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INVENTORY REDUCTION BY SMALLER PRODUCTION BATCH SIZE: CASE STUDY OF A CONFECTIONERY COMPANY

By

PANAVADEE NONTAPOT

A Final Report of the Six-Credit Course
SCM 2202 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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Master of Science in Supply Chain Management

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Inventory Reduction by Smaller Production Batch Size: Case Study of a Confectionery Company

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Assumption University
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Declaration of Authorship Form

I, Ms.Panavadee Nontapot 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 Reduction by Smaller Production Batch Size: Case Study of A Confectionery Company.

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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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7 Dec 2010

ABSTRACT

The confectionery company operation was studied to improve profits of the company in the recent competitive market. To achieve that, production batch size was analyzed under the assumption that smaller production batch size could provide optimal inventory and would consequently provide optimal safety stock and achieve service level target.

Computer simulation was used to simulate replenishment cycle of the studied product. Input of the simulation was historical data between January - May 2009. The simulation comprised of forty-four scenarios of replenishment operations.

This case study proved that smaller production batch size could reduce finished goods inventory of the studied product. Target service level was also achieved. In addition, implementing the smaller production batch size means shorter lead time of responsiveness. This provides opportunity for company's market expansion.

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I gratefully acknowledge who supported me in this graduate project. My advisor, Dr. Vatcharapol Sukhotu, provided valuable guidance and suggestions over the course.

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Finally, I was motivated in various ways by family and friends. My parents always gave me and support. My lovely sister reviewed and commented on my paper. My lovely nephews: Jeng and Jui also vitalized my energy.

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CHAPTER I

INTRODUCTION

It is generally known that inventory management is very simple concept; good inventory is not too much and not too little. Although, the concept is simple, for inventory management to get the optimal balance is complex. In making decisions about inventory, supply and demand is needed to be considered by companies. In general, inventory management can be explained by four functional factors: time, discontinuity, uncertainty and economy (Tersine, 1994).

Time factor involves period of time from production and distribution until goods reach the customer.

Discontinuity factor involves integration among supply chain operations: retailing, distributing, warehousing, manufacturing and purchasing. Discontinuity of integration leads to inventory problems.

Uncertainty factor concerns unforeseen circumstances that impact the inventory system such as demand forecast error, deviation in production and distribution. Generally, organizations have safety inventories as a protection to handle unanticipated events.

Economy factor involves cost perspective which enables organization to produce or purchase in economic quantity. Large production quantity can reduce change over time cost. Bulk purchasing yields discount cost and transportation cost reduction.

Each company has different characteristics. Therefore, optimal inventory of each company depends on its characteristic and its decision about trading off between these factors.

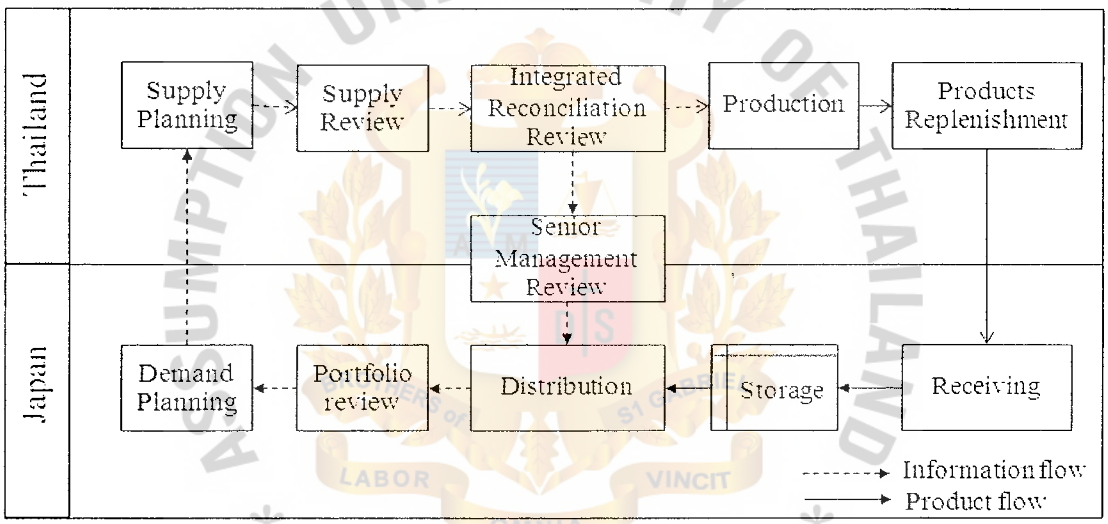
1.1 Background of the Case Study

The company in this study is leading global confectionery company with an outstanding portfolio of chocolate, gum and candy. The company was founded in

1824, and operates business in over 60 countries. It employs 50,000 people worldwide. In this study, Japan and Thailand sites will be studied.

The Japan site is considered as customers of the Thailand site as it imports gum products from Thailand. While the Thailand site is considered as suppliers of the Japan site. Both sites operate through Sales and Operation Planning (S&OP) process for demand and supply management. The S&OP process flow is as shown in Figure 1.1.

Figure 1.1: S&OP process flow

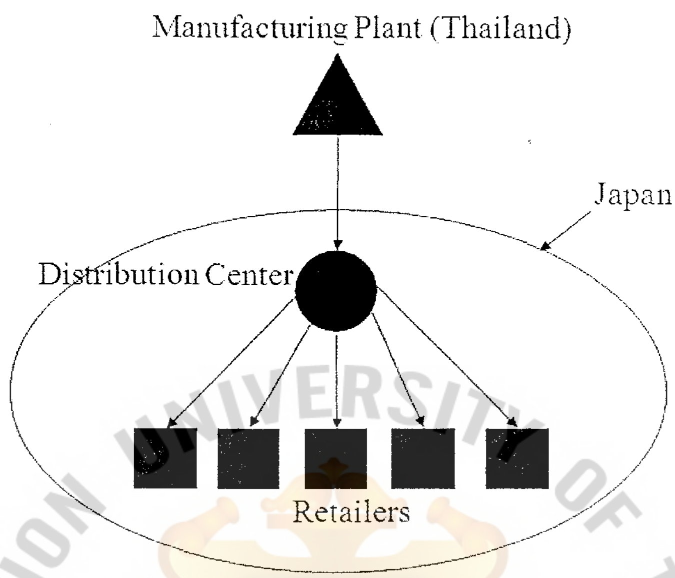


Source: Company data

At present, Japan places orders to Thailand on a monthly basis. The inventory policy is to maintain the inventory at the end of each month to be able to supply for the next month sales forecast.

Once the order is received, Thailand produces the finished product and delivers it to Japan. The daily production schedule is merely planned to get maximum output and fulfill total monthly orders. The echelon flow of the product is as shown in Figure 1.2; finished products are produced at the Thailand site, and then shipped to the distribution center at the Japan site. Then finally products are distributed to retailers.

Figure 1.2: Product flow echelon

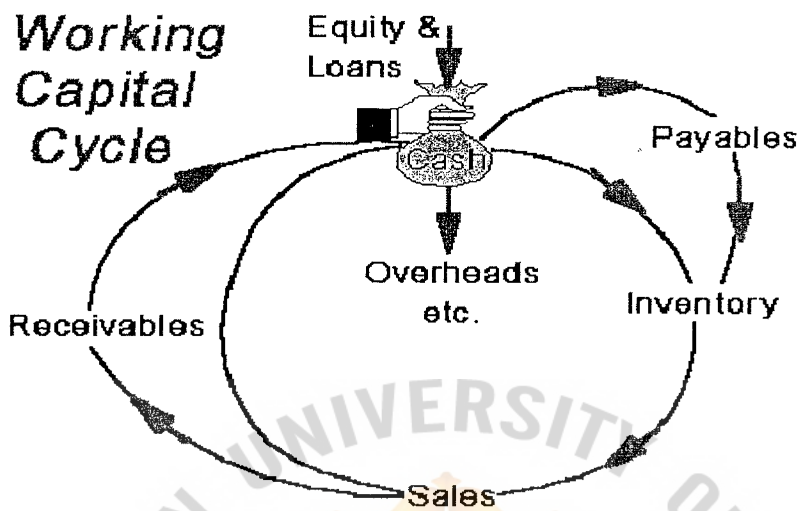


1.2 Statement of Problem

The goal of each company is to maximize profits. The Thailand and Japan sites focuses on its own benefits rather than benefits of total supply chain. Thailand as a manufacturing plant focuses on productivity optimization while Japan as a seller emphasizes customer service level to maximize sales. But in the presence of competitive market, inventory which is the indicator of company performance needs to be considered.

Inventory is an element in working capital cycle which absorbs cash (www.planware.org) as in Figure 1.3. Excess inventory can place heavy burden on cash, especially with confectionery products which have finite product shelf life. Holding stock for long periods of time ties up money and risk of product obsolescence. Therefore, inventory optimization is a challenge for supply chain to improve company profits.

Figure 1.3: Working capital cycle



Source: www.planware.org

In addition, the company has planned to increase sales by extending types of gum to other countries in South East Asia which are Malaysia, Philippines, Indonesia and Singapore. Thus, to supply variety of products to variety of markets efficiently, production lead time and replenishment quantity are key elements to be considered.

Lead time affects response time; less lead time gives better customer satisfaction because customers do not want to wait for goods for long time, they tend to switch to purchase from competitors who give shorter lead time. Thus the company loses the opportunity to sell its products. However, lead time relates to replenishment quantity; shorter lead time gives smaller replenishment quantity. By doing so, the company can deliver the product to more markets with more frequency. Moreover, delivery of products more frequency with smaller quantity reduces replenishment cycle and inventory (Anupindi, Chopra, Deshmukh, Mieghen and Zemel, 2006)

In this competitive market, both inventory challenge and market growth are company targets that every single employee must work on and find improvement opportunities during every day of work. The researcher has found three areas as opportunities:

1. Production batch size reduction

The Thailand site produces large batch sizes in order to minimize production change over time and to maximize production output. In so doing, it could influence longer lead time; larger production batch size requires longer production lead time. Therefore, large order size impacts to high inventory level at Japan and the researcher expects that the inventory can be decreased by producing smaller production batch sizes.

2. Optimal safety stock determination

The Japan site focuses on customer service level, since it is a company key indicator to evaluate performance. Presently, Japan lacks theoretical consideration in safety stock policy. Their policy seems to be a result of working experience. Regarding the long lead time of ordering goods from Thailand, Japan holds 1 month of sales (MOS) as safety stock at distribution center in order to ensure the continuity of supply. Therefore, the researcher expects that safety stock can be reduced by producing smaller production batch size.

3. Production batch size for market extension

Market extension requires shorter production lead time. If the company insists on producing the same production batch size, the response time to order will be long and high finished goods inventory level is required in order to keep service level. The example of production pattern and lead time relation is explained in Figure 1.4. Therefore, the researcher expects that the company can extend the market by having optimal inventory by producing smaller production batch sizes and delivering more frequency to markets.

Figure 1.4: Production pattern

	week1	week2	week3	week4
Large batch	Japan (JP)	Malaysia (MY)	Philippines (PH)	Indonesia (IN)
Small batch	JP, MY, PH	IN, JP, MY	PH, IN, JP	MY, PH, IN

Figure 1.4 indicates that large production batch size takes one week to produce products of Japan. Products Malaysia will be produced in the following week, and products for the Philippines the week after that. Therefore, the next order for products of Japan will be produced after first order of Indonesia has been completed. This means that Japan needs to hold finished goods inventory for at least four weeks in selling order for the second order to be completed in week5. And same inventory holding concept applies to other countries.

Small production batch size takes less time to produce each order; order of three countries can be completed in a week. By doing this, each country can keep finished goods inventory for less than two weeks while waiting for the next order that is received.

1.3 Research Objectives

As previously mentioned inventory is an element to improve company profits. In this study the main focus is to reduce finished goods inventory of the company by applying Economic Order Quantity (EOQ) theory to determine optimal inventory of the company.

Production batch size is a key variable in this study. .The researcher aims to prove that finished goods inventory of the company can be reduced by producing smaller production batch sizes. Moreover, smaller production batch sizes can reduce lead time and replenishment quantity. Then the company can deliver products to more markets with a shorter lead time which can support market expansion in the future.

However, optimal inventory is required to provide desired service level of the company. Increasing of service level increases the required safety inventory

(Anupindi et al., 2006). Therefore, to define optimal safety inventory is an important strategic decision. The researcher aims at determining optimal inventory for the company.

In summary, there are three main findings of this study:

1. To reduce finished goods inventory level.
2. To define optimal production batch size.
3. To define optimal safety inventory level.

