IMPROVING THE EFFICIENCY
IN SPARE PARTS INVENTORY CONTROL

NATTHANUN JANGSETTHAGUL

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STUDENT NAME	MR. NATTHANUN JANSETTHAGUL
STUDENT ID	53600706
DEGREE	MASTER OF SCIENCE
PROGRAM	LOGISTICS AND SUPPLY CHAIN MANAGEMENT
ADVISOR	ASST. PROF. DR. CHIVALAI TEMIYASATHIT

ABSTRACT

Statistical analysis of inventory data has been widely used to investigate the behavior of demand, the order execution and the delivery data in business industry. The analysis benefits the supplier in many ways. This study focuses on statistical analysis of spare parts management of Water Purifier's electronic modules. The challenge of this demand prediction is that the electronic modules have random failure as well as an uncertain delivery lead time and delivery quantity. Without implementing the ERP system, the spare parts ordering policy is an intuitive-based order. The present study investigates the suitable forecasting method for electronic module in After-Sales service department in Thailand. A study of probability distribution is incorporated in order to define sample probability distribution of uncertain delivery lead time and quantity. The new ordering policy based on a defined probability distribution is proposed to facilitate the elimination of intuitive-based ordering system, minimize the stock level, and improve the inventory management and control strategy. The results with real inventory data show that the proposed policy achieve satisfactory stock level as well as significantly reduce inventory cost while maintain a high customer service level.

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Mr. Natthanun Jangsetthagul

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT.)

Page

TABLE OF CONTENTS (CONT.)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (CONT.)

Page

APPENDIX

Chapter I

Introduction

Improving the efficiency in spare parts inventory control

1.1 Study Background

In the global enterprise environment nowadays, the after-sale service of a product has become a crucial part in marketing. While customers want a quality guarantee for a product, the after-sale service fulfills this need. In this sense, the after-sale service is considered to be either a professional maintenance of the product or a warranty for its spare part's availability. In order to achieve an excellent operational performance, spare parts need to be well managed. This includes a reliable demand forecasting techniques as well as an effective inventory control. As a result, an effective spare parts management can decrease the inventory cost and increase customer service's performance level at the same time, leading to higher customer's satisfaction.

Companies providing after-sale services usually store spare parts in their inventory as the spare parts' quantity demanded is hardly predictable. Flint (1995) has stated that the world's spare parts inventory in aviation industry was worth $45 billion at that time. Thus, any means to downsize the stock, without decreasing customer service, would be more than welcomed. Same situation also applies to other industries such as electronic equipment or car industry for example. The amount of money invested in spare parts inventory increases over the years. Due to this financial matter, there has been a great interest in cost-savings. Even if there is only a few percent saved, the cost in absolute terms can be deducted significantly already.[1]

From a manager's point of view, a general inventory control should be capable of providing materials when needed and those costs should be controlled. Donald Waters [2] has come up with three types of the objectives of inventory management. The first objective is to take a very broad view and to have the inventory management contributing to the smooth flow of materials through the entire supply chain. The second is to take an organizational view and to have the inventory management supporting logistics in achieving the overall aims of the organization. The third is to take a functional view and to have the inventory managers making sure that materials are available when needed.

This study will explore the forecasting and the stock controlling of the Water Treatment System (water purifier) which have been analyzed through the case study of a direct selling company in Thailand. The study aims to increase the service availability to consumers and reduce the overall stock level. The work has been conducted in collaboration with related officers in case company in Thailand such as the Financial Department, the Import-Export Department, the Inventory Planning Department and the Distribution Department. Also, the process of the work coordination between case company in Thailand and the planner of its headquarter in the Unites States will be discussed in the latter chapter.

The initiative intention to conduct this study is to reduce the amount of the stock to a desirable level. Currently, case company's spare parts central warehouse is carrying all items on average for 21 months each. To replenish the stock, the After Sales service officer will manually send the order via email to the officer at the United States case company Headquarter. All inventory data is recorded on excel files and manipulated manually. This might result in some deviation in the information's accuracy. The AS400 system used to operate the inventory only provides a basic control without much of assistance in ordering and managing. Moreover, the time it takes to transport the materials to the After Sales service office after the Headquarter receives the email usually varies. The number of spare parts shipped sometimes is also not as ordered. These limitations force the business to maintain the stock at a high level in order to prevent a stock out.

The lack of efficiency in inventory management and information system such as a program help managing spare parts called Enterprise Resource Planning (ERP) will eventually push the company to find a new methodology to improve for betterment.

The optimum solution is at the point where an acceptable inventory cost meets with a suitable customer service level.

1.2 Company Background

Case company is a direct selling company and manufacturer that uses network marketing to sell a variety of products, primarily in the health, beauty, and home care markets. Case company was founded in 1959. Based in ADA, Michigan, the company and family of companies under Parent company reported sales growth of 9.5%, reaching US$9.2 billion for the year ending December 31, 2010. Its product lines include home care products, personal care products, jewelry, electronics, dietary supplements, water purifiers, air purifiers, insurance and cosmetics. Case company commenced its activities and established in May of 1987. The company is at the forefront of the growing direct selling industry in Thailand. It has encouraged the industry to follow the World Federation of Direct Selling Associations' Code of Ethics in protecting consumers, direct sellers and selling companies. In year 2009, its net sales reached 13,300 million baht. Case company Thailand was certified on ISO 14001 Environmental Management System in 1997. Case company Thailand obtained ISO 9001:2000 certifications on July 30, 2001.

Case company's staff both at the Headquarter office and in Thailand use the term 'ADA' to refer to the Headquarter as it is where the main office is located. From this point, this study will also do use the word 'ADA' when mentioning the main office.

Case company has long been recognized as a leading producer of drinking water treatment systems. The Water Treatment System is case company's first in-home water treatment system using a combination of ultraviolet light technology and a patented multi-stage carbon block filter. It has been introduced in global marketing in 2005 and in Thailand since July 2005. It is the first in-home system that achieves the ANSI/NSF Standard 42, 52 and 55. It is also one of the most durable case company's products with top sales.

As well-known case company's Water Purifier has been introduced to the global market in 2006. The product has been successively sold well in the market. The Water Purifier systems are installed in many households in Thailand. The huge amount of products dispersed all over the country will be able to give a rough prediction of how many spare parts should be stored. However, the inventory management still needs to be investigated and studied further in this study.

The spare parts management has started when the study and development group of the United States case company Headquarter launches new products – in this case, the Water Purifier. To prepare services for customers, materials from all over the world will be initialized and assembled for their specific functions. Some of them are assigned to be produced by case company's manufacturer, while others could be produced by other factories located within or even outside of the United States, depending on case company's business strategies. Therefore, for an effective spare parts stocking and supply planning, all of case company's affiliates must communicate constantly and instantly. Then, ADA will take responsibilities of the logistics and the supply chain to replenish the spare parts' requirements. Each affiliate, including case company Thailand, will place the spare parts order to ADA's officer when the materials are used up. The spare parts ordered will be transported via sea shipment or air freight in case of urgency to the central warehouse.

So far, there has been no information system, such as Enterprise Resource Planning (ERP), integrated among ADA and its affiliates to share and provide useful information and real-time updates about inventory. Although there is an integration of selling products and inventory module called AS400 system, it is not real-timely synchronizing the information; there is a 1-or-2-day delay. The AS400 system links ADA's information system to other affiliates' information system but not directly with the inventory; unlike the transactions of the products that are sold in case company shops that will be recorded and updated automatically on the AS400 system as soon as they are sold. The spare parts daily uses are not stored in the AS400 but in the Product Repairing System (PRS) instead. A technician needs to transfer the data from the PRS to the AS400 on a daily basis. At the end of each day, the technician will manually update the number of spare parts in stock on the AS400 system. This results in a delay in information exchange as stated earlier. To decrease the gap in time, an excel spreadsheet for spare parts inventory has been created for the purpose of monitoring a stock level each month. This spreadsheet has the formula that can calculate the quantity of spare parts that should be ordered to replenish the stock. It contains the quantity of each spare parts left in stock, the quantity of each spare part's monthly use averaged from the previous three months, the in-transit quantity of each spare parts ordered and the quantity of each spare parts needed to be order in that month. The file is usually updated at the end of each month. This method helps controlling the inventory cost and ensuring that there is no stock out occurring.

Previously, there was an arbitrary policy stating that each spare parts should be kept for 9 months. This policy came from fluctuated lead times in transporting the supplies; generally takes about 1-3 months, but might take up to 6-8 months in some cases. Sometimes, the number of spare parts arrive the affiliate was not as ordered also. However, holding a huge amount of spare parts in stock meant that the business had to put more investment only on this matter. Therefore, there was a strong desire to search for the solutions that can reduce the inventory cost.

Case company in Thailand also set up some conferences to discuss this issue with the involved parties which were the representative of ADA's officer, Thai After-Sale Service staff, Thai marketing staff and Thai inventory planning staff. They came up with a conclusion that spare parts would be maintained in the warehouse for no longer than 3 months. ADA's officer promised to response to this new policy by shipping the spare parts to the affiliate within one month time. In other words, if the spare parts were required to replenish, they would have been transported to arrive the stock with one month lead time, in an exact amount as ordered. Nonetheless, the policy failed after a year of practice. The spare parts still arrived in 1-6 month time with deviant order quantities.

In conclusion, the excess amount of spare parts maintained in the central warehouse has been influenced by the uncertain lead time in transporting the materials as well as the fluctuated number of spare parts received. The inventory has to carry each item for approximately 21 months. The current ordering policy sets the controlled mechanic time up to 6-8 months. However, this policy still cannot guarantee that there will be no stock out occurring due to an occasional deficiency of spare parts.

Case company's customers can call for the after-sale services when necessary. The company provides a warranty to the Water Purifier System by changing its component if required. The product failures covered in the warranty are the failure caused by the spare part's life and the failure caused by the component's random damage. The age-based spare parts, such as a carbon filter or a tube for example, might have to be changed in every one to two years.

1.3 Objective of the study:

1. To investigate an effective forecasting technique for each categorized spare parts.
1. To improve the inventory management and control strategy in order to minimize stock level.
2. To propose an appropriate ordering policy.

1.4 State of problems

2. Due to the inefficiency in the current spare parts ordering method, it is essential to find a demand forecasting technique that can give an accurate result which could then allow the company to obtain an effective inventory management.

3. The current inventory management has been set up arbitrarily. It is not efficient enough to meet with the high expectation from the consumers. To reduce this problem, the company has to carry more cost and constraints more than it would have been if there was a more effective solution. The constituents of inventory management which this study needs to fill out are as following:

   i. Supply Chain Decisions (strategic)
      1. What are the potential alternatives of the inventory?
   ii. Replenishment Decisions (tactical/operational)

1. How often should inventory status be determined?
2. When should a replenishment decision be made?
3. How large should the replenishment be?

1.5 Scope of the study

The spare parts which are the components in the Water Treatment System are comprised of 129 items from three models. However, only two models are in use at the moment. Case company has stopped producing and selling the first water treatment model since 1999. It has also proposed to stop providing the model's spare parts. Even though there are still some of them remain in the warehouse, this study will not go into a deep analysis on these spare parts. Nonetheless, some further appropriate actions will be discussed later on this study.

All spare parts are classified as type A, B and C with two profiles - age-based part (replacement part) and random failure part. One spare part will be selected to be the representatives of the latest water treatment system. It will be tested using various forecasting methods and inventory model. The random failure part is called the "Electronic Module". It is composed of electronic and a Print Circuit Board (PCB). Its function is to read and display the remaining cartridge filter's life and the system status. If there is a problem in functioning, the part will give out signal. The spare parts are the suitable samples for this examination in this study is type A and is more expensive and frequently used.

The limited time and human resources that can be dedicated into this study might partially restrict the analysis of the entire spare parts inventory from being completed. However, the selected spare parts are the good sample for the examination due to its characteristic as already discussed. Therefore, a precise and accurate result can be expected to obtain from this investigation. This study will examine the spare parts for Water Treatment system related to its current inventory control in order to get the strategies or some recent approaches that might be useful for forecasting and lowering inventory cost without affecting the customer service level so much.

Chapter II

Literature Review

2.1 Spare parts introduction

This study primarily focuses on the policy management of spare parts composed of Water Treatment System. The classification of spare part's demand characteristics and the inventory management are the key factors of the guideline conducted. Several statistical models have been attempted in order to achieve the minimum level of on-hand inventory. Boylan and Syntetos [3] stated that service spare parts are ubiquitous in modern societies. Their need arises whenever a component fails or requires replacement. In some sectors, such as the aerospace and automotive industries, a wide range of service parts are held in stock, with significant implications for equipment performance and inventory holding. A good inventory management is therefore an important task.

2.2 Spare parts characteristics and demand

Typically, forecasting and inventory models for spare parts management have been built according to their characteristics. Huiskonen [4] found that spare part's characteristics can be divided into four main types as followed: 1) *criticality*, 2) *specificity*, 3) *demand pattern* and 4) *value of parts*. The *criticality* gives an idea how much loss there would be if there were no stock available for a specific spare parts. In other words, the criticality of spare parts is its downtime cost. These spare parts can be categorized into critical vs. non-critical demand. The measure to deal with this characteristic could be made depending on the degree of urgency the part needed to be replaced. Dekker et al. [5] developed a model of inventory policy that deal with equipment with high criticality in which spare parts demand originated from its failures. Simulated test by calculation of 200 different cases are conducted to find approximations of service level for critical and non-critical spare parts demand. The critical equipment generates a high cost when the corresponding parts are out of stock; thus, the stock is reserved for the demand of the critical defective parts. The spare parts demand follows a Poisson process where the inventory is controlled by a lot-for-lot policy, non-negative and deterministic lead times. After the model is tested on a simulation, it gives a good result with a high service level obtained from critical equipments. Chang et al. [6] proposes a (r,r,Q) spare parts inventory model which its demand is also classified as either critical or non-critical. The two parameters included in the model are the order quantity Q and the critical level r. The critical level is also equal to the reorder level. The space remained in the stock after a replenishment is done will be reserved for critical-demanded part; that is a semiconductor from a Taiwanese manufacturer, for this research. This is to prevent a stock failure. Along with that, the non-critical-demanded equipments will also be backlogged until the stock exceeds the r level. Eventually, the numerical examples could give out an optimal result. For standard spare parts with high criticality, Huiskonen [4] recommends that the suppliers might consider running a safety stock for them too. This would put the business at a more advantage point as it can provide an alternative choice for users who are finding specific spare parts. Certainly, customers will prefer the company that has got a better service such as 24-hour service or faster delivery.

The *specificity* explains two types of characteristics related to spare part's specificity; one is standard and another is user-specific. A standard part is the type that suppliers are willing to supply as it is widely used by customers. The demand for standard spare parts is so high that the suppliers can offer the economies of scale. On the contrary, a user-specific part is the type that only some certain customers use with specific purposes. Suppliers are not so willing to supply this type of spare parts; therefore, the responsibility for its availability falls on customer. For items with a high specificity, Huiskonen [4] suggests the supplier to hold a few safety stocks instead of to use a make-to-order principle. In the case where the lead time of transporting spare parts over to the inventory is longer than the maximum time the stockout can be handled, the management failure occurs. To prevent the situation from happening, it is better to trade of the cost of holding parts in stock with the lead time. Suomala et al.,

[7] study the after-sales service with customization of consumable spare parts in its machine. The customers can choose either the main core component provided or the customized consumable parts. The research team receives the result indicating that the customization does not impact the number of spare parts consumed nor the inventory cost. Moreover, when the business promotes the customizing policy, only the demand for high volume parts increased. Customization fills up customers' satisfaction and royalty to their preferences. Together with the fact that the demand of consumable parts is steady and predictable, the customization can enhance the consumable part's sales. These parts need to be replaced on schedule due to its limited life; after being used for a certain period they will become wear and tear [8]. For example, a car tire has a predictable period of life; therefore its demand can be forecasted and replenished more than other spare parts.

The *demand pattern* represents the volume of demand for each spare parts ranging from high to low. The higher the volume is, the easier it can be predicted. Vice versa, the less the volume is, the more difficult as the demand get influenced by the intermittence or the irregularity. The control of spare parts is even harder to handle if it has high criticality and price. Spare parts with low volume of demand are suggested to be held back to the upper stream of the supply chain and centralized. In addition, the spare parts demand pattern can also be classified as spare parts with random failure and spare parts with predictable random pattern. Wang and Syntetos [9] study demand forecast method regarding spare parts uses a maintenance-based model to compare with a time series Syntetos-Boylan Approximation (SBA). The model studies about the demand forecasting originated from preventive maintenance and corrective maintenance plan using a model concept of delay time inspection. The study reveals that the estimator (Ratio of demand size and demand interval at time T) of mean demand from the maintenance-based model outperforms SBA when there are spare parts' failure characteristics present. Otherwise, the time series, SBA will come in to render and maintain the accuracy of the performance. Since the characteristic of the demand for spare parts should be indicated as intermittence [9], both models are based on spare parts demand pattern so-called the 'intermittent or lumpy demand'. Two fundamental types of spare parts maintenances: preventive maintenance and corrective maintenance are the interest of maintenance-based model. The preventive maintenance is implemented when there is less need to stockpile the parts as their demand is predictable. The corrective maintenance or unplanned repair, however, requires a safety stock as a stockout cost is significantly high in order to serve a full customer service level [8]. Technicians could use these models to find a large amount of defective items between the delays time of failure. Fig.2.1 illustrates the demands for two spare parts from the Royal Air Force (RAF, UK). Both spare parts possess an intermittent property but have different profiles of the demand-size distribution[9]

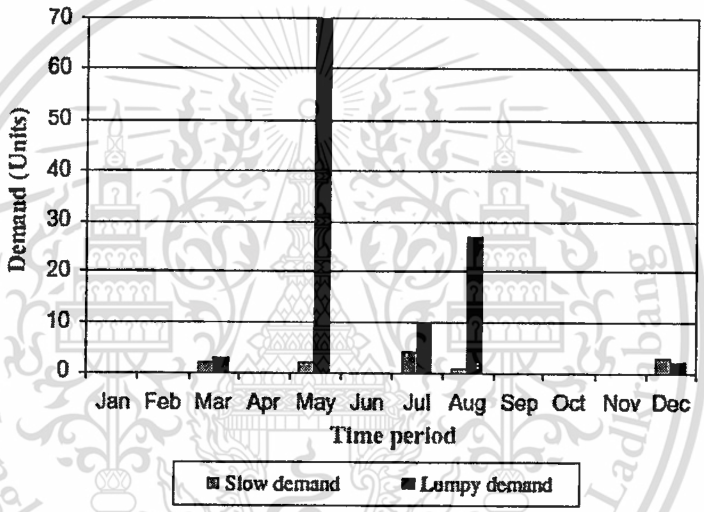


Figure 2.1 Intermittent demands [9]

Ralph Snyder [10] has conducted a study on a parametric bootstrap approach to modify a well-known intermittent demand forecasting technique, the Croston method (1972). The purpose is to determine the value of inventory control's parameters raised on the three selected representatives of car parts demanded. While the fast-moving demand is often forecasted by the Simple Exponential Smoothing (SES), the Croston approach will be thoroughly evaluated by theory and modification in this study.

