts to get the percentage of aggregate of sales volume.
5. Arrange the percentage of each imported part from highest percentage to lowest percentage.
6. Review the annual cost of sales volume distribution and classify imported parts to A, B and C groups based on the percentages shown in Table 3.1

**Table 3.1: Percentages Used in the ABC Classification**

| | % of Annaul cost sale volume | % of Total item |
|---|---|---|
| Group A | 80% | 20% |
| Group B | 15% | 40% |
| Group C | 5% | 40% |

## 3.2 Obtain Common Parameters for Minimum and Maximum Stock Level Model and (Q, r) Model Ordering Process

Both ordering models need parameters to simulate the inventory level in each month. Therefore the required parameters were separated by each model as follows:

### *3.2.1 General Data Parameters*

There are a number of parameters that must be selected for the parts which are required factors for use in the calculation of both models. These factors are shown in Table 3.2

**Table 3.2: Source of Common Factor Parameters**

| General parameter | Unit | Source |
|---|---|---|
| Part No/Part Name/Supplier | - | From material master data of ABC Company |
| Service level | % | From ABC Company policy |
| Supplier performance | - | From standard deviation of supplier lead time |
| Average demand | Pc/Week | From historical demand data (1 year) |
| Standard deviation | - | From historical demand data (1 year) |
| Lead time of replenishment | Week | From material master data of ABC Company |
| Part weight | Kg. | From material master data of ABC Company |
| Package dimension (W x L x H) | meter | From material master data of ABC Company |
| Purchase price | THB | From price list, which is activated on 2014 |

Source: Author

*3.2.2 Required Minimum and Maximum Stock Level Model Parameters*

A minimum stock level and maximum stock level ordering model is one type of inventory control model. Using this model the order is issued when the inventory level drops below the minimum stock level. Then the quantity to be ordered was calculated to fulfill to the maximum stock level.

The minimum and maximum stock level of ABC Company was calculated by the use the formulas shown in Equation 3.1 and Equation 3.2:

**Minimum stock level** = (SSF **x d x LT)** + **(d x** LT) (3.1)

**Maximum stock level** = GF x (Minimum stock level + d + STD) (3.2)

Where:

GF = Growth factor (130% is used by ABC Company)

SSF = Safety stock factor (50% of demand during lead time is used)

d = Average demand during periodical review

**LT** = Lead time of replenishment

STD = Standard deviation of demand

*3.2.3 Required (Q, r) Model Parameters*

The (Q, r) model is an inventory management model which monitors inventory levels continuously. The computation was used to reduce the total of inventory costs to find the appropriate order quantity and reorder point. According to this concept, there are four types of data that are required before a determination of the appropriate order quantity and reorder point can be made by the (Q, r) model in simulation:

1) The demand pattern of the selected part
2) The ordering cost of the selected part
3) The carrying cost of the selected part
4) The stock outs cost of the selected part

Each item of required data was determined by the calculations as follows:

**1) Determination of the Demand Pattern of the Selected Part**

- Determine if the (Q, r) model is appropriate for the demand pattern.

The (Q, r) model should be used when there is a high variability in demand. Therefore we must determine the pattern of demand such that it is appropriate to use the (Q, r) model. The tool to be used to make this determination is the variability coefficient (VC) discussed in Chapter 2.

In order to determine the variability of demand, we have to consider the value of the VC. If the VC is higher than 0.25, then the (Q, r) model technique is appropriate. On the other hand, if the VC is less than 0.25, the (Q, r) model is not appropriate for use with this demand pattern.

- Determination of the Distribution of Historical Demand

The historical demand was used to determine pattern of data distribution. The average demand and standard deviation of the data distribution becomes parameter for use in calculation in the (Q, r) model.

**2) Calculation of the Ordering Cost per Order**

CIF (Cost, Insurance and Freight) is the Inco-term of regular orders of the ABC Company. There are two types of shipping processes that are used. They are the Full Container Load (FCL) and Less than Container Load (LCL). The shipping type was selected depending on the quantity ordered each time. Therefore the shipping type for the ordered parts were selected by the limit of quantity ordered each time. The limit of quantities ordered was calculated by multiplying the target month of supply which by ABC Company policy is the average demand in each month. The calculation is shown in Equation 3.3:

**Limit of order quantity** = Target MOS x Avg. demand (3.3)

Where:

Target MOS = Target Month of Supply, (10 months is used)

Avg. demand = Average demand per month

Then the limit of order quantity is compared with the maximum units in an FCL as calculated in Equation 3.4

$$\textbf{Maximum unit for FCL} = \frac{\text{Total Container Volume}}{\text{Packaging of selected part volume}} \qquad (3.4)$$

Remark: Total Container Volume was 33.20 $m^3$ which is the standard total container volume of a 20 feet container.

FCL shipping type is selected if the limit of ordering quantity is more than the maximum unit for FCL. The LCL shipping type is selected, if the limit of order quantity is less than the maximum unit for an FCL.

Therefore the ordering cost per order was the sum of the total expense when the shipment has arrived. The expense of the shipment is composed of the following:

Transportation in land fee
Import clearance fee
Shipper and forwarder fee
Delivery order note fee
Operation fee

**3) Calculation of the Carrying Cost per Piece**

Carrying cost can be separate into two parts: the physical holding cost and the opportunity cost of holding. The calculation of each portion can be shown as follows:

- Calculation of the Physical Holding Cost

The physical holding cost per piece is composed of the storage cost per piece and the per piece operational cost of running the warehouse. Storage cost depends on size of the selected part but operational cost is the fixed costs of warehouse operations. The calculation is summarized in Equation 3.5:

$$\textbf{Physical holding cost} = \text{Storage cost} + \text{Warehouse Operational cost} \qquad (3.5)$$

*Calculation of the Storage Cost per Piece*

ABC Company uses an outsourced warehouse to keep their inventory of spare parts. Therefore storage costs can be calculated by rental rate of the warehouse used by ABC Company multiply by the space consumed by the selected part. The calculation is summarized in Equation 3.6:

$$\textbf{Storage cost per piece} \quad \text{WH rate x Consumption's area of part}$$

$$\text{WH rate x } \frac{\text{Area of package}}{\text{Row of stack's package}} \qquad (3.6)$$

Where:

WH rate = Warehouse rental rate (Baht per square meter per month)

$$\text{Area of package} \quad \text{Width of packaging x Height of packaging}$$

$$\text{Row of stack's package} \quad \frac{\text{Maximum load of package}}{\text{Weight of a packaging}}$$

*Calculation of the Operational Cost per Piece*

The warehouse operations cost of ABC Company can be calculated by summing all of the fixed operating expenses in the spare part warehouse. These include the 2014 figures for the salary of the warehouse staff, equipment rental and outsourced process cost (e.g., forklift, truck and other operational fixed cost incurred in 2014). Therefore the rate of warehouse operating cost per square meter can be calculated by dividing the sum all of warehouse expenses in 2014 by the space consumed by the selected parts' package area. The calculation of operational cost per piece is summarized in Equation 3.7:

**Operational cost per piece**

- Rate of warehouse operating cost x Space in warehouse consumed by the selected part's packages

$$\frac{\text{Sum all of warehouse expense in 2014}}{\text{Total area of warehouse}} \qquad \frac{\text{Area of package}}{\text{Row of stack's packages}} \tag{3.7}$$

*__Calculate the Opportunity Cost of Holding per Piece__*

The opportunity cost per piece was calculated using the Minimum Loan Rate (MLR) to be an expense of the funds invested in the inventory being held. For this study, Bangkok Bank's MLR (BBL’s MLR) in 2014 was converted to monthly rate for use in the calculation. Then the opportunity cost of holding inventory per piece can be determined by multiplying average MLR in 2014 by the purchase cost per piece of the selected parts. The calculation can be expressed as in Equation 3.8:

**Opportunity cost of inventory holding**

- Average BBL’s MLR in 2014x Purchased cost (3.8)

The physical holding cost per piece and opportunity cost of holding per piece can now be determined. Carrying cost per piece can be determined by adding the physical holding cost per piece and opportunity cost of inventory holding cost per piece together as Equation in 3.9:

**Carrying cost**

- Physical holding cost + Opportunity cost of inventory holding (3.9)

**4) Calculation of the Stock Out Cost per Piece**

The spare parts business is a trading business that is a wholesaler to authorized dealers in each region. Therefore stock out costs or penalty costs can be calculated by using the additional expense of ordering. This additional expense was required of

ABC Company to obtain the required parts for their within a few days so that is no effect on customer satisfactions. This cost was charged when the inventory level is not enough to meet actual demand in each period. ABC Company has a policy to refill the inventory level to the safety stock level when stock is out. Therefore a stock out situation was a charge cost per piece when adding the additional fee of purchase cost per piece and air-freight cost of transportation together. The calculation of each cost is shown as follows:

- Fee of Special Purchase Cost per Piece

A special purchase price was charged by the supplier to supply the part with a short lead time. The special purchase price was 125% of the regular purchase price. Therefore fee for the special purchase cost per piece was an additional 25% over the regular purchase price.

- Additional Air-Freight Cost per Piece

The cost ABC Company was higher than the regular transportation charges when air-freight transport is used. The additional air-freight cost per piece is calculated by finding difference in the cost per piece between air-freight costs and sea-freight costs per piece. The formula of additional air-freight cost per piece is shown in Formula 3.10:

**Additional air-freight cost**

$$\text{Weight} \times \left( \frac{\text{Sum of AFE in 2014}}{\text{Total weight of Air transport in 2014}} - \frac{\text{Sum of SFE in 2014}}{\text{Total weight of Sea transport in 2014}} \right)$$

(3.10)

Where:

AFE = Total air-freight expense

SFE = Total sea-freight expense

The additional fee for special purchase cost per piece and additional air-freight cost per piece can now be determined. Stock out cost per piece can then be determined by adding the additional fee of the special purchase cost per piece and additional air-freight cost per piece together as shown in Equation 3.11:

**Stock out cost per piece**

= Fee of special purchase cost + Additional air-freight cost (3.11)

## 3.3 Calculate The Optimal Order Quantity and Reorder Point by the (Q, r) Inventory Control Model

Equation 2.8 and Equation 2.9 provided in Chapter 2 together provide the formula needed to calculate the optimal order quantity and reorder point using the (Q, r) inventory control model. Both equations will use the inventory related costs in the calculation to find the optimal order quantity and reorder point.

**Table 3.3: Optimal Order Quantity and Reorder Point Calculation Table for the (Q, r) Inventory Control Model**

| No | Q | R | F ( R ) | n ( R ) | L ( z ) | Z-score |
|---|---|---|---|---|---|---|
| 1 | ( A ) | - | ( B ) | ( E ) | ( D ) | ( C ) |
| 2 | ( F ) | ( G ) | … | … | … | … |
| … | … | … | … | … | … | … |
| i | Optimal Order | Reorder point | - | - | - | - |

Source: Author

Where:

$$Q = \sqrt{\frac{2d[K+pn(R)]}{h}} \quad \text{or} \quad \sqrt{\frac{2Kd}{h}}$$

$$F(R) = 1 - \frac{Qh}{pd} \quad \text{or } z - \text{Score}$$

$$az +$$

$$n(R) = \sigma L(z)$$

$L(z)$ = Standard loss function

The steps in the calculation are explained in Table 3.3 which shows each step alphabetically from the 1st step (A) until the optimal order quantity and reorder point are reached. Each step is explained as follows:

(A) Calculate the EOQ for initial estimation
(B) Calculate the F( R) to use with the standard normal table
(C) Use the standard normal table to find the z-score of F( R )
(D) Use z-score with the loss function table to find L( z )
(E) Find n( R )
(F) Use n( R) with the inventory related cost to find Q for the next row
(G) Use the z-score in the 1St row to find R for the next row

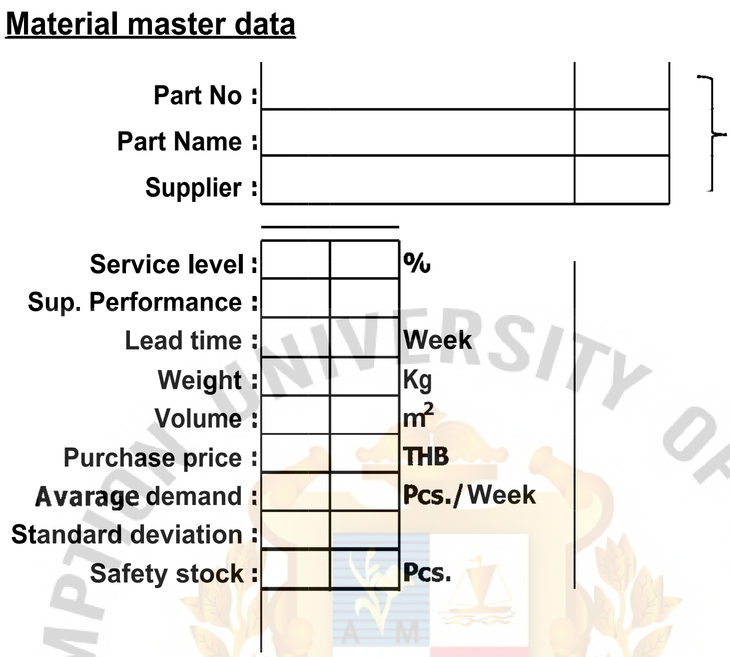
Then repeat (B) and (G) until Q and R converge which is implies both Q and R are the optimal order quantity and reorder point respectively.

**3.4 Build the simulation by using Microsoft Excel 2007**

The simulation was composed of three paths as shown below in Figure 3.2, Figure 3.3 and Figure 3.4. The details of each path are explained below:

## Path 1: Material Master Data

**Figure 3.2 : Material Master Data (Path 1)**




Source: Author

### 1. Details of selected part

There are three necessary details of the selected part which are described below:

1) Part Number - This is the part code of selected part which is composed of 10 digits to specify each part.
2) Part Name – This is the part name of the selected part.
3) Supplier – This shows the supplier code of the company who is currently the producer of the selected part.

### 2. Required parameter data

These parameters were gathered from 3.2.1 and 3.2.2 to be used in the calculations for such factors as safety stock and demand during the period.

## Path 2: Simulation of Current Ordering Process

**Figure 3.3 : Simulation Current Ordering Process (Path 2)**

| | | |
|---|---|---|
| **Min_Stock** | **X** | **Pcs.** |
| **Max Stock** | **Y** | **Pcs.** |
| **Start inventory** | **2** | **Pcs.** |

| | **Week#1** | **Week#2** | **Week#3** | **Week#4** | **Week#5** | **Week#6** | **Week#7** | **..** | **Week#51** | **Week#52** |
|---|---|---|---|---|---|---|---|---|---|---|
| Actual demand ($A_i$) | - | | - | | | - | | | - | |
| Safety stock ($B_i$) | | - | | | | | - | | - | |
| SO ($C_i$) | | | | - | | | | | | |
| MO ($D_i$) | | - | | | | | - | | | |
| Schedule_MO ($E_i$) | [redacted] | [redacted] | | | [redacted] | | | [redacted] | - | |
| Pending PO ($F_i$) | - | - | | - | | - | | | - | |
| Allocate ($G_i$) | | | | - | | - | | | - | |
| Inventory level ($H_i$) | - | | | - | | | | | | - |

Source: Author

For Figure 3.3, the simulation is calculated by for each variable as:

Each period in the simulation

Actual demand in each period

B, = Safety stock of the selected part (This was equal in all of periods)

C, = Special orders in each period (This was issued when the inventory level has dropped to zero in order to resupply to the safety stock level.

(Formula: if $G_i < 0$, then $C_i = B_i - G_i$, if not $C_i = 0$)

D, = Monthly order in each period. (This is the regular order in each period.)