1.4 Scope of the Project

The following factors are within the scope of this project:

1. Company; the confectionery company manufactures gum and candy products in Thailand and exports the products to Japan.
2. Products; gum product one SKU which is a major contribution to sales. Thus it is a major ratio of holding inventory.
3. Period of data; data and information used during the period of five months between January to May 2009.

The following factors are outside the scope of the project:

1. Others products; other products which besides the gum production mentioned in the scope.
2. Transportation cost; is out of scope because the studied product is basically shipped from Thailand to Japan in the same container as other products. Thus it is not affected.
3. Change over cost; is out of scope because this study focuses on inventory perspective. During the same period as this study, the company has another project to reduce change over cost which is an operation perspective.

1.5 Limitations of the Research

Because the company really exists in the market, some information cannot be revealed, therefore, some information is kept confidential. The operation process which includes inventory management strategy of the company is specific for this company; hence, it cannot be applied to other companies. In addition, the study is based on historical and present information. Therefore, the figures can change in the future.

1.6 Significance of the Study

Regarding the objectives of this study, variables that influence the inventory level that the company should consider will be presented. The synchronization in supply chain system is also an element to be considered in inventory optimization.

Findings of this study are expected to provide the following benefits:

1. Enhancement of the effectiveness of inventory management. The findings will present that the company can maintain the current customer service level while having less inventory level. This will directly impact better working capital.

2. Motivation of employees to apply theory to actual operation rather than rely merely on working experience. For example, there is old belief that producing larger batch sizes provides higher performance. However, the findings of this study will prove that the belief is not always true. In some situations, the batch size needed is large and in some situations the needed batch size may be small. This will be a step to encourage employees to embrace changes which could occur in the future.

3. "Arena" a computer simulation program which will be used to generate inventory model can be applied in the future. There is change in parameters and variables in the future because it gives high flexibility in modification. Therefore, the model can be adjusted easily by the change. If the company has forecasted higher sales in the next two years, the

company can simulate the situation by changing the sales pattern distribution to the forecasted sales pattern of the next two years. Therefore, the company might find that the current production batch sizes might be no longer optimal. And changing transportation mode from sea to air freight might be an alternative solution in the next two years.

1.7 Definition of Terms

Batch The size of an order or production in response to the economies of scale.

Blanket order is confirmed long term order by a buyer to a seller for supplying specified goods or services, for a fixed period or in a fixed quantity, at agreed-on prices or pricing method. After its acceptance by the supplier, supplies may be made against it periodically, on as-and-when-required basis, or specified in the order, without calling for new purchase orders.

Changeover The cleaning, resetting, or retooling of equipment in order for it to process a different product. Also called *setup*.

Confidence interval The range around the numeric statistical value obtained from a sample, within which the actual, corresponding value for the population is likely to fall, at a given level of probability.

Confidence level The specific probability of obtaining some results from a sample if it did not exist in the population as a whole, at or below which the relationship will be regarded as statistically significant.

Distribution center Name given to warehouse when it is actually used more for cross docking than for storage.

Economic Order Quantity (EOQ) The order quantity that minimizes the total cost of processing orders and holding inventory.

Electronic mail is commonly called email or e-mail, and is a method of exchanging digital messages across the Internet or other computer networks.

Holding cost The cost incurred for holding inventory in storage.

Lead time demand The total flows unit requirement during replenishment lead time.

Lot size The number of units processed consecutively after a setup. Also called *setup batch.*

Month of Supply (MOS) The amount of inventory on hand at the beginning of the month expressed in terms of the time it will take to sell. A six-month supply means it will take six months for the merchandise to sell. A six month supply is equivalent to an inventory turnover of two.

Order cost The direct variable cost associated with placing an order with the supplier.

Reorder point (ROP) The stock level at which a new order is placed.

Safety Inventory Inventory maintained to insulate the process from disruptions in supply or uncertainty in demand. Also called *safety stock.*

Service Level A measure used in inventory management to define the level of support or level of product availability; the number of items sold divided by the number of items demanded.

Simulation A broad collection of methods and applications to mimic the behavior of real systems, usually on a computer with appropriate software.

Stock-keeping unit (SKU) is a unique identifier for each distinct product and service that can be purchased.

Working capital is a financial metric which represents operating liquidity available to a business. Along with fixed assets such as plant and equipment, working capital is considered a part of operating capital.

CHAPTER II

REVIEW OF RELATED LITERATURE AND RESEARCH FRAMEWORKS

This chapter presents a review of literature and research framework relevant to this study. It is separated into three sections: definition and features of variables, previous studies and conceptual framework.

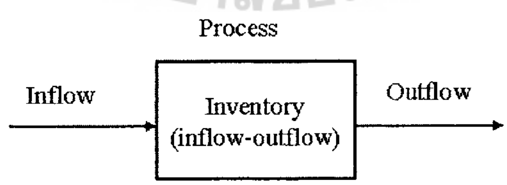
2.1 Definition and Feature of Variable

Regarding the objective of this study, inventory is the independent variable. Thus, in this section inventory definition and theory relevant to inventory will be presented. In addition, relationship of independent and dependent variables will also be expressed.

2.1.1 Inventory

Anupindi et al. (2006) explained that "Inventory is the total number of flow units present within the process boundaries". Generally, inventory level is driven by two elements: inflow rate and outflow rate. When inflow rate is higher than outflow rate, inventory level will be increased. In contrast, when inflow rate is lower than outflow rate, inventory level will be decreased.

Figure 2.1: Process boundary with inflow and outflow rate



Levy and Weitz (2007) defined that inventory is goods or merchandises available for resales.

Simchi-Levi et al. (2008) explained that inventory is dominant cost in supply chain, thus the main objective of inventory management is to have optimal inventory; not to much and not too less with no interruption in supply.

Wisner et al. (2005) explained that there are four categories of inventory:

1. Raw materials are materials for manufacturing the finished goods. And the materials are part of the finished goods.

2. Work-in-process is materials partially processed but not yet complete,

3. Finished goods are completed products which are ready to ship to the customer.

4. Maintenance, repair and operating (MRO) supplies are materials used in the manufacturing process but are not parts of the finished products such as solvents and lubricants.

Simchi-Levi et al. (2008) explained the reasons of inventory holding are:

1. Unexpected changes in customer demand since customer demand always changes.

2. The presence in uncertainty situations such as quantity and quality of supply, supplier costs and delivery times.

3. Lead time

4. Transportation economies of scale

Simchi-Levi et al. (2008) explained that many supply chain characteristics are required in inventory policy determination as follows.

1. Customer demand; generally customer demand may be known in advance or may not. Thus, forecasting tools may be used to predict customer demand from historical data.

2. Replenishment lead time; even replenishment lead time is known when placing orders. However, it is usually uncertain in the real situation.

3. The number of different products; the total inventory is the combination of inventory of each product, thus, policy of a product affects others.

4. The length of the planning horizon.

5. Cost, including order cost and inventory holding cost:

    1. Order cost typically consists of product cost and transportation cost.

    2. Inventory holding cost consists of: state taxes, property tax and insurance on inventories, maintenance cost, obsolescence costs and opportunity costs.

6. Service level requirement.

2.1.2 Demand Pattern

Demand definition was defined in www.investorwords.com as "The amount of a particular economic good or service that a consumer or group of consumers will want to purchase at a given price".

Silver et al. (1998) explained that demand pattern can be considered as a time series which is an essential tool in decision making and management. There are four types of components in a time series: trend, seasonal variations, cyclical movements and irregular random.

1. *Trend* is a smooth or regular movement reflecting growth or decline of a series over period of time.

2. *Seasonal variations* are periodic variations that recur over periods of time relating to two kinds: resulting from natural forces and arising from human decision or customs.

3. *Cyclical movements* are up and down movements or alternations between expansion and contraction of economic activity which reflect the business cycle.

4. *Irregular random* it is the residue from the other three components. The fluctuations are nonrecurring and unpredictable.

2.1.3 Replenishment lead time

Tersine (1994) explained that the prevalent variation in inventory analysis is demand and lead time variation.

Silver et al. (1998) defined replenishment lead time as " the time that elapses from the moment at which it is decided to place an order, until it is physically on the shelf ready to satisfy customer demands ". It consists of five components:

1. Administrative time at the stocking point which is order preparation time.
2. Transit time to the supplier is the time of order from purchaser to the supplier.
3. Time at the supplier is the duration from order arrival to the availability of stock at supplier.
4. Transit time back to stocking point
5. Time from order receipt until it is available on the shelf, such as time for inspection and cataloging.

2.1.4 Safety stock

Tersine (1994) mentioned that the variations in demand and lead time can be absorbed by safety stock.

Silver et al. (1998) explained that in customer perception, safety stock is an approach to satisfy customer demand. There are four methods for stockout protection:

1. Simple-minded approach; this approach is simplest as is done by assigning common safety factors to inventory or supply lead time.
2. Minimizing cost approach; this approach involves total cost minimization to the given cost of shortage.

3. Customer service approach; this approach controls a parameter known as "service level" which recognizes the severity of shortage.
4. Aggregate considerations approach; this approach uses given budget to establish safety stock of individual items in order to provide aggregated service level across a population of items.

2.1.5 Service level

Tersine (1994, p. 232) defined that "A service level indicates the ability to meet customer demand from stock, or in some other timely manner."

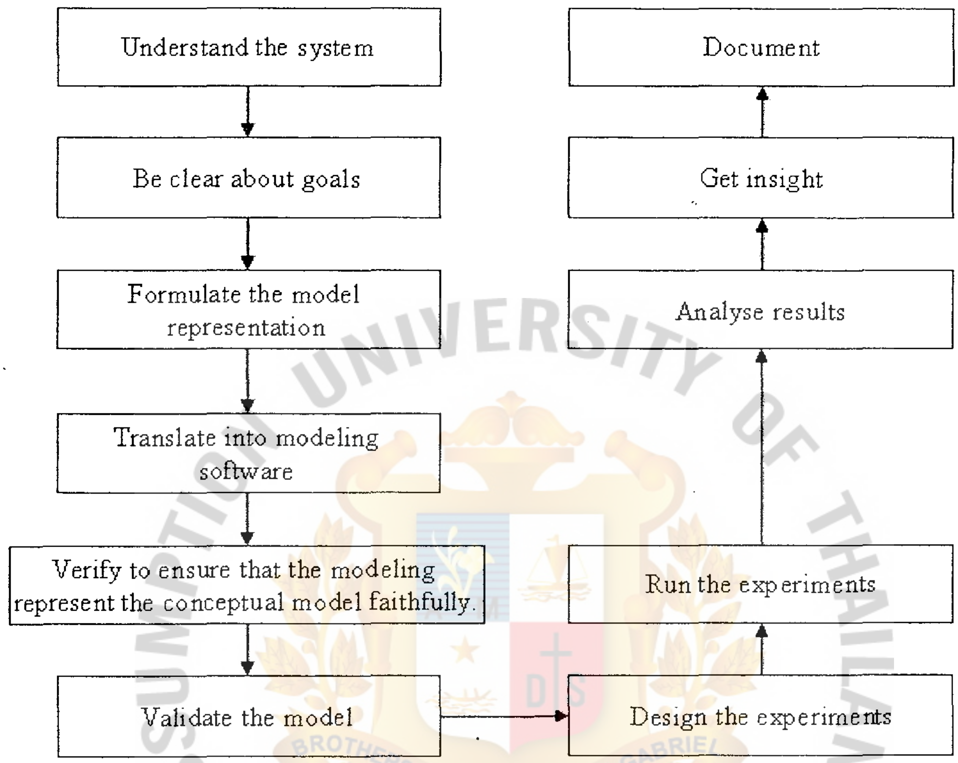
Relationship between service level and safety stock is positive; the higher safety stock will increase service level. There are two common uses of service level: service per order cycle and service per units demanded.

1. *Service per order cycle* concerns how often stockout occurs and indicates the probability of no stockout during replenishment lead time.
2. *Service per units demanded* indicates the percentage of satisfied units that customer demanded.

2.1.6 Computer Simulation

Simulation is a broad collection of methods and application to imitate real things or processes by computer software. Kelton et al. (2007) explained that there is no rule for simulation study, however there are several aspects normally used and followed as shown in Figure 2.2.