Most of the researches done on spare parts inventory management are frequently engaged with the demand that is difficult to predict. This demand is usually described by the terms 'intermittent', 'sporadic', 'irregular' and 'lumpy'. The material used to make these items are expensive, therefore it requires an even more careful management. Nonetheless, some of spare parts that have consumable or stationary characteristics can be handled by simply using traditionally inventory controlling method.

The last characteristic of spare parts is the *value of a part*. Parts that value differently will also receive different treatment. A high-priced part is not suggested to be hold but rather to find a delivery service from supplier. A low-priced part is suggested to be well managed in order to provide a suitable administrative cost that meets with its value. In the case of items with low demand volume but high value, a cooperative stocking pool can be implemented. The logistics of the spare parts would be virtually centralized whereas the inventory would hold a decentralized and internet-based application. However, low value parts can be stored in stock as it has no financial significance. A general replenishment should be applied regularly. Items would be ordered in a huge quantity at a time and the order can be made through computer.

There is also another effective practical method of spare parts with demand forecasting and inventory policy developed by Syntetos et al., [11]. It claims to be able to save at least 40% of the related cost. This study has investigated the case of a company wholesaling engineering supplies called VIP (Value Instruments Plus Ltd.), located in the UK. Originally the inventory management was done manually through the company's officers. It used some arbitrary ordering policy to review the number of spare parts that should be ordered every Friday. If the reordered point was equal to the number of the on-hand spare parts initiated before by the company's manager, the officer would make the order quantity equal to the demand of the previous week. In addition, the company's information system could not provide a convenient spare parts ordering process and inventory management.

The study[11] applies Pareto technique to classify the items in VIP Company into groups according to their individual characteristic. By using this technique, the set of 2,156 SKUs is divided into five classes of profit margin (selling price – item cost). The result comes out surprisingly that 11 items of the 2,156 SKUs generate 20% of the entire profit while only 233 items – 11% of the total – generate the rest 80% of the profit. Therefore, some strategies have been developed to deal with prioritizing inventory management such as monitoring the best-selling items closely and introducing Pareto scheme's periodic updates, discarding obsolete items to clear the stock by using the write-off strategy, using the Simple Exponential Smoothing (SES) as an application to forecast the demand of the non-intermittent demanded items which are the minority of the company and using the Syntetos-Boylan Approximation (SBA) to forecast the demand for the intermittent demanded items which are the majority of the company. These spare parts have the frequency recorded on the upper part of the 10-week demand interval.

This study[11] uses the periodic reorder point (T,r,Q) policy to manage the inventory control. For any given review period T, if the quantity of the stock is below r units, then the order Q units are being produced and will be received by a lead-time L. The reorder point is re-calculated at the end of every period. However, the order quantity is only computed once and will be used for every order cycle.

The two new forecasting methods, SES and SBA, have achieved the CSL of 87%, 91%, 95% and 99% after being operated on trial. The SBA, however, outperforms the SES by attaining a lower inventory-related cost

Out of the four characteristics, the importance of the criticality and the specificity of spare parts are emphasized more than others. These two are said to be the combination that give an analyzed control characteristic that will then offer the most distinctive opportunity to develop the operation of logistic system.

2.3 The spare parts characteristic of Water purifier and case studies

Numerous number of literatures related to spare parts inventory have focused their concern mostly on investigating models in electronic parts, aviation, automotive industry or plant equipment. So far, there has been no research conducted on water purifier or the Water Treatment System. It is the first in-home water treatment system using a combination of ultraviolet light technology and a patented multi-stage carbon block filter. A demand of water purifier's spare parts is stochastic but not intermittent arising from corrective maintenance which the spare parts probably are random or age-based failures but this study will focus on a random failure parts. The random failure part is called the "Electronic Module". It is composed of electronic and a Print Circuit Board (PCB). Its function is to read and display the remaining cartridge filter's life and the system status. If there is a problem in functioning, the part will give out signal. It is replacement part not repairable part so technicians only diagnose symptom of system and replace the spare parts which cause the failures.

Even though this research specifically concentrates on managing spare parts for water treatment system, the methodologies adopted in other work on general inventory management will certainly be studied. This chapter will also take into account what other literatures have done on spare parts inventory modeling and related spare parts logistics maintenance.

There has also been a research done on spare parts inventories from an overview point. W.J. Kennedy et al.,[8] has investigated some sample inventories and concluded that spare parts inventory is different from other inventories in many aspects. Spare parts inventory's function is to assist the technician to have the equipment ready for operation. Due to its maintenance, the spare parts stored in the inventory will always be altered accordingly to how they are used. On the contrary, the Work in Process (WIP) or the final product inventories can be easily managed or changed following the production rate or the schedule set. Spare parts inventory, however, contains only items that are dependent on the product's failure. It is very difficult to predict when the parts should be repaired or replaced into the product, especially when their dependent relationship is not known. The reliability of the product might be the only useful information to assist spare part's demand forecasting. The cost of a spare parts shortage is also difficult to estimate. At the same time, a part for some certain products might be obsolete as the model is becoming out of fashion. These issues added up would make most of all spare parts get stored in the inventory. Practically, the product or equipment that is expensive usually preferred to be replaced by the parts from stock keeping.

Kostas-Platon Aronis et al., [12] conduct a case study on improving the efficiency of forecasting and controlling inventory. They use the circuit packs for telephone switching system as samples. This study brings a Bayesian method to practice with an (S-1, S) inventory control policy. While the demand failure is originated from a stationary process, this study also uses the data obtained from a reliable prediction made during the design of the equipment and the initial estimation of the failure rate. The authors aim to improve the current method by not changing the policy. In conclusion, the Bayesian method could give a better performance by lowering the total stock to a desirable level.

Bacchetti and Saccani [13] examine the researches and practices between the classification and the forecasting related to durable products' inventory control from previous to recent. Their aim is to analyze the gap and provide proper guidelines for practitioners who manage the inventory. The guidelines are to help resolve the obstacles the manager might meet, for instance, an inaccurate forecasting, ineffective inventory management – no spare parts classification, lack of assisting system integrated among the supply chain such as ERP, etc. Therefore, the authors propose the directions to bridge the gap in the further research. They propose an integrated approach of spare parts management is illustrated in Fig 2.5 below. This flow of relationships shows the guidance of spare parts management steps that have been well prioritized.

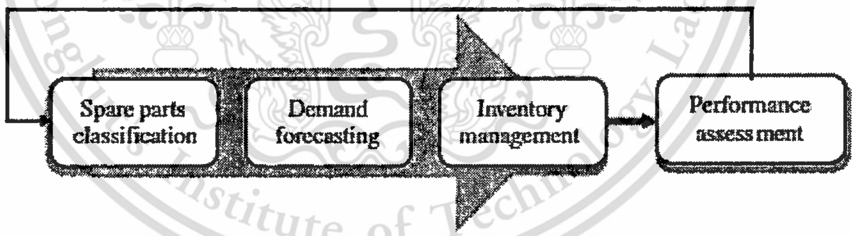


Figure 2.5 An integrated approach of spare parts managements[13]

They also encourage to organization to have a developing contingency – based managerial guidelines as it could provide a guideline to solve an organization issues that can be adopted from case studies. A difference in technological and environmental dimensions results in differences in structure, strategies and decision process, so organization will practice inventory management depending on contextual factors. These factors are scope of operations, size of organization, strategic relevant and industry. The plan needs to be addressed as there is no other previous research cited. The manager could possess skills that adopt some of their selected practice to apply with the work in his organization. The authors also emphasize on favoring the knowledge accumulation process. It helps the business indicate where their spare part- management's status is, and also evaluate the plan to develop managerial attributes. In addition, supplementing models with practical relevance is a good advantage. The beneficial model should always be introduced to the practitioner in order to enhance the managerial techniques, leading to a more quantitative complexity. While the manager or the company is facilitating the spare parts inventory, all available resources should be used in the practical implementation. The assessment of the benefits achievable from applied models by organizations should be determined and focused. In the last part of the research, the authors also emphasize the importance of the information system installed to share the data through the whole supply chain. This is a crucial part where the business should not neglect.

As stated earlier, this research aimed to study water purifier spare parts samples in Class A. Class A items are significantly important. Class A items' cost of replenishment, cost of carrying inventory, and out-of-stock cost are higher than those of Class B items. Thus, stock control will intensify in Class A items than Class B items. Silver et al., [14] provides suggestions for controlling Class A items by stating that Class A items should be monitored closely by recording details of Class A inventory and management should be informed necessary information. Demand should be forecasted through manual method. Failure demand and slow-moving parts should be forecasted with appropriate method so that safety stock is reserved while the expensive parts should be managed by a pool system in the supply chain. If there are seasonal fluctuations in demand, they are managed by altering the price structure, dealing with customers, managing shipment. To find a valid lead time and reduce any supply uncertainty, it necessary to negotiate with suppliers. The practitioner should always review the decision parameters including review period, the reorder level and the order quantity. For Class A items, there is low penalty cost but high stockout cost. When Class A items are nearly out-of-stock, it is necessary to send items via air freight immediately while service level still is set as high.

2.4 Case studies of demand and supply uncertainty

In recent years, few researches have studied how to cope with demand and supply uncertainty. According to those studies, a manufacturing have still faced some problems such as various types of consumer demand and supply chain disruptions. Supply chain disruptions are unwanted situations, adversely affecting supply chain performance such as poor weather, terrorist attacks and disease incidence. These disruptions consequently have impact on the availability of finished products. Lin and Wang[15] studied build-to-order (BTO) and build to stock (BTS) from manufacturing strategies. They designed supply chain network for mitigating supply disruption and demand uncertainty. They also proposed decomposition or L-shaped algorithms. Their findings showed decrease in total expected operating cost. Schmitt et al., [16] studied a model of the Single Stochastic Period (SSP) approximation to solve supply disruptions. Various types of demand are deterministic or stochastic and stochastic demand or supply yield significantly impact on a retailer. Thus, optimal base-stock policies provide good results. Besides, familiar newsboy fractile could trade off to prevent shortage occurrences.

Besides, demand and supply uncertainty is viewed as an obstacle to effective inventory management. Lead-time variability is also a challenge to maintain the optimal inventory level. An assemble-to-order (ATO) system is characterized by high volume sales, short production times, and individual assembly for such products as automobiles and personal computers. An assemble-to-order (ATO) strategy in the manufacturing environment is experimented when demand rate is subject to random variations, and purchase order for components experience random delays and its lead-time is random variable. Mohebbi and Choobineh[17] proposed a simulated experiment related to component commonality, random product demand and random procurement lead time. Their experiment showed good results in the ANOVA tests, indicating product structures, lead-time and demand uncertainties significantly impact all three dependent variables. It revealed that the lowering the average inventory level becomes more significant as the number of common components increases. Another study aimed to study inventory models with imperfect information in a random environment. Two formulations of single-item models with random supply in a random environment proposed by Arifo˘glu and O¨zekici[18]. Their first model is characterized by supply is random due to random capacity of production and random availability of transportation. Their second model is a model with random availability only with fixed-ordering cost. The state-dependent base-stock policy is optimal as the solution of the first model. The state- dependent (s,S) policy is optimal for inventory problems in the second model. Also they pointed out the problem with random lead times faced by the suppliers, affecting the inventory position (inventory on hand plus outstanding order). Therefore this problem is worth for future research. Inventory record inaccuracy is a problem faced by some firms with unknown inventory level, unknown demand distribution and lead time unreliability.

Bai et al,.[19] studied a two-bin inventory replenishment system with a fixed order quantity and periodic review used at a firm to cope with constraints. Moreover, the model does not require dynamic (re-) optimization and can be programmed in a spreadsheet or database software application. Eventually they found an experiment with optimal expected total cost per period. Since the lead time uncertainty is critical and affects inventory control, the delivery time lag is the most important evaluation factor. Shibuya et al, [20] analyzed the ordering models for spare parts which lead time fluctuation exists and inventory levels for a single product are reviewed continuously. The optimal timing of regular orders is considered as an analytic problem. The conclusion of optimal policies which minimizes the expected cost during one cycle is obtained.

2.5 Summary

These studies give an idea and guideline for applying a new empirical method for inventory management of spare parts in this study. Especially the classification of spare parts is based on Pareto technique[11] which is beneficial to arrange a group of spare parts according to priority[4, 7]. Eventually the study gives practitioner the whole idea to follow guidelines for integrated inventory management of spare parts [13]. These can help the business to manage the spare parts inventory to meet customer demand, high customer satisfaction, while maintaining lowest inventory level in the warehouse.

The scope of this study aimed to handle with uncertainty of critical factors in spare parts inventory control system encountered by the company. Besides, the company in this study implemented inappropriate ordering policy. In real situation, this company who provides spare parts for water treatment system to its customer has the problems related with demand fluctuation, supply unreliability together with random lead times. Moreover, its inventory system fails to keep useful information including historical data or real- time update of spare parts. All literatures reviewed have not studied such problems of inventory systems as uncertainty in demand, supply and lead time. This study thus conducts the statistical analysis of inventory data focusing on the delivery and order execution from the past. These useful data originate the statistical ratio and generate sets of random numbers, which is essential to conduct a new empirical model for spare parts inventory management. The new ordering model which could be constructed under spread sheet and provide many simulations through Matlab program. At the end of the simulation, optimal spare parts inventory model, providing lower inventory cost could be obtained.

Chapter III

Research background

Before going into a deeper analysis on research methodology, this study will examine the background of the present situation regarding the spare parts inventory and its control of the Water Treatment System in detail. There are problems presented in the current inventory control policy. Thus, each of them will be discussed in depth, in order to determine the significance that each one affects the system. Appropriate recommendations will be given to handle the problems. From observation and research, the following lists are the data collection process and the identified problems.

3.1 Data Collection

All of the data that are necessary in implementing the inventory control are collected from the case company's resources through the following procedure.

3.1.1 Spare Parts- demand system

There are 2 main systems involving the spare parts management.

3.1.1.1 PRS (Product Repairing System), the software system developed to keep track of all spare parts that are used in customers' unit repair. Therefore, all spare parts demands are stored here.

3.1.1.2 AS400 the main operating system contains all company's products in the inventory, including spare parts. These records are the number of available on-hand items,.the number of shipments and deliveries from past to present and the number of the 'on-order' items that are in the process of transportation, waiting to be delivered.

The previous order record from the case company is done without using the ERP (Enterprise Resource Planning) system. ADA and the case company in Thailand do not have the system that provides information that enhances inventory forecasting and replenishing. The transactions and orders are only recorded on excel spread sheets created by Thai operator to help calculate the order quantity. The spread sheet keeps the order up-to-date from previous to present. Therefore, it is the only tool used for recording. The data are not stored in either PRS or AS400 system. For more understanding this, please see the table 3.1 Spare parts information system source below.

Table 3.1 Spare parts data source and information systems

Spare parts data	Information- system sources		
	PRS	AS400	Neither
Daily spare parts demand	√		
Monthly spare parts demand	√		
Number of on- hand spare parts		√	
Number of shipments		√	
Number of deliveries		√	
Number of on-order spare parts		√	
Date of on-order spare parts		√	
Spare parts cost		√	
Spare parts-order quantity			√
Number of forecasting spare parts			√
Spare parts-order lead time			√
Date of shipment			√
Spare parts-quantity box		√	
SKU and descriptions	√	√	

3.2 The inventory cost

The method used in acquiring inventory cost from various sources is a fundamental tool for determining inventory policy.

The total relevant costs consist of:

Ordering cost Ordering cost = 428.66 Baht/One time ordering

Carrying cost = 0.71 Baht/unit/month

Product cost (Electronic module) = 1,361.85 Baht/Unit

Please see more details of the inventory cost in Appendix C - The case application for EOQ model (Economic Order Quantity) Page 90.

All the inventory cost can be extracted from shipment invoices and pertinent warehouse documents, which are under financial staff's responsibility. Data collection of this study is conducted manually. Therefore, the assistance of financial staff in providing relevant costs would be essential to this research. These costs are counted as the most reliable costs that can possibly be found.

3.3 Problems

As mentioned in the introduction that the challenging aims of this study is to improve spare parts forecasting technique and ordering policy. After a period of observation and analysis, the current method where the company in Thailand uses is considered inefficient. The identifications of the problem are ranked in order of importance to determine its severity. The attempt to improve the system will start from there.

Maintaining high inventory level results in a high investment. Thus, the manager should pay special attention to the inefficiency problem. The customer service level should not also be neglected. The spare parts availability should be manipulated against the stock out.

This study initially uses the traditional tool, i.e. cause and effect diagram, to identify the causes of the problem found in the inventory control. The crucial part of the problem is the situation when there are excess spare parts or high inventory level. The causes & effect diagram is illustrated as shown below.

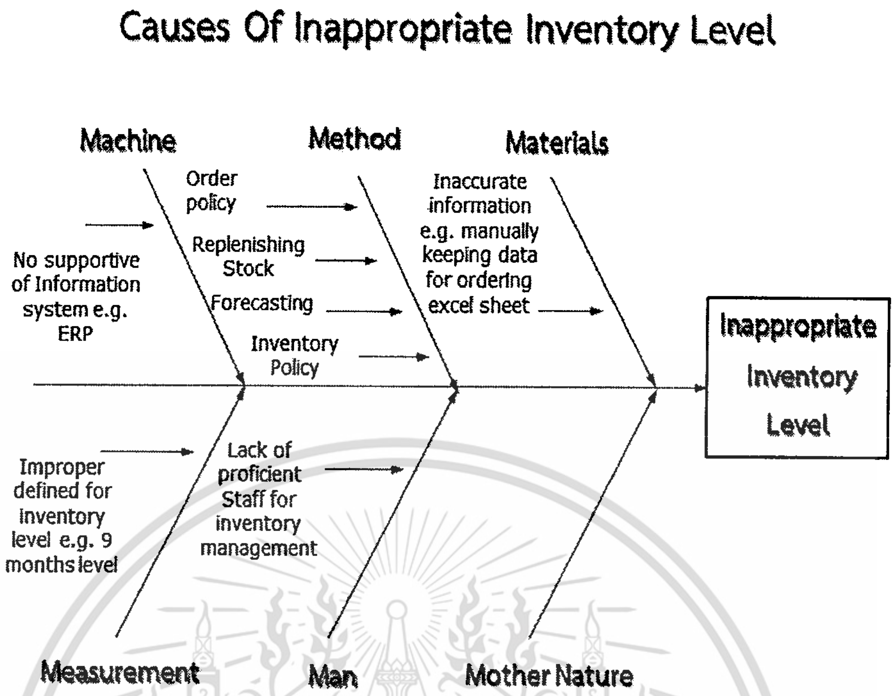


Figure 3.1 Causes and effect diagram describing inappropriate inventory level

The diagram above represents the majority of the cause and effect of spare parts inventory at a high level. There are 6 major causes that specify the reasons of high inventory level as listed.