(Formula: if $F_i + H_i < X$, then $D_i = Y - (F_i + H_i)$, if not $D_i = 0$)

E, = Delivery of monthly order in each period

F, = Current purchase order in lead time

(Formula: Summary of $E_i$ during lead time)

G, = Assumed inventory in each period

(Formula: $(H_{i-1} + E_i)$ -

Hi = Actual inventory in each period

(Formula: If $C_i > 0$, then $H_i = B_i$, if not $H_i = (H_{i-1} + E) - A_i$)

<u>Remark:</u> $H_{i-1}$ was equal to Z in the 1 week.

## Path 3: Simulation of (Q, r) Model Ordering Process

**Figure 3.4 : Simulation (Q, r) Model Ordering Process (Path 3)**

| | | |
|---|---|---|
| ROP | X | Pcs. |
| EOQ | Y | Pcs. |
| Start inventory | Z | Pcs. |

| | Week#1 | Week#2 | Week#3 | Week#4 | Week#5 | Week#6 | Week#7 | ... | Week#51 | Week#52 |
|---|---|---|---|---|---|---|---|---|---|---|
| Actual demand (A) | - | - | - | - | - | - | - | - | - | - |
| Safety stock (B) | - | - | - | - | - | - | - | - | - | - |
| SO ($C_i$) | | | - | | - | | - | | | |
| MO ($D_i$) | - | - | [redacted] | | | | | | | |
| Schedule_MO | | | [redacted] | | | | | | | |
| Pending PO (F) | | - | - | - | - | - | - | | - | - |
| Allocate (G) | - | | - | | - | - | | - | - | - |
| Inventory level ($H_i$) | - | - | - | - | - | | - | - | - | - |

Source: Author

For Figure 3.4, the simulation is calculated for each variable as:

Each period in the simulation

A, = Actual demand in each period

B, = Safety stock of the selected part (This was equal in all of periods)

Special order in each period (This was issued when the inventory level has dropped to resupply to the safety stock level.

(Formula: if $G_i < 0$, then $C_i = B_i - G_i$, if not $C_i = 0$)

$D_i$ = Monthly order in each period. (This is the regular order in each period.)

(Formula: if $F_i +$ $< X$, then $D_i = Y$, if not $D_i = 0$)

$E_i$ = Delivery of monthly order in each period

F, = Current purchase order in lead time

(Formula: Summary of E1 during lead time)

G, = Assumed inventory in each period

(Formula: $(H_{i-1} + E_i) - A_i$)

Hi = Actual inventory in each period

(Formula: If $C_i > 0$, then $H_i = B_i$, if not $H_i =$ $+ E_i) - A_i$)

Remark: $H_{i-1}$ was equal to Z in the 1 week.

## 3.5 Compare Total Inventory Cost Between Current and (Q, r) Model Ordering Policy

After simulating both ordering processes, measurements were conducted using the total inventory cost in 2014. This compared the current ordering policy and the proposed ordering policy (which is the (Q, r) model). The ordering policy that provided the lowest total inventory cost was selected. The inventory costs used in this study, there were the following:

1) Ordering cost in 2014
2) Carrying cost in 2014
3) Stock out cost in 2014
4) Total inventory cost in 2014

Each item of required data was determined by the calculations that follow:

### *3.5.1 Calculation of the Ordering Cost in 2014*

Ordering cost for 2014 were calculated by summing the ordering costs for each month as shown in equation 3.10:

**Ordering cost in 2014**

$$= \sum_{i=1}^{12} \text{No. of orders}(i) \times \text{Ordering cost per times} \qquad (3.10)$$

Where (i) is the number of months in 2014

### *3.5.2 Calculation of the Carrying Cost in 2014*

Carrying cost for 2014 can be calculated by summing the carrying costs for each month as shown as below in equation 3.11:

**Carrying cost in 2014**

$$= \sum_{i=1}^{12} \text{Inventory quantity(i) x Carrying cost per piece} \quad (3.11)$$

Where (i) is the number of months in 2014

*3.5.3 Calculation of the Stock Out Cost in 2014*

Shortage cost in 2014 can be calculated by summing the stock out costs in each month which is shown in equation 3.12 below:

**Stock out cost in 2014**

$$= \sum^{12} \text{Stock out quantity(i) x Stock out cost per piece} \quad (3.12)$$

Where (i) is the number of months in 2014

*3.5.4 Total Inventory Cost in 2014*

Total inventory cost in 2014 can be calculated by summing the carrying costs for 2014 and shortage costs for 2014. This cost was used as a factor to determine the ordering policy for this study. This calculation can be expressed as equation 3.13 below:

**Total inventory cost in 2014**

= Ordering cost in 2014 + Carrying cost in 2014 + Shortage cost in 2014 (3.13)

**3.6 Perform Sensitivity Analysis when Actual Demand Increases and Decreases within Defined Percentages**

Changing demand has always been occurring in this market situation. Therefore it would be more advantageous to analyze what the effect on total inventory cost would be if the demand is increased or decreased. The changing percentages will be started at minus 100% and increased to plus 200% of actual demand in 2014.

### 3.7 Summary

There are two categories of data that must be gathered for this research which include selected part data and general data. Selected part data is composed of historical demand data, replenishment lead time, purchase prices, weight of parts and supplier performance. For these the actual data from ABC Company was used drawing from that which they stored in their record keeping system. General data was composed of the details of freight cost, warehouse rental rate, service level policy, and minimum loan rate and companies expense. All of the general data were gathered using the standard rates for ABC Company that it is calculated from historical demand data. The result of comparison between the current ordering policy and the (Q, r) model is described in next chapter.

# CHAPTER IV

# PRESENTATION AND CRITICAL DISCUSSION OF RESULTS

The previous chapter explained the steps of this research needed to compare the current inventory management policy with the (Q, r) model policy. This chapter starts by selecting the imported part to be used in the analysis. This was done using the ABC classification methodology. Then the simulation of each policy will be computed along with the inventory level in each period of time for total inventory cost comparison. Finally, the appropriate policy was selected as the one that minimized the total inventory cost.

## 4.1 Classify Inventory by Applying ABC Classification Method

### *4.1.1 Calculation of Annual Cost of Usage for each Part in 2014*

The annual demand for each part from January 2014 to December 2014 was collected to multiply each by its purchase cost. Then the annual cost of usage was calculated for each part for use in the ABC classification. Example 4.1 shows how to calculate the annual cost of usage:

<u>Example 4.1</u>: Calculation of annual cost of usage for ASSY SEAL OIL which is part number TC010-99600.

Annual demand of ASSY SEAL OIL in 2014 = 27,626 Pieces.

Purchase cost of ASSY SEAL OIL in 2014 = 338 Baht/piece

Thus, the annual cost of usage of ASSY SEAL OIL was calculated as

Annual demand in 2014 x Purchase cost in 2014

= 27,626 pieces x 338 Baht per piece

= 9,335,378 Baht

An abbreviated version of the annual cost of usage for each part is summarized in Table 4.1

| No | Material | Material number | Purchased cost per piece | Annual demand in 2014 | Annual cost of usage | Accumulate annual cost of usage |
|---|---|---|---|---|---|---|
| 1 | TC010-99600 | ASSY SEAL OIL | 338 | 27,626 | 9,335,378 | 9,33 3,78 |
| 2 | [illegible]-12010 | ASSY GEAR BEVEL | 2,915 | 2,737 | 7,[illegible]7,[illegible] | 17,312,529 |
| 3 | TA020-12013 | ASSY GEAR BEVEL | 2,260 | 2,580 | 5,830,38[illegible] | 23,142,916 |
| 4 | [illegible] | SHAFTHYD.ARM LIFT | 1,24[illegible] | 2,854 | 3,548,275 | 26,691,191 |
| 5 | 3C081-82202 | HYDRAULIC PUMP | 10,4[illegible]8 | 316 | 3,2[illegible] | 29,989,554 |
| 6 | 3C051-42300 | ASSY GEAR BEVEL 10-23T | 4,7[illegible] | 614 | 2,899,141 | 32,888,695 |
| 7 | 3C315-42300 | ASSY GEAR BEVEL | 3,344 | 630 | 2,106,720 | 34,995,415 |
| 8 | 3 1 1 [illegible]4200 | ASSY SYNCHRONIZER | 12,[illegible]5 | 1 1 | 2,066,4[illegible] | 37,061,[illegible]46 |
| : | | : | : | : | | : |
| 3,610 | 3A111-98180 | LABEL MAIN SWITCH | 15 | 1 | 15 | 169,58[illegible]80 |
| 3,611 | 38240-18220 | CUSHION | 4 | 2 | 8 | 169,58[illegible]88 |
| | | Total annual cost | | | | 169,58[illegible]88 |

Source: Data from ABC Company.

N *Arrange the Annual Cost of Usage for Each Part from Largest to Smallest*

arranged from highest percentage of annual cost to the lowest percentage of annual cost. Table 4.2 shows some parts that are classified as group A and then skips to the end of the list to show the parts with the smallest percentage which are part of the group C classification.

**Table 4.2: ABC Classification Analysis for ABC Company (Unit:Baht)**

| No | at rial | Material number | Annual cost of usage | Accumulate annual cost of usage | e ce age | Cumulative percentage | Group |
|---|---|---|---|---|---|---|---|
| 1 | [illegible]C01 )-99600 | ASSY SEAL OIL | 9,335,378 | 9,33[illegible] 3[illegible] 8 | [illegible]1% | 5 51% | |
| 2 | TD030-12010 | ASSY GEAR BEVEL | [illegible]9[illegible]7.151 | 17,312,529 | 70% | 10.21% | |
| 3 | TA020-12013 | ASSY GEAR BEVEL | 5,830,387 | 23,142,916 | 3.44% | 13.65% | |
| 4 | TC222-37432 | SHAFT HYD.ARM LIFT | 3,548,275 | 26,69[illegible] 1[illegible]1 | [illegible].09% | 15.74% 1 | |
| in | 3C081-82202 | HYDRAULIC PUMP | 3,29[illegible] 36[illegible] | [illegible]9[illegible] 554 | [illegible]5% | 17.69% | |
| 6 | 3C051-42300 | ASSY GEAR BEVEL 10-23T | 2,899,141 | 32,888,695 | .71% | [illegible]9 40% | |
| 7 | 3C315-42300 | ASSY GEAR BEVEL | 2,106,720 | 34.9[illegible]415 | .24% | 20.64% | |
| 8 | 3A161-34700 | ASSY SYNCHRONIZER | 2,06 43 | 37,061,846 | 1.22% | Z1 [illegible] | |
| : | | : | | : | : | : | |
| 3,610 | 3A111-98180 | LABEL MAIN SWITCH | [illegible] | 169 5[illegible] | 0.000009% | 99.90[illegible] | |
| 3,611 | 38240-18220 | CUSHION | 00 | 169,[illegible] 8 | 0.000005% | 100.00% | |

Source: Data from ABC Company.

Of the 3,611 items of carried by ABC Company, the number items in each of the ABC classification categories are shown below:

Group A is composed of 442 items (12.24% of the total items, 79.98% of the total annual cost of usage)

Group B is composed of 882 items (24.42% of the total items, 15.02% of the total annual cost of usage)

Group C is composed of 2,287 items (63.34% of the total items, 5.00% of the total annual cost of usage)

### 4.2 Selecting the Most Important Part

Using the results of this ABC classification analysis the first ranked imported part shown in the ABC classification table was used in the analysis. This part is the ASSY SEAL OIL (TC010-99600). This selected import part became the pilot project for use in studying improvement of the inventory management policy of the ABC Company.

### 4.3 Determination of the Required Parameters of the Selected Part

In order to simulate of current ordering model and the (Q, r) model, the required parameters of the selected import part were required as follow

*4.3.1 General Data Parameters of the Selected Part*

ABC Company policy considers that in order to satisfy customers an order or fill rate should be set at 98% fulfillment of the total customers' orders. So ABC Company has chosen the service level of safety stock calculation to be 98%. The supplier performance will be considered by use the standard deviation of supplier replenishment lead time in 2014 which is equal 0.6. Some of the parameters to be used in the simulation are common to both models and were selected from the material master parameter list of ABC Company as of December 31, 2014. These parameters common to both models are shown in Table 4.3:

**Table 4.3: Parameters of the Selected Part Common to Both Models**

| General parameter | Unit | Data |
|---|---|---|
| Part No/Part Name/Supplier | - | TC010-99600 / ASSY SEAL OIL / KBT |
| Service level | % | 98% |
| Supplier performance (Standard diviation of lead time) | - | 0.60 |
| Average demand | Pc/Week | 531.27 |
| Standard deviation of demand | - | 292.64 |
| Lead time of replenishment | Week | 16 |
| Part weight | Kg. | 0.12 |
| Package dimension (W x L x H) | meter | 0.14 X 0.22 X 0.01 |
| Purchase cost | THB | 338.00 |

Source: Data from ABC Company.

After the common parameters have been gathered, the safety stock level for a 98% service level was calculated using Equation 2.7 as follows:

Safety Stock level $= \quad Z\sqrt{\overline{LT}\sigma_d^2 + \bar{d}^2\sigma_{LT}^2}$

$$2.05\sqrt{(16 \times 292.64^2) + (531.27^2 \times 0.6^2)}$$

2,491.58

Therefore the safety stock level for a 98% service level was rounded to 2,492 pieces.

*4.3.2 Minimum and Maximum Stock Level for use in the Current Ordering Model*

There are some parameters which are used for calculation in the minimum and maximum stock level ordering model. Each parameter and the source of those parameters are shown as follows:

Then the minimum and maximum stock level was calculated as follows:

1. Minimum stock level

= (SSF x d x LT) + (d x LT)

= (0.5 x 531.27 x 16) + (531.27 x 16)

= 4,250.16 + 8,500.32

= 12,750.48

Therefore the minimum stock level was rounded to 12,751 pieces.

2. Maximum stock level

Since the tolerance factor of ABC Company is 50% the maximum stock level was calculated as:

= Tolerance factor x (Minimum stock level + d + STD)

= 130% x (12,751.00 + 531.27 + 292.64)

= 17,647.38

Therefore the maximum stock level was rounded to 17,648 pieces.

Using these required parameters, the current model of ASSY SEAL OIL can be from the parameters shown in Table 4.4:

**Table 4.4: Summary of ASSY SEAL OIL Parameters Required for the Current Model Calculation**

| No | Required parameter | Value | Unit |
|---|---|---|---|
| 1 | Average demand by historical data | 531.27 | Piece/Week |
| 2 | Standard deviation during lead time | 292.64 | - |
| 3 | Lead time of replenishment | 16.00 | Week |
| 4 | Safety stock | 2,492 | Piece |
| 5 | Minimum stock level | 12,751 | Piece |
| 6 | Maximum stock level | 17,648 | Piece |

Source: Data from ABC Company.