Figure 2.2: Computer simulation generation process



Source: Kelton et al. (2007)

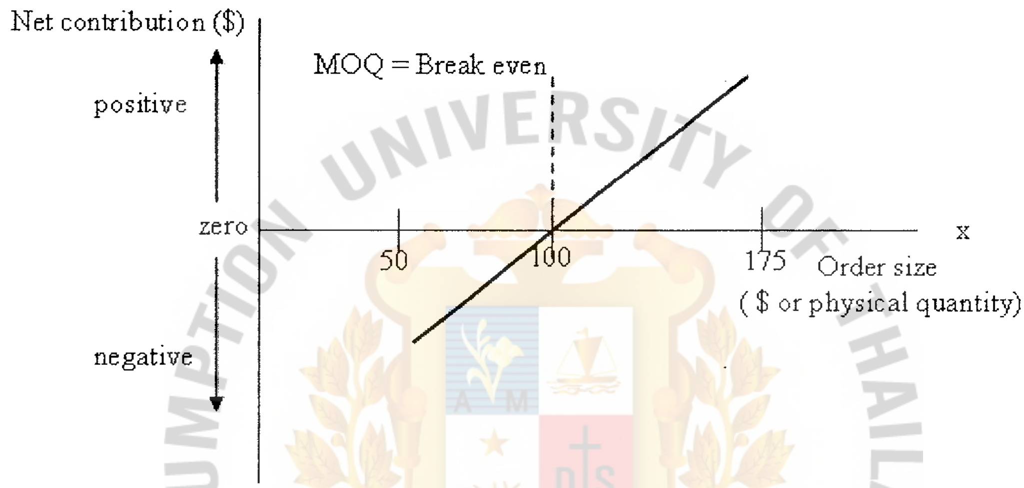
2.2 Previous Study

Lambert et al. (2007) presented a number of policies to deal with small orders. Placing small orders is a strategy of retailers to shift cost of inventory holding to wholesalers or manufacturers in the view of inventory cost reduction. Thus, the cost of small orders is increased as a result of variable manufacturing costs, variable selling costs, variable transportation and material handling costs and variable order processing cost.

However, there are alternatives policies to handle smaller orders such as standardizing of processing for smaller order, volume discounting, order consolidation and automated order handling which marketing channels undertake. Minimum order quantity (MOQ) is another alternative to handle small orders by calculating the break-even of order size and contribution as shown in Figure 2.3.

Small orders are not easy to deal with; however, it is an advantage strategy of the company to be competitive in recent years as order quantity influences the inventory and marketing perspective

Figure 2.3: Calculating the break even MOQ



Jeffery, Butlet and Malone (2008) explained that in recent competitive market, companies are pressured to provide high customer service level with fewer resources. They presented inventory modeling by using regression modeling of historical data to explore relationship between inventory levels, service level and sales rate.

The studied company is Intel Corporation, a large semiconductor manufacturer. Two similar product families are selected for the study. They found that inventory level is the response variable with forecast error, order lead time and variation of demand. Inventory level results in customer service level; incremental of inventory level yields higher customer service level.

However, trading off between inventory and customer service level is required in inventory management in order to determine the minimum cost.

Brooking, Hailey, Parker and Woodruff in 1994 conducted a study to answer how production technologies relate to inventory ordering models. Three types of inventories are considered in this study: buffer inventory, transition inventory and investment inventory.

Typically, inventory units enter the production system as lot-sized buffer inventory, and are out of production system in lot size. Therefore, changes in production technology influences the inventory ordering model. However, evolving of production technology intensifies measuring cost of holding inventory and placing orders for inventory which are important for efforts to buffer inventory level reduction.

Presently, the company aims to reduce buffer inventory near to zero, thus transition inventory will become a dominant inventory. Therefore, the company manages the inventory by JIT-based operating policies to acquire inventory at variable rate equal to the rate of customer needs.

Investment inventory is recommended to be executed only in acceptable compliance since it involves greater risk than buffer or transition inventory ordering.

In summary it was found that production technology influences lot size which consequently affects inventory levels. Customers request for more frequent deliveries with smaller lot size. Therefore, smaller production lot size should be considered in the recent competitive market.

Talluri, Cetin and Gardner in 2004 conducted a study of integrating demand and supply variability into safety stock evaluation of a large multinational pharmaceutical company in managing its made-to-stock inventories. The current inventory model company uses in unscientific method which results in inaccurate safety stock levels.

In the study, the researchers compared safety stock level of current model to proposed models. Firstly, current model compared to demand variability while lead time is constant; the stock level of the proposed model is lower than the current model. Secondly, current model compared to demand and lead time variability; the stock level of the proposed model is lowest. Thus, the findings of the study indicates condition of same customer service level. The variability of demand and lead time is positively related to safety inventory levels; higher variability required higher safety stock.

Jie and Li (2008) proved that the inventory model can be simulated in Arena; computer simulation software by finding the optimal inventory in OptQuest software.

These studies brought ideas to answer the question; what is the optimal inventory of the given customer service level under the uncertainty of demand, and does smaller production batch size yield inventory reduction? Another idea is that, Arena software can simulate the inventory movement and gives necessary data for analysis in order to determine optimal inventory of the studied company.

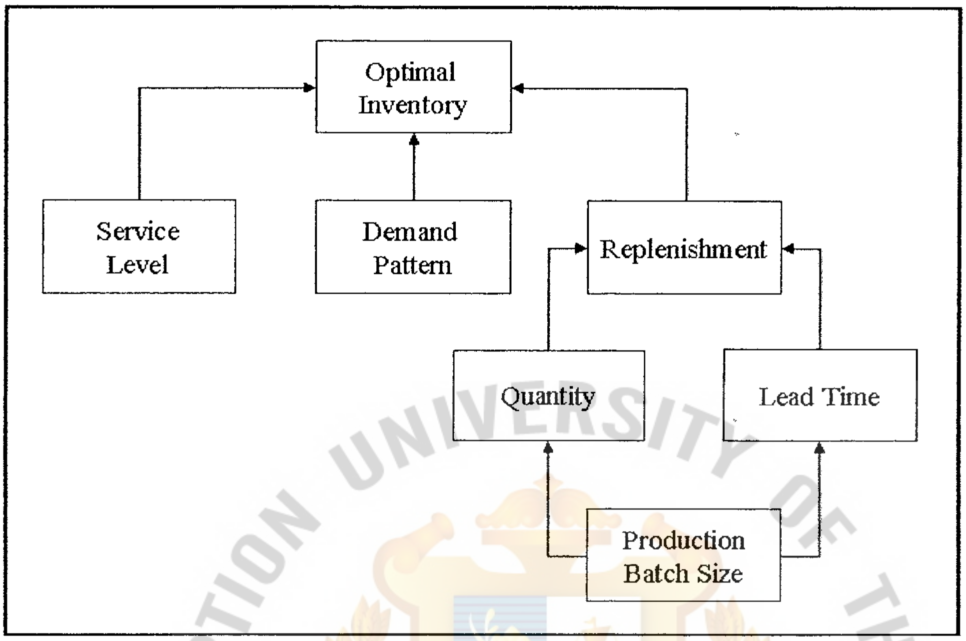
2.3 Conceptual Framework

The conceptual framework of this study is presented in Figure 2.4. It shows relationship of variables:

Optimal inventory which is the dependent variable depends on 3 main independent variables: service level, demand patterns and replenishment.

1. Service level; theoretically higher inventory will increase service level.
2. Demand pattern; in reality demand always varies with time. It is considered as the outflow of the process which influences inventory levels. The imbalance of demand and supply will lead to inventory problems.
3. Replenishment; typically depends on two variables which are considered as sub-independent variables in this study: quantity and lead time. Both the sub-independent variables depend on production batch size. Larger production batch size consumes longer lead time.

Figure 2.4: Conceptual framework

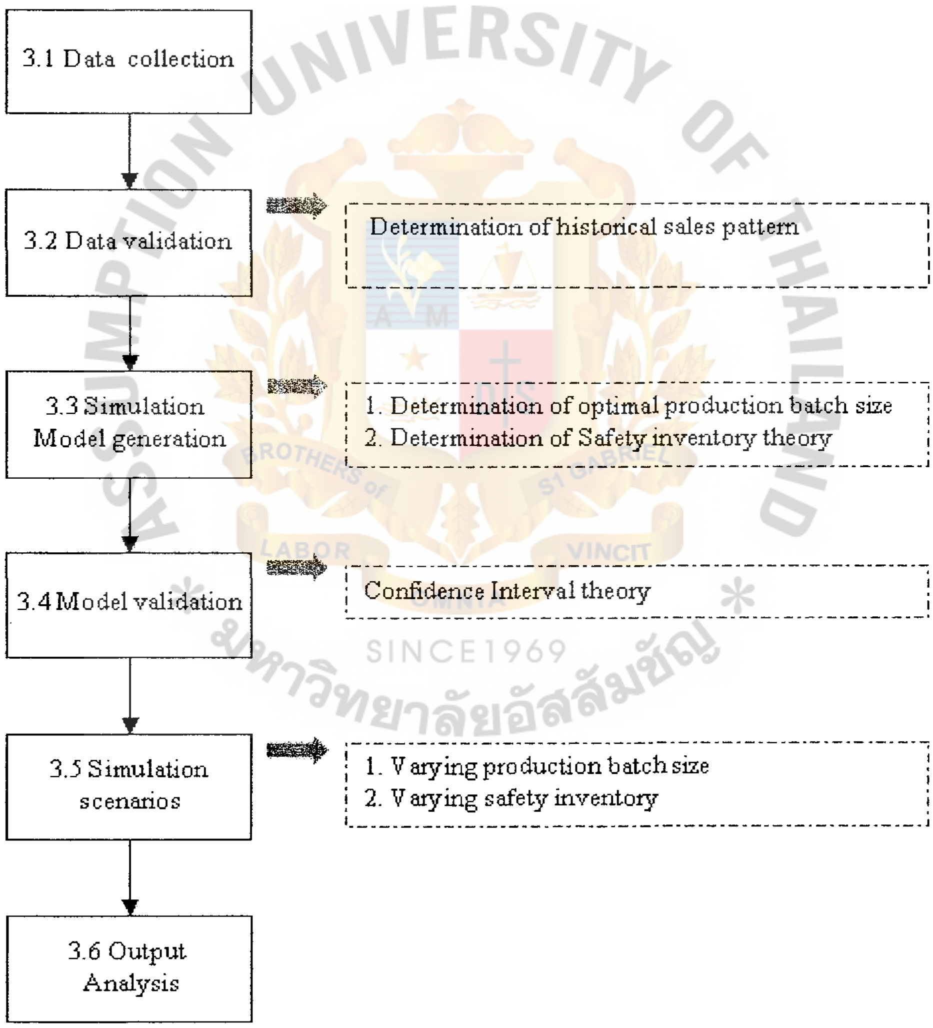


CHAPTER III

RESEARCH METHODOLOGY

This chapter presents research methodology of this study which is separated into six steps: data collection, data validation, model generation, model validation, simulation scenarios and output analysis. The methodology flowchart is as shown in Figure 3.1

Figure 3.1: Methodology Flowchart



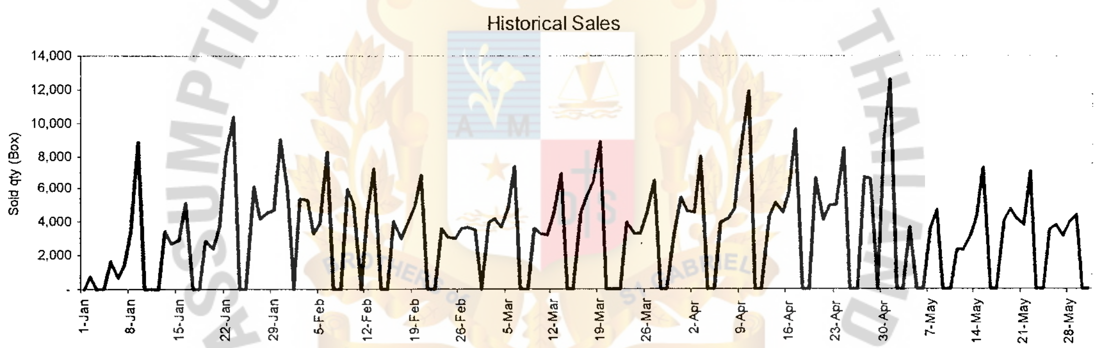
3.1 Data Collection

Information in this paper was primarily collected from the company used in the study. The required information is already available. Three types of information were collected: historical sales, general information and finished goods inventory level.

3.1.1 Historical Sales

The historical sales were used to identify sales arrival rate. In this study daily historical sales over the period of January to May 2009 was used and presented in a graphical form as indicated in figure 3.2.