Machine – Having no ERP (Enterprise Resource Planning) system to assist the inventory forecasting and replenishing, the case company in Thailand has to find an alternative method to process the orders. To keep the process flow, spare parts are required to be stored in the warehouse for 3-9 months. However, due to technical complications in the company, the case company in Thailand is not capable of getting the ERP system installed. The software issue that affects the inventory management will not be focused in this study.

Method – There are four issues that contribute to high inventory level; ordering process, replenishing stock, forecasting and inventory policy. Each of them leaves a significant impact on the amount of spare parts kept in the warehouse. Therefore, these issues will be studied deeper in the next causes and effects diagram.

Materials – The information determining the optimal quantity of spare parts that should be ordered must be as accurate as possible. From the previous practice, case company's operator collects the information from AS400 and PRS system, then put them into an excel sheet. The operator calculates the yield of the order quantity. Since the process is done manually, the operator needs to have no human error in order to produce a perfect work. Otherwise the operator will have to take a lot of time to complete it. Either way, it results in a lack of efficiency in the process. So this human error may happen while the ordering process is performed. However, this aspect beyond the scope of this study and this issue is worth for further analysis to determine a new ordering policy.

Measurement – The Company's measurement of inventory management is the stock level that allows spare parts to be maintained in the warehouse no more than the equivalent amount used in 9 months. For example, if 100 pieces of spare parts are used monthly, the stock level of this type of part cannot exceed 900 pieces. This practice has been directed from the previous managers and applied to all of products. This is a traditional policy that this study will not intervene in.

Man – The operator who is responsible for ordering and replenishing spare parts needs to be well-trained and possesses good knowledge of management and forecasting techniques. Incompetent staff will use undefined ordering method that depends on his arbitrary decision. This will easily cause an excessive spare parts stocking.

Mother Nature – There is no issues involved with the environment affecting inventory management. Thus, this issue will not be analyzed.

After determining each of the factors mentioned above, the most critical factor affecting the inventory cost is “Method”. Basically, most businesses emphasize on investment and aim to lower the inventory cost. Improving and enhancing “Method” can lower the inventory cost as the ordering policy with appropriate forecasting technique, order quantity with the right time to order, and suitable replenishment result in lower spare parts inventory level maintained in the warehouse. Thus “Method” would be efficient and plays its roles to inventory cost. Besides, reducing excess inventory is suggested to include in inventory policy[14]. For more study on causes of the main impact of high inventory level, this study will pick out a ‘method’ to be analyzed in further details illustrated by figure 3.2

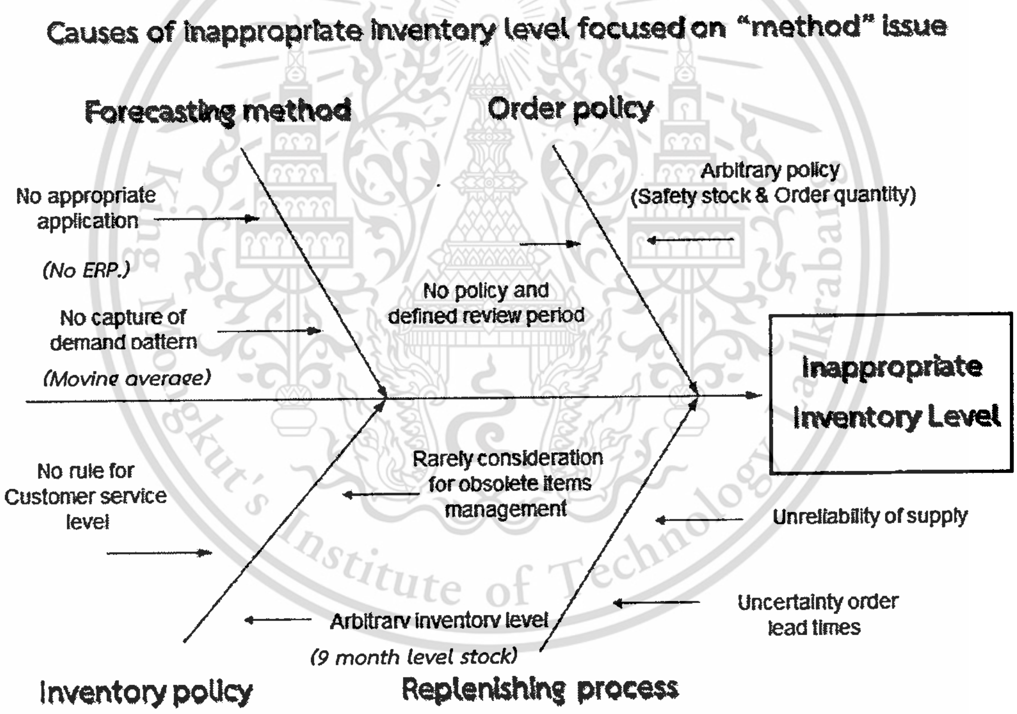


Figure 3.2 Causes and effects diagram describing inappropriate inventory level focused on “Method” issue.

The assessment of excessive spare parts that their roots cause can be summarized as follows.

3.3.1 Current ordering policy

The ordering policy is defined by the current mechanism as the order quantity. It is an arbitrary inventory level that relies on the operator's decision on safety stock. This number is fluctuated between 3-9 months. This means that the ordering method within 9 months has to cover its cycle in order to maintain a stable inventory level. It shows that the ordering method is undefined and has no logical analysis to support. There is also only a one-month periodic review, set up for operator's convenience; no formal consideration for reviewing period.

The operator has created the amount of order via spread sheet showing the stock level as the reserve stock for demand during lead time. However, the amount of safety stock or order quantity is determined based on an operator's arbitrary judgment or lack of logical analysis support. Moreover, large amount of the order is often determined to prevent against stock outs from uncertainty in supply and lead time. Calculating the amount of the order is considered from the number of spare parts to be kept on hand, demand for spare parts and the number of expected deliveries (on order) and its expected date to be received, which are fluctuated and uncertain.

For spare parts ordering process, an operator needs to update and put necessary data from PRS and AS400 systems into purchase order spread sheet, determine the amount to make an order and send order request via email to the planner in USA. Then, an operator waits for a reply email indicating order amount and delivery date from the planner. Please see figure 3.3 Flowchart of spare parts ordering process for additional details

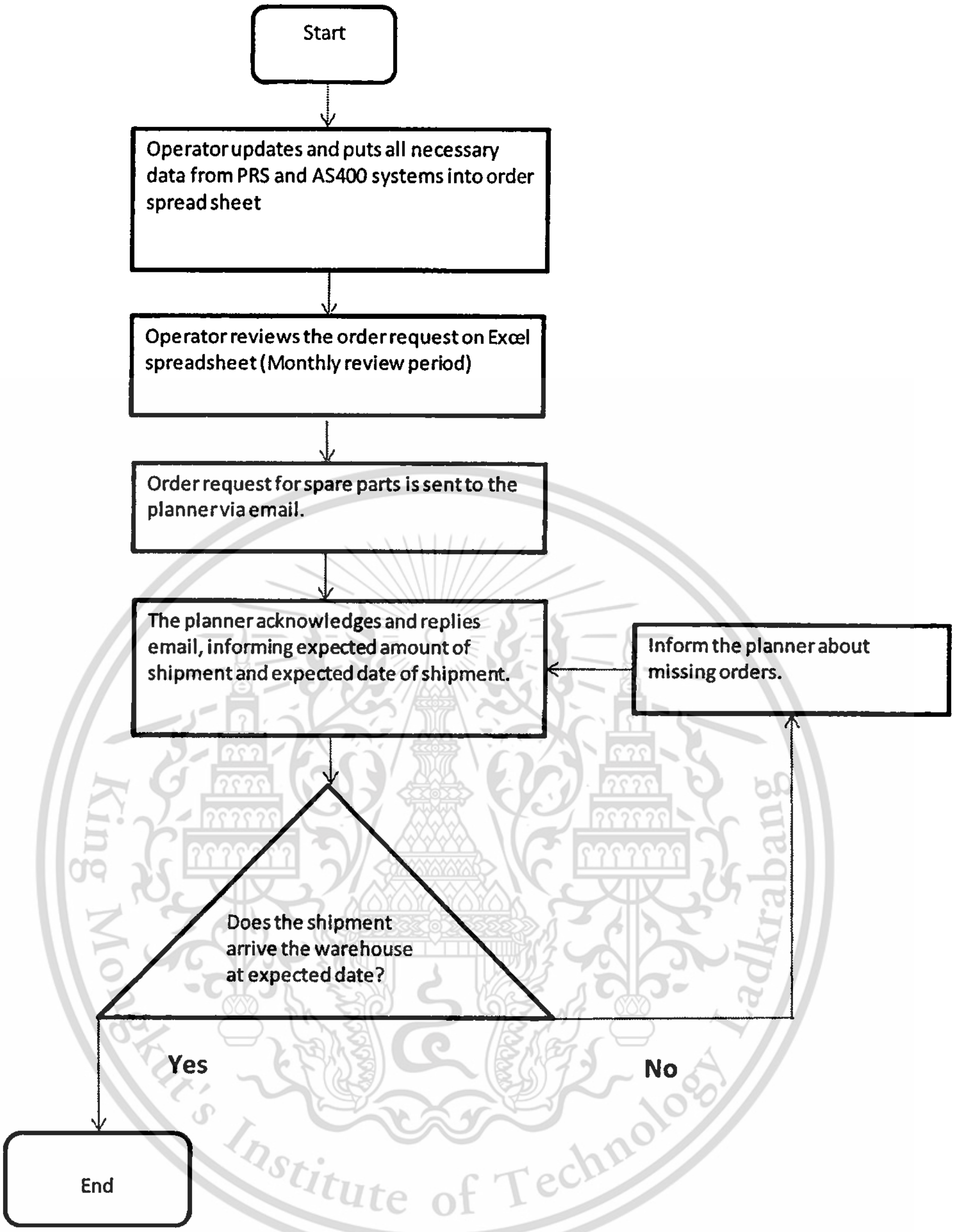


Figure 3.3 Flowchart of spare part-ordering process

2.3.2 Replenishing process

There is unreliability in supplies sent from ADA to the company in Thailand. For example, the amount of supplies received does not exactly match with what is ordered. Fluctuations in amount of supplied received depend on supply situation. If the amount of supplies received is less than the amount requested at the first place, the missing amount will be later made up to the next shipment. Also, the shipment from ADA is not predictable with variable 1-3 months lead time. Once replenishing to order is requested to ADA, then the planner may reply an email, informing what expected shipment date is. However, sometimes, the reply for some request for spare parts is not found. The answer will be obtained later if they could get the actual information from their supplier. If there is a supply disruption affecting spare parts production, it causes longer lead time that is up to 6-8 months. Moreover, there is lead time uncertainty in transportation. To ensure the availability of spare parts, the company needs to stock and orders more spare parts, creating a higher than necessary stock level.

2.3.3 Current forecasting method

The current forecasting method is three-month moving average, as it is the simplest way that can be thought of. The company does not take the issue of the least variance into consideration. In other words, it uses the moving average method without analyzing whether or not the deviation of the forecasted demand from the absolute demand is the least. The operator is also unaware that an inaccurate demand forecast will result in a high stock level.

2.3.4 Inventory policy

There is no policy that controls customer service level. Even though stockout is undesirable, sometimes items can be out of stock or temporarily not available. The stockout event could affect customer satisfaction. The customers may complain since they have to wait for longer time until the delivery of the spare parts. Also stock out event could lead to customer loyalty risk. Although most customers may not turn to use other competitor's product, they may be forced to do so in case of serious situation. If the stock out event frequently happens, it affects company's image and reputation. In terms of inventory management, this issue should be focused on and examined further.

The arbitrary inventory level that depends on the operator's decision has a lot of influences on the excess in stock as discussed already. Some obsolete items such as an old version part of the water treatment system are not continued to be used in the repair anymore. Such items are left in the warehouse, waiting to be recycled or kept longer for future use. Even though this issue is not the most aspect that is concerned, it would still be worth studying in the future.

3.4 Current status

The problems discussed previously reflect an undesirable stock level, resulting from the major cause, CPFR (Collaborative Planning, Forecasting and Replenishment). The CPFR method aims to achieve supply chain integration by using internet based technologies. The method of operation planning begins at the upstream (ADA) and passes to downstream (case company in Thailand). There are back and forth interactions between the two offices.

Because the PRS (Product Repairing System) does not synchronize with the AS400 system, therefore all of spare parts information is not completely stored in any of the case company's system. Staff must input spare parts demand into the AS400 system daily to keep ADA updated with the same information. This data transfer can cause a delay and inaccuracy in the supply chain record. In the long run, the spare parts information cannot meet the planning requirement. It impacts the inventory management in terms of specifying the bottom line cost. However, this problem is, to some extent, far beyond the scope of this study. It can be studied in the future if this study is extended in a certain area. It is suggested that the company should develop some further implementation.

In this study, the company has faced with the problems of replenishment process from headquarter in USA. As mentioned earlier, there is supply unreliability since the amount of supplies received from USA does not exactly match with the amount of supplies ordered from Thailand. When the amount of spare parts is less than expectation, it causes stock out event. In contrast, the excessive amount of order causes an excessive stock level affecting higher inventory cost. Moreover, variable 1-3 months lead time always happens. Sometimes there is supply disruptions informed by the planner from headquarter in USA. The worst case happens when the headquarter delays order delivery for more than 3 months. Besides, the company has not only experienced the uncertainty in supply and lead time but also inefficient ordering policy. The operator needs to ensure the availability of spare parts for a water treatment system. Thus a large number of safety stocks is reserved on monthly basis. The important process in "Method" is focused on replenishment, and ordering policy which includes ordering process and some inventory policy. What most businesses concern is an investment or inventory cost. The inventory level can be determined to meet the customer demand and high customer satisfaction. Therefore order replenishment and ordering policy play important roles to spare parts inventory management.

After investigating the causes of inefficient spare parts control, the next step is to focus on the demand forecasting method, replenishment, ordering policy and reducing of excessive inventory. The moving average, simple exponential and linear regression techniques will be used in forecasting the demand. The ordering policy will be improved by updating the order quantity based on the relationship of the actual data that are related to order quantity, such as a spare parts demand, its forecasted demand, its on-hand amount, previous orders and delivery quantities.

The three fundamental questions should be answered in order to determine a better inventory control techniques. The questions are 'How often the inventory should be reviewed', 'How much to order?' and 'When to order?'[14].

The main objective of this study in controlling inventory is to minimize the total inventory costs. Total inventory costs are made up of cost of items, cost of ordering, cost of holding and cost of stock outs. This study will use the spare part – Electronic Modules (EM) to investigate and analyzed the related costs.

At present, the ordering schedule and amount are not reliable. The demand is also uncertain, making it hard to predict. The safety stock needs to be reserved to prevent stock outs. Neither the traditional Economic Order Quantity (EOQ) nor a service level (Probabilistic Model) can cope with this situation, please see the application case of EOQ model in Appendix C. Therefore, this study must analyze the data in the past that relates to the current policy and try to generate a new empirical inventory model.

Chapter IV
Research Methodology

4.1 Overview

An important of spare parts inventory management design must be realized before a decision made to implementation. Reason to such carefully decision defined that is affecting to overall effectiveness and inventory cost existing from the firm's business. An approach outline this study selects adopted for practitioner as the good guidelines integrated view by Bacchetti and Saccani [13] as depicted in figure 2.5 An integrated approach to spare parts management

This perspective approach is the critical guideline to follow each step of effective spare parts management in spare parts companies. This systemic perspective showing the relation among the step of spare parts classification, demands forecasting and inventory management, and the performance assessment. Eventually this study suggests that the way handled each spare parts categories obtained should be treated with differentiated approach followed their classification, demand and inventory management techniques. Therefore this study will conduct the spare parts study accordingly on this approach perspective. Eventually, the process to be guideline will be adopted from this approach described as below:

4.2 Spare parts inventory study process

For a better understanding, the flow chart of inventory study is outlined in figure 4.1

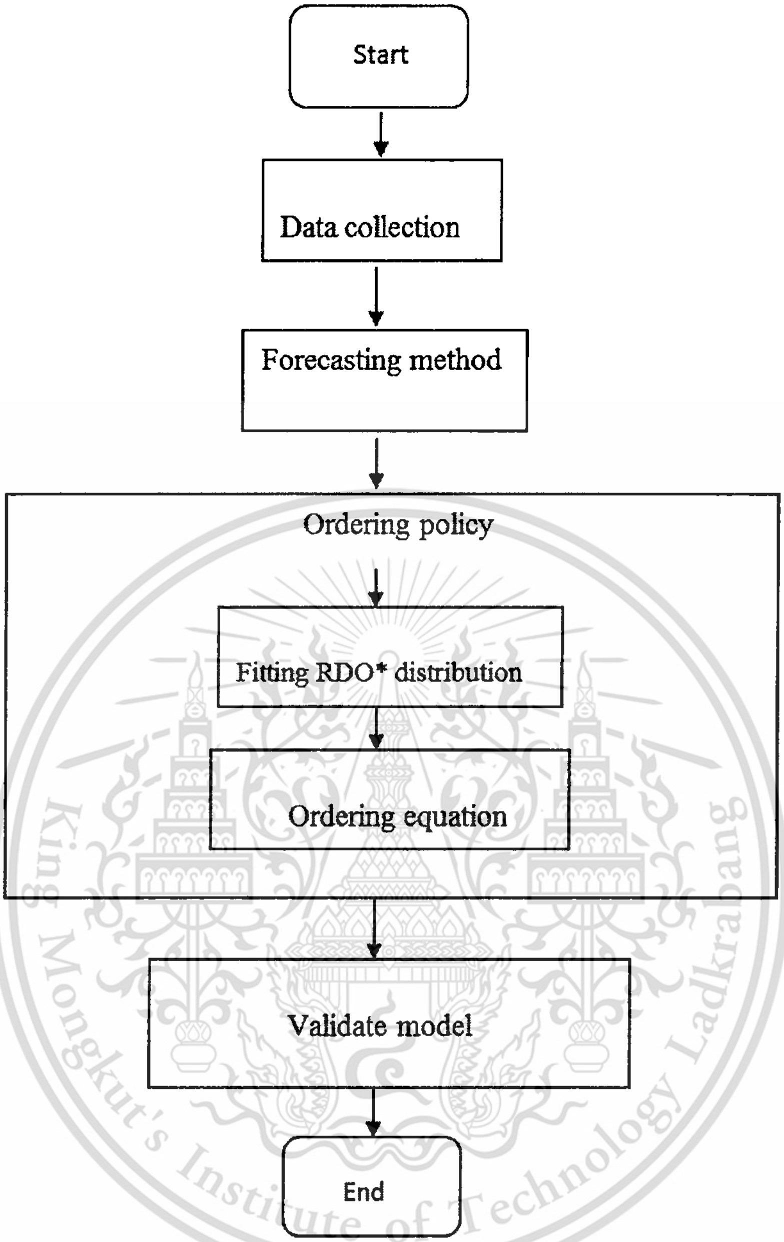


Figure 4.1 Flow chart illustrating Water treatment system inventory study

Note that: RDO = is the ratio between number of cumulative delivery and cumulative order quantity in monthly review period.