*4.3.3 Required Parameters for the (Q, r) Model*

There are four types of data for the selected part that must be calculated to find the optimal order quantity and reorder point using the (Q, r) model. They are:

**1) The Demand Pattern of the Selected Part**

- *Determination as to Whether the Demand Pattern is Appropriate for Use With the (Q, r) Model*

The process of determining the variability coefficient (VC) of the ASSY SEAL OIL (TC010-99600) parts for the (Q, r) model can be accomplished using the weekly demand for that part from 2014 weekly records. The data gathered to calculate the variability coefficient (VC) is shown in Table 4.5:

**Table 4.5: Weekly ASSY SEAL OIL Demand Variability in 2014**

| No. of week | Customer requirement (d) | $- \bar{d}^2$ |
|---|---|---|
| Week - 01 | 49 | -279,846 |
| Week - 02 | 333 | -171,358 |
| Week - 03 | 103 | -271,638 |
| Week - 04 | 760 | 295,353 |
| Week - 05 | 941 | 603,234 |
| Week - 06 | 307 | -187,998 |
| Week - 07 | 608 | 87,417 |
| Week - 08 | 458 | -72,483 |
| Week - 09 | 552 | 22,457 |
| Week - 10 | 152 | -259,143 |
| Week - 11 | 927 | 577,082 |
| Week - 12 | 785 | 333,978 |
| Week - 13 | 255 | -217,222 |
| Week - 14 | 734 | 256,509 |
| Week - 15 | 741 | 266,834 |
| Week - 16 | 1151 | 1,042,554 |
| Week - 17 | 941 | 603,234 |
| Week - 18 | 390 | -130,147 |
| Week - 19 | 915 | 554,978 |
| Week - 20 | 748 | 277,257 |
| Week - 21 | 805 | 365,778 |
| Week - 22 | 1034 | 786,909 |
| Week - 23 | 58 | -278,883 |
| Week - 24 | 157 | -257,598 |
| Week - 25 | 505 | -27,222 |
| Week - 26 | 1045 | 809,778 |
| Week - 27 | 57 | -278,998 |
| Week - 28 | 235 | -227,022 |
| Week - 29 | 485 | -47,022 |
| Week - 30 | 201 | -241,846 |
| Week - 31 | 516 | -15,991 |

**Table 4.5: VC of ASSY SEAL OIL Demand in 2014 by Weekly (Continued)**

| No. of week | Customer requirement (d) | $d_i^2 - \bar{d}^2$ |
|---|---|---|
| Week - 32 | 663 | 157,322 |
| Week - 33 | 207 | -239,398 |
| Week - 34 | 641 | 128,634 |
| Week - 35 | 282 | -202,723 |
| Week - 36 | 510 | -22,147 |
| Week - 37 | 308 | -187,383 |
| Week - 38 | 554 | 24,669 |
| Week - 39 | 959 | 637,434 |
| Week - 40 | 479 | -52,806 |
| Week - 41 | 849 | 438,554 |
| Week - 42 | 579 | 52,994 |
| Week - 43 | 337 | -168,678 |
| Week - 44 | 300 | -192,247 |
| Week - 45 | 822 | 393,437 |
| Week - 46 | 586 | 61,149 |
| Week - 47 | 308 | -187,383 |
| Week - 48 | 238 | -225,603 |
| Week - 49 | 670 | 166,653 |
| Week - 50 | 283 | -202,158 |
| Week - 51 | 441 | -87,766 |
| Week - 52 | 662 | 155,997 |
| **Avg. demand (d)** | **531.27** | |

Source: Data from ABC Company

According to the Formula given in equations 2.10 and 2.11 the variability coefficient (VC) can be calculated as shown below:

Est. Var D — $d^2$

83,990.12

$d^2$ = 282,246.99

VC = 0.30

The variability coefficient (VC) is calculated to be 0.30, which is more than the 0.25 standard used to indicate that the demand in each week is considered high in variability. Therefore the (Q, r) model can be applied for the ASSY SEAL OIL part that is being used as a pilot project to improve the inventory management policy of ABC Company.

**-** *Determination of the Distribution of Historical Demand*

The Anderson-Darling test of normality was conducted on the data using a 95% confidential level. The p-value for the historical demand data obtained was 0.268, which is more than 0.05. Therefore it was concluded that this historical demand data is normally distributed. The mean and standard deviation of this historical demand data are 531.27 and 292.64 respectively. Figures 4.1 and 4.2 shows the normality test result scatter plot and a histogram of the historical data distribution respectively.

**Figure 4.1: The Normality Test Result**

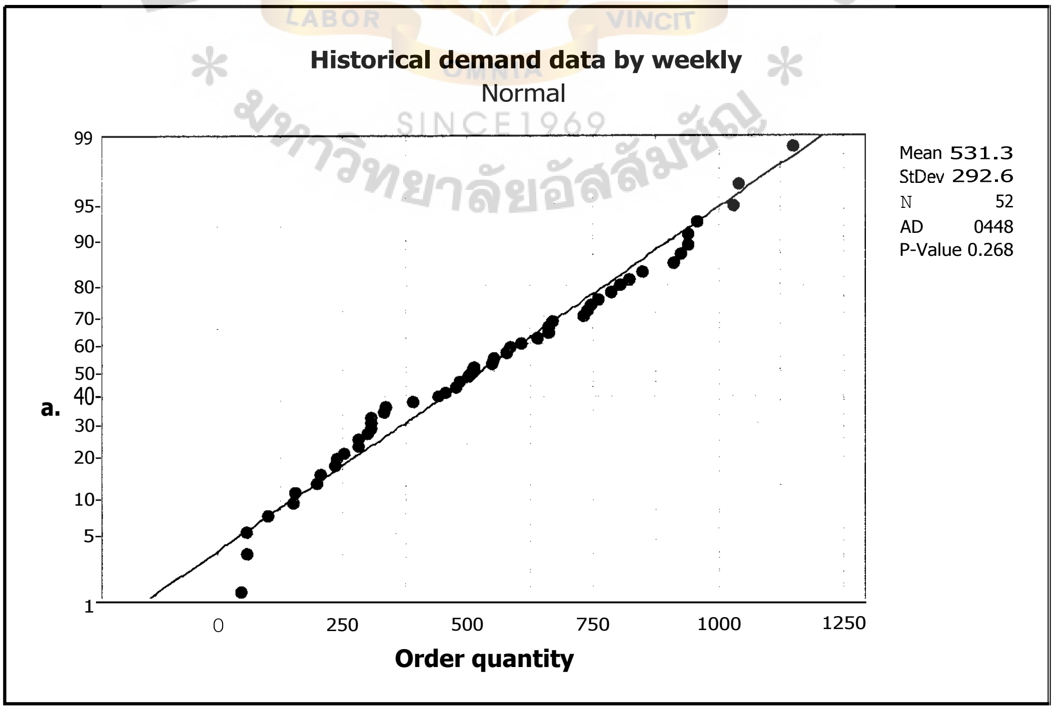
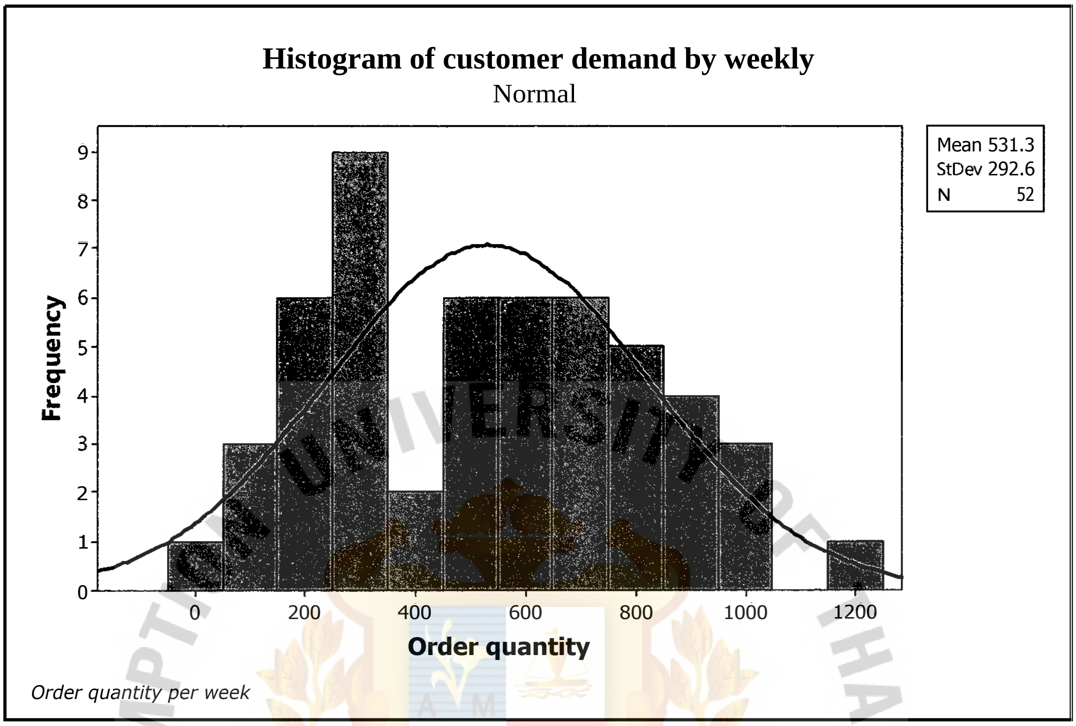


**Figure 4.2: Histogram of Historical Demand Data**




### 2) The Ordering Cost of the Selected Part

The ASSY SEAL OIL (TC010-99600) part, was selected for comparing the limit of order quantity and maximum units for FCL which was explained in Chapter 3. The calculation of limit of order quantity and maximum unit for FCL is shown in detail below:

**Limit of order quantity** Target MOS x Avg. demand per month

$$\frac{10 \times (531.27 \times 52)}{12}$$

23,021.70 Pcs.

**Maximum unit for FCL** $\dfrac{\text{Total Container Volume}}{\text{Packaging volume of selected part}}$

$$\frac{33.20 \text{ Cubic meters}}{0.000308 \text{ Cubic meters/Pc}}$$

$$= \quad 107{,}792.21 \text{ Pcs.}$$

Therefore the limit of order quantity is less than the maximum units for a FCL, the LCL type was selected for the ASSY SEAL OIL parts.

**Table 4.6: Order Cost Details of the ASSY SEAL OIL parts**

| No | Expense | Fixed cost (Baht/order) | Variable cost (Baht/order) |
|---|---|---|---|
| 1 | Transportation in land fee | 2,500 | - |
| 2 | Import clearance fee | 200 | - |
| 3 | Shipper and forwarder fee | 200 | |
| 4 | Delivery order note fee | 1,200 | - |
| 5 | Terminal handling charge | 350 | |
| 6 | Operation fee | - | 1,200 |

Source: Data from ABC Company

The details of each expense in Table 4.6 are explained as follows:

1) The transportation in land fee is a fixed expense of the truck to deliver from the port to the ABC Company each time.
2) The import clearance fee is a fixed cost for import customs per shipment.
3) The shipper, customs and forwarder fee is a fixed cost of expense per shipment for the shipper and forwarder company.
4) The delivery order note fee is a fixed cost for issuing the delivery order note document per shipment.
5) The terminal handling charge is a fixed cost of the terminal charge per shipment.

6) The operation fee is a variable cost of total handling per shipment at the port, which is calculated by the average total expense of the LCL mode in 2014.

Therefore the total ordering cost of the ASSY SEAL OIL parts was the sum of all of the costs in shown in Table 4.7 which equals 5,650 Baht per order.

**3) The Carrying Cost of the Selected Part**

The carrying cost of the selected part per piece is composed of the physical holding cost per piece and the opportunity cost of holding per piece. The details of the calculation of each component of cost are shown below:

- Physical Holding Cost per Piece

The physical holding cost is the cost of the warehouse which has two cost components: storage cost per piece and operational cost per piece. The calculations are shown below:

*Calculation of storage cost per piece*

ABC Company has rented a warehouse area to store the spare parts. Therefore the storage cost per piece was the warehouse rental rate per square meter multiplied by the package area of the ASSY SEAL OIL (TC010-99600) parts, and then divided by row of the stacked packages as shown in Equation 3.6. The details of calculation are shown as below detail:

| | | | |
|---|---|---|---|
| 1. Warehouse rental rate | = | 165 | Baht/$m^2$ /month |

Remark: This rate is based on a rental rate agreement of ABC Company and warehouse outsourcer in 2014.

| | | | |
|---|---|---|---|
| 2. ASSY SEAL OIL's package area | = | 0.14 x 0.22 | m. |
| | = | 0.031 | $m^2$ |
| 3. Row of stacked packages | = | 125 | |

Remark: Row of stacked packages can be calculated as maximum load of packages divided by the weight of a package. Therefore the row of stacked packages is 15 kilograms divided by 0.12 kilograms which equals 125. Therefore the maximum stack equals 125.

The storage cost per piece of the ASSY SEAL OIL parts is shown in the calculation below:

4. Space in the warehouse consumed by the part's package area = 0.031/125

= 0.000248

5. Storage cost per piece = 0.000248 x 165

= 0.041 Baht/piece/month

*Calculation of the operational cost per piece*

The operational cost per piece is calculated by the rate of the warehouse operating cost per square meter, multiplied times the space in the warehouse consumed by part's package area. Therefore the estimated total expense of warehouse must be divided by total area of warehouse to get the rate of the warehouse operating cost per square meter. This is shown in the details that follow:

**Table 4.7: Estimated Warehouse Expense in 2014**

| No | Expense | Quantity | Fixed cost (Baht/month) | Variable cost (Baht/month) |
|---|---|---|---|---|
| 1 | Warehouse manager | 1 | 90,000 | 30,000 |
| 2 | Assistant manager | 2 | 80,000 | 30,000 |
| 3 | Engineer | 5 | 150,000 | 40,000 |
| 4 | Foreman | 5 | 135,000 | 50,000 |

**Table 4.7: Estimated Warehouse Expense in 2014 (Continued)**

| No | Expense | Quantity | Fixed cost (Baht/month) | Variable cost (Baht/month) |
|---|---|---|---|---|
| 5 | Operator | 96 | 960,000 | 672,000 |
| 6 | Outsource packing | 1 | - | 300,000 |
| 7 | Facility (Folk lift rental) | 12 | 480,000 | - |
| 8 | Facility (Computer rental) | 22 | 121,000 | - |
| 9 | Other expenses | 1 | - | 40,000 |

Source: Data from ABC Company

The details of the calculation of each expense in Table 4.7 that is shown below:

Fixed cost

1. Total salary is approximately 1,415,000 baht per month for all of the warehouse's staff.
2. There are 12 folk lifts which are rented from an outsourcer for warehouse operations. The rental rate is 40,000 Baht per month. Therefore the expense of the folk lift rental in 2014 was 480,000 Baht per month.
3. There are 22 computers which are rented from an outsourcer for warehouse operations. The rental rate is 5,500 Baht per month. Therefore the expense of the computer rental in 2014 was 121,000 Baht per month.

Variable cost

1. The total benefits for all of the warehouse's staff including overtime pay and is approximate 822,000 Baht per month.

2. The packing process is operated by an outsourced company. The rate of the packing process is 1 Baht per piece. The average quantity of parts which must be packaged is around 200,000 pieces per month. Therefore the outsourced packing cost was approximately 200,000 Baht per month.
3. Other expense includes maintenance of the facility in the warehouse and costs approximately 40,000 Baht per month.