Figure 3.2: Daily Historical Sales



3.1.2 General Information

General information was used as input parameters in the simulation model. The parameters are parts of the operation process in this study. There were two types of information collected: production process and logistics lead time.

3.1.2.1 Production Process

There are six production processes as shown in Figure 3.3.

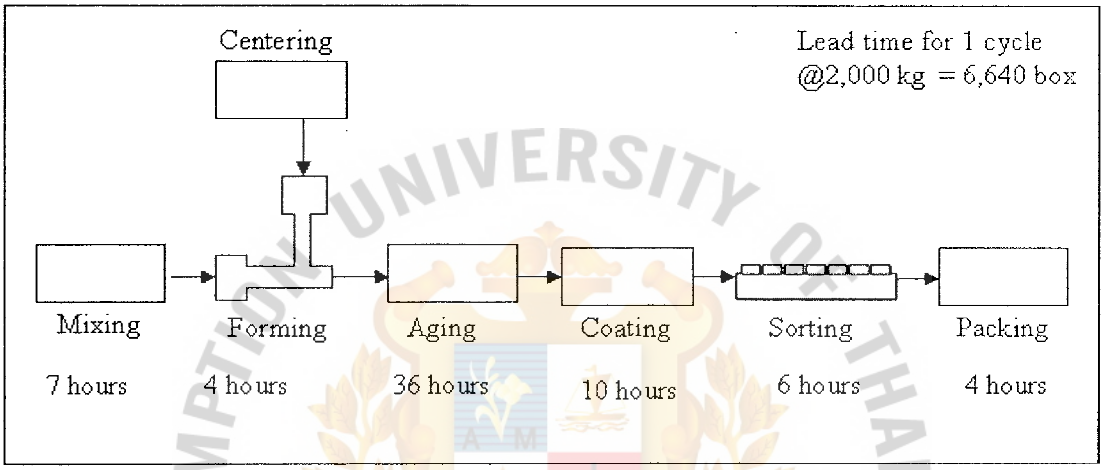
1. Mixing
2. Forming and Center filling
3. Aging

4. Coating

5. Sorting

6. Packing

Figure 3.3: Production Process



Source: Company data

As figure 3.3 indicates, the process presents 1 production cycle; the cycle lead time is 67 hours which is equal to finished goods 6,640 boxes or 2,000 kg. Presently, the company minimum production quantity is 11 cycles which represents 1 batch size in this study. The production lead time of 1 batch size is 2.8 days; it depends on bottle necks which is a coating process.

Mixing process; ingredients will be mixed in a mixing drum. This process takes 7 hours.

Forming and center filling process; the mixed ingredient will be formed. At this step, liquid center is filled into the mixed ingredient which is now called 'core'. This process takes 4 hours.

Aging process; the core will be stored in a conditioned room where texture will be set. This process takes 36 hours.

Coating process; after the aging process, the core will be coated with sugar-free substances which is now called 'coated gum'. The process takes 10 hours.

Sorting process; the defected coated gum will be sorted out at this process. The process takes 6 hours.

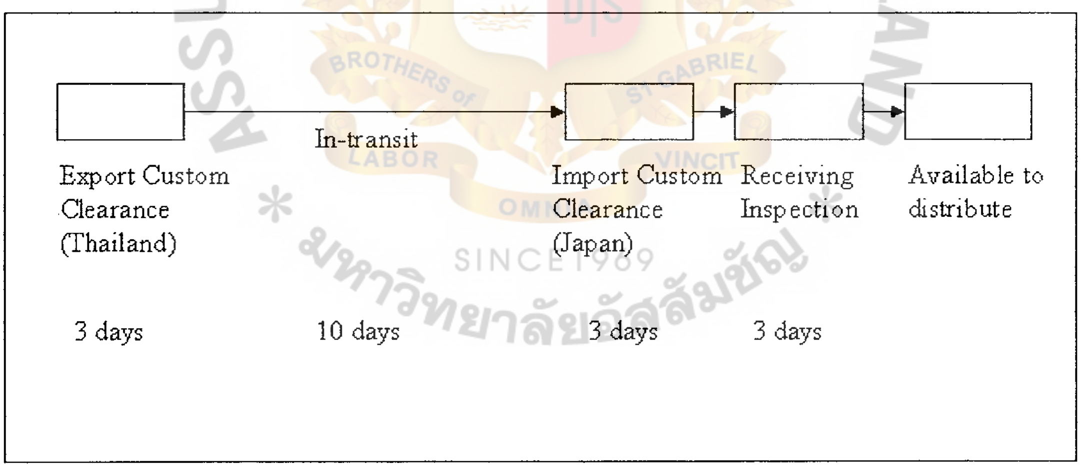
Packing process; this is the final process of the product. After the sorting process, the coated gum will be packed into packages which are ready for delivery.

In addition to production process, logistics lead time will also be used in simulation model which will be discussed next.

3.1.2.2 Logistics Lead time

In this study, 4 types of logistics lead time will be used as shown in Figure 3.4.

Figure 3.4: Logistics Lead time



Source: Company data

Export customs clearance lead time at Thai seaport is 3 days.

In transit lead time from Thai to Japanese seaport is 10 days.

Import customs clearance lead time at Japanese seaport is 3 days.

Receiving inspection lead time is 3 days. It is excluded in total lead time because finished goods is considered as inventory upon the arrival at the distribution center.

In summary, the total lead time is the summation of production lead time and logistics lead time. The logistics lead time is fixed at 16.0 day while production lead time depends on how many cycles are in the production run. The more cycles required the longer the time. The bottle neck of the process is the coating process. Thus the process lead time of mixing process and forming process is considered only after one cycle time. The total lead time from production cycle 1 to 11 is shown in Table 3.1.

Table 3.1: Lead time

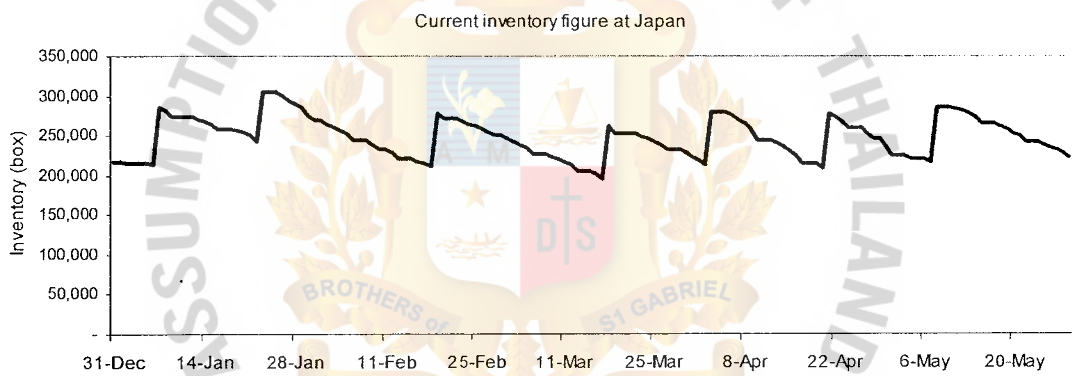
Process/ production cycle	11	10	9	8	7	6	5	4	3	2	1
Mixing (hr)	7	7	7	7	7	7	7	7	7	7	7
Forming (hr)	4	4	4	4	4	4	4	4	4	4	4
Aging (hr)	36	36	36	36	36	36	36	36	36	36	36
Coating (hr)	110	100	90	80	70	60	50	40	30	20	10
Sorting (hr)	6	6	6	6	6	6	6	6	6	6	6
Packaging (hr)	44	40	36	32	28	24	20	16	12	8	4
Total (hr)	207	193	179	165	151	137	123	109	95	81	67
Total (day)	8.6	8.0	7.5	6.9	6.3	5.7	5.1	4.5	4.0	3.4	2.8
Production lead time (day)	8.6	8.0	7.5	6.9	6.3	5.7	5.1	4.5	4.0	3.4	2.8
Logistics lead time (day)	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0	16.0
Total lead time (day)	24.6	24.0	23.5	22.9	22.3	21.7	21.1	20.5	20.0	19.4	18.8

Moreover, historical sales, general information and finished goods inventory level of the company was also collected. It is a key measurement of this study which will be presented next.

3.1.3 Inventory Level

The daily finished goods inventory at the distributor of the company was collected from the period of January to May 2009 as shown in Figure 3.5. The inventory level depends on 2 factors: demand quantity and replenishment quantity. The average inventory during the period was 247,692 boxes.

Figure 3.5: Inventory level



At this stage, the required information in this study were collected: historical sales; general information and inventory levels. The information was validated so as to ensure the reliability and validity of information before use. The data validation process is presented in the next section.

3.2 Data Validation

In this study the data validation process will follow the procedure as shown is Figure 3.6.

Figure 3.6: Data validation procedure

1. Data treatment; data treatment is the process of thoroughly understanding the data, and to filter out abnormal data. Doing so will assure that the data could represent the data with good quality for further analysis.

2. Data analysis and pattern determination; Bank (1998) explained that a simple plot method can be used to determine data patterns; the method was mainly used in this study to evaluate the stability of data distribution. After that, data patterns will be determined; the yielding pattern will be representative of the information, and ready for further use.

In the next section, the validation of historical sales was presented by following the mentioned procedure.

3.2.1 Historical Sales Validation

Data Treatment

The abnormal data was filtered out as follows:

1. Saturday, Sunday and holidays were not included because the distribution center does not operate on these days.

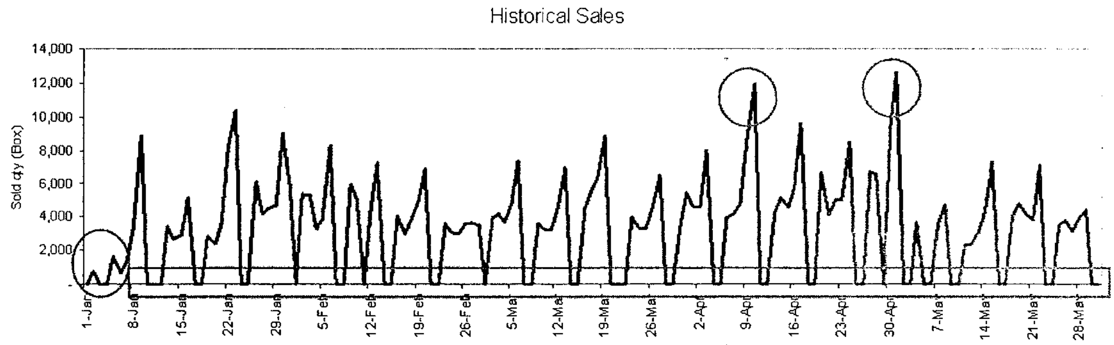
2. Data during Jan 1^{st} to 7^{th}, is not collected because during the period was a long holiday. Some wholesaler and retailers did not operate as usual, thus the sold quantity was lower than usual.

3. Data on April 10^{th}, is not collected because of promotional campaigns. The sold quantity was higher than usual.

4. Data on May 1^{st}, is not collected because the sold quantity was higher than usual, and the wholesalers and retailers required higher inventory in order to support the sales during May 2^{nd} to May 6^{th} which was long holiday.

This abnormal data is also shown in Figure 3.7.

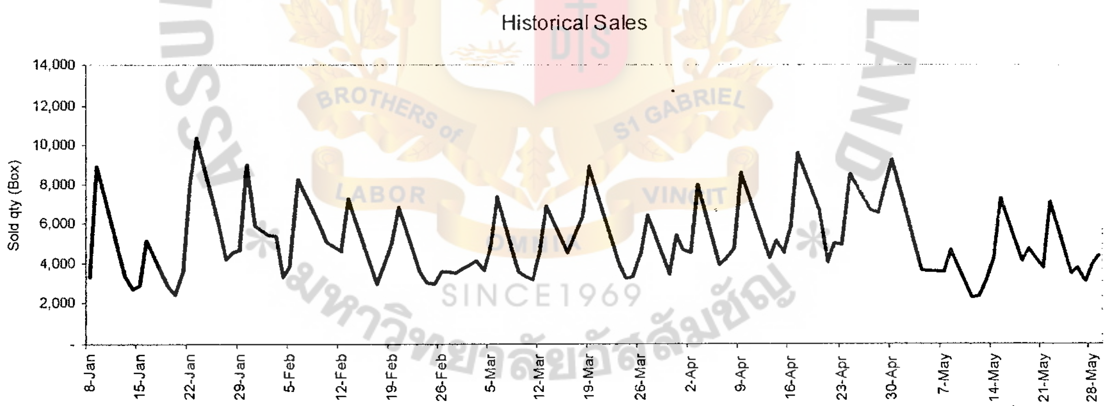
Figure 3.7: Abnormal sales



Data Analysis and Pattern Determination

After abnormal data were filtered out, the new set of data without the abnormal data now called 'treated data' was used as shown in Figure 3.8.