4.2.1 Data Collection

The data collection starts from collecting relevant data from the one spare parts samples of the water treatment system i.e. **EM** (electronic module). The sample is the representative of the overall spare parts. EM is type A classification. The data collected, then, is the spare parts demands, its pattern and cost such as order and delivery quantity from May 2010 to December 2011, demand lead time and monthly closing stock, ordering cost, carrying cost and product cost.

The first step, this study need to classify the spare parts inventory according to their importance in term of investment and the criticality. Knowing their importance and criticality mean a practitioner can manage the inventory with efficiency and effectiveness. Thus this study aims to focus on their characteristics how to handle with appropriate inventory policy. The classifications of these spare parts are defined with traditional well known, Pareto technique categorized as A-B-C classification [14, 21, 22]. According to being the most of 80% that inventory consumes and costs always is invested in ad hoc spare parts such as class A type, which the business need to closely monitor its inventory. Surely, a few of spare parts in class A which obtains around 20% are the representative sample selected in this study. EM is spare parts accounted to class A which is used to perform the further simulated model.

4.2.2 Forecasting method.

According to Wang and Syntetos [2] reveals that the estimator, Ratio of demand size and demand interval at time T, of mean demand from the maintenance-based model outperforms SBA, a time series Syntetos-Boylan Approximation when there are spare parts' failure characteristics present. Otherwise, the time series, SBA will come into render and maintain the accuracy of the performance. Therefore their study uses the modification of Simple Exponential Smoothing (SES) as an application to forecast the demand of the non-intermittent demanded items. As well as Ralph Snyder [3] conducted a study on a parametric bootstrap approach to modify a well-known intermittent demand forecasting technique, the Croston method (1972). Ralph Snyder[10] also states that the fast moving demand is often forecasted by the Simple

Exponential technique. Hence this study will use Simple exponential and some of Time-series models such as Simple moving average, Moving average and regression to forecast spare parts for water treatment. A robust forecast technique will allow us to obtain an accurate amount of order.

4.2.3 Ordering policy

Ordering policy is the core of this study in terms of lowering the average stock level at the end of each month. As earlier mentioned the demand, the lead time and spare parts supply are very fluctuating, the new inventory model could not be applied with EOQ or probabilistic model. As the result of EOQ application for this case company, the time between orders equal 2 months; it means placing an order every 2 months. This study reveals that it does not give the lower number of closing stock or inventory cost regarding the new ordering model. Please see the EOQ application applied for this case in Appendix C.

So this study brings the actual data related to delivery and order quantity to be investigated in finding the solution for new ordering model.
Therefore, the fundamental of new ordering policy comprises three elements as follows:

4.2.3.1 Fitting RDO distribution

The investigation of the relationship between the delivery and the order quantity can provide a useful set of data. Their ratio can generate a random distribution which will be used to do ordering simulation. RDO is ratio between number of cumulative delivery and cumulative order quantity in monthly review period. Fitting RDO distributions for EM's RDO can build up a series of data set of random generations. The random generations can impact the simulated model testing i.e. varying with the closing stock each month.

4.2.3.2 Ordering equation

The most important step to do is building the master ordering equation. This equation is obtained from the fruitful of relation number created from RDO. It is used in simulate table of ordering period starting from available data in 2010 June to the end of 2011.The expected result is the number of order quantity to make each month reflecting the lowest final closing stock at the bottom line.

4.2.4 Validate model

A robust model will be tested by master ordering equation. The inventory cost of the simulate model will be compared with the one of the current practice. The expected result is the number of spare parts in the closing stock obtained from the model being less than the one of the current practice. The new ordering process integrated from this simulation will be applied in real use, yielding a lower inventory cost.

4.2.4.1 Performance assessment

The method to appraisal to compare how well the new inventory model approach betters enough to change the inventory policy from previous one is to measure the asset the company invests in decreasing or increasing. The last inventory left each month in the specific month period selected will be measured on hand left. The approach inventory model should lower the current amount on hand

4.2.4.2 Inventory management

The aim of efficiency inventory management is to optimize the availability of the inventory to serve demand of spare parts replaced to the units and level of stock keeping. The company needs to set the policy how much to reserve stock or buffer in the warehouse by service level set. At the business's goal it is needed to satisfy the customer requirement responsively with high level of satisfaction while lower the inventory cost.

To find appropriate inventory policy, it is required to calculate how much to order quantity, time to order, what a reorder level and how much to maintain the buffer level to prevent stock out. The calculation to obtain the answers to those questions would be derived from historical data from the spare parts inventory described in the next section. Necessarily, having the higher accuracy forecasting is a mission to get the optimal order quantity reflecting to no excess inventory.

4.3 Demand forecasting

Time – series forecasting method is traditional technique to predict the future of any demand selected in business. These models make the assumption that what will happen in the future is referred to what has happened in the past. So the series of past data in the specific period can be used in forecasting.

This study selects three types of forecasting techniques that are moving average, exponential smoothing and linear regression as a preliminary study due to computational simplicity of these techniques. Several parameters of each technique will be investigated in order to achieve high accuracy model. The best fit model and their corresponding parameters will be applied for later part of this study. The historical demand of the sample selected as EM from water treatment spare parts is extracted since January 2008 to December 2011 to be forecasted data base. All of the following equations have been brought from the book, Quantitative Analysis for Management.[23]

4.3.1 Moving averages

Moving average (MA) technique is summation of recent series of demands for a specific period in order forecast the demand in one step ahead. The future demand can be calculated from:

$$F_{t+1} = \frac{Y_t + Y_{t-1} + \cdots + Y_{t-n+1}}{n} \qquad (4.1)$$

where $F_{t+1} =$ *forecast for time period* $t+1$
$Y_t =$ *actual value in time period* t
$n =$ *number of periods to average*

4.3.2 Exponential Smoothing

Exponential smoothing is a type of moving average technique; it calculates using a few of past data. The latest forecast of demand is equal to the previous forecast adjusted by a fraction of the error (last period's actual demand minus the previous estimate). The smoothing constant (α) represent a weight of the forecast error. The closer its value comes to zero, the forecast line become more smoothing but has more forecast error. On the other hand, the more its value closes to 1, the less smoothing to forecast line but more responsive.

$$F_{t+1} = F_t + \alpha\,(Y_t - F_t) \qquad (4.3)$$

where
$F_{t+1} =$ *new forecast (for time period* $t+1$*)*
$F_t =$ *previous forecast(for time period* t*)*
$\alpha =$ *smoothing constant* $(0 \leq \alpha \leq 1)$
$Y_t =$ *previous period's actual demand*

4.3.3 Regression

Generally, regression analysis is applied for multiple variable forecasting. The technique fits a trend line that minimizes the sum of the squared error to a series of historical data point. A trend line can be written as a linear regression equation which is employed for the future forecasts. In this study, the independent variable (x) denotes the time point, while (Y) represents values of predicted variable. b_o is the intercept and b_1 is the slope of the line.

$$\hat{Y} = b_0 + b_1 x \qquad (4.4)$$

where
$\hat{Y} =$ *predicted value*
$b_o =$ *intercept*
$b_1 =$ *slope of the line*
$X =$ *time period* $(X = 1, 2, 3, \ldots, n)$

This study uses the POM-QM for window (Excel QM) obtained from the book, Quantitative Analysis for Management [23] for regression analysis.

4.3.4 Forecasting accuracy

To find the best forecasting model, the forecasted values are compared with the actual or observed values in order to calculate the forecast error. One measure of accuracy is the mean absolute deviation (MAD).

$$e_i = A_t - F_t \tag{4.5}$$

where

$$e_i = forecast\ error$$
$$A_t = actual\ demand$$
$$F_t = forecast\ value$$

$$MAD = \frac{\sum |e_i|}{n} \tag{4.6}$$

While the other is the mean squared error (MSE).

$$MSE = \frac{\sum e_i^2}{n} \tag{4.7}$$

4.4 Finding ordering policy

The method to find how much to order will directly impact to the level of inventory. Ordering policy is one of the crucial matters in term of lower the month-end stock level at the end of each month. Since, the delivery lead time and quantity are very fluctuating; a basic Economic Order Quantity model (EOQ), and service level model cannot be applied in this study. The assumptions of constant and known demand, constant lead time, and instantaneous replenishment are violated. The intuitive suggests that if one could find even slight relationship in the historical data, the improved ordering policy could be constructed based on that relationship.

4.4.1 Fitting distribution

Due to uncertainty of delivery lead time and quantity so observation is made to the ratio of actual historical data between the cumulative delivery and the cumulative order quantities from "EM" spare parts. The investigation of historical data reveals that they could provide a useful set of information. Ratio between cumulative delivery and cumulative order (RDO) can be obtained from Eq. 4.8.

$$RDO = \frac{CD}{CO} \quad (4.8)$$

Where

$RDO =$ *The ratio of cumulative delivery to cumulative order*
$CD =$ *Cumulative Delivery*
$CO =$ *Cumulative Order*

4.4.1.1 Histogram

As the unreliable demand supply so observation is made to the ratio of that actual historical data between the cumulative order quantity received and the cumulative actual delivery quantity from "EM" spare parts. Its histogram reveals that there is a relationship between the quantities among those two data as their ratio can be illustrated as figure 4.2

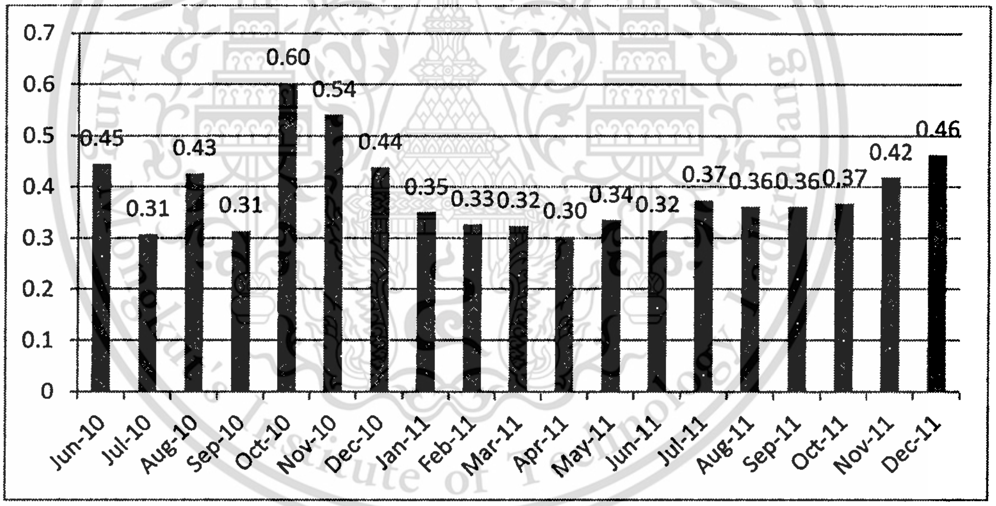


Figure 4.2 The ratio of cumulative delivery to cumulative order quantity of EM (electronic module)

According to lack of data, ordering amount prior to May 2010 so the starting month of the ratio contained in the figure below are from June 2010 to December 2011.

The figure above shows that they look like the distribution is characterized by a density function that is rectangular called **"Continuous uniform distribution"**.[24]

However, it needs to make sure that it is proofed by statistical science. Therefore, hypothesis testing needed to be analyzed further.

4.4.1.2 Box plot

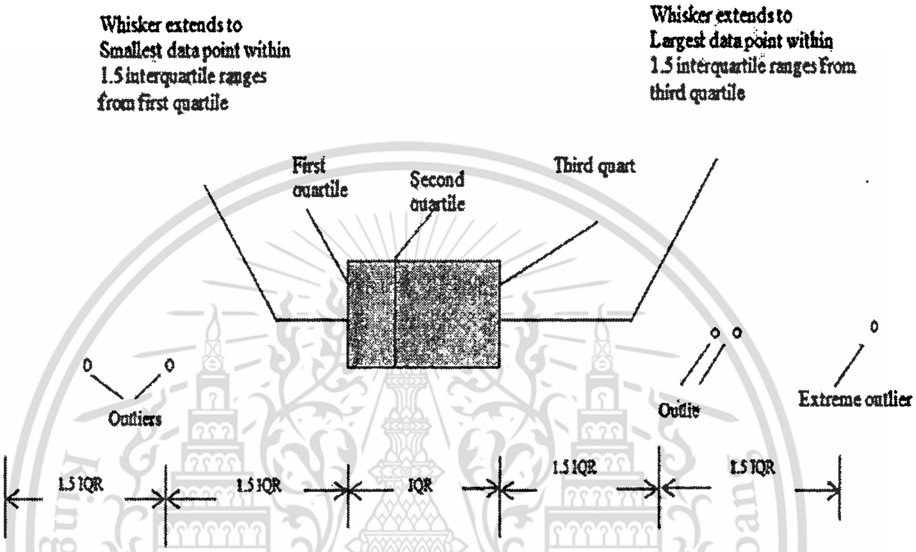


Figure 4.3 Description of a box plot[24]

A box plot [24] displays the three quartiles, the minimum and the maximum of the data on a rectangular box, aligned either horizontally or vertically. As it is very useful in graphical comparison among data set so that the ratio of cumulative delivery per cumulative order of "EM" is drawn by the box plot with outlier comparing no outlier as figure illustrated below.

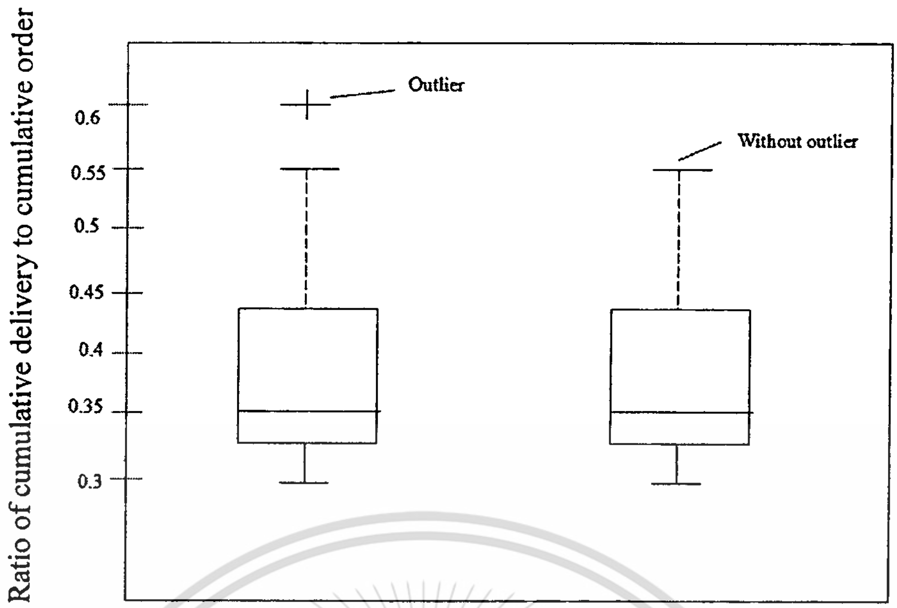


Figure 4.4 Box plot with outlier and without outlier

4.4.1.3 Continuous uniform distribution

After outlier is eliminated, so their shape looks the same as a rectangular which is continuous uniform distribution. The distribution of probability that focused on is the ratio of cumulative delivery per cumulative order that follow the historical spare parts data "EM". Thus its ratio would have a probability that could fall in an interval of fixed length within [*A, B*] which is constant. So the density function for a uniform random variable on the interval [A, B] [24]is shown in figure 4.5.

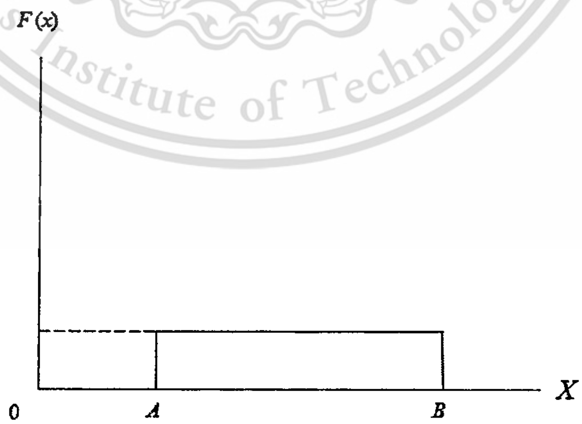


Figure 4.5 The density function for a random variable on the interval [*A, B*][24]

4.4.1.4 Goodness of fit test

Now the underlying distribution of the population is not clear whether it is "Continuous uniform" so that testing the hypothesis to know which type of distribution for "EM" spare parts are necessary required in this stage. In case of "Continuous uniform distribution" must be performed a formal goodness of fit test procedure based on the chi-square distribution[24].

The hypothesis-testing procedure will be described as following, using $\alpha = 0.05$;

1. The variable of interest is the ratio of the cumulative delivery per cumulative order.
2. Ho: The form of the distribution of RDO is continuous uniform distribution.
3. H_1: The form of the distribution of RDO is not continuous uniform distribution.

   Reject Ho: if p – value is less than 0.05,

   Reject Ho imply that RDO is not continuous uniform distribution while fail to reject Ho imply that the form of the distribution of RDO is continuous uniform.
4. The test statistic is

$$X_0^2 = \sum_{i=1}^{k} \frac{(o_i - E_i)^2}{E_i} \tag{4.9}$$

5. The Goodness of fit test will be analyzed in Matlab.

4.4.1.5 Random generation

The result that needed to conclude that Ratio of the cumulative delivery per cumulative order behave like contrinuous uniform distribution would be strong desirable. If so the random generation for the ratio will be used for ordering in the further analysis.