Therefore the total expense of the warehouse in 2014 is the sum of all costs shown in Table 4.7 which equals 3,178,000 Baht per month. The total expense of warehouse was divided by the total area of the warehouse to get the rate of warehouse operating costs per square meter. The details of the calculation are shown below:

| | | | | |
|---|---|---|---|---|
| 1. | Total expense of the warehouse in 2014 | = | 3,178,000 | Baht |
| 2. | Total area of the warehouse | = | 28,000 | m2 |
| 3. | Warehouse operating cost per square meter | = | 3,178,000/28,000 | Baht/m |
| | | = | 113.50 | Baht/m |



Therefore the warehouse operating cost per piece was calculated by multiply the rate of operating cost per square meter times the amount of spaced consumed by the part's package area. The details of the calculation are shown as follows:

| | | | |
|---|---|---|---|
| 1. | Space consumed by the part's package area | = 0.000248 $m^2$ | |
| 2. | Warehouse operations cost per piece | = 0.000248 x 113.50 | Baht/piece/month |
| | | = 0.028 | Baht/piece/month |

The physical holding cost per piece is calculated by summing the storage cost per piece with the operations cost per piece. The details of this calculation follow:

| | | | |
|---|---|---|---|
| The physical holding cost per piece | = | 0.041 + 0.028 | Baht/piece/month |
| | = | 0.069 | Baht/piece/month |

- Opportunity Cost of Holding per Piece

The average minimum loan rate (MLR) of Bangkok bank (BBL) in 2014 was 6.775% BBL's MLR can be converted to a monthly rate by dividing 6.775% by 12. BBL's MLR expressed as a monthly rate equals 0.565%. Therefore the opportunity cost of inventory holding per piece is determined by multiplying BBL's MLR's expressed as a monthly rate times the purchase cost of the ASSY SEAL OIL (TC010-99600) parts. The details of calculation are shown as follows:

Opportunity cost of inventory holding

= Average monthly BBL MLR in 2014 x Purchase cost

= 0.565% x 338 Baht/piece/month

= 1.909 Baht/piece/month

The carrying cost per piece can be determined by summing the physical holding cost per piece with the opportunity cost of inventory holding per piece, which shown as follows:

Carrying cost per piece = Physical holding cost + Opportunity cost of holding

= 0.069 + 1.909 Baht/piece/month

= 1.978 Baht/piece/month

**4) The Stock Outs Cost of the Selected Part**

When the inventory level is not enough to meet actual demand a stock out occurs. This happens in each period. Therefore the stock outs costs are an incurred cost of the ABC Company. The stock outs cost is composed of the items shown below:

- Fee for Special Purchase Orders

The fee for special purchase orders per piece is an additional 25% above regular price. Therefore the fee for special purchase orders of the ASSY SEAL OIL (TC010-99600) part was calculated as shown below:

Fee for special purchase orders of the ASSY SEAL OIL part per piece

= 0.25 x 338 Baht per piece

= 84.50 Baht per piece

- Additional Air-freight Cost per Piece

The additional air-freight cost per piece was found by calculating the difference in the cost of air-freight in 2014 per piece and versus the cost of sea-freight in 2014 per piece. Therefore both types of freight costs in 2014 were transformed to a rate per piece. The details of this calculation are shown in Table 4.8

**Table 4.8: Calculation of Additional Air-Freight Cost**

| No | Expense | Total Air-freight cost in 2014 | Total Sea-freight cost in 2014 |
|---|---|---|---|
| 1 | Inco term | FCA | CIP |
| 2 | Transportation in land fee | 157,288 | 408,600 |
| 3 | Freight cost | 2,400,488 | - |
| 4 | Import clearance fee | 163,500 | 81,900 |
| 5 | Shipper and forwarder fee | 151,531 | 158,600 |

**Table 4.8: Calculation of Additional Air-Freight Cost (Continued)**

| No | Expense | Total Air-freight cost in 2014 | Total Sea-freight cost in 2014 |
|---|---|---|---|
| 6 | Delivery order note fee | 93,550 | 32,524 |
| 7 | Operations fee | 75,168 | 149,618 |
| 8 | Insurance fee | 45,270 | - |
| 9 | Total expense in 2014 | 3,086,795 | 831,242 |
| 10 | Weight of total shipment (Kg.) | 53,188 | 293,952 |
| 11 | Rate of freight cost per piece (9) ÷ (10) (Baht per kilogram) | 58.05 | 2.83 |

Source: Data from ABC Company

Therefore the addition air-freight cost of the ASSY SEAL OIL (TC010-99600) part per piece was the weight of part multiply by rate calculated for the difference between the two types of freight costs. This calculation is shown below:

The additional air-freight cost of the ASSY SEAL OIL part per piece

= 0.12 Kilogram per piece x (58.05 Baht per kilogram – 2.83 Baht per kilogram)

= 6.63 Baht per piece

Therefore the stock out cost of the ASSY SEAL OIL (TC010-99600) part per piece is the sum of fee for special order per piece and the additional air-freight cost per piece which was found to equal 91.13 Baht per piece.

Having identified the value of all of the required parameters, the optimal order quantity and reorder point of the (Q, r) model for the ASSY SEAL OIL part can be Calculated. The values of the required parameters are shown in Table 4.9.

**Table 4.9: Summary of ASSY SEAL OIL Parameters for Use in the (Q, r) Model Calculation**

| No | Required parameter | Value | Unit |
|---|---|---|---|
| 1 | Variability coefficient (VC) | 0.30 | - |
| 2 | Demand during lead time | 8,500.31 | Piece |
| 3 | Standard deviation during lead time | 1,170.55 | - |
| 4 | Lead time of replenishment | 16 | Weeks |
| 5 | Safety stock | 2,492 | Piece |
| 6 | Ordering cost | 5,650 | Baht/Order |
| 7 | Carrying cost | 1.978 | Baht/Piece/Month |
| 8 | Stock out cost | 91.13 | Baht/Piece |

Source: Data from ABC Company

## 4.4 Calculate The Optimal Order Quantity and Reorder Point Using the (Q, r) Inventory Control Model

The parameters provided in Table 4.10 are parameters of the (Q, r) inventory control model calculation. Then Table 3.3 was used to find the optimal order quantity and reorder point. This information is shown in Table 4.10

**Table 4.10: Optimal Order Quantity and Reorder Point Calculation Table**

| No | Q | R | F ( R ) | n ( R ) | L ( z ) | Z-score |
|---|---|---|---|---|---|---|
| 1 | 6,035.00 | - | 0.98 | 8.86 | 0.00757 | 2.04 |
| 2 | 6,452.00 | 10,891.00 | 0.98 | 9.55 | 0.00816 | 2.01 |
| 3 | 6,483.00 | 10,859.00 | 0.98 | 9.61 | 0.00821 | 2.01 |
| 4 | 6,486.00 | 10,856.00 | 0.98 | 9.61 | 0.00821 | 2.01 |
| 5 | 6,486.00 | 10,856.00 | 0.98 | 9.61 | 0.00821 | 2.01 |

Source: Data from ABC Company

Finally Q and R are converged in the $4^{th}$ and $5^{th}$ step. Therefore the calculation will be stopped in $5^{th}$ step, then the optimal order quantity and reorder point of the (Q, r) inventory control model are 6,486 pieces and 10,856 pieces respectively.

### 4.5 Simulate Total Inventory Cost for Both Models

After all associated data have been calculated, they were used in the simulation model. The common parameters (shown in Table 4.3) were input into the simulation for both models. The monthly related inventory cost was calculated by using the actual demand from 2014. Then the related inventory cost in each month was the results of simulation such as:

1) Total ordering cost
2) Total carrying cost
3) Total stock out cost

Finally all of related inventory costs were summed to get the total inventory cost which is the factor used for comparison between ABC Company's current model and the (Q, r) Model.

*4.5.1 Simulation of the Total Inventory Costs for the Current Model*

After using the related data in Table 4.4 in the simulation, the inventory cost was computed for each month as shown in Table 4.11

**Table 4.11: Summary of Related Inventory Cost Using the Current Model**

| No. of week | Ordering Cost | Carrying Cost | Stock out Cost | Total Inventory Cost |
|---|---|---|---|---|
| Week - 01 | - | 17,521.12 | - | 17,521.12 |
| Week - 02 | - | 16,862.45 | - | 16,862.45 |
| Week - 03 | - | 16,658.72 | - | 16,658.72 |
| Week - 04 | - | 15,155.44 | - | 15,155.44 |
| Week - 05 | - | 13,294.14 | - | 13,294.14 |
| Week - 06 | - | 12,686.89 | - | 12,686.89 |
| Week - 07 | - | 11,484.27 | - | 11,484.27 |
| Week - 08 | - | 10,578.34 | - | 10,578.34 |
| Week - 09 | - | 9,486.49 | - | 9,486.49 |
| Week - 10 | - | 9,185.83 | - | 9,185.83 |
| Week - 11 | - | 7,352.23 | - | 7,352.23 |
| Week - 12 | - | 5,799.50 | - | 5,799.50 |
| Week - 13 | 5,650.00 | 22,266.35 | - | 27,916.35 |
| Week - 14 | - | 20,814.49 | - | 20,814.49 |
| Week - 15 | - | 19,348.80 | - | 19,348.80 |
| Week - 16 | - | 17,072.12 | - | 17,072.12 |
| Week - 17 | - | 15,210.82 | - | 15,210.82 |
| Week - 18 | - | 14,439.40 | - | 14,439.40 |
| Week - 19 | - | 12,629.53 | - | 12,629.53 |
| Week - 20 | - | 11,149.99 | - | 11,149.99 |
| Week - 21 | - | 9,557.70 | - | 9,557.70 |
| Week - 22 | - | 7,512.44 | - | 7,512.44 |
| Week - 23 | - | 7,397.72 | - | 7,397.72 |
| Week - 24 | - | 7,087.17 | - | 7,087.17 |
| Week - 25 | - | 6,088.28 | - | 6,088.28 |
| Week - 26 | 5,650.00 | 14,605.55 | - | 20,255.55 |

**Table 4.11: Summary of Related Inventory Cost Using the Current Model (Continued)**

| No. of week | Ordering Cost | Carrying Cost | Stock out Cost | Total Inventory Cost |
|---|---|---|---|---|
| Week - 27 | - | 14,492.81 | - | 14,492.81 |
| Week - 28 | - | 14,027.98 | - | 14,027.98 |
| Week - 29 | - | 13,068.65 | - | 13,068.65 |
| Week - 30 | - | 12,671.07 | - | 12,671.07 |
| Week - 31 | - | 11,650.42 | - | 11,650.42 |
| Week - 32 | - | 10,339.01 | - | 10,339.01 |
| Week - 33 | 5,650.00 | 19,813.63 | - | 25,463.63 |
| Week - 34 | - | 18,545.73 | - | 18,545.73 |
| Week - 35 | - | 17,987.93 | - | 17,987.93 |
| Week - 36 | - | 16,979.15 | - | 16,979.15 |
| Week - 37 | - | 16,369.93 | - | 16,369.93 |
| Week - 38 | - | 15,274.12 | - | 15,274.12 |
| Week - 39 | - | 13,377.21 | - | 13,377.21 |
| Week - 40 | - | 12,429.75 | - | 12,429.75 |
| Week - 41 | 5,650.00 | 21,168.56 | - | 26,818.56 |
| Week - 42 | - | 20,023.29 | - | 20,023.29 |
| Week - 43 | - | 19,356.71 | - | 19,356.71 |
| Week - 44 | - | 18,763.31 | - | 18,763.31 |
| Week - 45 | - | 17,137.39 | - | 17,137.39 |
| Week - 46 | - | 15,978.28 | - | 15,978.28 |
| Week - 47 | - | 15,369.06 | - | 15,369.06 |
| Week - 48 | - | 14,898.30 | - | 14,898.30 |
| Week - 49 | - | 13,573.04 | - | 13,573.04 |
| Week - 50 | - | 13,013.26 | - | 13,013.26 |
| Week - 51 | - | 12,140.96 | - | 12,140.96 |
| Week - 52 | - | 10,831.53 | - | 10,831.53 |
| **Total:** | **22,600.00** | **730,526.83** | | **753 126.83** |

The simulation calculated the total inventory costs for 2014 using the current model. From this, the following costs were obtained:

1) Total ordering cost in 2014 equals 22,600.00 Baht/year

2) Total carrying cost in 2014 equals 730,526.83 Baht/year

3) Total stock out cost in 2014 is zero.

4) Total inventory cost in 2014 equals 753,126.83 Baht/year

### *4.5.2 Simulation of the Total Inventory Costs for the (Q, r) Model*

After using the related data in Table 4.9 in the simulation, the inventory cost was computed for each month as shown in Table 4.12

**Table 4.12: Summary Related Inventory Costs for (Q, r) Model**

| No. of week | Ordering Cost | Carrying Cost | Stock out Cost | Total Inventory Cost |
|---|---|---|---|---|
| Week - 01 | - | 17,521.12 | - | 17,521.12 |
| Week - 02 | - | 16,862.45 | - | 16,862.45 |
| Week - 03 | - | 16,658.72 | - | 16,658.72 |
| Week - 04 | - | 15,155.44 | - | 15,155.44 |
| Week - 05 | - | 13,294.14 | - | 13,294.14 |
| Week - 06 | - | 12,686.89 | - | 12,686.89 |
| Week - 07 | - | 11,484.27 | - | 11,484.27 |
| Week - 08 | - | 10,578.34 | - | 10,578.34 |
| Week - 09 | - | 9,486.49 | - | 9,486.49 |
| Week - 10 | - | 9,185.83 | - | 9,185.83 |
| Week - 11 | - | 7,352.23 | - | 7,352.23 |
| Week - 12 | - | 5,799.50 | - | 5,799.50 |
| Week - 13 | 5,650.00 | 22,266.35 | - | 27,916.35 |
| Week - 14 | - | 20,814.49 | - | 20,814.49 |
| Week - 15 | - | 19,348.80 | - | 19,348.80 |
| Week - 16 | - | 17,072.12 | - | 17,072.12 |
| Week - 17 | - | 15,210.82 | - | 15,210.82 |
| Week - 18 | - | 14,439.40 | - | 14,439.40 |
| Week - 19 | - | 12,629.53 | - | 12,629.53 |
| Week - 20 | - | 11,149.99 | - | 11,149.99 |
| Week - 21 | - | 9,557.70 | - | 9,557.70 |
| Week - 22 | - | 7,512.44 | - | 7,512.44 |
| Week - 23 | - | 7,397.72 | - | 7,397.72 |

**Table 4.12: Summary Related Inventory Costs for (Q, r) Model (Continued)**

| No. of week | Ordering Cost | Carrying Cost | Stock out Cost | Total Inventory Cost |
|---|---|---|---|---|
| Week - 24 | - | 7,087.17 | - | 7,087.17 |
| Week - 25 | - | 6,088.28 | - | 6,088.28 |
| Week - 26 | - | 4,021.27 | - | 4,021.27 |
| Week - 27 | - | 3,908.53 | - | 3,908.53 |
| Week - 28 | - | 3,443.70 | - | 3,443.70 |
| Week - 29 | 5,650.00 | 15,313.68 | - | 20,963.68 |
| Week - 30 | - | 14,916.10 | - | 14,916.10 |
| Week - 31 | - | 13,895.45 | - | 13,895.45 |
| Week - 32 | - | 12,584.04 | - | 12,584.04 |
| Week - 33 | - | 12,174.59 | - | 12,174.59 |
| Week - 34 | - | 10,906.69 | - | 10,906.69 |
| Week - 35 | - | 10,348.90 | - | 10,348.90 |
| Week - 36 | - | 9,340.12 | - | 9,340.12 |
| Week - 37 | 5,650.00 | 21,560.20 | - | 27,210.20 |
| Week - 38 | - | 20,464.39 | - | 20,464.39 |
| Week - 39 | - | 18,567.49 | - | 18,567.49 |
| Week - 40 | - | 17,620.02 | - | 17,620.02 |
| Week - 41 | - | 15,940.70 | - | 15,940.70 |
| Week - 42 | - | 14,795.44 | - | 14,795.44 |
| Week - 43 | - | 14,128.85 | - | 14,128.85 |
| Week - 44 | - | 13,535.45 | - | 13,535.45 |
| Week - 45 | - | 11,909.54 | - | 11,909.54 |
| Week - 46 | - | 10,750.43 | - | 10,750.43 |
| Week - 47 | - | 10,141.21 | - | 10,141.21 |
| Week - 48 | - | 9,670.44 | - | 9,670.44 |
| Week - 49 | - | 8,345.18 | - | 8,345.18 |
| Week – 50 | - | 7,785.41 | - | 7,785.41 |
| Week - 51 | - | 6,913.11 | - | 6,913.11 |
| Week - 52 | - | 5,603.67 | - | 5,603.67 |
| **Totals:** | **16 950.00** | **635,224.81** | | **652,174.81** |

The simulation calculated the total inventory cost in 2014 for the (Q, r) model. From this, the following costs were obtained:

1) Total ordering cost in 2014 equals 16,950.00 Baht/year.
2) Total carrying cost in 2014 equals 635,224.81 Baht/year.
3) Total stock out cost in 2014 is zero.
4) Total inventory cost in 2014 equals 652,174.81 Baht/year.