Figure 3.8: Treated data



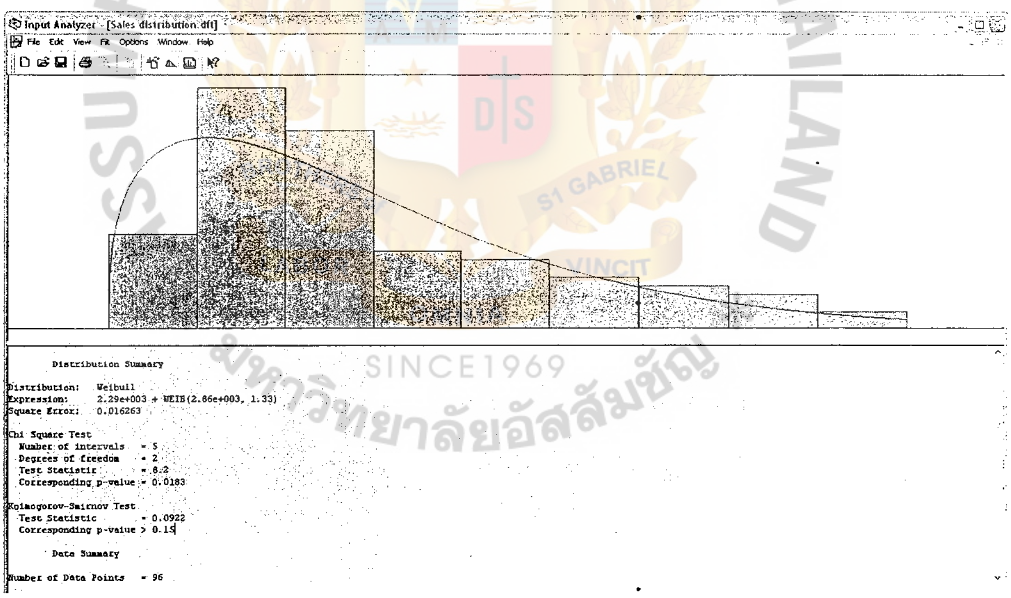
Treated historical sales were further analyzed in order to incorporate the data into simulation model.

In this study, the Kolmogorov-Smirnov (K-S) goodness-of-fit hypothesis test; the standard statistical hypothesis test will be used to assess whether a fitted theoretical distribution is a good fit to the historical sales data. The hypothesis test will be tested in the Input Analyzer which is standard tool of the Arena program; it is designed specifically to fit distributions to observe data, provide estimates of their parameters, and measure how well they fit the data. (Kelton et al., 2007) From the

Input Analyzer report, the *corresponding p-value* indicates goodwill of data fit; the larger *p-value* indicates better fit; if the value is 0.1 or greater it indicates that the distribution has fair degree of confidence to use its distribution.

Therefore, the treated historical sales data was input in Input Analyzer. From the report, the *p-value* of K-S test for Weibull distribution is greater than 0.15 as shown in Figure 3-9. Thus, the expression 2.29e+003 + WEIB(2.86e+003,1.33) is selected and will be used in the simulation model. It represents the arrival rate of customer orders at distribution center. Weibull distribution; Weibull(α,β) is widely used in lifetime distribution in engineering; however, it is a versatile distribution which can be used in representing many characteristics of data because the variety of β value gives different shape of data (www.weibull.com).

Figure 3.9: Input Analyzer result



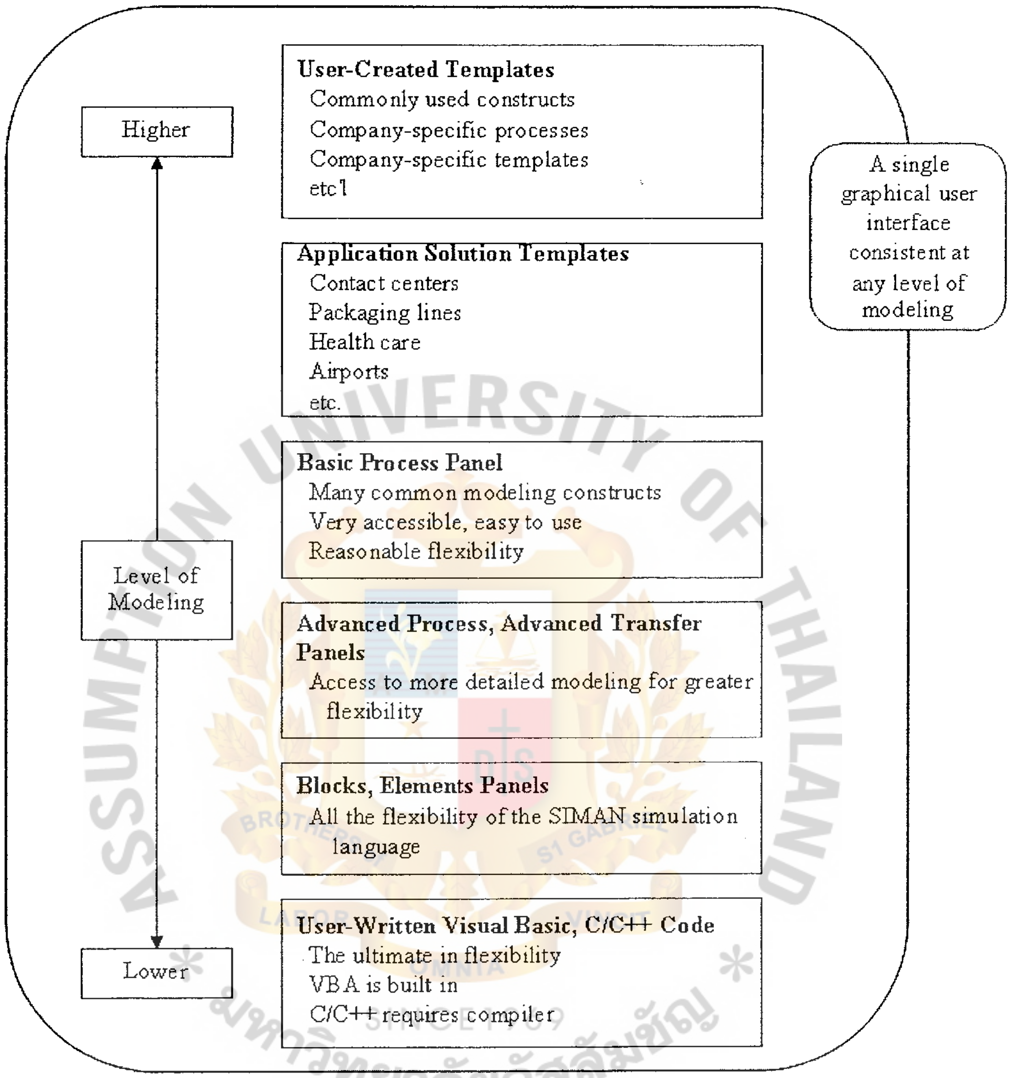
At this stage, required information were collected and validated. The next step is incorporating this information into the simulation model; the simulation model generation was discussed in the next section.

3.3 Simulation Model Generation

The simulation model was generated in the computer simulation program; Arena Academic version 11.00. The simulator was selected because it is easy to use; the researcher has studied Arena in the class and found that it is an appropriate tool . The book is easy for the reader to follow and even a beginner who is not familiar with programming language can easily use it because Arena gives flexibility of simulation languages by being fully hierarchical as shown in Figure 3.10. It provides alternative and interchangeable templates of graphical simulation modeling and analysis modules that can be combined to build a variety of simulation models, and modules from different panels can be mixed together in the same model. The model in this study used modules from basic process and advanced process panels. Moreover, Arena also provides advantage of simulation technique as follows:

1. It represents real the system which can simulate a variety of scenarios without the real experiment. The real experiment usually takes a long time and uses more money.
2. It can run repetitively without fatigue.
3. Its model structure, algorithms and variables can be changed quickly to see how it affects the system.
4. It is able to provide performance results which are not obtainable through the analytical model.

Figure 3.10: Arena's Hierarchical Structure



Source: Kelton et al. (2007)

The model simulated the selling and replenishment operation process of the company. Generally, there are two types of simulation time frame; *terminating simulation* which the model that dictates specific starting and stopping condition, and *steady-state simulation* which the model that is defined in long run; i.e. over theoretically infinite time frame (Kelton et al., 2007). In this study terminating simulation was used over a specific period; January – Dec 2009 in order to investigate inventory movement on an annual basis.

Firstly, the model logic was designed to simulate the companys operation process which is as follows:

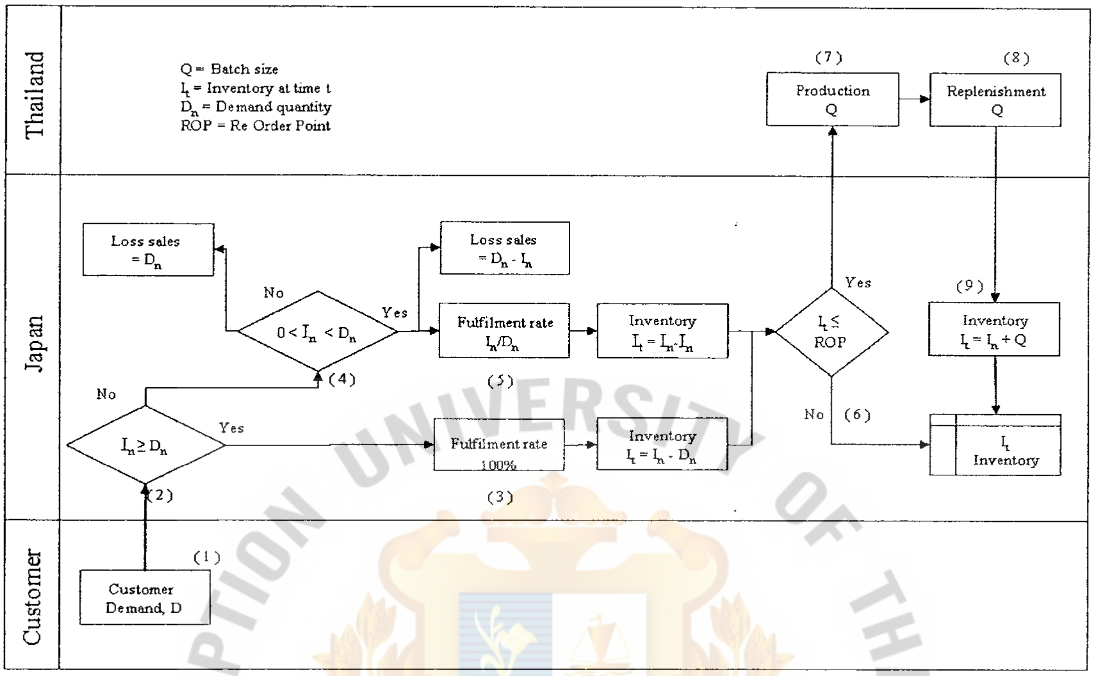
Model Logic

The model demonstrates the selling and replenishment operation processes of the company as shown in Figure 3.11. The logic was separated into 4 steps:

1. Customers place orders to the distribution center. This is an input of the simulation model; the pattern of the order was collected as 'historical sales' which mentioned in the previous section.
2. The distribution center fulfills the customer orders. Thus, the inventory is deducted by customer order quantity. Up until the inventory level drops to reorder point (ROP), the distribution center places new orders to the manufacturing plant.
3. Upon new replenishment order receipt, the manufacturing plant produces finished goods based on production batch size and production lead time as previously mentioned.
4. The finished goods are shipped from the manufacturing plant to the distribution center by sea-freight; the in transit lead time is 20.5 days as previously mentioned. Upon the receipt at the distribution center, the inventory is incremented by replenishment quantity.

The above was the overview for the reader to understand the overview process. In the next section, logical details including inventory calculation at each condition stage and decision condition of new order placement at reorder point (ROP) is presented step by step.

Figure 3.11: Modeling Logic



(1) Customers place orders to the distribution center; the demand quantity is represented by D which is now called 'customer demand'. The arrival rate is Weibull distribution 2.29e+003 + WEIB(2.86e+003,1.33) as previously defined.

(2) On hand inventory is checked upon the customer demand receipt. There are two possibilities:

1. If on hand inventory is greater than customer demand, the customer demand will be fulfilled. Then on hand inventory is deducted by customer demand quantity as (3).