4.4.2 Ordering equation

This study will use the RDO (the ratio of cumulative delivery per cumulative order) to derive an ordering equation. Firstly, an idea to invent the equation is that the order quantity this month O_n originated from the amount of discrepancy between the cumulative this $period_n$ and previous cumulative $period_{n-1}$ described as follow:

$$O_n = CO_n - CO_{n-1} \tag{4.10}$$

where

$O_n = Order\ quantity\ for\ time\ period_n$
$ED = Expected\ delivery\ quantity$
$CD = Cummulative\ delivery\ quantity$
$CO = Cummulative\ order\ quantity$
$n = month\ period\ making\ an\ order$
$RDO = the\ ratio\ of\ cummulative\ delivery\ per\ cummulative\ order\ quanitity$

Now we want to extend any possible variables in the above O_n equation from other relevant factors. As $RDO = \frac{CD}{CO}$ (Eq 4.8), so $CO_n = \frac{CD_n}{RDO_n}$,
But as the fact that if we make an ordering this $period_n$ then it suppose that the delivery amount would arrive in the next 2 months on average. (Generally, the variation replenishment will be one to three months), Thus $CO_n = \frac{CD_{n+2}}{RDO_n}$, with this CO_n it is substituted to be the below O_n equation:

$$O_n = \frac{CD_{n+2}}{RDO_n} - CO_{n-1} \tag{4.11}$$

The above relation equation can use CD_{n+2} to find more involved factors. Basically, the cumulative delivery amount for this $period_n$ is originated from previous cumulative amount of the $period_{n-1}$ plus the delivery amount for this $period_n$. According to the delivery amount should be expected number because the supply fluctuation from ADA and the delivery quantity would not be received as the order quantity placed as the described equation as follow:

$$CD_n = CD_{n-1} + ED_n$$

As we want to extend the CD_{n+2} into the equation with relevant variables, then it is derived as here:

$$CD_{n+2} = CD_{n+1} + ED_{n+2}; \text{ then}$$
$$CD_{n+1} = CD_n + ED_{n+1}$$

From the above equations, it is decomposed into sub-equations illustrated as follows:

$$CD_{n+2} = CD_n + ED_{n+1} + ED_{n+2}$$

$$CD_{n+2} = CD_{n-1} + ED_n + ED_{n+1} + ED_{n+2}$$

$$CD_{n+2} = ED_n + ED_{n+1} + ED_{n+2} + CD_{n-1} \quad (4.12)$$

Let's substitute CD_{n+2} with $ED_n + ED_{n+1} + ED_{n+2}$ CD_{n-1} to the equation 4.18.1, then the new O_n is illustrated as below:

$$O_n = \frac{ED_{n+2} + ED_{n+1} + ED_n + CD_{n-1}}{RDO_n} - CO_{n-1} \quad (4.13)$$

where

O_n = Order quantity for time period n
ED = expected delivery quantity
CD = cummulative delivery quantity
CO = cummulative order quantity
n = month period making an order
RDO = the ratio of cummulative delivery per cummulative order quanitity

4.4.2.1 Expected delivery

The fundamental order amount will engaged with the expected delivery amount that equal the amount of month forecasts that cover usage of the months that also equal selected review period. The assumption supposed that Thai operator makes an order this month, and then the next two month the order replenishment expected to be arrived. According to the fact that uncertainty lead time demand that order would be received in around two months so the equation will be fixed two months lead time.

For example as illustrated in figure 4.6 if we place the order at $period_1$, then the shipment would arrive in next two months or the beginning of $period_3$ with expected delivery quantity that cover usage of the months for $period_3$+$period_4$. This case selects two month review period so the next reorder will be placed at $period_3$ and expected delivery quantity will arrive at $period_5$ with the reserved usage for $period_5$ and $period_6$. Note that : the order at $period_1$ is not equal to ED_3 due to the uncertainty in delivery quantity, but ED_n can be adopted to calculate O_n by the use of RDO_n as shown in Eq. 4.13.

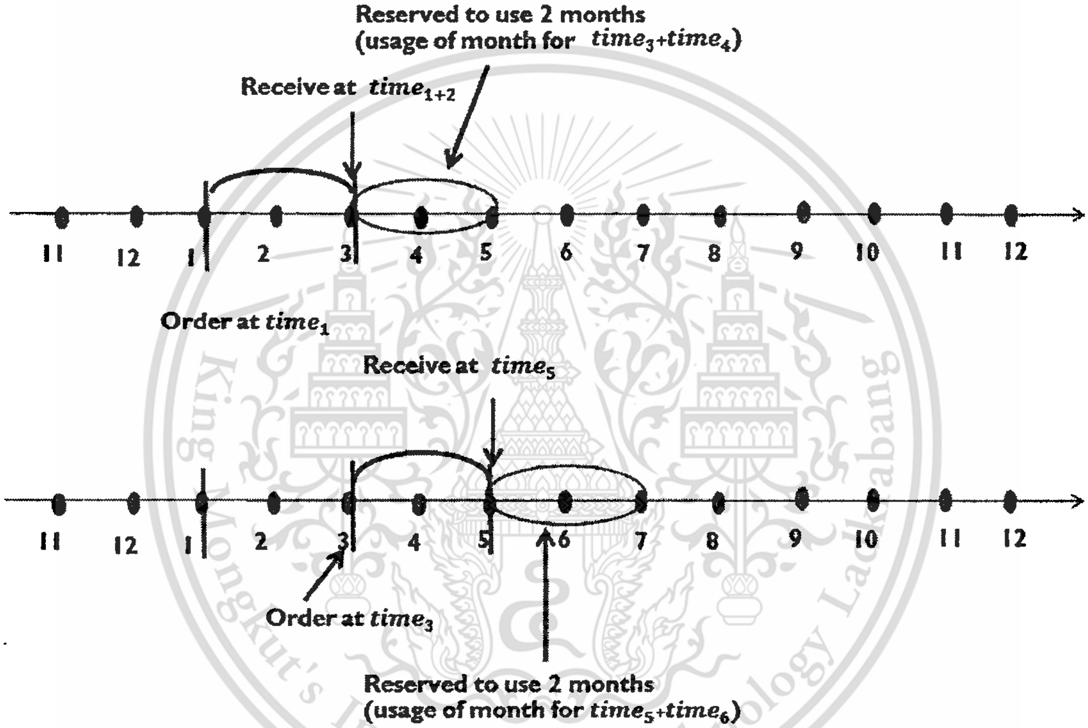


Figure 4.6 the example of placing an order at $period_1$ and $period_3$

The operator is required to take the on-hand inventory, $On\ hand_1$, which has included the expected delivery at $period_1$, ED_1, into consideration as well as the demand of spare parts for $period_1$ and $period_3$. Because the operator is going to place an order at the beginning of $period_1$, the actual demands for all periods starting from $period_1$ remain unknown; consequently, actual demands for future time period are substituted with the forecasted demands (F_n).

$$ED_3 = F_3 + F_4 - (OH_1 - F_1 - F_2) + SS \qquad (4.14)$$

Considering the conditions previously mentioned, ED_3 composes of demand for $period_3$ and $period_4$ $(F_3 + F_4)$ and the spare parts carried over from $period_1$ through $period_3$. The carried over spare parts can be referred as the on-hand inventory at $period_1$, OH_1 , deducted by the forecasted usage during $period_1$ and $period_2$, $(F_1 + F_2)$. To avoid supply disruption, the safety stock level (SS) can be added to (4.14).

To determine the order amount to make each month based on review period which is the month interval to make an order. The amount to make an order follows equation below derived from the equation 4.14 but varying on reviewing period to review an order.

$$ED_{n+2} = F_{n+2} - OH_n + F_n + F_{n+1} + SS \qquad (4.15)$$

Monthly review period

$$ED_{n+2} = F_{n+2} + F_{n+3} - OH_n + F_n + F_{n+1} + SS \qquad (4.16)$$

Every two months review period

$$ED_{n+2} = F_{n+2} + F_{n+3} + F_{n+4} - OH_n + F_n + F_{n+1} + SS \qquad (4.17)$$

Every three months review period

$$ED_{n+2} = F_{n+2} + F_{n+3} + F_{n+4} + F_{n+5} - OH_n + F_n + F_{n+1} + SS \qquad (4.18)$$

Every four months review period

where

$ED = expected\ delivery\ quantity$
$n = period\ month\ to\ make\ an\ ordering$
$F = spare\ part\ monthly\ forecasting\ demand$
$OH = spare\ part\ on\ hand\ quantity$
$SS = number\ of\ safety\ stock$

Because this study tries to identify a way with a lower inventory cost, it needs to modify the expected delivery equation from Eq. 4.15 to 4.18. The numbers of forecasted demand term are eliminated out of these equations in order to decrease the stock at the end of each month. These new equations called "Scheme 2" will be used for 4 alternatives of the review periods; every one, two, three and four months as depicted in Eq. 4.19 below. So equations from 4.15 to 4.18 are called "Scheme 1".

The equations obtained from scheme 1 and scheme 2 are calculated and put into column "H" in the example of master tables, please see Appendix A-1 and A-2.

$$ED_{n+2} = -OH_n + F_n + F_{n+1} + SS \tag{4.19}$$

Finally, month-end inventory or closing stock amount according to the new proposed ordering policy can be obtained from

$$Closing\ stock_n = Closing\ stock_{n-1}(On\ hand_n) - d_n + D_n \tag{4.20}$$

Where d_n = The actual demand at $period_n$
D_n = *generated* Delivery

To find the generated delivery amount, it can be derived from the generated cumulative delivery (RDO_n) adopted from (4.8) as the following equation:

$$CD_n = CO_n \times RDO_n \tag{4.21}$$

$$D_n = CD_n - CD_{n-1} \tag{4.22}$$

Nevertheless, the order amount to receive in previous historical also indicates uncertainty or fluctuation quantity so the order made in last two month's was only the expected delivery quantity which could be unreliability. Therefor this study will use the probability of the delivery amount that exist from actual data with actual order amount to be further analysis to find new ordering policy.

4.5 Creating Simulated-Order Model

A simulated-order model is a new ordering model that this study established as the master table in excel spreadsheet in order to gather data on generated-order amount, generated- delivery amount, the set of uniform random number, and integrated with some actual data. The purpose of this simulation is to obtain a lower closing stock amount at the end of each month.

4.5.1 Master Table of Simulated-Order Model

Exploring the simulated-order model that yields a lower closing stock compared to the current order management. All of the simulated tables are established under testing pattern depicted as Figure 4.7. For example, monthly order is tested by 4 levels of safety stocks from 0, 0.5, 1, to 2 months. Besides, 100 random number sets are used for testing and yielding simulated-cumulative delivery quantity. An order for every two, three and four months is tested in similar way.

Figure 4.7 Testing pattern of EM simulated-order model

The initial idea of simulated-order model is to compare the obtained number of closing stock each month with historical number during May 2010 and December 2011. The important equations applied in simulated-order model or master table created on excel spreadsheet are as follows:

Order amount = (Eq. 4.13)

Expected delivery = (Eq. 4.15 – 4.19)

Generated cumulative delivery = (Eq. 4.21)

Generated delivery = (Eq. 4.22)

Some of actual data are integrated with generated data to run the ordering simulation. The actual data includes the number of opening- stock column during May 2010 and December 2011, actual- delivery data during the first three months of expected- delivery column and a few numbers of cumulative- expected delivery, generated- cumulative delivery (See spread sheet in Appendix A-1 and A-2).

Order equations (equation 4.13) are used to calculate desired order quantity under the terms of the review period, including monthly, 2-month, 3-month and 4-month period to make an order. For example, if 2-month is applied as a review period and the beginning of March is a month to make an order, the next review period is n+2 with (n= 3) , that is 3+2=5. So, next periods are May, July, September, and so on. Order equation (4.13) will be shown in column E in Appendix A-1 and A-2.

The generated- cumulative delivery quantity, "L" column (see Appendix A-1, A-2) is measured by using the equation 4.21 and generated delivery quantity using equation 4.22, "K" column. The values vary from the RDOs or the set of uniform random number with the range of variable A = 0.3029 and B = 0.5402. The uniform random numbers that are used to simulate the model gradually have been adjusted B value to meet the appropriate point. By considering and identifying an alternative with less inventory cost, B parameter is changed by trial and error from 0.5402 to 0.500 and 0.400.This requires random number generator, which each has 100 set of numbers. Each set will be placed in the master table to generate the outputs which will be compared to their closing stock quantities.

4.5.2 The example of the results calculated from master table.

According to the analysis result of simulated-order model, it is concluded that making an order in every month with no safety stock can provide the lowest amount of closing stock for total 20 months using the RDO set from parameter A=0.5402, B=0.4000 , during May 2010 and December 2011.(Please see the all of results as illustrated on

Table 5.5 in Chapter V). To clarify the process of simulated-order model, different cases from Expected delivery equation- Scheme 1 and 2 are necessary shown for 2 cases below.

Case 1- Expected delivery quantity: ***Scheme 1***

Review period: every month

No safety stock reserved

RDO set of uniform random number; A= 0.3029, B= 0.4000

Table 4.1 The example of EM master table (Monthly review period with 0 month for safety stock) using Expected delivery equation by *scheme 1* and set of uniform random number by variable (A = 0.0329, B = 0.4000)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Month-Year	Opening stock	Actual demand	Demand forecasted by Simple exponential α 0.76	Order amount	Cumulative Order	Actual Delivery	Expected Delivery	Cumulative of expected Delivery	The set of uniform random number using variable A = 0.3029, B = 0.4000	Simlated delivery	Simulated cumulative Delivery	Simulated closing stock
2	May-10	963	329	380	0	0	384	384	384	0.0000	*0*	*384*	*634*
3	Jun-10	634	341	341	2912	2912	347	347	731	0.3860	*740*	1124	*1033*
4	Jul-10	1033	346	341	155	3067	0	0	731	0.3680	*5*	1129	*692*
5	Aug-10	692	354	345	1004	4071	664	393	1124	0.3537	*311*	1440	*649*
6	Sep-10	649	292	352	1218	5288	0	5	1129	0.3319	*315*	1755	*672*
7	Oct-10	672	306	306	127	5416	1428	311	1440	0.3713	*255*	2011	*622*
8	Nov-10	622	318	306	1301	6717	500	315	1755	0.3400	*273*	2283	*576*
9	Dec-10	576	260	315	395	7112	0	255	2011	0.3580	*263*	2546	*579*

Now by looking at September 2010, how much an order can be made with no safety stock? Firstly, it needs to find expected delivery quantity including $ED_{11}, ED_{10}, ED_{9}, ED_{8}$ as calculated on column H in Table 4.1.

The simulated-order model is performed under master spreadsheet classifying by testing pattern as shown in figure 5.8 and table 4.1. All related numbers are put into the relevant equations as depicted in table 4.1 and Appendix A-1. Note that the below output numbers are slightly different from the decimal number.

Then let's n substituted by different numbers as follows:

$$ED_{9+2} = F_{9+2} - OH_9 + F_9 + F_{9+1} + 0$$

$$ED_{11} = 306.08 - 649 + 351.79 + 306.35 + 0$$
$$= 315.22$$

For ED_{10}, ED_9, are similarly used the calculation in the same way as ED_n ,which equal to 310.95, 4.64 respectively.

Now, $order\ quantity\ for\ time\ period\ n$ can be calculated by the equation 4.13 and shown on column E in table 4.1 as follows:

$$O_9 = \frac{ED_{11} + ED_{10} + ED_9 + CD_8}{RDO_9} - CO_8$$

$$O_9 = \frac{315.22 + 310.95 + 4.64 + 1{,}124}{0.3319} - 4{,}071$$
$$= 1216.13$$

So EM order quantity in September 2010 is 1216 pieces and which expected to delivery in November 2010 for 315.22 (calculated from ED_{11}). In other words, about 315 pieces of EM have the lead time of 2 months. But this expected delivery quantity is only expected number. The delivery quantity obtained in the simulation model must be based on the actual data so this study uses the RDO or cumulative delivery to cumulative order quantity ratio obtained from the real data. In this case, the RDO of uniform distribution random number is based on unif ([0.3029,0.4000]) as it provides the lowest closing stock compared to 3 alternatives.

To find the cumulative delivery amount, it can be obtained from Eq. 4.21 as follows:

$$Cumulative\ delivery_9 = RDO_9\ X\ Cumulative\ order_9$$

$$Cumulative\ delivery_9 = 0.3319\ \mathrm{X}\ 5{,}288$$
$$= 1{,}755.08$$

Delivery quantity in period 9 is the amount discrepancy from the cumulative delivery period 8 and 9. Thus the delivery amount in period 9 is 315.28 as calculated below equation (Eq. 4.22).

$$Delivery_9 = Cumulative\ delivery_9 - Cumulative\ delivery_8$$

$$Delivery_9 = 1{,}755.08 - 1{,}440$$
$$Delivery_9 = 315.08$$

Now the amount of closing stock in period 9 can be calculated as Eq 4.20 accordingly:

$$Closing\ stock_9 = On\ hand_9 - demand_9 + Delivery_9$$

$$Closing\ stock_9 = 649 - 292 + 315.08$$

$$Closing\ stock_9 = 672.08$$

So the closing stock in period 9 is 672

Case 2 - Expected delivery quantity: Scheme 2

Review period: every month

No safety stock reserved

RDO set of uniform random numbers consisting of A= 0.3029, B= 0.4000

Table 4.2 The example of EM master table (Monthly review period with 0 month for safety stock) using Expected delivery equation by *scheme* 2 and set of uniform random number by variable (A = 0.0329, B = 0.4000)

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Month-Year	Opening stock	Actual demand	Demand forecasted by Simple exponential α 0.76	Order amount	Cumulative Order	Actual Delivery	Expected Delivery	Cumulative of expected Delivery	The set of uniform random number using variable A = 0.3029, B = 0.4000	Simlated delivery	Simulated cumulative Delivery	Simulated closing stock
2	May-10	963	329	380	0	0	384	384	384	0.0000		384	634
3	Jun-10	634	341	341	2019	2019	347	347	731	0.3860	395	779	688
4	Jul-10	688	346	341	99	2117	0	0	731	0.3680	0	779	342
5	Aug-10	342	354	345	1087	3205	664	48	779	0.3537	354	1134	343
6	Sep-10	343	292	352	1161	4366	0	0	779	0.3319	316	1449	366
7	Oct-10	366	306	306	201	4567	1428	354	1134	0.3713	246	1695	306
8	Nov-10	306	318	306	1346	5913	500	316	1449	0.3400	315	2010	303
9	Dec-10	303	260	315	498	6411	0	246	1695	0.3580	285	2295	328

By looking at September 2010, to calculate expected delivery quantity, it requires the similar concept as previous calculation in Case 1 but needs little change by using the equation 4.19 instead. So, $ED_{11}, ED_{10,} and\ ED_{9,}$ can be obtained as the results below.

$$ED_{9+2} = -OH_9 + F_9 + F_{9+1} + SS$$

$$ED_{11} = -343 + 351.79 + 306.35 + 0$$
$$= 315.14$$

For $ED_{10,}\ ED_{9,}$ are similarly used the calculation in the same way as ED_n ,which equal to 354.60, -2.15 respectively.

Note that: $ED_9 = -2.15$, it means that the expected delivery quantity is 0 because it is impossible to have negative stock being shipped anyway. So to calculate replenishment order quantity in $\boldsymbol{Period_9}$, it still requires the same equation 4.13 as below:

$$O_9 = \frac{ED_{11} + ED_{10} + ED_9 + CD_8}{RDO_9} - CO_8$$

$$O_9 = \frac{315.14 + 354.60 + 0 + 779.18}{0.3319} - 3{,}204.61$$
$$= 1{,}160.92$$

The order equation scheme 2 obtains order amount to make 1161 pieces in the period 9, September 2010 with expected delivery for November 2010 (ED_{11}), 315.14 or 315 pieces. Now the delivery amount will be derived from cumulative delivery amount as calculated below.

$$Cumulative\ delivery_9 = RDO_9\ X\ Cumulative\ order_9$$

$$Cumulative\ delivery_9 = 0.3319\ \mathrm{X}\ 4{,}366.01$$
$$= 1{,}449.08$$

$$Delivery_9 = Cumulative\ delivery_9 - Cumulative\ delivery_8$$

$$Delivery_9 = 1{,}449.14 - 1{,}133.60$$
$$Delivery_9 = 315.54$$

Now the amount of closing stock in period 9 can be calculated as follows:

$$Closing\ stock\ _9 = Opening\ stock_9 - EM\ demand_9 + Delivery_9$$

$$Closing\ stock_9 = 343\text{-}292\text{+}315.54$$
$$Closing\ stock_9 = 366.54$$

For summary of both cases results calculated by relevant equations so that they are described as details in table 4.3 below:

The table 4.3. Comparison of the output by expected- delivery equations between scheme 1 and 2.