*4.5.3 A Comparison of the Total Inventory Cost Between the Current Model and (Q, r) Model*

Both models simulated inventory related costs and the total inventory cost for use in comparison. The chosen model was selected based upon because it provided the lowest total inventory cost for ABC Company. The comparison of each inventory related cost is shown as three cost comparisons.

1) Total ordering cost in 2014

**Table 4.13: Comparison of Ordering Costs for Both Models**

| Month | Current Model | (Q, r) Model | Unit |
|---|---|---|---|
| Ordering time in 2014 | 4 | 3 | Times |
| Ordering Cost per time | 5,650.00 | 5,650.00 | Baht/Time |
| Total ordering cost in 2014 | 22,600.00 | 16,950.00 | Baht/Year |

Table 4.13 shows that orders were placed 4 times in 2014 the current ordering for a total ordering cost 22,600.00 Baht/year. However, if the (Q, r) model had been used the order times would have been reduced to 3 times in 2014 for a total ordering cost of 16,950.00 Baht/year. Therefore if the (Q, r) model had been used the total ordering cost would have been reduced by 5,650 Baht/year or 25.00 percent.

2) Total carrying cost for 2014

**Figure 4.3: A Comparison of Inventory Levels for Both Models**

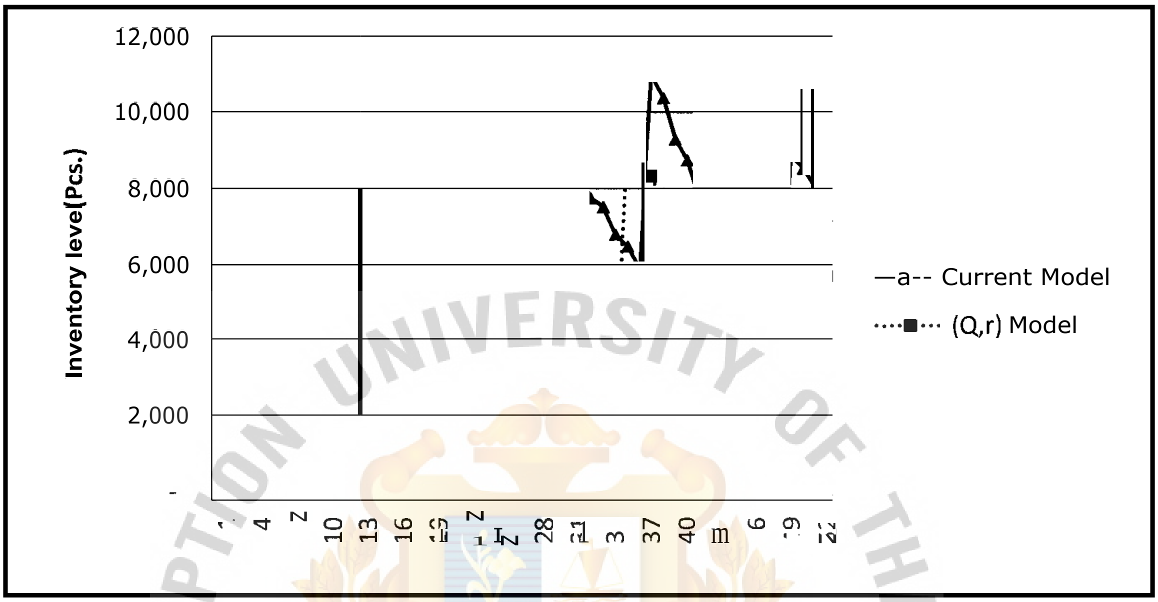



**Table 4.14: A Comparison of Carrying Costs for Both Models**

| No. of week | Total Carrying Cost | | Difference | % Difference |
|---|---|---|---|---|
| | Current Model | (Q, r) Model | | |
| Week - 01 | 17,521.12 | 17,521.12 | - | 0.00% |
| Week - 02 | 16,862.45 | 16,862.45 | - | 0.00% |
| Week - 03 | 16,658.72 | 16,658.72 | - | 0.00% |
| Week - 04 | 15,155.44 | 15,155.44 | - | 0.00% |
| Week - 05 | 13,294.14 | 13,294.14 | - | 0.00% |
| Week - 06 | 12,686.89 | 12,686.89 | - | 0.00% |
| Week - 07 | 11,484.27 | 11,484.27 | - | 0.00% |
| Week - 08 | 10,578.34 | 10,578.34 | - | 0.00% |
| Week - 09 | 9,486.49 | 9,486.49 | - | 0.00% |
| Week - 10 | 9,185.83 | 9,185.83 | - | 0.00% |
| Week - 11 | 7,352.23 | 7,352.23 | - | 0.00% |
| Week - 12 | 5,799.50 | 5,799.50 | - | 0.00% |
| Week - 13 | 22,266.35 | 22,266.35 | - | 0.00% |
| Week - 14 | 20,814.49 | 20,814.49 | - | 0.00% |

**Table 4.14: A Comparison of Carrying Costs for Both Models (Continued)**

| No. of week | Total Carrying Cost | | Difference | % Difference |
|---|---|---|---|---|
| | Current Model | (Q, r) Model | | |
| Week - 15 | 19,348.80 | 19,348.80 | - | 0.00% |
| Week - 16 | 17,072.12 | 17,072.12 | - | 0.00% |
| Week - 17 | 15,210.82 | 15,210.82 | - | 0.00% |
| Week - 18 | 14,439.40 | 14,439.40 | - | 0.00% |
| Week - 19 | 12,629.53 | 12,629.53 | - | 0.00% |
| Week - 20 | 11,149.99 | 11,149.99 | - | 0.00% |
| Week - 21 | 9,557.70 | 9,557.70 | - | 0.00% |
| Week - 22 | 7,512.44 | 7,512.44 | - | 0.00% |
| Week - 23 | 7,397.72 | 7,397.72 | - | 0.00% |
| Week - 24 | 7,087.17 | 7,087.17 | - | 0.00% |
| Week - 25 | 6,088.28 | 6,088.28 | - | 0.00% |
| Week - 26 | 14,605.55 | 4,021.27 | -10,584.28 | -72.47% |
| Week – 27 | 14,492.81 | 3,908.53 | -10,584.28 | -73.03% |
| Week – 28 | 14,027.98 | 3,443.70 | -10,584.28 | -75.45% |
| Week – 29 | 13,068.65 | 15,313.68 | 2,245.03 | 17.18% |
| Week – 30 | 12,671.07 | 14,916.10 | 2,245.03 | 17.72% |
| Week – 31 | 11,650.42 | 13,895.45 | 2,245.03 | 19.27% |
| Week – 32 | 10,339.01 | 12,584.04 | 2,245.03 | 21.71% |
| Week – 33 | 19,813.63 | 12,174.59 | -7,639.04 | -38.55% |
| Week – 34 | 18,545.73 | 10,906.69 | -7,639.04 | -41.19% |
| Week – 35 | 17,987.93 | 10,348.90 | -7,639.04 | -42.47% |
| Week – 36 | 16,979.15 | 9,340.12 | -7,639.04 | -44.99% |
| Week – 37 | 16,369.93 | 21,560.20 | 5,190.27 | 31.71% |
| Week – 38 | 15,274.12 | 20,464.39 | 5,190.27 | 33.98% |
| Week - 39 | 13,377.21 | 18,567.49 | 5,190.27 | 38.80% |
| Week – 40 | 12,429.75 | 17,620.02 | 5,190.27 | 41.76% |
| Week - 41 | 21,168.56 | 15,940.70 | -5,227.85 | -24.70% |
| Week - 42 | 20,023.29 | 14,795.44 | -5,227.85 | -26.11% |
| Week – 43 | 19,356.71 | 14,128.85 | -5,227.85 | -27.01% |
| Week - 44 | 18,763.31 | 13,535.45 | -5,227.85 | -27.86% |

**Table 4.14: A Comparison of Carrying Costs for Both Models (Continued)**

| No. of week | Total Carrying Cost | | Difference | % Difference |
|---|---|---|---|---|
| | Current Model | (Q, r) Model | | |
| Week - 45 | 17,137.39 | 11,909.54 | -5,227.85 | -30.51% |
| Week – 46 | 15,978.28 | 10,750.43 | -5,227.85 | -32.72% |
| Week - 47 | 15,369.06 | 10,141.21 | -5,227.85 | -34.02% |
| Week - 48 | 14,898.30 | 9,670.44 | -5,227.85 | -35.09% |
| Week – 49 | 13,573.04 | 8,345.18 | -5,227.85 | -38.52% |
| Week - 50 | 13,013.26 | 7,785.41 | -5,227.85 | -40.17% |
| Week - 51 | 12,140.96 | 6,913.11 | -5,227.85 | -43.06% |
| Week - 52 | 10,831.53 | 5,603.67 | -5,227.85 | -48.27% |
| **Totals:** | **730 526.83** | **635,224.81** | **-95,302.02** | **-13.05%** |

As shown in Figure 4.3 and Table 4.14 the average inventory level of the current model would be higher than the average inventory level of the (Q, r) model. The total carrying cost of current model would have been 730,526.83 Baht/year. If the (Q, r) model was used the total ordering cost would have been 635,224.81 Baht/year which is a reduction of 95,302.02 Baht/year or 13.05 percent.

3) Total stock out cost for 2014

Based on the simulation, the results of total stock out costs in 2014 showed no difference between the current ordering model and the (Q, r) ordering model. The stock out cost of both models was zero for both models in 2014.

Finally all of inventory related cost was summed to get the total inventory cost. The model that provides the lowest total inventory cost would be selected for use by the ABC Company.

**Table 4.15: A Comparison of Total Inventory Costs for Both Models**

| No. of week | Total Inventory Cost | | Difference | %Difference |
|---|---|---|---|---|
| | Current Model | (Q, r) Model | | |
| Week - 01 | 17,521.12 | 17,521.12 | - | 0.00% |
| Week - 02 | 16,862.45 | 16,862.45 | - | 0.00% |
| Week - 03 | 16,658.72 | 16,658.72 | - | 0.00% |

Table 4.15: A Comparison of Total Inventory Costs for Both Models (Continued)

| No. of week | Total Inventory Cost | | Difference | %Difference |
|---|---|---|---|---|
| | Current Model | (Q, r) Model | | |
| Week - 04 | 15,155.44 | 15,155.44 | - | 0.00% |
| Week - 05 | 13,294.14 | 13,294.14 | - | 0.00% |
| Week - 06 | 12,686.89 | 12,686.89 | - | 0.00% |
| Week - 07 | 11,484.27 | 11,484.27 | - | 0.00% |
| Week - 08 | 10,578.34 | 10,578.34 | - | 0.00% |
| Week - 09 | 9,486.49 | 9,486.49 | - | 0.00% |
| Week - 10 | 9,185.83 | 9,185.83 | - | 0.00% |
| Week - 11 | 7,352.23 | 7,352.23 | - | 0.00% |
| Week - 12 | 5,799.50 | 5,799.50 | - | 0.00% |
| Week - 13 | 27,916.35 | 27,916.35 | - | 0.00% |
| Week - 14 | 20,814.49 | 20,814.49 | - | 0.00% |
| Week - 15 | 19,348.80 | 19,348.80 | - | 0.00% |
| Week - 16 | 17,072.12 | 17,072.12 | - | 0.00% |
| Week - 17 | 15,210.82 | 15,210.82 | - | 0.00% |
| Week - 18 | 14,439.40 | 14,439.40 | - | 0.00% |
| Week - 19 | 12,629.53 | 12,629.53 | - | 0.00% |
| Week - 20 | 11,149.99 | 11,149.99 | - | 0.00% |
| Week - 21 | 9,557.70 | 9,557.70 | - | 0.00% |
| Week - 22 | 7,512.44 | 7,512.44 | - | 0.00% |
| Week - 23 | 7,397.72 | 7,397.72 | - | 0.00% |
| Week - 24 | 7,087.17 | 7,087.17 | - | 0.00% |
| Week - 25 | 6,088.28 | 6,088.28 | - | 0.00% |
| Week - 26 | 20,255.55 | 4,021.27 | -16,234.28 | -80.15% |
| Week – 27 | 14,492.81 | 3,908.53 | -10,584.28 | -73.03% |
| Week – 28 | 14,027.98 | 3,443.70 | -10,584.28 | -75.45% |
| Week – 29 | 13,068.65 | 20,963.68 | 7,895.03 | 60.41% |
| Week – 30 | 12,671.07 | 14,916.10 | 2,245.03 | 17.72% |
| Week – 31 | 11,650.42 | 13,895.45 | 2,245.03 | 19.27% |
| Week - 32 | 10,339.01 | 12,584.04 | 2,245.03 | 21.71% |
| Week – 33 | 25,463.63 | 12,174.59 | -13,289.04 | -52.19% |
| Week – 34 | 18,545.73 | 10,906.69 | -7,639.04 | -41.19% |
| Week – 35 | 17,987.93 | 10,348.90 | -7,639.04 | -42.47% |

**Table 4.15: A Comparison of Total Inventory Costs for Both Models (Continued)**

| No. of week | Total Inventory Cost | | Difference | %Difference |
|---|---|---|---|---|
| | Current Model | (Q, r) Model | | |
| Week – 36 | 16,979.15 | 9,340.12 | -7,639.04 | -44.99% |
| Week – 37 | 16,369.93 | 27,210.20 | 10,840.27 | 66.22% |
| Week – 38 | 15,274.12 | 20,464.39 | 5,190.27 | 33.98% |
| Week - 39 | 13,377.21 | 18,567.49 | 5,190.27 | 38.80% |
| Week – 40 | 12,429.75 | 17,620.02 | 5,190.27 | 41.76% |
| Week - 41 | 26,818.56 | 15,940.70 | -10,877.85 | -40.56% |
| Week - 42 | 20,023.29 | 14,795.44 | -5,227.85 | -26.11% |
| Week – 43 | 19,356.71 | 14,128.85 | -5,227.85 | -27.01% |
| Week - 44 | 18,763.31 | 13,535.45 | -5,227.85 | -27.86% |
| Week - 45 | 17,137.39 | 11,909.54 | -5,227.85 | -30.51% |
| Week – 46 | 15,978.28 | 10,750.43 | -5,227.85 | -32.72% |
| Week - 47 | 15,369.06 | 10,141.21 | -5,227.85 | -34.02% |
| Week - 48 | 14,898.30 | 9,670.44 | -5,227.85 | -35.09% |
| Week – 49 | 13,573.04 | 8,345.18 | -5,227.85 | -38.52% |
| Week - 50 | 13,013.26 | 7,785.41 | -5,227.85 | -40.17% |
| Week - 51 | 12,140.96 | 6,913.11 | -5,227.85 | -43.06% |
| Week - 52 | 10,831.53 | 5,603.67 | -5,227.85 | -48.27% |
| **Totals:** | **753,126.83** | **652,174.81** | **-100,952.02** | **-13.40%** |

According to Table 4.15, the difference in the total inventory costs started in the 26th week. This is because of both simulation models have the same starting inventory level as common parameters.

The total inventory cost in 2014 using the current model was 753,126.83 Baht/year. However if the (Q, r) model had been applied the total inventory cost in 2014 using the (Q, r) model would have been 652,174.81 Baht/year. Therefore the total inventory cost would have been reduced by 100,952.02 Baht/year or 13.40 percent.

**4.6 Performance of The Sensitivity Analysis when Actual Demand has Changed within Defined Percentages**

As shown in the study's simulation the total inventory cost was reduced by 100,952.02 Baht/year or 13.40 percent using actual demand. The researcher then conducted a sensitivity analysis to explore the effects of fluctuating demand within defined percentages. The study simulated the fluctuation from minus 100% to plus 200% of actual demand.