2. If on hand inventory is lower than customer demand, the customer demand is unfulfilled. Then on hand inventory is checked as (4).

(3) Consequence of (2). In case customer demand is fulfilled. Thus the inventory is deducted by customer demand quantity and is represented as equation 3-1.

$$I_t = I_n - D \qquad (3\text{-}1)$$

Where; I_t = Inventory at time t

I_n = On hand inventory

D = Customer demand

(4) Consequence of (2). If on hand inventory is checked, there are two possibilities:

1. If on hand inventory is greater than zero, the customer demand is partially fulfilled as on hand inventory quantity available. Then the inventory is adjusted as (5).

2. If on hand inventory is zero, the customer demand is unfulfilled which is considered as loss of sales.

(5) Consequence of (4). If the customer demand is partially fulfilled, the customer receives the finished goods as many as on hand inventory available. The unfulfilled quantity is considered as loss sales quantity. Thus after selling the product to the customer, the on-hand inventory is zero as shown calculation in the equation 3-2;

$$I_t = I_n - I_n \quad (3\text{-}2)$$

Where; I_t = finished goods inventory at time t

I_n = current finished goods inventory

(6) In the next decision of placing new replenishment order is made. As explained previously that once the on-hand inventory drops to reorder point (ROP), the new replacement order is placed. The reorder point is defined by equation 3-3. (Anupindi, Chopra, Deshmukh, Mieghen & Zemel, 2006).

$$ROP = LTD + I_{safety} \quad (3\text{-}3)$$

Where; ROP = Reorder point

LTD = Average lead time demand

I_{safety} = Safety inventory

In this study, LTD is customer demand multiplied by total lead time which is;

$$2.29e+003 + WEIB(2.86e+003, 1.33) \times 20.5$$

The decision can result in two possibilities:

1. If on hand inventory is greater than reorder point, new replenishment orders will not be placed.

2. If on hand inventory is lower than reorder point, new replenishment orders will be placed. The order quantity is multiplied by minimum order quantity which is equal to production batch size. Thus, the replenishment order quantity is calculated as equation 3-4.

$$\text{Order quantity} = \text{Multiple of } MOQ \times B$$

$$Q = m \times B$$

Re written; $$Q = RoundUp\left(\frac{ROP}{MOQ}\right) \times B \qquad (3\text{-}4)$$

Where m = Integer number

ROP = Reorder Point

B = Production batch size

(7) Upon the new replenishment order receipt, the manufacturing plant produces products based on production batch size and lead time as previously mentioned.

(8) After production completion, finished goods are shipped to Japan by sea-freight. The replenishment quantity is represented by Q.

(9) Upon the shipment arrival at the distribution center, on hand inventory is incremented by replenishment quantity as equation 3-5.

$$I_t = I_n + Q \tag{3-5}$$

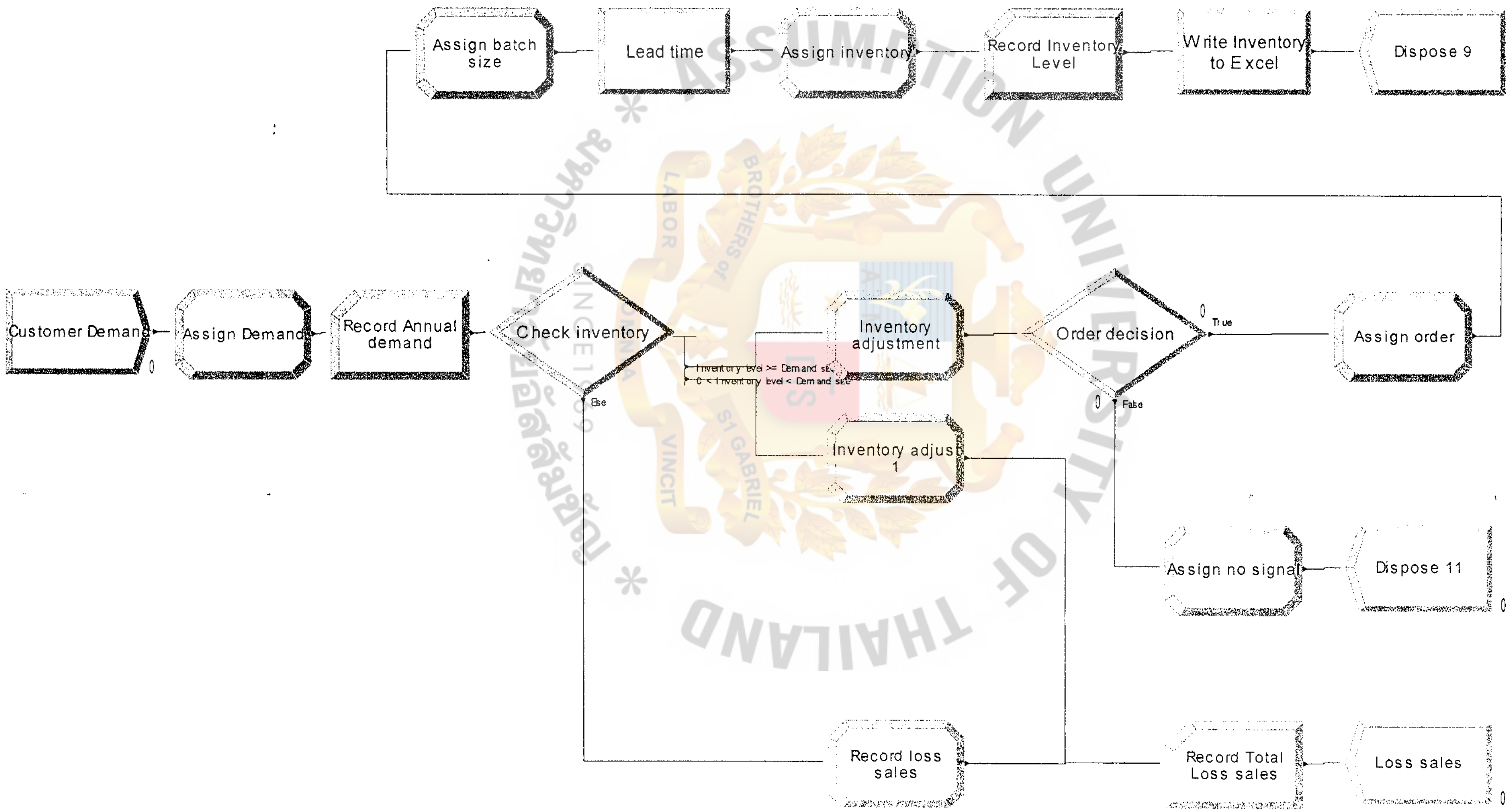
Where; I_t = Inventory level at time t.

I_n = On-hand inventory

Q = Production quantity

The simulation model has been generated by Arena program that was explained previously. The model is shown in Figure 3.12.

Figure 3.12: Arena model



In the simulation run, four variables; customer demand, number of replenishment orders, on hand inventory and lost sales quantity were collected during daily hours at the distribution center position. These variables are used in the analysis section in order to finding the objectives which will be explained later. However, to perform the simulation run requires validity of the model to ensure that the simulation model can represent the actual operation. Thus, model verification is performed in this study as presented in the follow section.

3.4 Model Validation

Model verification and validation is a crucial process of simulation modeling to assure that the conceptual simulation model is correctly translated in to a computer program which represents true system behavior close enough for the model to be used as a substitute for the real operation.

3.4.1 Model Verification

In this study two verification techniques were used:

1. Use tracing function to display that each event occurs in sequence and comparing it with hand calculations.
2. Use fixed values/distributions to assist tracing.

In addition to model verification, determination of number of replication runs was presented in this study to ensure that output from simulation run was good enough for further analysis. It is the sample size in statistical sample. A larger number leads to higher precision of data (Kelton et al., 2007). The determination of the number of replications is explained in the next section.

3.4.2 Number of Replication Determination

Conceptually, number of replication in simulation represents number of samples for statistical analysis to reflect the output reliability; confidence level. The larger number of replication, the narrower confidence interval. (Kelton et al., 2007) The appropriate number of replications to achieve a particular confidence level cannot be determined in advance as it is a function of the sample size itself. However, an approximate value can be determined by half width from initial set of replications and then calculated for the number of replications; n from equation 3-6. (Kelton et al., 2007)

$$n = n_0 \frac{h_0^2}{h^2} \qquad (3\text{-}6)$$

Where n = number of replication

n_0 = initial replications

h_0 = half width of initial replications

h = desired half width

In this study, ten replications of simulation runs were conducted in the initial set. Then number of replications was calculated as shown in equation 3-6.

Half width of average inventory from ten replication was 11160.31 which represented h_0. The report of the results from Arena are shown in Figure 3.13.

Figure 3.13: Arena result of ten replications.

9:24:46PM **Category Overview** December 30, 2009

Values Across All Replications

Unnamed Project

Replications: 10 Time Units: Days

User Specified

Tally

Expression	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Record Inventory Level	259440.98	11,160.31	242686.22	294861.17	73040.00	377620.47

Counter

Count	Average	Half Width	Minimum Average	Maximum Average
Record Annual demand	1266671.90	40,562.72	1176415.00	1362123
Record Total Loss sales	0.00	0.00	0.00	0.00

The company production allowance is 10 percent, therefore, desired half width is 664 represented h .

$$n = 10\frac{11160.31^2}{664^2} = 2,825$$

Therefore, in this study, 2,825 replications run are required for each simulation run in order to ensure the reliability at 95% confidence interval.

The simulation model is validated and ready to be used in this study. The simulation run will be conducted for 2,825 replications. With the advancement of computer simulation technology, various scenarios can be simulated in order to find alternative solutions. Thus in order to find objectives of this study, 44 simulation scenarios were conducted which is presented in the next section.

3.5 Simulation Scenario

The values of three variables were varied in the simulation scenario for production batch size (Q) eleven values were set from 1 to 11 production cycle. For safety inventory (I_{safety}) four values were set: 0.25, 0.50, 0.75 and 1.00 Month of supply (MOS). And lead time (L) are set at each of production batch size value. The parameter setting is indicated in Table 3.2.

Regarding the parameter setting, the different value of production batch sizes and safety inventory yielded different on hand inventory levels. The larger production batch sizes required less safety inventory. Improper safety inventory leads to out of stock (OOS) which has an impact on customer service level. Therefore, the scenario which gives the lowest total inventory cost and achieves service level of the company was selected. As a result of selected scenario, the production batch size and safety inventory value are defined as '*optimal production batch size*' and '*optimal safety inventory*' respectively. The detail of analysis is presented in the next section of this report.

Table 3.2: Setting parameters for simulation scenario

Scenario	Q	D	I_{safety}	L
1	11 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	1.00 MOS	24.6
2	11 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.75 MOS	24.6
3	11 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.50 MOS	24.6
4	11 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.25 MOS	24.6
5	10 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	1.00 MOS	24.0
6	10 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.75 MOS	24.0
7	10 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.50 MOS	24.0
8	10 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.25 MOS	24.0
9	9 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	1.00 MOS	23.5
10	9 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.75 MOS	23.5
11	9 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.50 MOS	23.5
12	9 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.25 MOS	23.5
13	8 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	1.00 MOS	22.9
14	8 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.75 MOS	22.9
15	8 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.50 MOS	22.9
16	8 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.25 MOS	22.9
17	7 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	1.00 MOS	22.3
18	7 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.75 MOS	22.3
19	7 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.50 MOS	22.3
20	7 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.25 MOS	22.3
21	6 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	1.00 MOS	21.7
22	6 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.75 MOS	21.7
23	6 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.50 MOS	21.7
24	6 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.25 MOS	21.7
25	5 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	1.00 MOS	21.1
26	5 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.75 MOS	21.1
27	5 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.50 MOS	21.1
28	5 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.25 MOS	21.1
29	4 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	1.00 MOS	20.5
30	4 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.75 MOS	20.5

31	4 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.50 MOS	20.5
32	4 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.25 MOS	20.5
33	3 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	1.00 MOS	20.0
34	3 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.75 MOS	20.0
35	3 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.50 MOS	20.0
36	3 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.25 MOS	20.0
37	2 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	1.00 MOS	19.4
38	2 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.75 MOS	19.4
39	2 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.50 MOS	19.4
40	2 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.25 MOS	19.4
41	1 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	1.00 MOS	18.8
42	1 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.75 MOS	18.8
43	1 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.50 MOS	18.8
44	1 cycle	2.29e+003 + WEIB(2.86e+003,1.33)	0.25 MOS	18.8

3.6 Output Analysis

This section of the report presents the analysis of output from the simulation run which proves whether the objectives of this study are met or not. The finding of the analysis aims to determine if the simulation scenario gives optimal inventory with regard to the 2 main variables: production batch size and safety inventory.