Expected-delivery equation	Order amount	Expected delivery amount	Delivery amount	Closing stock amount
Scheme 1	1216.13	315.22	315.08	672.08
Scheme 2	1160.92	315.14	315.54	366.54

However, this study aims to find the solution in order to get optimal amount of leftover each month. The remaining inventory level should not be too high and meet the demand of customer. Further analysis is to simulate the model for several times by changing the input criteria to perform the master table. The input criteria consist of 3 alternatives by adjusting B value from 0.5402, 0.5000 and 0.4000. Moreover, another one criterion is added whose expected delivery equation is summarized as figure 4.8.

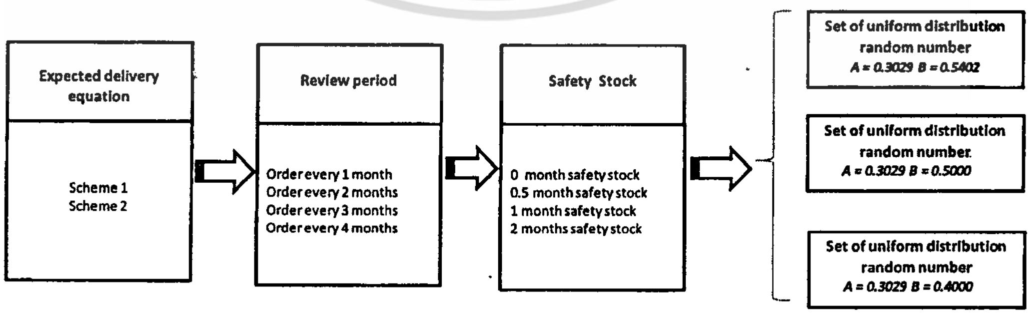


Figure 4.8 Testing pattern of EM simulated-order model by multiple criteria

Every alternative is computed and run by the master table to determine the amount of closing stock simulated during 20 months. So, if a set of uniform distribution random number is selected, the result would be 3,200 (100 * 2 * 4* 4). The number of simulation runs is 3,200, computed by 3 alternatives. So, the total number of simulation runs is 9,600 (3,200 *3). However, there are numerous numbers of uniform distribution random numbers and multiple criteria, as well as limited time and human resources. Writing command-code in Matlab program can be a tool to help in computing the simulation.

It is necessary that the simulated-order model should provide the least amount of closing stock. If the model can give lower inventory cost than before, it is important to consider and compare the amount of closing stock identified by simulated-order model. By using Matlab, it can provide outputs that show the amount of closing stock for all 3 alternatives. In this study, choosing the best alternative is based on testing criteria as described by figure 4.8.

Chapter V

The application and results

5.1 The classification of spare parts inventory

The first group of water purifier spare parts samples is classified as Class “A” items. According to Pareto analysis [14, 21, 22], almost 80 percent of the effects derive from 20 percent of the causes. This study discusses about the effects of investment or inventory cost, caused by fluctuated number of items in inventory. Of all items in inventory, 20 percent of them are the high value and fast moving items which are important for monitoring. In this study, it focuses on studying these items with the aim of reducing inventory cost.

With regard to “ABC” approach [14, 21, 22], items in the inventory are classified according to their priority or value. Generally, annual dollar value is used as classification criteria. The annual dollar value can be derived from dollar value per unit multiplied by annual usage rate. Typically, items can be classified in to three classes based on their priority, including, Class “A” refers to most important items, Class “B” refers to moderate important items, and Class “C” refers to least important items. While the amount of items in Class “A” accounts for 10-20 percent of all items, its annual dollar value is around 60 to 70 percent of all items.

The number of electronic module part, “EM” is selected as representative of an entire Class “A” population. By considering Class A spare parts, whereas total inventory cost is 82.67 percent, EM accounted for 52.42 percent of an entire inventory cost as depicted below.

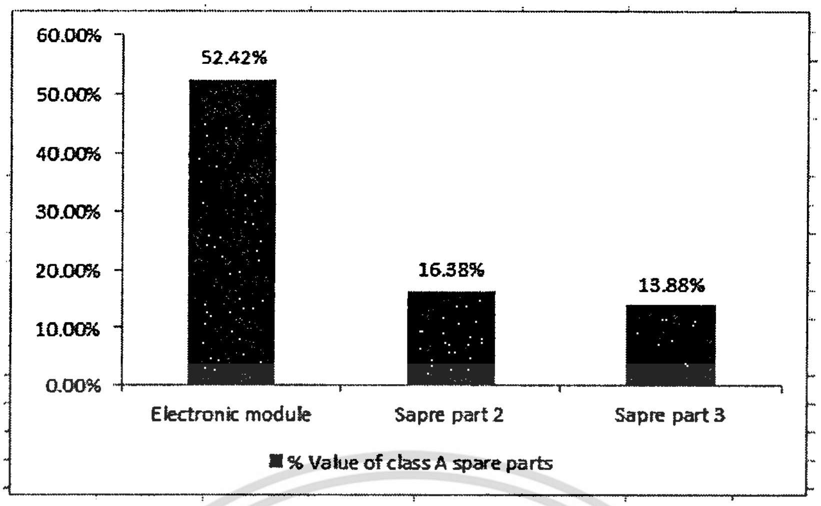


Figure 5.1 Classification of spare parts inventory (Class A)

Since "EM" is the spare parts in Class A with the largest share of the whole, it is our primary focus in this study in order to improve spare parts inventory management policy. The Pareto-analysis curve will show relationship of 80/20 Rule as illustrated in figure 5.2 below.

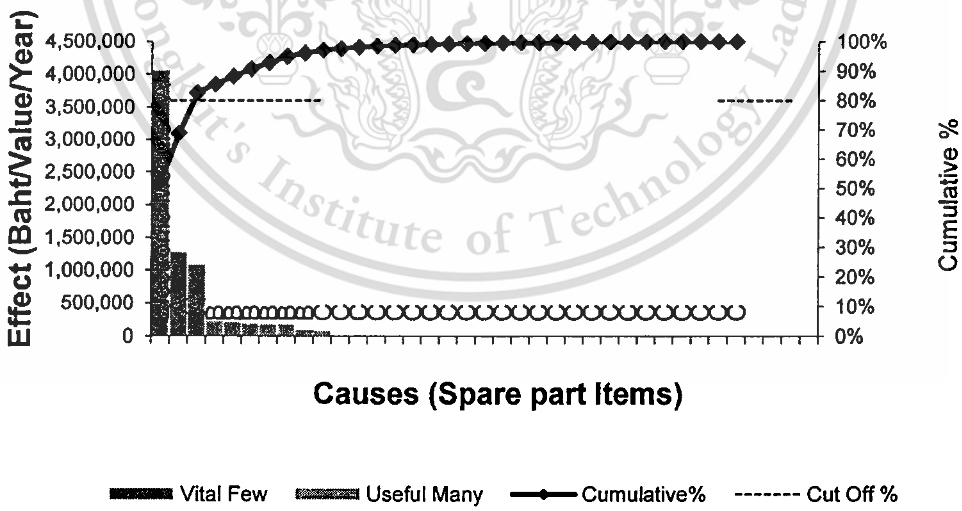


Figure 5.2 Causes and Effects of spare parts – water treatment system inventory

Table 5.1 Cumulative percentage of spare parts values

Cumulative Percentage Cutoff: 80%

#	Causes (Spare part Items)	Effect (Baht/Value/Year)	Cumulative%
1	Electronic Module - A	4,063,752	52.4%
2	A	1,269,576	68.8%
3	A	1,075,942	82.7%
4	B	229,173	85.6%
5	B	207,335	88.3%
6	B	185,225	90.7%
7	B	168,199	92.9%
8	B	162,745	95.0%
9	B	90,983	96.1%
10	C	68,199	97.0%
11	C	45,475	97.6%
12	C	39,066	98.1%
13	C	28,714	98.5%
14	C	15,500	98.7%
15	C	13,244	98.8%
16	C	12,975	99.0%
17	C	12,065	99.2%
18	C	11,911	99.3%
19	C	8,605	99.4%
20	C	8,208	99.5%
21	C	7,179	99.6%
22	C	5,996	99.7%
23	C	4,849	99.8%
24	C	3,967	99.8%
25	C	3,769	99.9%
26	C	2,688	99.9%
27	C	2,676	99.9%
28	C	2,393	100.0%
29	C	1,343	100.0%
30	C	814	100.0%
31	C	465	100.0%
32	C	403	100.0%
33	C	225	100.0%

From the table 5.1, total value of entire inventory in Class A (three types of spare parts) is 82.7 percent. Clearly, "EM" is a type of spare parts with the highest value among Class "A" inventory. So it deserves to be investigated to determine further inventory management policy.

5.2 Demand Forecasting

Prior to identifying an approach to inventory management, it needs the forecasting process. The data on historical demand for "EM" is available. To forecast, data were collected from January 2008 to December 2011. Data on historical demands could be searched and traced from the AS400 system as depicted in figure 5.3.

As mentioned earlier, this study chooses three forecasting techniques for measuring demand forecast accuracy. These three techniques include moving average methods, exponential smoothing technique and linear regression technique.

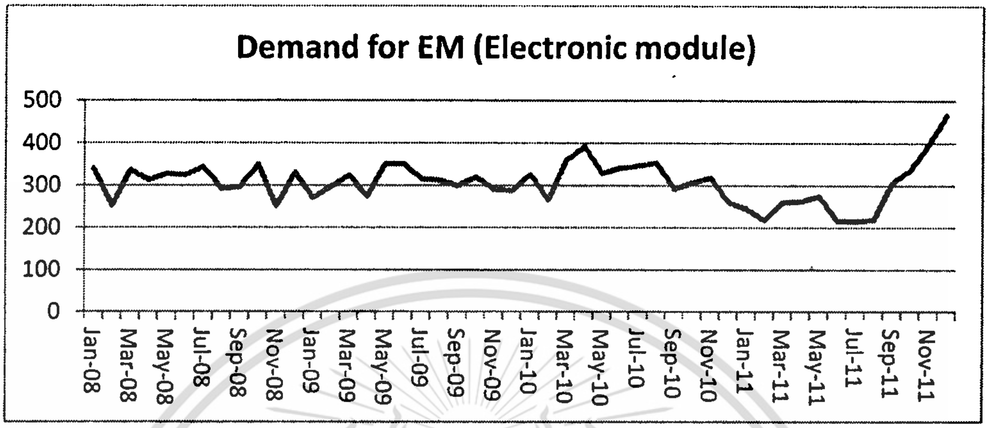


Figure 5.3 Demand for EM (Electronic module)

Figure 5.3 illustrates the demand for EM. The variation in demand can be described by statistical values shown below. The statistics are calculated from excel functions given as follows:

Max = 465

Min = 216

Mean (average) = 307.31

Median = 312.5

Standard deviation = 48.97

As the above statistics, the average monthly demand for EM is 307.31. According to [14], it stated that if there is a demand for more than 10 items per month, these items are considered as fast moving items . The simple exponential smoothing is not suitable for intermittent demand stated by Croston (1972) but it works well for fast moving inventories [10, 25]. So this means that demand for EM could be used simple exponential smoothing to forecast its demand.

Forecasting process is conducted in order to find which forecasting methods will give the least error. Forecasting alternatives are obtained from the software, POM-QM for window (Excel QM) as shown in table 5.2.

Table 5.2 Comparison of forecasting methods, classifying by different forecast accuracy measures

	Forecast method			
Forecast error	Simple Exponential α 0.76	2 month - period Moving average	3 month - period Moving average	Regression
MAD	**35.14**	35.90	36.46	37.37
MSE	1919.64	**1838.56**	2032.90	2373.48

Forecast error is used to measure forecasting accuracy. Forecast error is the difference between actual demand and forecast demand. In this study, demand was predicted for a specific time-period (From January 2008 to December 2011). To obtain the lowest forecast error, MAD, MSE are considered to evaluate the performance of the forecasting system.

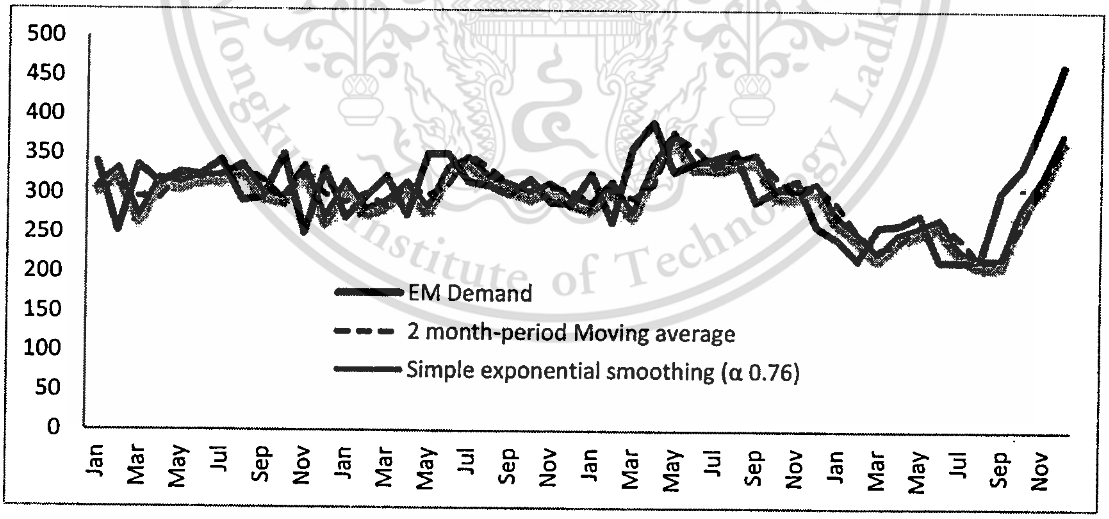


Figure 5.4 Comparison of forecasting methods of demand for EM

The forecast results from the table 5.2 and figure 5.4 show that the best result of all forecasting methods is not obvious. As simple exponential smoothing with alpha of 0.76 has the lowest of MAD at 35.14, whereas moving average two month period outperforms the first one for MSE at 1838.56. In the first stage, we will use the simple exponential smoothing with alpha of 0.76 to be the first forecasting technique to find the ordering policy. Then the latter will be performed at the end of this study to compare their results which technique could give the betterment.

5.3 Simulation model to find optimized inventory control policy

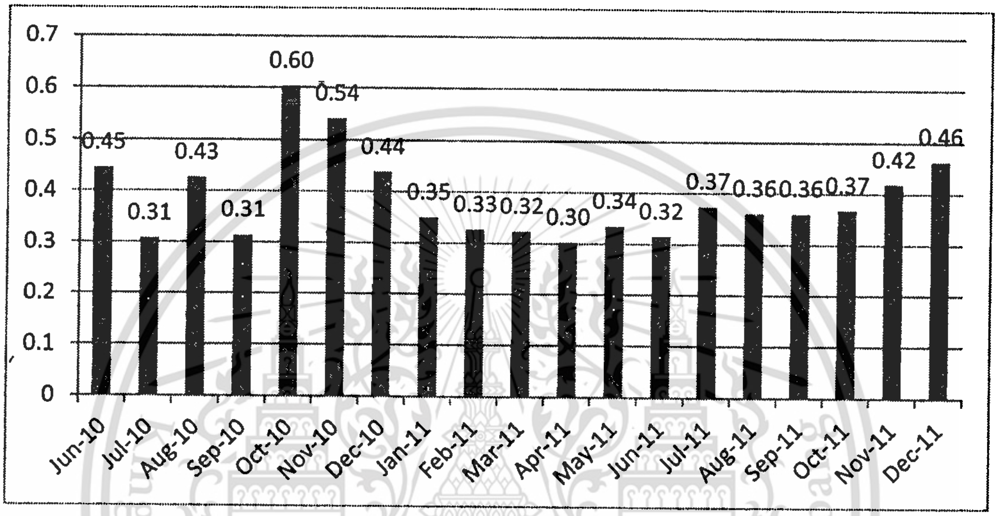
The fundamental aims of inventory control are to consider the following issues; how often to review the inventory level, when an order for replenishment should be placed at the time of review and how large the order size should be made. Regarding the simulation model of this study, it is necessary to find the solution of these questions. Historical data is traced to put into the model integrated between actual data from AS400 system and some simulated data. The simulated-order model is designed under excel spreadsheet. The results are shown as master tables to find the solutions (Please see Appendix A-1, A-2). The final results should not only cover the following solutions; when to order, how much to order and when to review, but it should provide solution to lower inventory cost.

The initial problems of this study come from uncertainty in lead-time, supply and demand. Moreover, previously the portion of delivery quantity and order quantity is used in the form of ratio. A simulated-order model is designed and established from those data. There are four-critical areas needed to solve the problems as follows.

5.3.1 Distribution Fitting

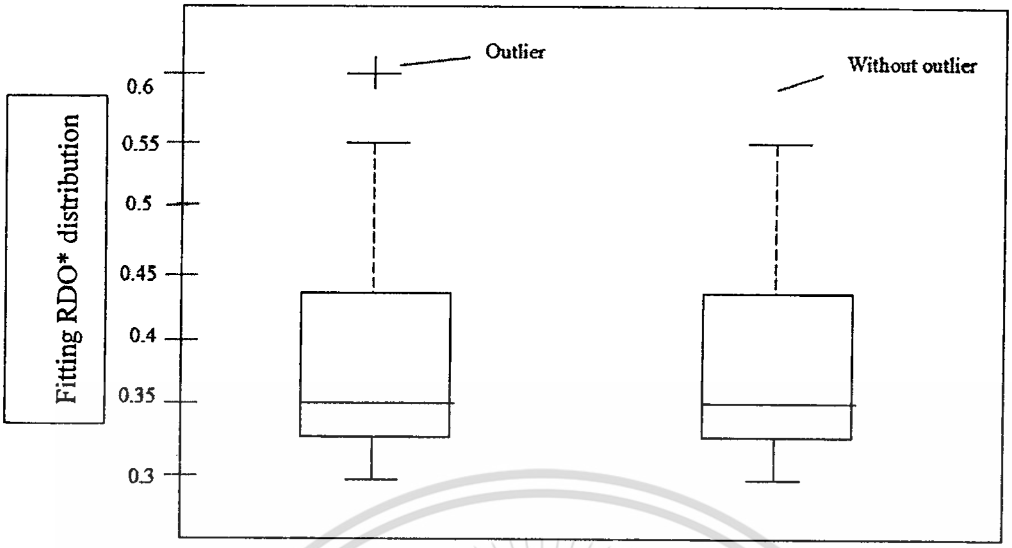
While the actual amount for delivering EM is extracted from AS400 system starting from Jun 2010 to December 2011, the amount of EM per order is available from manual data sheet created by the operator. Some of the data are missing and only available for this period. To answer the study questions, it needs two sources of data, including the amount for delivering EM and the amount of replenishment order at the specific period as mentioned above. Cumulative delivery quantity and cumulative order quantity are calculated as a ratio.