**1) Sensitivity Analysis for Total Ordering Costs**

After performing simulations on the ordering process for both models when actual 2014 demand was fluctuated from minus 100% to plus 200%, the total ordering costs changed as shown in Figure 4.4 and Table 4.16.

**Figure 4.4: A Comparison of the Total Ordering Costs for Both Models When Demand Fluctuates**

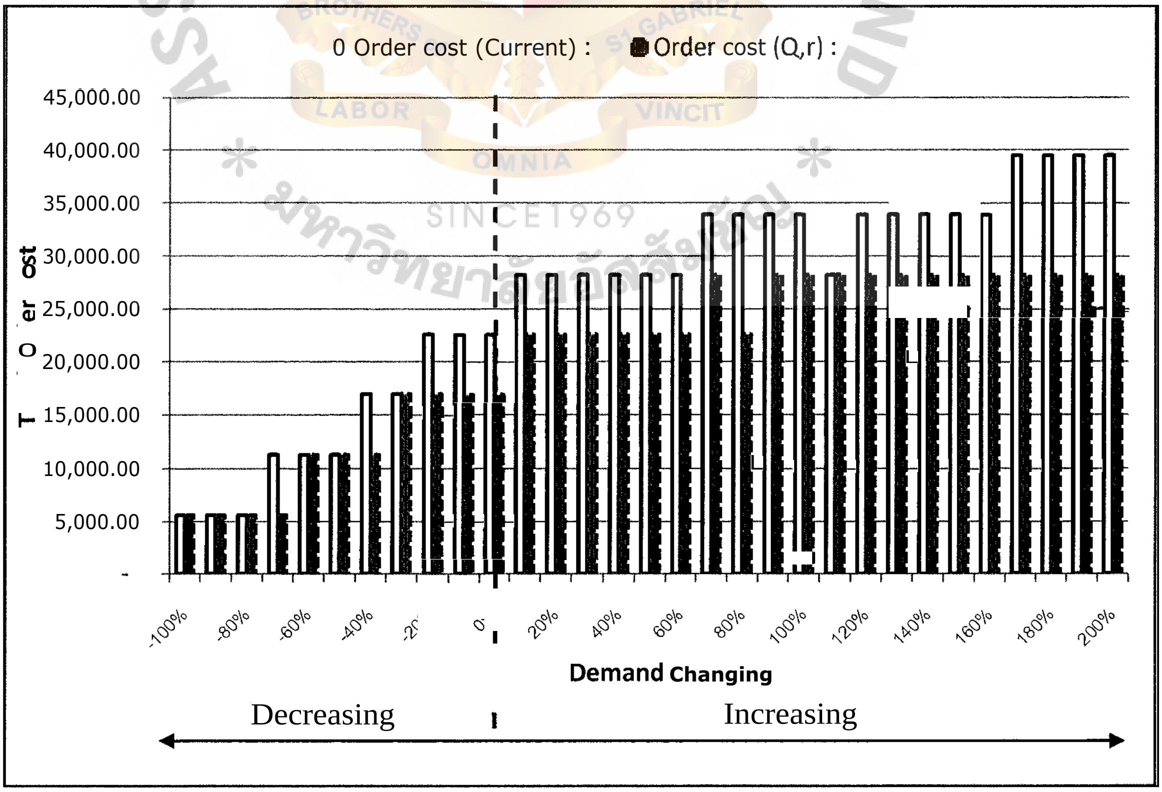


**Table 4.16: Sensitivity Analysis for the Two Models When Demand is Changed (Total Ordering Cost)**

| Changed | Total Ordering Cost (Current) | Total Ordering Cost (Q, r) | Difference | % Difference |
|---|---|---|---|---|
| -100% | 5,650.00 | 5,650.00 | - | 0.00% |
| -90% | 5,650.00 | 5,650.00 | - | 0.00% |
| -80% | 5,650.00 | 5,650.00 | - | 0.00% |
| -70% | 11,300.00 | 5,650.00 | -5,650.00 | -50.00% |
| -60% | 11,300.00 | 11,300.00 | - | 0.00% |
| -50% | 11,300.00 | 11,300.00 | - | 0.00% |
| -40% | 16,950.00 | 11,300.00 | -5,650.00 | -33.33% |
| -30% | 16,950.00 | 16,950.00 | - | 0.00% |
| -20% | 22,600.00 | 16,950.00 | -5,650.00 | -25.00% |
| -10% | 22,600.00 | 16,950.00 | -5,650.00 | -25.00% |
| 0% | 22,600.00 | 16,950.00 | -5,650.00 | -25.00% |
| 10% | 28,250.00 | 22,600.00 | -5,650.00 | -20.00% |
| 20% | 28,250.00 | 22,600.00 | -5,650.00 | -20.00% |
| 30% | 28,250.00 | 22,600.00 | -5,650.00 | -20.00% |
| 40% | 28,250.00 | 22,600.00 | -5,650.00 | -20.00% |
| 50% | 28,250.00 | 22,600.00 | -5,650.00 | -20.00% |
| 60% | 28,250.00 | 22,600.00 | -5,650.00 | -20.00% |
| 70% | 33,900.00 | 28,250.00 | -5,650.00 | -16.67% |
| 80% | 33,900.00 | 22,600.00 | -11,300.00 | -33.33% |
| 90% | 33,900.00 | 28,250.00 | -5,650.00 | -16.67% |

**Table 4.16: Sensitivity Analysis for the Two Models When Demand is Changed (Total Ordering Cost) (Continued)**

| % Changed | Total Ordering Cost (Current) | Total Ordering Cost (Q, r) | Difference | % Difference |
|---|---|---|---|---|
| 100% | 33,900.00 | 28,250.00 | -5,650.00 | -16.67% |
| 110% | 28,250.00 | 28,250.00 | - | 0.00% |
| 120% | 33,900.00 | 28,250.00 | -5,650.00 | -16.67% |
| 130% | 33,900.00 | 28,250.00 | -5,650.00 | -16.67% |
| 140% | 33,900.00 | 28,250.00 | -5,650.00 | -16.67% |
| 150% | 33,900.00 | 28,250.00 | -5,650.00 | -16.67% |
| 160% | 33,900.00 | 28,250.00 | -5,650.00 | -16.67% |
| 170% | 39,550.00 | 28,250.00 | -11,300.00 | -28.57% |
| 180% | 39,550.00 | 28,250.00 | -11,300.00 | -28.57% |
| 190% | 39,550.00 | 28,250.00 | -11,300.00 | -28.57% |
| 200% | 39,550.00 | 28,250.00 | -11,300.00 | -28.57% |
| **Average** | **26,245.16** | **20 959.68** | **-5,285.48** | **-20.14%** |

The results of the total ordering costs when demand is changed ranging from minus 100% to plus 200% indicate that the average ordering cost would have decreased by 5,285.48 Baht/year or 20.14 percent.

**2) Sensitivity Analysis for Total Carrying Costs**

After performing simulations on the ordering process for both models when actual 2014 demand was fluctuated from minus 100% to plus 200%, the total carrying cost is changed as shown in Figure 4.5 and Table 4.17.

**Figure 4.5: A Comparison of the Total Carrying Costs Using both Models When Demand is Changed**

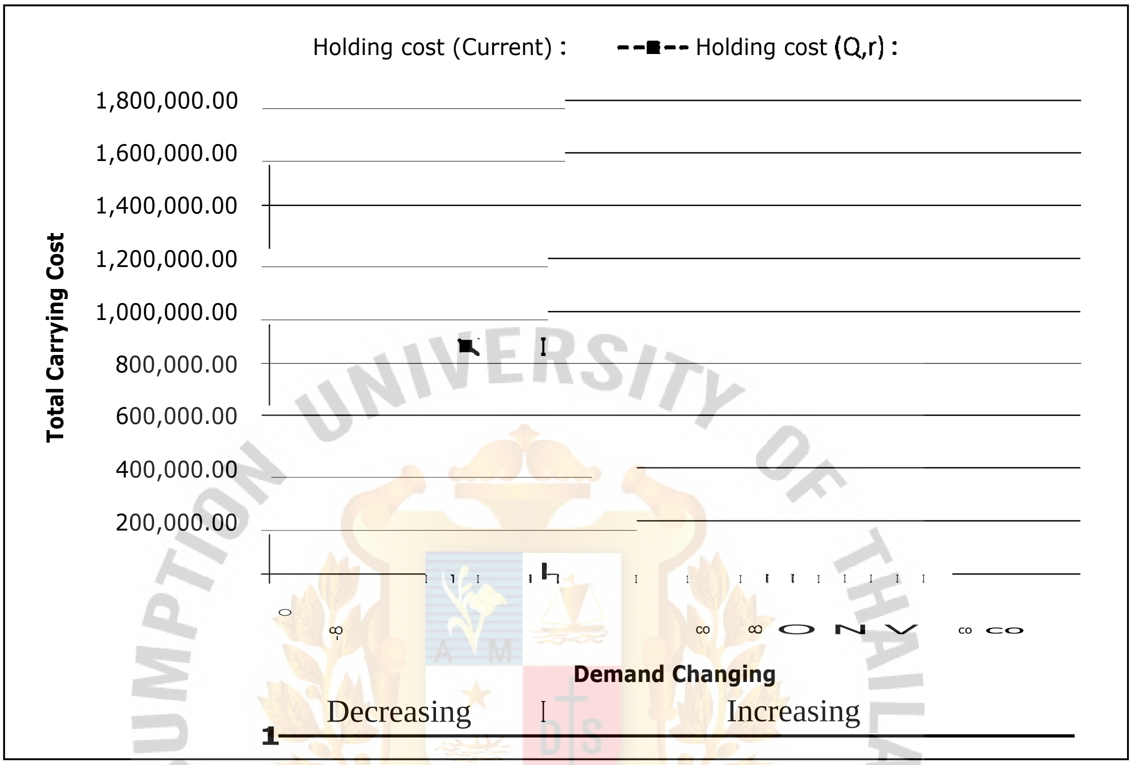



**Table 4.17: Sensitivity Analysis for the Two Models When Demand is Changed (Total Carrying Cost)**

| Changed | Total Carrying Cost (Current) | Total Carrying Cost (Q, r) | Difference | % Difference |
|---|---|---|---|---|
| **-100%** | 1,594,987.99 | 1,594,987.99 | - | 0.00% |
| -90% | 1,446,412.50 | 1,446,412.50 | - | 0.00% |
| -80% | 1,299,375.89 | 1,299,375.89 | - | 0.00% |
| -70% | 1,248,654.04 | 1,151,732.04 | -96,922.00 | -7.76% |
| -60% | 1,179,572.39 | 1,094,597.51 | -84,974.88 | -7.20% |
| -50% | 1,068,064.62 | 1,062,943.57 | -5,121.04 | -0.48% |

**Table 4.17: Sensitivity Analysis for the Two Models When Demand is Changed (Total Carrying Cost)**

| % Changed | Total Carrying Cost (Current) | Total Carrying Cost (Q, r) | Difference | % Difference |
|---|---|---|---|---|
| -40% | 1,011,145.69 | 954,001.27 | -57,144.42 | -5.65% |
| -30% | 936,260.59 | 870,711.64 | -65,548.94 | -7.00% |
| -20% | 870,680.00 | 800,540.12 | -70,139.88 | -8.06% |
| -10% | 803,196.57 | 717,153.57 | -86,043.00 | -10.71% |
| 0% | 730,526.83 | 635,224.81 | -95,302.02 | -13.05% |
| 10% | 649,535.64 | 576,454.47 | -73,081.17 | -11.25% |
| 20% | 646,728.86 | 570,567.95 | -76,160.91 | -11.78% |
| 30% | 632,311.22 | 531,176.08 | -101,135.14 | -15.99% |
| 40% | 544,319.89 | 435,925.49 | -108,394.40 | -19.91% |
| 50% | 573,451.87 | 505,147.57 | -68,304.30 | -11.91% |
| 60% | 501,701.90 | 481,223.66 | -20,478.23 | -4.08% |
| 70% | 447,878.54 | 402,788.05 | -45,090.49 | -10.07% |
| 80% | 426,146.25 | 426,241.20 | 94.94 | 0.02% |
| 90% | 434,598.25 | 417,152.29 | -17,445.96 | -4.01% |
| 100% | 414,450.34 | 397,439.54 | -17,010.80 | -4.10% |
| 110% | 407,845.80 | 422,763.87 | 14,918.08 | 3.66% |
| 120% | 396,333.84 | 410,512.14 | 14,178.30 | 3.58% |
| 130% | 390,022.04 | 396,861.96 | 6,839.92 | 1.75% |
| 140% | 388,447.55 | 314,484.20 | -73,963.35 | -19.04% |
| 150% | 361,267.85 | 375,113.85 | 13,846.00 | 3.83% |

**Table 4.17: Sensitivity Analysis for the Two Models When Demand is Changed (Total Carrying Cost) (Continued)**

| % Changed | Total Carrying Cost (Current) | Total Carrying Cost (Q, r) | Difference | % Difference |
|---|---|---|---|---|
| 160% | 364,782.76 | 343,153.33 | -21,629.43 | -5.93% |
| 170% | 381,591.80 | 315,692.76 | -65,899.05 | -17.27% |
| 180% | 357,400.86 | 303,555.75 | -53,845.12 | -15.07% |
| 190% | 356,216.04 | 305,185.62 | -51,030.42 | -14.33% |
| 200% | 355,013.42 | 307,379.22 | -47,634.20 | -13.42% |
| **Average** | **684,481.35** | **640 854.84** | **-43,626.51** | **-6.37%** |

The results of the total carrying cost when demand is changed ranging from minus 100% to plus 200%, indicate that the average carrying cost would have decreased by 43,626.51 Baht/year or 6.37 percent.

### 3) Sensitivity Analysis for Total Stock Out Cost

After performing simulations on the ordering process for both models when actual 2014 demand was fluctuated from minus 100% to plus 200%, the total stock out cost are changed as shown in Figure 4.6 and Table 4.18.