The determination of optimal production batch size and safety inventory are trade off between total cost and service level. The scenario that yields lowest cost and achieves service level of the company have been defined as the optimal scenario. Therefore, the production batch size and safety inventory of the scenario have been defined as optimal production batch size and safety inventory respectively.

The following section presents the analysis detail of total inventory cost and service level:

3.6.1 Total Inventory Cost

Theoretically, total inventory cost involves trading off between the fixed costs of ordering and the cost of holding inventory. As the production batch size increases, fewer production batches are produced, reducing the ordering cost. However, increasing batch size results in higher holding cost because of increasing of holding inventory. Thus in this study, the total inventory cost of each scenario were calculated using the equation as indicated in 3-10.

Total annual cost = Total annual fixed order cost (1)

+ Total annual inventory holding cost (2)

+ Total cost of material (3)

(1) Total annual fixed order cost = Fixed cost per order × Annual order frequency

or $$S \times \frac{R}{Q} = S \times F \qquad (3\text{-}7)$$

Where; S = Fixed cost per order

R = Annual demand

Q = Order size

F = Annual order frequency

(2) Total annual inventory holding cost = Unit holding cost per year × Average inventory

or $$H \times \frac{Q}{2} = H \times I_{cycle} \qquad (3\text{-}8)$$

Where; H = Total unit inventory holding cost

Q = Order size

I_{cycle} = Average inventory

(3) Total cost of material = Unit cost × Annual demand

or $$C \times R \qquad (3\text{-}9)$$

Where; C = Unit variable cost

R = Annual demand

Thus, the total annual cost (TC) is;

$$TC = S \times F + H \times I_{cycle} + C \times R \qquad (3\text{-}10)$$

In this analysis, the variables are that used in the total inventory cost in equation 3-10 were collected from simulation run:

1. Average inventory; I_{cycle}
2. Annual demand; R

The example of inventory cost calculation of scenario1 was presented as follows;

Equation (3.7) total annual fixed order cost:

$$S \times \frac{R}{Q} = S \times F = 1 \times \frac{1{,}280{,}771}{73{,}040} = 18 \text{ baht}$$

Equation (3.8) total annual inventory cost:

$$H \times I_{cycle} = 5.9 \times 255{,}303 = 1{,}506{,}287 \quad \text{baht}$$

Equation (3.9) total cost of material:

$$C \times R = 125 \times 1{,}280{,}770.5 = 160{,}096{,}313 \quad \text{baht}$$

Therefore, total annual cost (3.10) is the summation of equation (3.7), (3.8) and (3.9):

$$TC = S \times F + H \times I_{cycle} + C \times R = 18 + 1{,}506{,}287 + 160{,}096{,}313 = 161{,}602{,}617$$

The total inventory cost of each scenario was calculated in the same way as the example for further analysis.

3.6.2 Service Level

Theoretically, safety inventory has positive relation on service level; higher service level requires higher safety inventory (Anupindi et al., 2006). Thus higher safety inventory yields higher cost of inventory holding.

As previously mentioned, service level is a key measurement in optimal inventory determination. Thus optimal inventory needs to contribute at least 97.5% service level which is the company policy.

Currently, the company calculates service level based on units demanded which indicates percentage of satisfied demand. The service level calculation is indicated in equation 3-11 (Tersine, 1994).

$$SL_u = 1 - \frac{M}{D} \qquad (3\text{-}11)$$

Where; SL_u = Service Level bases on units demanded

M = Number of stockouts in unit

D = Total number of units demanded

M and D are collected from each simulation run and calculated service level by equation 3-11.

The example of service level calculation of scenario 1 was presented as follow:

Equation (3.11) service level:

$$1 - \frac{M}{D} = 1 - \frac{725.2}{1,280770.5} = 0.999$$

Service level of each scenario was calculated same as the example.

At this stage, total inventory cost and service level of each simulation scenario is ready for the analysis. As previously mentioned, the total inventory cost and service level have been traded off; the lowest inventory cost yields at least 97.5% service level is determined as optimal scenario. The output and analysis will be discussed in the next chapter.

CHAPTER IV

PRESENTATION OF DATA AND CRITICAL DISCUSSION OF RESULTS

This chapter presents data and a critical discussion of the results which are as follows:

The variables were input in simulation software and simulated for forty four scenarios.

1. Demand patterns were defined from historical sales data.
2. Replenishment pattern consists of lead time and quantity. The replenishment quantity was called "production batch size".
3. Safety inventory

The variables; annual demand, average inventory and number unit of stock out were collected from each scenario, which were then used to calculate annual inventory cost and service level.

Finally, the optimal inventory was defined by trading off the inventory cost and service level. The optimal point was the scenario which had lowest inventory cost while target service level (97.5%) was still met.

4.1 Results

Eleven production batch size (1 to 11 production cycles) were simulated, at each production batch size. Four safety inventory is (0.25, 0.50, 0.75 and 1.00 MOS) were simulated. Therefore, there were forty four scenarios simulated in this study. At each scenario; annual demand, average inventory and number of stock out were collected.

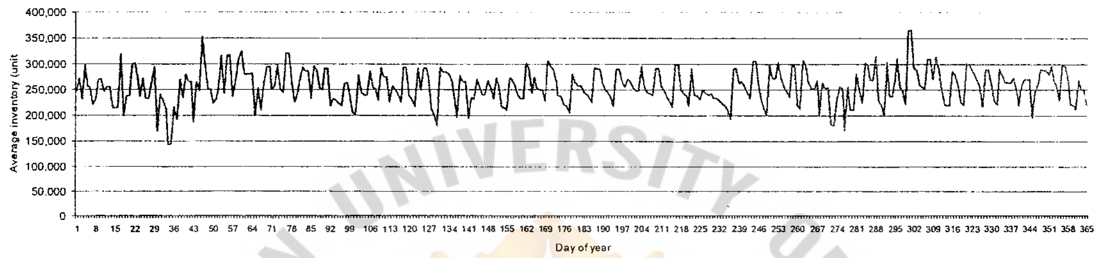
Annual demand and average inventory were calculated in equation (3-10) to find annual inventory cost and the number of units of stock out and annual demand were calculated in equation (3-11) to find service level. Result of the study are shown in Table 4.1.

Table 4.1: Result of the study

scenario#	Batch size (cycle)	Safety stock (MOS)	Average inventory (unit)	Number unit of stock out (unit)	Inventory cost (baht)	Service level (%)
1	11	0.10	255,303	725	161,602,617	99.9%
2	11	0.75	231,890	1,924	161,464,483	99.8%
3	11	0.50	210,833	1,933	161,340,245	99.8%
4	11	0.25	189,850	2,040	161,216,446	99.8%
5	10	0.10	247,411	375	161,556,057	100.0%
6	10	0.75	222,323	1,325	161,408,035	99.9%
7	10	0.50	201,323	1,328	161,284,140	99.9%
8	10	0.25	179,497	1,540	161,155,366	99.9%
9	9	0.10	237,853	221	161,499,667	100.0%
10	9	0.75	212,705	989	161,351,292	99.9%
11	9	0.50	191,289	998	161,224,940	99.9%
12	9	0.25	169,191	1,182	161,094,559	99.9%
13	8	0.10	227,115	116	161,436,317	100.0%
14	8	0.75	202,371	652	161,290,328	99.9%
15	8	0.50	180,189	667	161,159,451	99.9%
16	8	0.25	157,900	960	161,027,947	99.9%
17	7	0.10	215,507	74	161,367,830	100.0%
18	7	0.75	190,887	445	161,222,575	100.0%
19	7	0.50	168,588	470	161,091,010	100.0%
20	7	0.25	145,761	769	160,956,330	99.9%
21	6	0.10	203,126	42	161,294,786	100.0%
22	6	0.75	178,878	270	161,151,726	100.0%
23	6	0.50	156,233	289	161,018,121	100.0%
24	6	0.25	133,457	765	160,883,738	99.9%
25	5	0.10	189,872	13	161,216,595	100.0%
26	5	0.75	165,939	130	161,075,391	100.0%
27	5	0.50	143,116	164	160,940,737	100.0%
28	5	0.25	120,021	647	160,804,474	99.9%
29	4	0.10	175,244	5	161,130,298	100.0%
30	4	0.75	151,462	73	160,989,985	100.0%
31	4	0.50	128,584	139	160,855,009	100.0%
32	4	0.25	105,542	891	160,719,059	99.9%
33	3	0.10	157,461	8	161,025,397	100.0%
34	3	0.75	134,025	70	160,887,122	100.0%
35	3	0.50	111,279	210	160,752,923	100.0%
36	3	0.25	88,356	1,868	160,617,678	99.9%
37	2	0.10	134,041	39	160,887,249	100.0%
38	2	0.75	111,099	209	160,751,895	100.0%
39	2	0.50	88,641	737	160,619,394	99.9%
40	2	0.25	66,100	6,867	160,486,399	99.5%
41	1	0.10	93,033	970	160,645,401	99.9%
42	1	0.75	72,007	2,607	160,521,345	99.8%
43	1	0.50	51,183	13,699	160,398,482	98.9%
44	1	0.25	31,912	84,894	160,284,787	93.4%

The daily inventory of each scenario was collected to enable the study with more visibility in the daily inventory movement. The inventory movement of the current situation (production batch size was 11 cycles and safety inventory was 1.00 MOS) over year 2009 as shown in Figure 4.1. The current inventory was 255,303 units.

Figure 4.1: Inventory movement



4.2 Result Evaluation and Interpretation

As mentioned in chapter III, to define optimal production batch size and safety inventory it is trade off between inventory cost and service level. Thus relation of studied variables and interpretation of the results were discussed as follows:

4.2.1 Inventory Cost, Safety Inventory and Production Batch size

Four values of safety inventory (0.25, 0.50, 0.75 and 1.00 MOS) and eleven values of production batch size (1 to 11 cycles) were graphically plotted for inventory cost as shown in Figure 4.2 and 4.3. Inventory cost had positive relation to safety inventory. Inventory cost was increased with higher safety inventory. Inventory was increased when bigger production batch sizes was produced.

Therefore, considering the inventory cost and safety inventory, the lowest inventory was 160,284,787 baht when production batch size 1 cycle was produced and safety inventory was 0.25 MOS.