As stated at section 3.4 in chapter 3, RDO, a relative ratio, is the ratio of cumulative delivery quantity to cumulative order quantity in the specific monthly review period. The RDO is calculated according to the data set available and has the output as depicted in figure 4.2



Refer to figure 4.2: the ratio of cumulative delivery to cumulative order quantity of EM (electronic module)

The figure 4.2 shows that the relation between cumulative delivery and order has significance. We construct the box plot of EM using RDO in order to test how the RDO looks like. The figure 4.4 presents the boxplot of EM data, which is ratio of the cumulative delivery to cumulative order quantity.



Refer to Figure 4.4: Comparison between box plot with outlier and without outlier

The maximum RDO value of 0.6029 appears to be an outlier according to figure 4.4. Thus, it is eliminated out in order to adjust the range extending from 0.3029 to 0.5402. As illustrated from histogram in figure 5.5 below, A line equals to 0.3029 and B line equals to 0.5402.The range between A and B line is expected to be the continuous uniform distribution of the RDO.

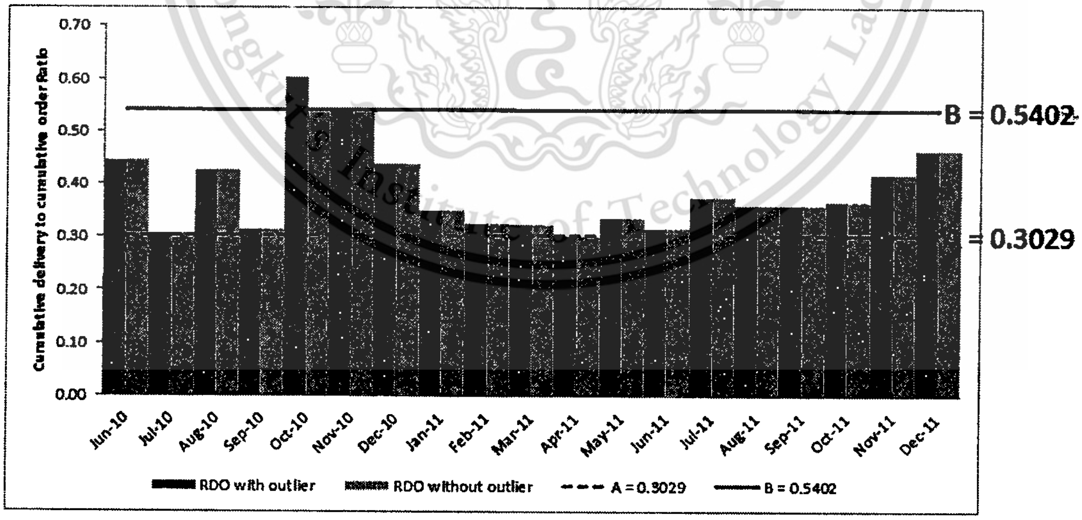


Figure 5.5 Comparison between the cumulative delivery to cumulative order quantity ratio with and without outlier

The probability distribution of the cumulative delivery to cumulative order quantity ratio is assumed to be continuous uniform distribution[24]. Thus the ratio would have a constant probability that could fall within any interval of fixed length [A= 0.3029, B=0.5402], the density function of a uniform random variable on the interval [A, B] is shown in figure 5.6.

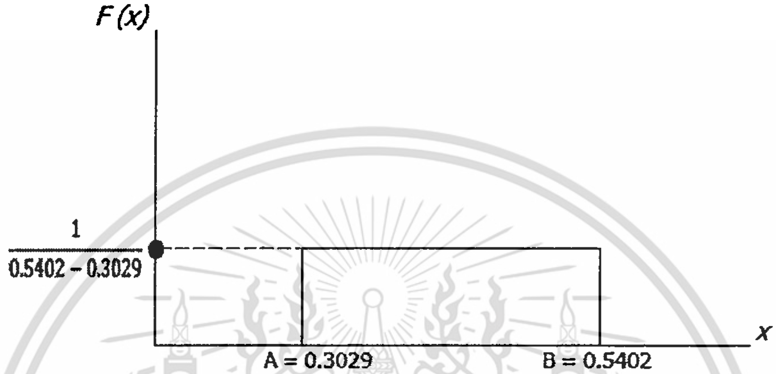


Figure 5.6: The density function of a random variable on the interval [0.3029, 0.5402]

5.3.2 Test of goodness of fit

This section involves with the hypothesis-testing procedure in which the population or probability is unknown. Because it is unknown that the underlying distribution of the population from the ratio of cumulative delivery to cumulative order quantity of EM, this study intends to test and satisfy the hypothesis as a population model. A density or rectangular function called "Continuous Uniform Distribution" is expected to be tested by a formal goodness-of-fit test based on the chi-square distribution[24] with minimum of 0.3029 and maximum of 0.5402 (unif[0.3029,0.5402]). Please see appendix B. The p-value of 0.0593 confirms that RDO follows the continuous uniform distribution at 95% significant level.

Since p-value 0.0593 is more than α 0.05, then we fail to reject H_o and conclude with 95% confidence that the form of the distribution of RDO follows continuous uniform distribution unif([0.3029,0.5402]).

5.3.3 Random number generation

Necessarily, this study simulates some artificial-delivery amount obtained from random number output generated by Matlab program. Command Code is written for this specific purpose.

The set of 100 random numbers is generated from cumulative delivery to cumulative order ratio. Each set contains 20 ratios which stand for RDO from May 2010 to December 2011 (May is a month added for a value of 0.00 ratio and also some actual necessary- based data to be starting period and to fit the equations in master table, please see Appendix A-1, A-2). The 100 set of random numbers will be used to run the further simulated-order model. The random numbers are advantageous to find artificial-delivery amount when creating a master table of simulated-order model. Please see Appendix D -1, D-2, and D-3.

5.4 The results

The proposed ordering policy is established under testing pattern illustrated in figure 4.8 and depicted as two equations for expected delivery, four ordering frequencies and three level of safety stock for a total of 32 combinations but there is also 100 random numbers from 3 alternatives of B values. The four ordering frequencies are range from ordering every one month, two month, three month, and up to four month. Whereas four levels of safety stock are set at 0, 0.5, 1 and 2 month. Thus number of simulation runs would be 3,200 (2x4x4x100), computed by 3 alternatives totally 9,600 times.

For comparison between the model and current ordering policy, the amount of each month remains from actual data available. Table 5.3 shows actual data of closing stock or the remaining EM spare parts at the end of the month from May 2010 to December 2011 (total of 20 months).

Table 5.3 Actual closing stock of EM (Electronic module)

May-10	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10	Jan-11	Feb-11
1018	1024	678	988	696	1818	2000	1740	1496	1374

Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11	Oct-11	Nov-11	Dec-11
1306	1043	1268	1051	1635	1416	1110	1279	1652	1862

The results obtained from Matlab suggest that an alternative with B variable (0.4000) using Scheme 2- expected delivery equation outperforms other alternatives as it can give lowest mean amount of EM-closing stock as depicted in figure 5.12. Moreover, comparing all of alternative results with B = 0.5402. 0.5000 and 0.4000 that obtain from Scheme 1 and Scheme 2- expected delivery Scheme. It is obviously indicated that the results from Scheme 2 could get the betterment in term of less mean amount of the EM- spare parts left over at each month. The results are shown as figure 5.7-5.12 and table 5.5. Note that: SS level stands for safety stock amount for 0 month, 0.5 month, 1 month and 2 months.

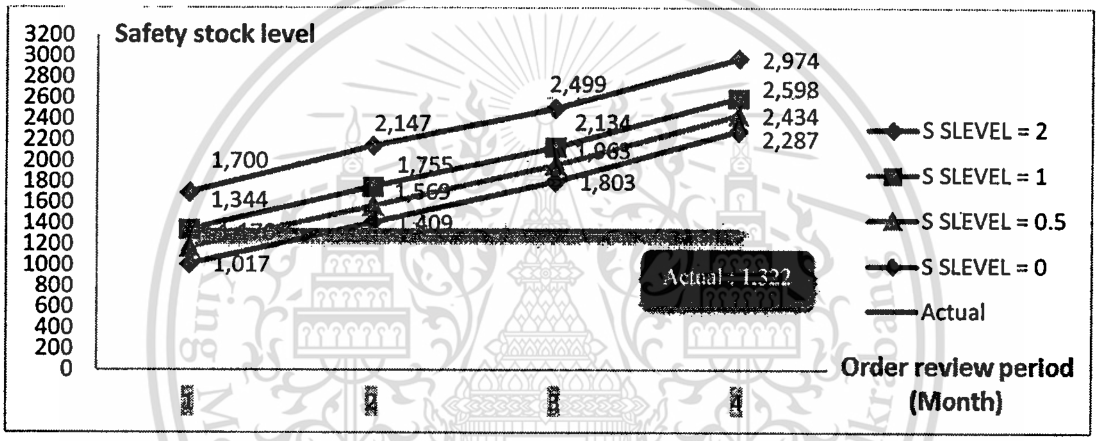


Figure 5.7 Mean amount of EM-closing stock with a set of uniform random number; A = 0.3029, <u>B = 0.5402</u> , Using expected delivery - *<u>Scheme 1</u>*

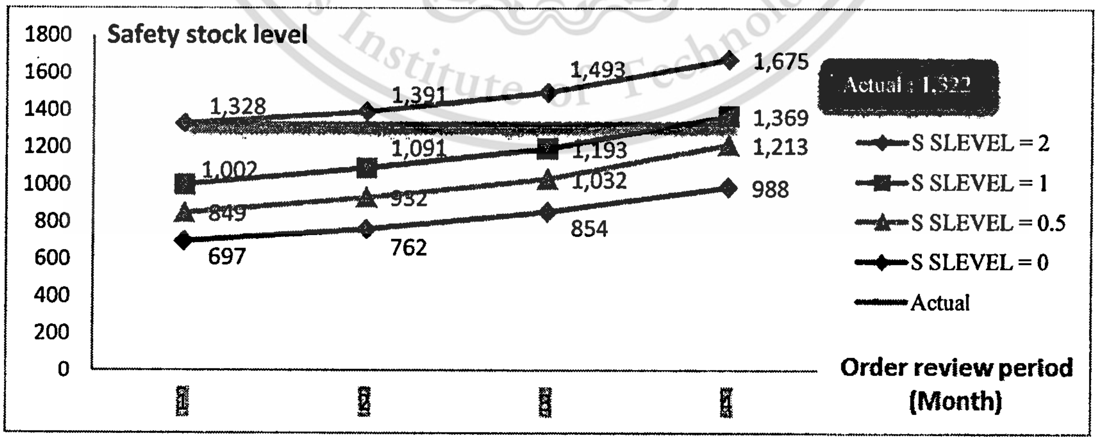


Figure 5.8 Mean amount of EM-closing stock with a set of uniform random number; A = 0.3029, B = 0.5402 Using expected delivery - Scheme 2

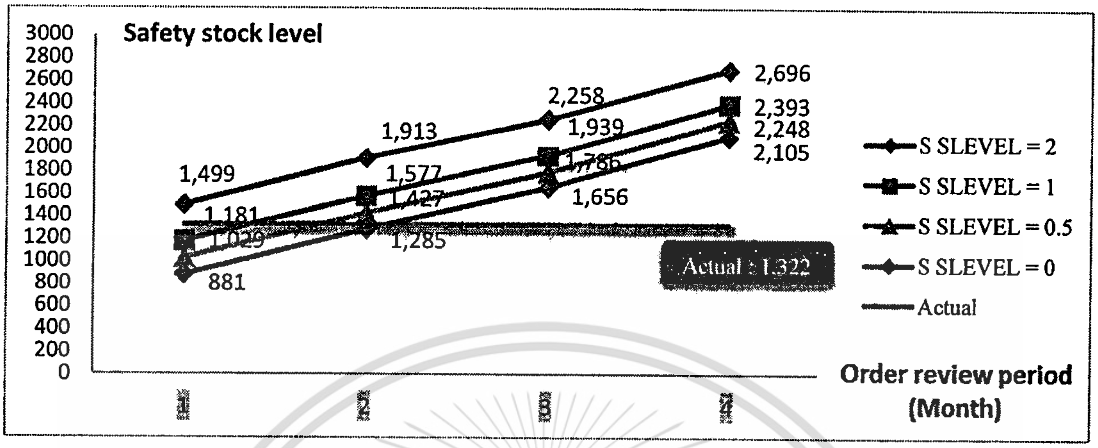


Figure 5.9 Mean amount of EM-closing stock with a set of uniform random number; A = 0.3029, B = 0.5000 , Using expected delivery – *Scheme1*

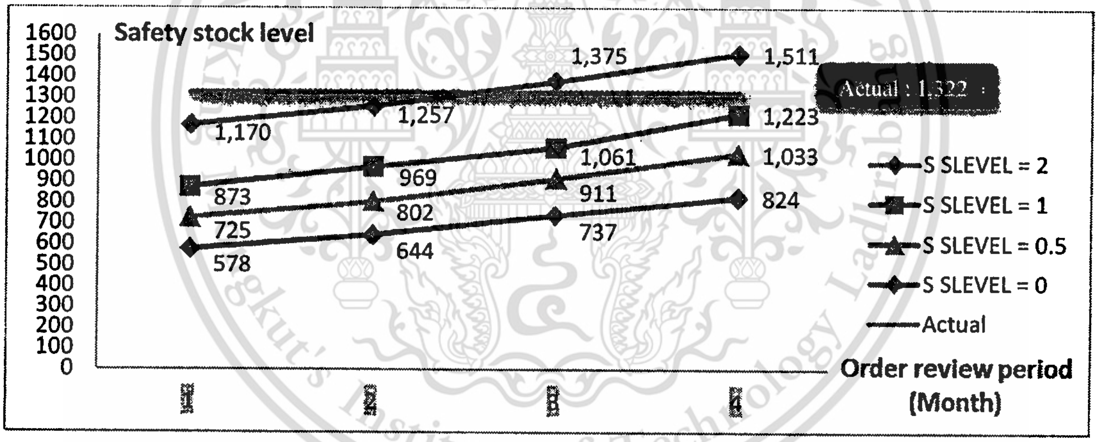


Figure 5.10 Mean amount of EM- closing stock with a set of uniform random number; A = 0.3029, B = 0.5000 , Using expected delivery – Scheme2

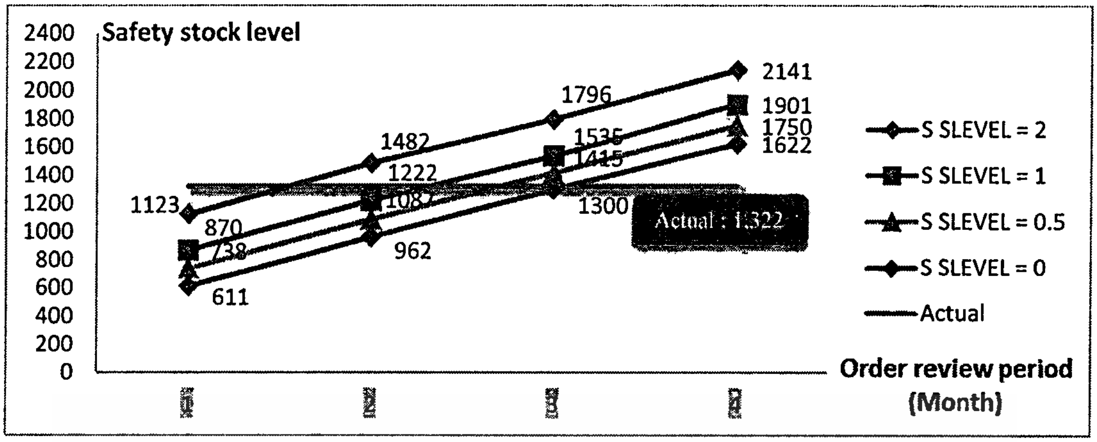


Figure 5.11 Mean amount of EM-closing stock with a set of uniform random number; A = 0.3029, B = 0.4000 , Using expected delivery – *Scheme1*

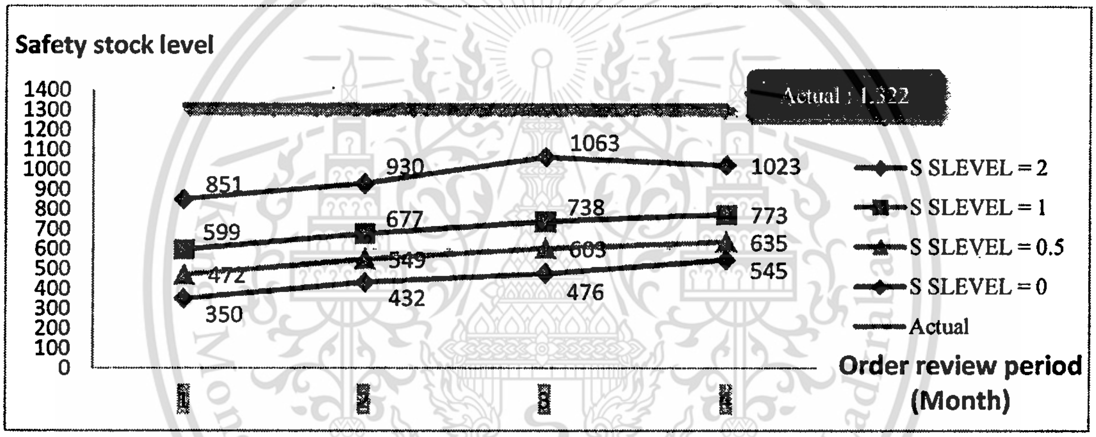


Figure 5.12 Mean amount of EM-closing stock with a set of uniform random number; A = 0.3029, B = 0.4000 , Using expected delivery – *Scheme2*

Table 5.4 Comparison of the results for mean amount of EM-closing stock with a set of uniform random number and mean of actual closing stock

Applied by Scheme 1 - expected delivery equation

Set of uniform random number	Safety stock level	Order review period (month)			
		1	2	3	4
A= 0.3029, B= 0.5402	2	1700	2147	2499	2974
	1	1344	1755	2134	2598
	1/2	1176	1569	1963	2434
	0	1017	1409	1803	2287
A= 0.3029, B= 0.5000	2	1499	1913	2258	2196
	1	1181	1577	1939	2393
	1/2	1029	1427	1780	2248
	0	881	1285	1656	2105
A= 0.3029, B= 0.4000	2	1123	1482	1796	2141
	1	870	1222	1535	1901
	1/2	738	1087	1415	1750
	0	611	962	1300	1622
Actual closing stock	2	1322	1322	1322	1322
	1	1322	1322	1322	1322
	1/2	1322	1322	1322	1322
	0	1322	1322	1322	1322

Table 5.5 Comparison of the results for mean amount of EM-closing stock with a set of uniform random number and mean of the actual closing stock *Applied by Scheme 2* - expected delivery equation

Set of uniform random number	Safety stock level	Order review period (month)			
		1	2	3	4
A= 0.3029, B= 0.5402	2	1328	1391	1493	1675
	1	1002	1091	1193	1369
	1/2	849	932	1032	1213
	0	697	762	854	988
A= 0.3029, B= 0.5000	2	1170	1257	1375	1511
	1	873	969	1061	1223
	1/2	725	802	911	1033
	0	578	644	737	824
A= 0.3029, B= 0.4000	2	851	930	1063	1023
	1	599	677	738	773
	1/2	472	549	603	635
	0	350	432	476	545
Actual closing stock	2	1322	1322	1322	1322
	1	1322	1322	1322	1322
	1/2	1322	1322	1322	1322
	0	1322	1322	1322	1322

The combination of A variable (0.3029) and B variable (0.4000) provides lowest amount of EM-closing stock. As illustrated in figure 5.12 and table 5.5, the bottom line with zero safety stock level implies lowest cost. It could be concluded that suggested ordering policy should give the lowest amount of closing stock, place an order every a single month, with no safety stock, by applying Scheme 2 – expected delivery equation to calculate. With on month review period and zero safety stock level, the amount of closing stock is only 350 units, signifying lowest amount, while with different safety stock levels (1/2, 1, and 2), the amounts of closing stock include 472, 599 and 851 units, respectively.