**Figure 4.6: A Comparison of the Total Stock Out Cost Using both Models When Demand is Changed**

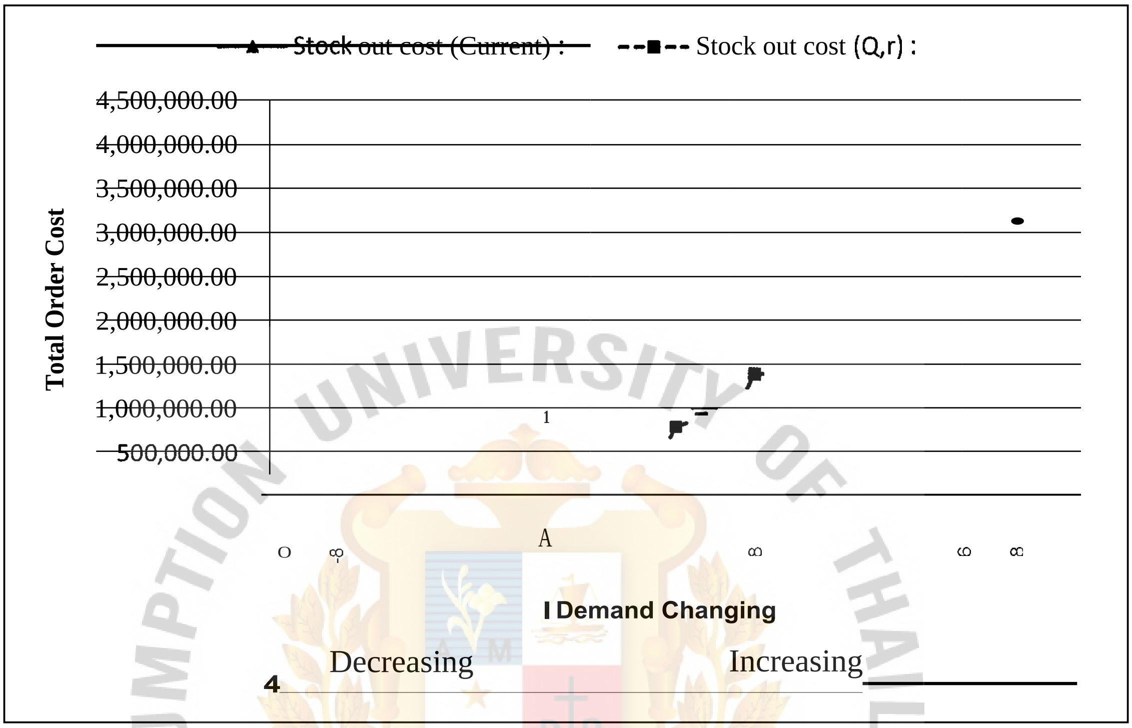



**Table 4.18: Sensitivity Analysis for the Two Models When Demand is Changed (Total Stock Out Cost)**

| % Changed | Total Stock out Cost (Current) | Total Stock out Cost (Q, r) | Difference | % Difference |
|---|---|---|---|---|
| **-100%** | - | - | - | 0.00% |
| -90% | - | - | - | 0.00% |
| -80% | - | - | - | 0.00% |
| -70% | - | - | - | 0.00% |
| -60% | - | - | - | 0.00% |
| -50% | - | - | - | 0.00% |

**Table 4.18: Sensitivity Analysis for the Two Models When Demand is Changed (Total Stock Out Cost) (Continued)**

| % Changed | Total Stock out Cost (Current) | Total Stock out Cost (Q, r) | Difference | % Difference |
|---|---|---|---|---|
| -40% | - | - | - | 0.00% |
| -30% | - | - | - | 0.00% |
| -20% | - | - | - | 0.00% |
| -10% | - | - | - | 0.00% |
| 0% | - | - | - | 0.00% |
| 10% | - | - | - | 0.00% |
| 20% | - | - | - | 0.00% |
| 30% | 256,257.56 | 256,257.56 | - | 0.00% |
| 40% | 248,784.90 | 248,784.90 | - | 0.00% |
| 50% | 505,315.85 | 793,195.52 | 287,879.67 | 56.97% |
| 60% | 533,930.67 | 896,263.55 | 362,332.88 | 67.86% |
| 70% | 846,142.05 | 823,450.68 | -22,691.37 | -2.68% |
| 80% | 835,115.32 | 1,393,651.09 | 558,535.77 | 66.88% |
| 90% | 1,101,670.57 | 1,405,771.38 | 304,100.81 | 27.60% |
| 100% | 1,302,521.09 | 1,520,686.31 | 218,165.22 | 16.75% |
| 110% | 1,691,099.41 | 1,739,853.96 | 48,754.55 | 2.88% |
| 120% | 1,634,598.81 | 2,179,465.08 | 544,866.27 | 33.33% |
| 130% | 1,944,805.33 | 2,362,362.99 | 417,557.66 | 21.47% |
| 140% | 2,192,952.32 | 2,206,621.82 | 13,669.50 | 0.62% |
| 150% | 2,495,868.44 | 2,632,836.83 | 136,968.39 | 5.49% |

**Table 4.18: Sensitivity Analysis for the Two Models When Demand is Changed (Total Stock Out Cost) (Continued)**

| % Changed | Total Stock out Cost (Current) | Total Stock out Cost (Q, r) | Difference | % Difference |
|---|---|---|---|---|
| 160% | 2,706,652.13 | 2,791,038.51 | 84,386.38 | 3.12% |
| 170% | 2,774,635.11 | 2,874,969.24 | 100,334.13 | 3.62% |
| 180% | 2,829,313.11 | 3,097,508.70 | 268,195.59 | 9.48% |
| 190% | 3,028,796.68 | 3,572,296.00 | 543,499.32 | 17.94% |
| 200% | 3,226,184.26 | 3,821,901.07 | 595,716.81 | 18.47% |
| **Average** | **972,730.44** | **1,116,674.68** | **143,944.24** | **14.80%** |

The results of the total stock out cost when demand is changed ranging from minus 100% to plus 200%, indicate that the average stock out cost would have increase by 143,944.24 Baht/year or 14.80 percent.

**4) Sensitivity Analysis for Total Inventory Cost**

The average total inventory cost when actual 2014 demand was fluctuated from minus 100% to plus 200% was calculated by summing the average ordering cost, average carrying cost and average stock out cost. The comparison of the average total inventory costs are shown in Figure 4.7.

**Figure 4.7: A Comparison of the Total Inventory Costs Using Both Models When Demand is Changed**

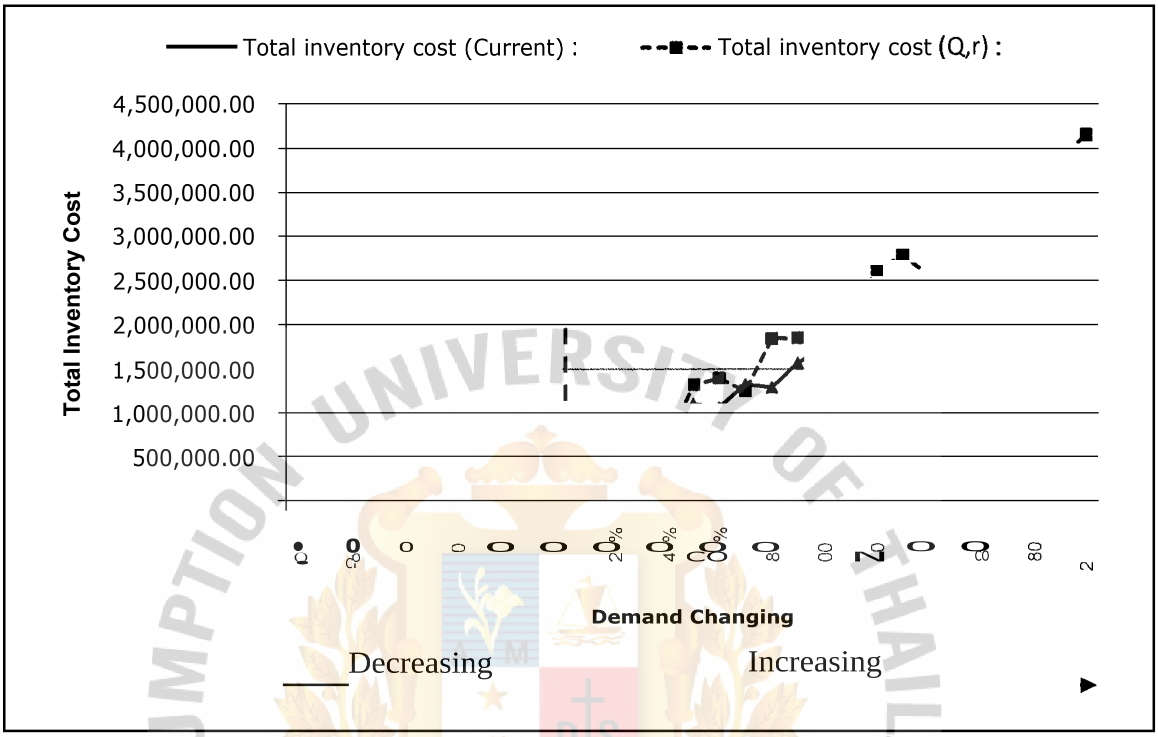



**Figure 4.18: A Comparison of the Total Inventory Cost Change (%) by Using Both Models When Demand is Changed**

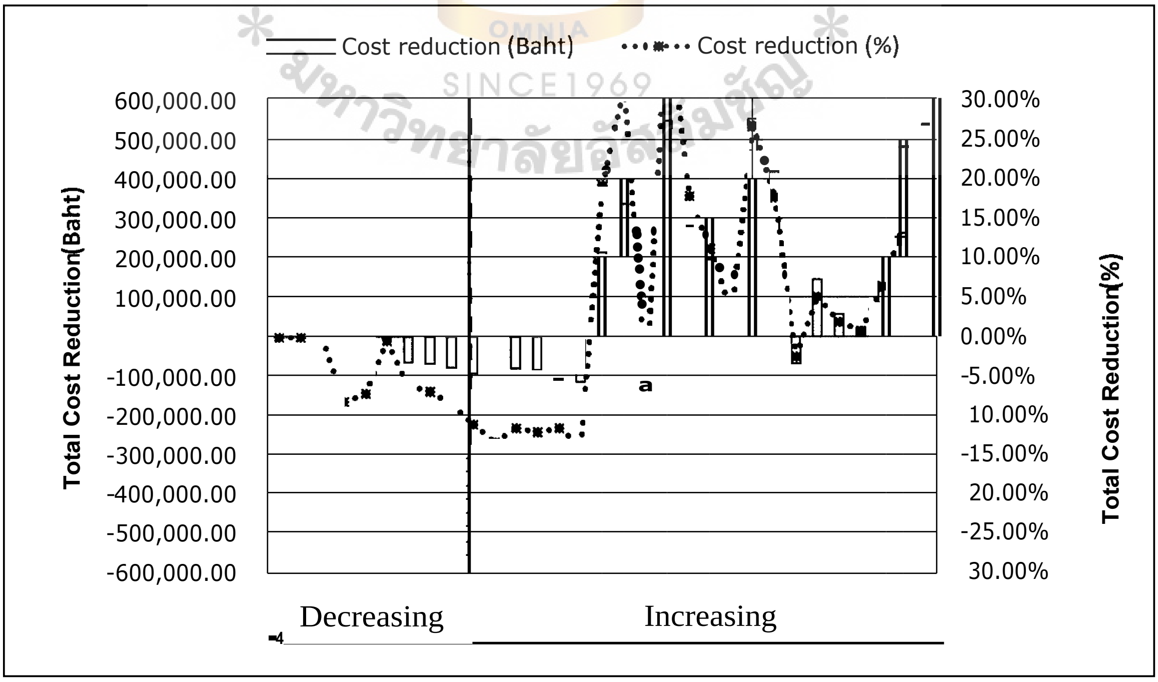


**Table 4.19: Sensitivity Analysis for the Two Models When Demand is Changed (Total Inventory Cost)**

| % Changed | Total Inventory Cost (Current) | Total Inventory Cost (Q, r) | Difference | % Difference |
|---|---|---|---|---|
| -100% | 1,600,637.99 | 1,600,637.99 | - | 0.00% |
| -90% | 1,452,062.50 | 1,452,062.50 | - | 0.00% |
| -80% | 1,305,025.89 | 1,305,025.89 | - | 0.00% |
| -70% | 1,259,954.04 | 1,157,382.04 | -102,572.00 | -8.14% |
| -60% | 1,190,872.39 | 1,105,897.51 | -84,974.88 | -7.14% |
| -50% | 1,079,364.62 | 1,074,243.57 | -5,121.04 | -0.47% |
| -40% | 1,028,095.69 | 965,301.27 | -62,794.42 | -6.11% |
| -30% | 953,210.59 | 887,661.64 | -65,548.94 | -6.88% |
| -20% | 893,280.00 | 817,490.12 | -75,789.88 | -8.48% |
| -10% | 825,796.57 | 734,103.57 | -91,693.00 | -11.10% |
| 0% | 753,126.83 | 652,174.81 | -100,952.02 | -13.40% |
| 10% | 677,785.64 | 599,054.47 | -78,731.17 | -11.62% |
| 20% | 674,978.86 | 593,167.95 | -81,810.91 | -12.12% |
| 30% | 916,818.78 | 810,033.64 | -106,785.14 | -11.65% |
| 40% | 821,354.79 | 707,310.39 | -114,044.40 | -13.88% |
| 50% | 1,107,017.72 | 1,320,943.09 | 213,925.37 | 19.32% |
| 60% | 1,063,882.57 | 1,400,087.21 | 336,204.65 | 31.60% |
| 70% | 1,327,920.59 | 1,254,488.73 | -73,431.86 | -5.53% |
| 80% | 1,295,161.57 | 1,842,492.29 | 547,330.71 | 42.26% |

**Table 4.19: Sensitivity Analysis for the Two Models When Demand is Changed (Total Inventory Cost) (Continued)**

| % Changed | Total Inventory Cost (Current) | Total Inventory Cost (Q, r) | Difference | % Difference |
|---|---|---|---|---|
| 90% | 1,570,168.82 | 1,851,173.67 | 281,004.85 | 17.90% |
| 100% | 1,750,871.43 | 1,946,375.85 | 195,504.42 | 11.17% |
| 110% | 2,127,195.21 | 2,190,867.83 | 63,672.63 | 2.99% |
| 120% | 2,064,832.65 | 2,618,227.22 | 553,394.57 | 26.80% |
| 130% | 2,368,727.37 | 2,787,474.95 | 418,747.58 | 17.68% |
| 140% | 2,615,299.87 | 2,549,356.02 | -65,943.85 | -2.52% |
| 150% | 2,891,036.29 | 3,036,200.68 | 145,164.39 | 5.02% |
| 160% | 3,105,334.89 | 3,162,441.84 | 57,106.95 | 1.84% |
| 170% | 3,195,776.91 | 3,218,912.00 | 23,135.08 | 0.72% |
| 180% | 3,226,263.97 | 3,429,314.45 | 203,050.47 | 6.29% |
| 190% | 3,424,562.72 | 3,905,731.62 | 481,168.90 | 14.05% |
| 200% | 3,620,747.68 | 4,157,530.29 | 536,782.61 | 14.83% |
| **Average** | **1,683,456.95** | **1,778,489.20** | **95 032.25** | **5.65%** |

The results of the average total inventory cost when the demand is changed ranging from minus 100% to plus 200% indicate that the average total inventory cost was increased by 95,032.25 Baht/year or 5.65 percent. As shown in Figure 4.7, Figure 4.8 and Table 4.19, a total inventory cost reduction occurred continuously until the demand was increased by 40% of actual demand. Beyond that point there was uncontrollable of cost reduction.

Therefore it can concluded that the (Q, r) ordering model can reduce the total inventory cost when compared with ABC Company's current ordering model, if demand is not increased over 40% of the 2014 actual demand.

### 4.7 Summary

The type of demand selected for investigation in this study was uncertain demand which was evaluated using a variability coefficient technique. The inventory related costs were calculated for use as parameters in the (Q, r) ordering model. Then ABC Company's current inventory ordering model and the (Q, r) ordering model were employed to simulate total inventory costs for use in comparison.

Based upon the results of the simulation, the (Q, r) ordering model reduces the total inventory costs by 100,952.02 Baht/year or 13.40 percent when compared with current ordering model.

However, if the demand is increased over 40% the (Q, r) ordering model will provide no cost reduction when compared with current ordering model.

# CHAPTER V
# SUMMARY FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

The summary of the findings, conclusions, theoretical and managerial implications, and recommendations are explained in this chapter.

## 5.1 Summary of the Findings

ABC Company can improve its fill rate of customer orders which can improve customer satisfaction. Inventory cost improvements can provide ABC Company with a competitive advantage in the agricultural part supply business. However, inventory holding costs have been increasing continuously which is causing ABC Company to lose profitability. There are many inventory management costs that have been increasing such as expense of warehousing, opportunity costs, etc. This leads to the question of "How can ABC Company improve their inventory management to reduce total inventory cost?" The main objective of this research was to test the (Q, r) model technique which is an inventory management technique for use with uncertain demand. The ASSY SEAL OIL (TC010-99600) part was the part selected for this study because this part had the highest annual cost volume usage of all parts carried by ABC Company in 2014 as identified using the ABC inventory classification methodology.