Figure 4.2: Relation of inventory cost and safety inventory

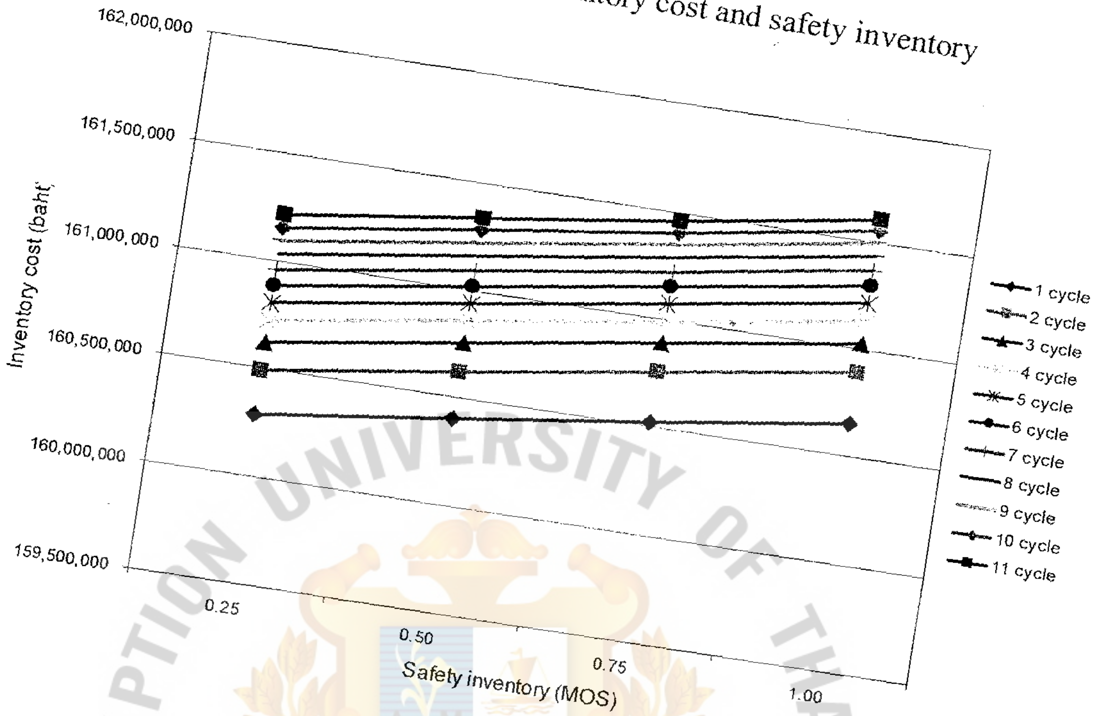
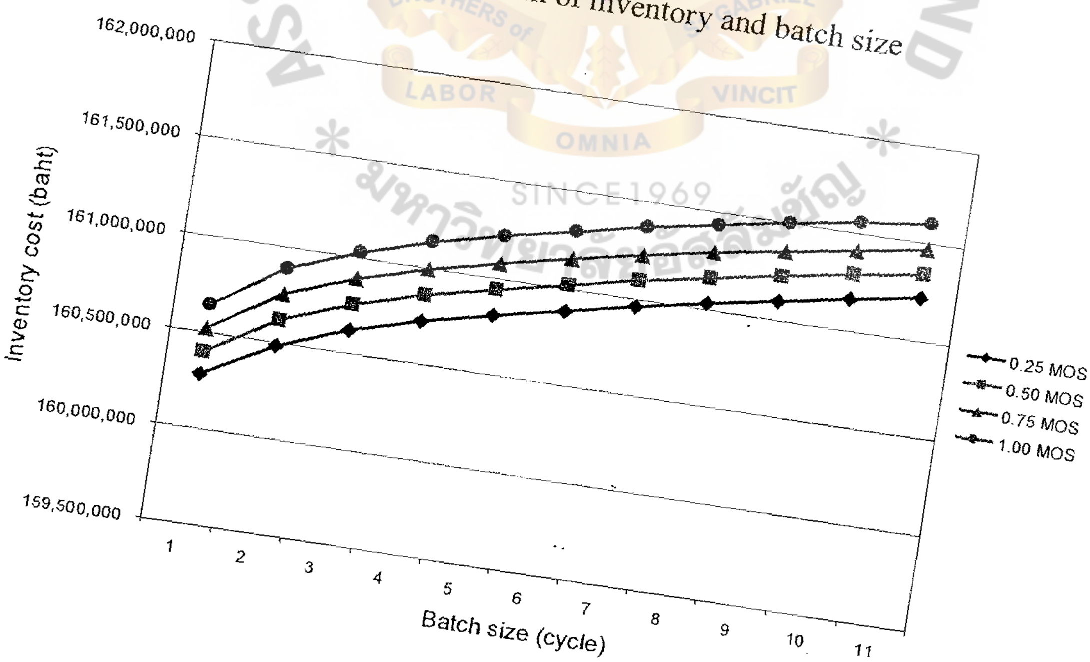


Figure 4.3: Relation of inventory and batch size

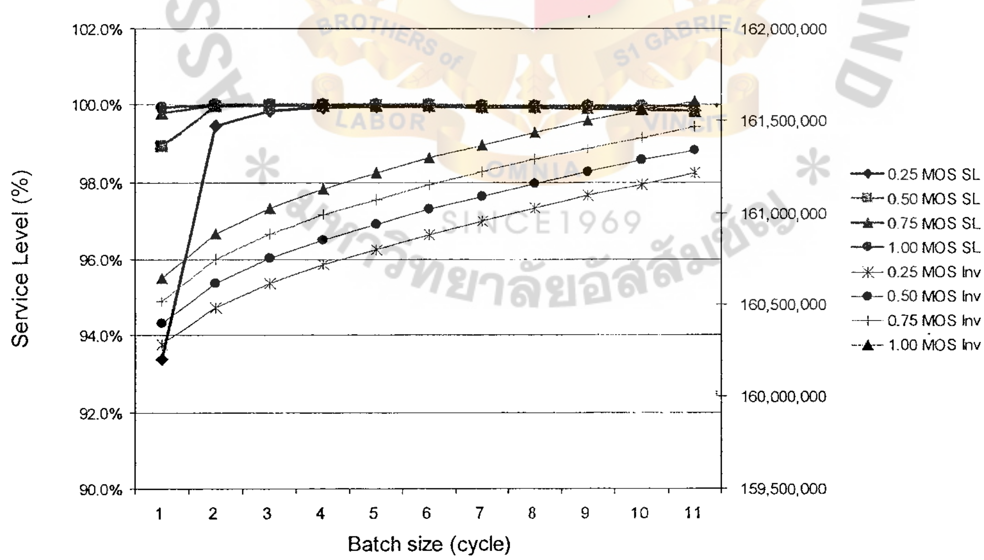


4.2.2 Inventory Cost and Service Level

Eleven values of production batch size (1 to 11 cycles) and four safety stock value (0.25, 0.50, 0.75 and 1.00 MOS) were graphically plotted to service level and inventory cost as shown in Figure 4.4. Service level was increased when inventory cost was increased, and service level was decreased when inventory cost was decreased. Thus service level had a positive relationship with inventory cost.

As mentioned in chapter III, the company service level target is 97.5%, therefore, service level from forty three scenarios were acceptable because their service level was higher than 97.5%. One scenario (production batch size 1 cycle and safety inventory is 0.25 MOS) was rejected because its service level was 93.4% which is lower than the target. In summary, in terms of service level perspective, the lowest inventory cost which its service level (98.9%) met target was 160,398,482 baht, when production batch size 1 cycle was produced and safety inventory was 0.50 MOS.

Figure 4.4: Relation of inventory and service level



To prove validity of the results, statistical data provided by computer software (SPSS Statistics version 17.0) was used as follows:

Three sets of daily inventories were tested. Each set of data contained 365 samples that were tested:

1. Current inventory: production batch size was 11 cycles and safety inventory was 1.00 MOS.

2. The recommended#1 scenario: production batch size was 1 cycle and safety inventory 0.25 MOS.

3. The recommended#2 scenario: production batch size was 1 cycle and safety inventory 0.50 MOS.

Hypothesis test:

H_0: $\mu_1 = \mu_2$, daily inventory of the two data sets are not significantly different.

H_1: $\mu_1 \neq \mu_2$, daily inventory of the two data sets are significantly different.

Decision rules:

- Reject H_0 if *p* value (probability of hypothesis) is less than significance or α at 95 percent confidence limit.

- Accept H_0 if *p* value (probability of hypothesis) is greater than significance or α at 95 percent confidence limit.

The result of the testing are shown in Table 4.2.

Table 4.2: Pair samples statistics test of inventory

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Current	255303.1671	365	33397.64510	1748.11264
	Reccommend1	31911.8849	365	14152.17429	740.75866
Pair 2	Current	255303.1671	365	33397.64510	1748.11264
	Reccommend2	51182.7836	365	16210.61832	848.50254

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Current - Reccommend1	2.23391E5	35865.27617	1877.27435	2.19700E5	2.27083E5	118.998	364	.000
Pair2	Current – Recommend2	2.04120E5	36933.94079	1933.21082	2.00319E5	2.07922E5	105.586	364	.000

The paired sample test at 95% confidence level had Sig. (2-tailed) less than 0.05, therefore, H_0 was rejected while H_1 was accepted. The results proved that the annual inventory cost of the company was reduced from 161,602,617 baht to 160,284,787 baht when production batch size was reduced from 11 cycles to 1 cycle, and safety inventory was reduced from 1.00 MOS to 0.25 MOS. By doing this, service level was 93.4%. The annual inventory cost of the company was reduced from 161,602,617 baht to 160,398,482 baht when production batch size was reduced from 11 cycles to 1 cycle. The reduction of annual inventory cost reduced majority from holding cost 1,506,287 baht to 301,977 baht. Safety inventory was reduced from 1.00 MOS to 0.50 MOS. Therefore, service level of the company was 98.9%.

CHAPTER V

SUMMARY FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

In this chapter, the findings, conclusions and recommendations from the study were presented.

5.1 Summary of Finding and Conclusion

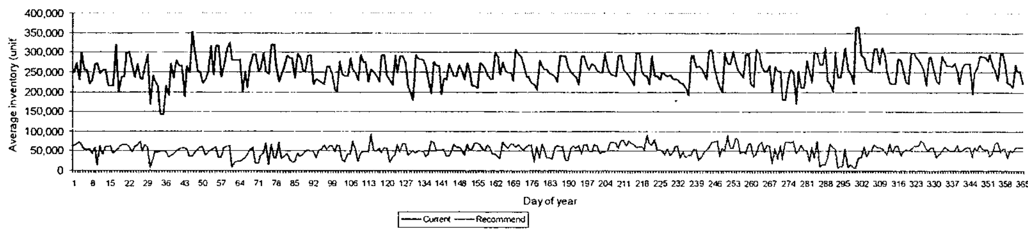
The study proved that smaller production batch sizes could reduce finished goods inventory of the company. And computer simulation could provide optimal inventory and optimal safety inventory. The findings of this study are as follow:

1. Finished goods inventory reduction

Finished goods inventory was reduced when production batch size is reduced. Optimal inventory was determined on the basis of decision. Optimal inventory must provide the lowest inventory cost and achieve target service level of the company (97.5%).

The results of this study indicated reduced production batch size from 11 cycles to 1 cycle, and reduced safety inventory from 1.00 to 0.50 Month of Supply (MOS); the annual finished goods inventory was reduced from 161,602,617 baht to 160,398,482 baht. Holding cost was reduced 1,204,310 baht (80% reduction) and order cost was increased 175 baht. The order cost is small because the order from Japan to Thailand are blanket orders placed once a year and quantity requirement will be requested via electronic mail. This means that the company could gain higher profit of 1,204,134 baht annually. Service level is 98.9%. The graphically inventory movement comparison of the current situation and optimal point is shown in Figure 5.1. The average inventory was reduced from 255,303 units to 51,183 units. Therefore, 160,398,482 baht was determined as optimal inventory of the company.

Figure 5.1: Inventory movement of current situation and optimal point



2. Optimal safety inventory

As previously mentioned in section 1; target service level was still achieved when safety inventory was reduced from 1.00 to 0.50 Month of Supply (MOS). It proved that the current safety inventory of the company (1.00 MOS) is excessive inventory. Safety inventory 0.50 MOS was defined as optimal point.

3. Optimal production batch size

As previously mentioned in section 1, inventory was reduced when production batch size was reduced. It proved that smaller production batch size could yield inventory reduction. From the results, batch size 1 cycle was defined as optimal point.

4. Lead time reduction

Replenishment lead time of production batch size 11 and 1 cycle is 24.6 and 18.8 days respectively. It proved that smaller production batch size could provide shorter replenishment lead time. This means that the responsiveness time to market is shorter. The company could fulfill customer satisfaction, and provide opportunities to expand markets in the future.

Smaller production batch size yielded higher number of orders; Japan has to place orders to the Thailand site more frequency. Theoretically, higher number of orders increases total annual fixed order cost (equation 3-7). Fortunately fixed cost per order of the company is insignificant because annual blanket order is used in the company. An order is sent through the internet which is convenient and there is no additional expense. Therefore, the inventory reduction from this study was mainly from inventory holding cost.

5.2 Recommendation and Limitation

The findings mentioned in section 5.2 were concluded from replenishment cycle during the studied period (January – May 2009). The replenishment cycle could not forever represent replenishment cycle of the future when variables were changed. Therefore, the researcher would recommend the company to periodically review elements of replenishment patterns, and to evaluate and adjust variables appropriate to the situation. The key recommended variables are transportation cost, change over cost, market situation and forecast accuracy.

1. Transportation cost

   Transportation cost in the current situation was not affected because the studied product has been combined with other products in container and shipped from Thailand to Japan. However, if in the future less products are supplied from Thailand to Japan. The production batch size 1 cycle might not be shipped in full container loads. Thus transportation cost will be increased. In this case production batch size is no longer optimal. The company should re-evaluate and determine new optimal points.

2. Change over cost

   Basically, smaller production batch size yields higher number of change over time. Consequently, change over cost will be increased. Therefore, change over time requires effective management in the company operations. The researcher would recommend the company to consider change over time cost in decision making.

3. Market situation and forecast accuracy

Market situation and forecast accuracy is also recommended because market share and product performance in the real market at consumer level changes all the time. The company is recommended to periodically review and evaluate the situation. With this the company would adjust supply chain configuration appropriately, especially in inventory management which is an important variable to control total cost of supply chain.

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