In conclusion, the major findings of this study are as follows:

1. The demand pattern of the ASSY SEAL OIL part in 2014 had a variability coefficient (VC) of 0.30 which indicates high variability. Therefore this part met the variance assumption for use with the (Q, r) model.
2. The Anderson-Darling normality test using a 95% confidential level was applied to test the weekly ordering distribution of the ASSY SEAL OIL part demand for 2014. The p-value of the demand data was 0.268, which is more than 0.05. Therefore

it is correct to assume that this demand data is normally distributed. The data has mean and a standard deviation of 531.27 and 292.64 respectively. Consequently, the (Q, r) inventory management ordering technique was appropriate for use with this part.

3. When the (Q, r) model technique was applied for use with the ASSY SEAL OIL part, the total inventory cost was reduced from 753,126.83 Baht/year to 652,174.81 Baht/year or 13.40 percent.

**Table 5.1: Details of the Total Inventory Cost Reduction**

| Inventory Costs in 2014 | Current Model | (Q, r) Model | Difference | % |
|---|---|---|---|---|
| Total Ordering Cost | 22,600.00 | 16,950.00 | -5,650.00 | -25.00% |
| Total Carrying Cost | 730,526.83 | 635,224.81 | -95,302.02 | -13.04% |
| Total Stock Out Cost | - | - | - | - |
| **Total Inventory Cost** | **753 126.83** | **652 174.81** | **-100,952.02** | **-13.40%** |

4. If demand is not increased over 40% of the actual 2014 demand, the (Q, r) ordering model will help ABC Company to reduce their total inventory costs when compared with their current ordering model.

## 5.2 Conclusions

Based on the findings of this study, ABC Company can conclude that the (Q, r) model could have reduced their total inventory cost from 753,126.83 Baht/year to 652,174.81 Baht/year or 13.40 percent had this model been used in 2014. However if demand is not increased over 40% of the actual 2014 demand, the (Q, r) model would still help ABC Company reduce their total inventory costs when they use (Q, r) model for their inventory order management.

## 5.3 Theoretical Implications

Joint calculation of order quantity and reorder level or the (Q, r) model is one of inventory control models used for uncertain demand. It was selected for use in this study.

The demand pattern for agricultural spare parts is uncertain demand. Therefore the inventory of these parts should be controlled by a probabilistic inventory control model which uses inventory related costs such as ordering cost per time, carrying costs and penalty costs to find the optimal order quantity and reorder point for selected parts. This inventory control model will reduce the total inventory cost of ABC Company which should help to improve profitability.

## 5.4 Managerial Implications

ABC Company can reduce total inventory costs by implementing the proposed (Q, r) model for inventory control with selected parts. This inventory control model was used in a simulation with a selected part that had the highest volume of consumption in 2014. The data was used for the simulation (actual demand, warehouse expense, freight cost, etc.) was actual ABC Company 2014 data.

As a result of this study, ABC Company has gained more knowledge about inventory management when demand is uncertain. The probabilistic model will be adopted for their use which can reduce total inventory costs for ABC Company. Moreover, ABC Company should be able to obtain additional cost reductions if they implement this model with other spare parts that also have uncertain demand.

## 5.5 Limitations and Recommendations for Future Research

This study focused on total inventory cost reduction of an imported part at ABC Company by using the (Q, r) inventory management model. The results of data analysis showed the optimal order quantity and the reorder point for the part selected under uncertain demand. There are several limitations to this study as shown below:

- The selected part is an imported part which has a high ordering cost per order and long lead time of delivery. Therefore the results of (Q, r) model from this study would be inappropriate for use with local spare parts.

  This study was based on the historical data of ABC Company from January 2014 to December 2014.
- This study focused on normal requirements from customers.

  This study focused on an imported part that had the highest annual cost of usage for all imported parts of ABC Company.

The recommendations for future research would be:

- This study selected only a part in group A to test the improvement to the ordering policy. However, there may be many spare parts in groups A and B where the (Q, r) inventory management model can be used to reduce total inventory costs as explained in this study.
- The inventory related costs are the raw data for calculation by the (Q, r) inventory management model. Therefore employees must re-check the data continuously which helps the Company to get more benefits by using (Q, r) inventory management model.
- The company should continuously review the consumption pattern such as every quarter. Because of the consumption may be changed in the future from another effect such as promotion, weather situation, pestilence.

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# APPENDICES

# APPENDIX A

Current Ordering Process
(Minimum and Maximum Inventory Management)

| Details | Value | Unit |
|---|---|---|
| Part No | TC010-99600 | - |
| Part Name | ASSY SEAL OIL | - |
| Supplier | KBT | - |
| Supplier Performance | 0.6 | - |
| Lead time | 16 | Weeks |
| Service Level | 98% | - |
| Average Demand | 531.27 | Pc/Week |
| Standard Deviation | 292.64 | - |
| Pending PO (W13) | 8,580 | Pcs. |
| Safety Stock | 2,492 | Pcs. |
| Minimum Stock level | 10,992 | Pcs. |
| Maximum Stock level | 17,725 | Pcs. |
| On Hand Stock | 8,907 | Pcs. |

| Week | Actual demand | Special Order | Monthly Order | Schedule Monthly Order | Project On Hand | Allocate | Inventory Level |
|---|---|---|---|---|---|---|---|
| W1 | 49 | - | - | - | 17,438 | 8,858 | 8,858 |
| W2 | 333 | - | - | - | 17,105 | 8,525 | 8,525 |
| W3 | 103 | - | - | - | 17,002 | 8,422 | 8,422 |
| W4 | 760 | - | - | - | 16,242 | 7,662 | 7,662 |
| W5 | 941 | - | - | - | 15,301 | 6,721 | 6,721 |
| W6 | 307 | - | - | - | 14,994 | 6,414 | 6,414 |
| W7 | 608 | - | - | - | 14,386 | 5,806 | 5,806 |
| W8 | 458 | - | - | - | 13,928 | 5,348 | 5,348 |
| W9 | 552 | - | - | - | 13,376 | 4,796 | 4,796 |
| W10 | 152 | - | - | - | 13,224 | 4,644 | 4,644 |
| W11 | 927 | - | 5,351 | - | 12,297 | 3,717 | 3,717 |
| W12 | 785 | - | - | - | 16,863 | 2,932 | 2,932 |
| W13 | 255 | - | | 8,580 | 16,608 | 11,257 | 11,257 |
| W14 | 734 | - | - | - | 15,874 | 10,523 | 10,523 |
| W15 | 741 | - | - | - | 15,133 | 9,782 | 9,782 |
| W16 | 1,151 | - | | - | 13,982 | 8,631 | 8,631 |

| Week | Actual demand | Special Order | Monthly Order | Schedule Monthly Order | Project On Hand | Allocate | Inventory Level |
|---|---|---|---|---|---|---|---|
| W17 | 941 | - | - | - | 13,041 | 7,690 | 7,690 |
| W18 | 390 | - | 4,997 | - | 12,651 | 7,300 | 7,300 |
| W19 | 915 | - | - | - | 16,733 | 6,385 | 6,385 |
| W20 | 748 | - | - | - | 15,985 | 5,637 | 5,637 |
| W21 | 805 | - | - | - | 15,180 | 4,832 | 4,832 |
| W22 | 1,034 | - | - | - | 14,146 | 3,798 | 3,798 |
| W23 | 58 | - | - | - | 14,088 | 3,740 | 3,740 |
| W24 | 157 | - | - | - | 13,931 | 3,583 | 3,583 |
| W25 | 505 | - | - | - | 13,426 | 3,078 | 3,078 |
| W26 | 1,045 | - | 5,267 | 5,351 | 12,381 | 7,384 | 7,384 |
| W27 | 57 | - | - | - | 17,591 | 7,327 | 7,327 |
| W28 | 235 | - | - | - | 17,356 | 7,092 | 7,092 |
| W29 | 485 | - | - | - | 16,871 | 6,607 | 6,607 |
| W30 | 201 | - | - | - | 16,670 | 6,406 | 6,406 |
| W31 | 516 | - | - | - | 16,154 | 5,890 | 5,890 |
| W32 | 663 | - | - | - | 15,491 | 5,227 | 5,227 |
| W33 | 207 | - | - | 4,997 | 15,284 | 10,017 | 10,017 |
| W34 | 641 | - | - | - | 14,643 | 9,376 | 9,376 |
| W35 | 282 | - | - | - | 14,361 | 9,094 | 9,094 |
| W36 | 510 | - | - | - | 13,851 | 8,584 | 8,584 |
| W37 | 308 | - | - | - | 13,543 | 8,276 | 8,276 |
| W38 | 554 | - | - | - | 12,989 | 7,722 | 7,722 |
| W39 | 959 | - | 5,618 | - | 12,030 | 6,763 | 6,763 |
| W40 | 479 | - | - | - | 17,169 | 6,284 | 6,284 |
| W41 | 849 | - | - | 5,267 | 16,320 | 10,702 | 10,702 |
| W42 | 579 | - | - | - | 15,741 | 10,123 | 10,123 |
| W43 | 337 | - | - | - | 15,404 | 9,786 | 9,786 |
| W44 | 300 | - | - | - | 15,104 | 9,486 | 9,486 |
| W45 | 822 | - | - | - | 14,282 | 8,664 | 8,664 |
| W46 | 586 | - | - | - | 13,696 | 8,078 | 8,078 |

| Week | Actual demand | Special Order | Monthly Order | Schedule Monthly Order | Project On Hand | Allocate | Inventory Level |
|---|---|---|---|---|---|---|---|
| W47 | 308 | - | - | - | 13,388 | 7,770 | 7,770 |
| W48 | 238 | - | - | - | 13,150 | 7,532 | 7,532 |
| W49 | 670 | - | 5,168 | - | 12,480 | 6,862 | 6,862 |
| W50 | 283 | - | - | - | 17,365 | 6,579 | 6,579 |
| W51 | 441 | - | - | - | 16,924 | 6,138 | 6,138 |
| W52 | 662 | - | - | - | 16,262 | 5,476 | 5,476 |

# APPENDIX B

## Proposed Ordering Process
## (Q, r) Inventory Management

| Details | Value | Unit |
|---|---|---|
| Part No | TC010-99600 | - |
| Part Name | ASSY SEAL OIL | - |
| Supplier | KBT | - |
| Supplier Performance | 0.6 | - |
| Lead time | 16 | Weeks |
| Service Level | 98% | - |
| Average Demand | 531.27 | Pc/Week |
| Standard Deviation | 292.64 | - |
| Demand during LT | 8,500.31 | Pcs. |
| STD during LT | 1,170.55 | - |
| Pending PO (W13) | 8,580 | Pcs. |
| Safety Stock | 2,492 | Pcs. |
| ROP | 10,856 | Pcs. |
| Optimal Order | 6,486 | Pcs/Time |
| On Hand Stock | 8,907 | Pcs. |

| Week | Actual demand | Special Order | Monthly Order | Schedule Monthly Order | Project On Hand | Allocate | Inventory Level |
|---|---|---|---|---|---|---|---|
| W1 | 49 | - | - | - | 17,438 | 8,858 | 8,858 |
| W2 | 333 | - | - | - | 17,105 | 8,525 | 8,525 |
| W3 | 103 | - | - | - | 17,002 | 8,422 | 8,422 |
| W4 | 760 | - | - | - | 16,242 | 7,662 | 7,662 |
| W5 | 941 | - | - | - | 15,301 | 6,721 | 6,721 |
| W6 | 307 | - | - | - | 14,994 | 6,414 | 6,414 |
| W7 | 608 | - | - | - | 14,386 | 5,806 | 5,806 |
| W8 | 458 | - | - | - | 13,928 | 5,348 | 5,348 |
| W9 | 552 | - | - | - | 13,376 | 4,796 | 4,796 |
| W10 | 152 | - | - | - | 13,224 | 4,644 | 4,644 |
| W11 | 927 | - | - | - | 12,297 | 3,717 | 3,717 |
| W12 | 785 | - | - | - | 11,512 | 2,932 | 2,932 |
| W13 | 255 | - | - | 8,580 | 11,257 | 11,257 | 11,257 |
| W14 | 734 | - | 6,486 | - | 10,523 | 10,523 | 10,523 |

| Week | Actual demand | Special Order | Monthly Order | Schedule Monthly Order | Project On Hand | Allocate | Inventory Level |
|---|---|---|---|---|---|---|---|
| W15 | 741 | - | - | - | 16,268 | 9,782 | 9,782 |
| W16 | 1,151 | - | - | - | 15,117 | 8,631 | 8,631 |
| W17 | 941 | - | - | - | 14,176 | 7,690 | 7,690 |
| W18 | 390 | - | - | - | 13,786 | 7,300 | 7,300 |
| W19 | 915 | - | - | - | 12,871 | 6,385 | 6,385 |
| W20 | 748 | - | - | - | 12,123 | 5,637 | 5,637 |
| W21 | 805 | - | - | - | 11,318 | 4,832 | 4,832 |
| W22 | 1,034 | - | 6,486 | - | 10,284 | 3,798 | 3,798 |
| W23 | 58 | - | - | - | 16,712 | 3,740 | 3,740 |
| W24 | 157 | - | - | - | 16,555 | 3,583 | 3,583 |
| W25 | 505 | - | - | - | 16,050 | 3,078 | 3,078 |
| W26 | 1,045 | - | - | - | 15,005 | 2,033 | 2,033 |
| W27 | 57 | - | - | - | 14,948 | 1,976 | 1,976 |
| W28 | 235 | - | - | - | 14,713 | 1,741 | 1,741 |
| W29 | 485 | - | - | 6,486 | 14,228 | 7,742 | 7,742 |
| W30 | 201 | - | - | - | 14,027 | 7,541 | 7,541 |
| W31 | 516 | - | - | - | 13,511 | 7,025 | 7,025 |
| W32 | 663 | - | - | - | 12,848 | 6,362 | 6,362 |
| W33 | 207 | - | - | - | 12,641 | 6,155 | 6,155 |
| W34 | 641 | - | - | - | 12,000 | 5,514 | 5,514 |
| W35 | 282 | - | - | - | 11,718 | 5,232 | 5,232 |
| W36 | 510 | - | - | - | 11,208 | 4,722 | 4,722 |
| W37 | 308 | - | - | 6,486 | 10,900 | 10,900 | 10,900 |
| W38 | 554 | - | 6,486 | - | 10,346 | 10,346 | 10,346 |
| W39 | 959 | - | - | - | 15,873 | 9,387 | 9,387 |
| W40 | 479 | - | - | - | 15,394 | 8,908 | 8,908 |
| W41 | 849 | - | - | - | 14,545 | 8,059 | 8,059 |
| W42 | 579 | - | - | - | 13,966 | 7,480 | 7,480 |
| W43 | 337 | - | - | - | 13,629 | 7,143 | 7,143 |
| W44 | 300 | - | - | - | 13,329 | 6,843 | 6,843 |

| Week | Actual demand | Special Order | Monthly Order | Schedule Monthly Order | Project On Hand | Allocate | Inventory Level |
|---|---|---|---|---|---|---|---|
| W45 | 822 | - | - | - | 12,507 | 6,021 | 6,021 |
| W46 | 586 | - | - | - | 11,921 | 5,435 | 5,435 |
| W47 | 308 | - | - | - | 11,613 | 5,127 | 5,127 |
| W48 | 238 | - | - | - | 11,375 | 4,889 | 4,889 |
| W49 | 670 | - | 6,486 | - | 10,705 | 4,219 | 4,219 |
| W50 | 283 | - | - | - | 16,908 | 3,936 | 3,936 |
| W51 | 441 | - | - | - | 16,467 | 3,495 | 3,495 |
| W52 | 662 | - | - | - | 15,805 | 2,833 | 2,833 |