To ensure the combination of A variable (0.3029) and B variable (0.4000) outperforms other alternatives, it is necessary to compare their inventory costs. All relevant inventory costs from actual data are arranged. 100 data sets are generated by Matlab program. The figure 5.13 shows inventory cost of three combinations and actual cost of the EM-closing stock.

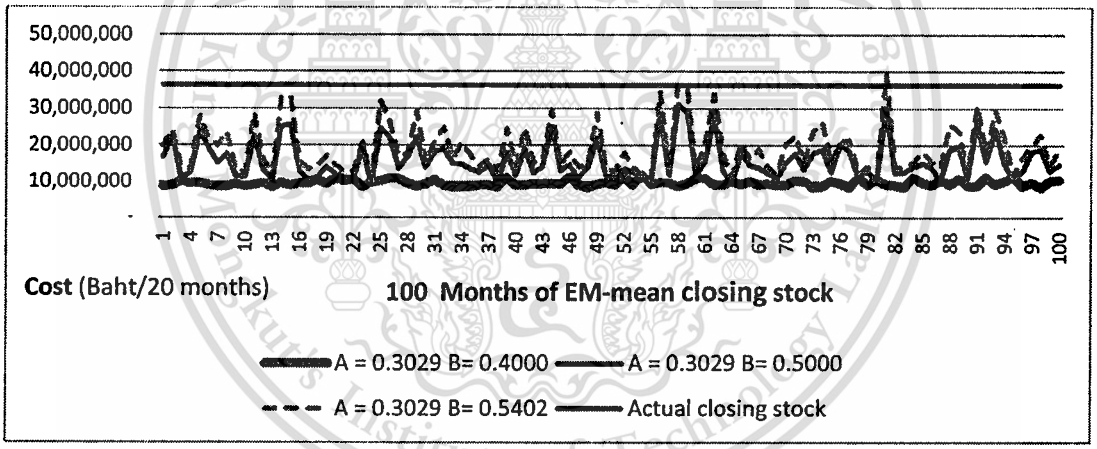


Figure 5.13 The inventory costs of three alternatives and actual cost of the EM-closing stock applied by *Scheme 2* – expected delivery equation.

The figure 5.13 shows three combinations of A variable (0.3029) and B variables (0.3300, 0.3500 and 0.4000.). These are alternatives with three inventory costs, which are computed by order cost, caring cost and product cost. Please see details of the inventory cost in Appendix C -The case application for EOQ model (Economic Order Quantity, P.90). 100 data sets of closing stock during 20 months are used to process and shown as aggregate cost. The cost calculation of all 3 alternatives is used as supportive information.

The figure 5.13 is also an output of 100 times repeat for random generation from RDO which becomes random number generation depending on seed number. If the seed number changes, to simulate 100 times it reveal that RDO from B variable; 0.4000 could give the lowest output, however applying random generation would be a great performance in this simulation.

The figure 5.14 below provides more details and illustrates the mean inventory costs of all 3 alternatives and the actual cost of EM- closing stock.

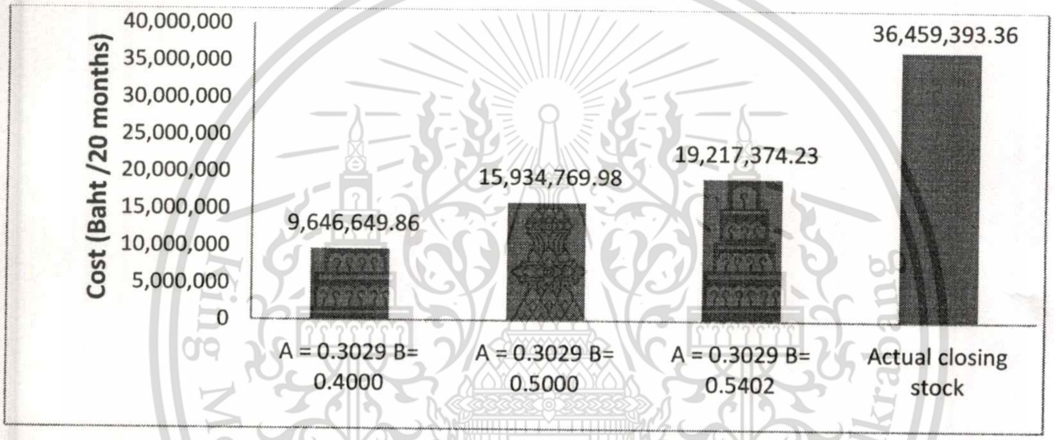


Figure 5.14 Mean inventory costs of three alternatives and actual value of closing stock applied by *Scheme 2* – expected delivery equation.

According to the figure 5.14, the combination of A variable (0.3029) and B variable (0.4000) provides the best result, suggesting lowest amount of closing stock and lowest inventory cost. More importantly, it is essential to identify which forecasting method can give lowest cost. Therefore three forecasting techniques are tested through master table and Matlab program. The table 5.6 below reveals the comparison cost of the different alternatives and different forecasting methods results.

Table 5.6 Mean inventory cost of 3 different alternatives and different forecasting methods

(Cost/Baht)	Forecast Method	
Set of uniform random number by variable	2 period-Moving average	Exponential smoothing (α 0.76)
A = 0.3029 B= 0.4000	9,680,565	9,646,650
A = 0.3029 B= 0.5000	16,056,785	15,934,770
A = 0.3029 B= 0.5402	19,378,856	19,217,374
Actual closing stock	36,459,393	36,459,393

As shown in table 5.6, it is obvious that Simple exponential smoothing (α 0.76) is a forecasting method that provides lowest inventory cost (by selecting A= 0.3029 and B = 0.4000). Finally, it can be concluded that a new ordering policy for EM performed by the simulated-order model can be implemented as the following steps:

Forecasting method: Simple exponential smoothing (α 0.76),

Review period: Every month,

Safety stock: 0 month level,

Expected- delivery equation: Using Scheme 2,

RDO set of uniform random number: Variable A = 0.3029 and B = 0.4000.

Chapter VI
The conclusion and recommendations

6.1 The summary of problems

In this study, an initiative to improve the management of water purifier spare parts, Electronic Module (EM) inventory, has been proposed. It concerns ordering policy that deals with inventory replenishment control problem under supply uncertainty as well as the fluctuation in supply lead-times and order quantity to be received. Also, uncertainty in spare parts demand is an obstacle to make an order. Moreover, the company's current inventory system does not provide efficient solution for the manager to deal with issues of order placement and replenishment order quantity because it does not provide all of the related-historical data and lacks linkage between the company's and ADA's (a headquarter in USA) useful- inventory information. The present ordering policy is based on the manager's arbitrary decision making or an intuitive-based decision making. According to inventory management problem mentioned earlier, this study has a strong desire to find a solution as well as to discover a new empirical model of inventory management.

6.2 The solution

According to the classification of the spare parts inventory under Pareto Analysis, it indicated that EM inventory acts as the representative of Class A items population. It accounts for 52.42 percent of an entire inventory cost. The total inventory cost equals to 82.67 percent. The EM spare parts are suitable to be chosen for conducting simulation test, which provides a new model of inventory management, leading to lower inventory cost. EM items have the highest inventory cost. Therefore, this is the study to perform the simulated-order model.

This study aims to find a suitable forecasting method that provides the least forecast error and also can be implemented in practices. However, the EM demand seems to be unpredictable; on the other hand, it is not intermittent but fast moving item as shown in figure 5.3. Firstly, forecasting method alternatives are compared. It was not found that the simple exponential method using α of 0.76 nor 2 month- period moving average that has result for the best in term of least error. Eventually they are tested which forecast method could give the least inventory cost. At the end of this study analysis, the simple exponential method is selected as a forecasting method to implement to a new model of ordering policy as it provides lowest inventory cost.

With a new empirical model of ordering policy, actual data on cumulative delivery quantity and order quantity during May 2010 and December 2011 are used. The data on cumulative delivery quantity to order quantity ratio are used to generate the distribution probability and random number generation. The ratio of cumulative delivery quantity to cumulative order quantity is applied to the model simulation giving a significant relationship ratio of 0.31 – 0.60. Therefore the statistical theory, the continuous uniform distribution and random number generation can be integrated to test the simulated-order model. It is proved that continuous uniform distribution is a behavior of random generation number from RDO, ratio of cumulative delivery quantity to cumulative order quantity, of Electronic Module (EM) as shown in the equation 4.8. Hypothesis testing is conducted by using Matlab program. Formal goodness of fit test procedure is based on the chi-square distribution and obtained the density function for a uniform random variable on the interval [0.3029 ,0.54020]; A variable (0.3029) and B variable (0.5402). The set of 100 random numbers is generated from cumulative delivery quantity to cumulative order quantity ratio in order to simulate the necessary delivery quantity and order quantity. The equations are integrated in a simulated-order model in the form of excel spread sheet.

The new ordering policy has been discovered by the equations created in simulated-order model such as expected delivery equation depicted in 4.15-4.19. These equations derived from the actual data, expected delivery equations and the RDO. As shown in equation 4.19, Scheme 2 equation could give the better result than Scheme 1 equation as depicted in equation 4.15-4.18. The study's analysis test is performed in various testing patterns as figure 4.8. The simulation is created in form of excel spreadsheet as illustrated in Appendix A-1 and A-2. Moreover, Matlab, a tool program is able to help saving time to perform the multiple simulations (9,600 times), with 3 combinations between A variable (0.3029) and B variable (0.5402, 0.5000 and 0.4000). Multiple tests through simulated-order model give the outputs of 100 data sets for 20 months. The best alternative is to make an order every month with no reserved safety stock, and with the combination between A variable (0.5402) and B variable (0.4000). This alternative gives the lowest closing stock, outperforming other alternatives and current intuitive-based method as illustrated in figure 5.12 and table 5.5. Moreover, to compare the combination between A variable (0.3029) and B variable (0.4000) with other alternatives, it is necessary to compare inventory cost. Therefore, it needs to consider and compare the quantity of closing stock left over the specific 20 months among 3 alternatives. Eventually, the result found that the combination between A variable of 0.3029 and B variable of 0.4000 gives lowest inventory cost as depicted in figure 5.13 and 5.14. In summary, a new inventory policy is approached and it is recommended to make an order every month as it is a suitable review period. Determining the amount to place an order is upon the derivative of Scheme 2- expected delivery and order equation with no safety stock to reserve, while the combination between A variable (0.3029) and B variable (0.4000) is selected. This alternative can provide lower inventory cost to the company.

6.3 The recommendations

Further practices or some suggestions can be summarized as follows:

According to Pareto analysis, EM (Electronic module) spare part is categorized as Class A inventory. However, future study should extend the study scope to Class A inventory.

A random number generation and probability distribution are both useful to find an optimal spare parts ratio to generate simulated-delivery quantity as well as order quantity.

The company should have tradeoff between the cost and simple forecasting method. According to the result of the study shows that simple exponential smoothing could give the better output than moving average. Thus the company might choose moving average in order to decrease the difficulty of forecasting process or using the simple exponential smoothing if focusing on the lower inventory cost depending on the company's policy.

With continuous improvement for the spare parts inventory management, the company should consider in eliminating the uncertainty matters by learning the headquarter and supplier management. To find a valid lead time and reduce any supply uncertainty, it necessary to negotiate with suppliers [14].

In simulated-order model placing an order every one month with no safety stock using a set of uniform distribution by B variable = 0.4000 and calculated by scheme 2-expected delivery equation, it was found a few of shortage in EM closing stock during 20-month period. The highest number of spare parts shortage may occur only 0.58 month (mean figure generated by 100 times), or 0.35 times in a year according to result from new ordering model as Appendix A3. So, customer service and royalty service costs may incur regarding decreasing a goodwill of the company. Those costs are hard to estimate. In practice, air transportation would be considered as it shortens delivery lead time. The planning staff at a headquarter in USA. always permits air transportation method and accepts its air transportation cost to send the spare parts to warehouses in Bangkok under the right replenishment order. The shortage of spare parts found in a simulation model can be solved by a practitioner who immediately foresees a low level of spare parts. Before a shortage event, a practitioner must ask for sending spare parts to warehouse via air transportation methods. Moreover, the air transport cost can be absorbed by a headquarter in USA in all cases except in case of executing wrong replenishment order. Therefore, EM spare parts shortage event at the end of some months does not matter than appropriate replenishment order quantity and order time.

To gain a good inventory system, any organization should provide two effective functions to serve customer demand’s responsiveness[22]. One system could track any items available in the inventory and the quantity on hand, and the other, the system could tell how much and when to order. The fact is that in this study, the company has faced the troubles of tracking historical data on delivery quantity and order quantity as well as inventory movement in real time. Also arbitrary decision making by an operator to place an order is troublesome. Moreover, the spare parts inventory system lacks of full linkage to share information between Thai and USA locations. It also has no real time online system to capture the spare parts order movement. Those problems create wrong order quantity or bullwhip effect, which means misunderstanding on actual demand for the spare parts. The solution of the present problems is to apply an ERP approach (enterprise resource planning), an integrated system to use computer technology to link various functions so that it provides information sharing among the entire organization's supply chain. Especially, one of the modules in ERP has an inventory management function which can cope with the problems as it can track the entire spare parts inventory in Thai and U.S warehouses. The benefit of ERP is to determine what size should an order be made and when to make an order for efficient demand forecasting. At the end, with ERP approach, the response will meet the customer's demand with optimal inventory level, which will be an ultimate desire of the organization.

6.4 The conclusion

Multiple tests through simulated-order model give the outputs of 100 data sequences of random numbers for 20 months. The best alternative is to make an order every month with no reserved safety stock, with using RDO from continuous uniform distribution. This alternative can provide lower inventory cost to the company. It can save the cost for approx. 73.54% with a current ordering policy provides the actual closing stock of 36,459,393 baht per month for 20- month period, the new model of ordering policy gives the actual closing stock of 9,646,649 baht per month. Therefore, the new ordering policy can give lowest inventory cost compared to 3 competitive alternatives and the current inventory policy meanwhile it can maintain spare parts availability level.

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Appendix

Appendix A – EM master table for new ordering model.

A-1 EM master table (Monthly review period with 0 month for safety stock) using Expected delivery equation by ***scheme 1*** and set of uniform random number by variable (A = 0.0329, B = 0.4000). Supposing, we place an order at the beginning of September 2010.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Month-Year	Opening stock	Actual demand	Demand forecasted by Simple exponential α 0.76	Order amount (1)	Cumulative Order	Actual Delivery	Expected Delivery (2)	Cumulative of expected Delivery	The set of uniform random number using variable A = 0.3029, B = 0.4000	Generated delivery (4)	Generated cumulative Delivery (3)	Generated closing stock (5)
2	May-10	963	329	380	0	0	384	384	384	0.0000	0	384	634
3	Jun-10	634	341	341	2912	2912	347	347	731	0.3860	740	1124	1033
4	Jul-10	1033	346	341	155	3067	0	0	731	0.3680	5	1129	692
5	Aug-10	692	354	345	1004	4071	664	393	1124	0.3537	311	1440	649
6	Sep-10	649	292	352	1218	5288	0	5	1129	0.3319	315	1755	672
7	Oct-10	672	306	306	127	5416	1428	311	1440	0.3713	255	2011	622
8	Nov-10	622	318	306	1301	6717	500	315	1755	0.3400	273	2283	576
9	Dec-10	576	260	315	395	7112	0	255	2011	0.3580	263	2546	579
10	Jan-11	579	244	273	0	7112	0	273	2283	0.3891	221	2768	557
11	Feb-11	557	218	251	397	7510	96	263	2546	0.3848	122	2889	460
12	Mar-11	460	260	226	607	8117	192	171	2717	0.3902	278	3167	478
13	Apr-11	478	263	252	695	8812	0	172	2889	0.3941	306	3473	521
14	May-11	521	275	260	908	9720	500	278	3167	0.3821	241	3714	487
15	Jun-11	487	217	271	3308	13028	0	306	3473	0.3030	234	3948	504
16	Jul-11	504	216	230	536	13564	800	241	3714	0.3032	165	4113	453
17	Aug-11	453	219	219	514	14077	0	234	3948	0.3114	271	4384	505
18	Sep-11	505	306	219	261	14339	0	165	4113	0.3282	323	4706	521
19	Oct-11	521	335	285	2609	16947	504	271	4384	0.3051	465	5171	651
20	Nov-11	651	395	323	0	16947	768	323	4706	0.3441	660	5831	916
21	Dec-11	916	465	378	0	16947	675	465	5171	0.3360	0	5695	451

All important equations are applied on A-1 EM master table as follows:

1. Order amount (Column E, (1)) = Eq. (4.13) and the excel formula is

   =IF(((H8+H7+H6+I5)/J6)-F5>0,((H8+H7+H6+I5)/J6)-F5,0)

2. Expected-delivery amount, ***Scheme 1*** (Column H,(2)) = Eq.(4.15) and the excel formula is **=IF((D6-B4+D4+D5)>0,(D6-B4+D4+D5),0)**

3. Generated-cumulative delivery amount (Column L,(3)) = Eq.(4.21) and the excel formula is **=J6*F6**

4. Generated delivery (Column K,(4)) = Eq.(4.22) and the excel formula is

   =IF((L6-L5)>0,(L6-L5),0)

5. Generated-closing stock = Eq.(4.20) and the excel formula is =B6-C6+K6

A-2 EM master table (Monthly review period with 0 month for safety stock) using Expected delivery equation by ***scheme 2*** and set of uniform random number by variable (A = 0.0329, B = 0.4000). Supposing, we place an order at the beginning of September 2010.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Month-Year	Opening stock	Actual demand	Demand forecasted by Simple exponential α 0.76	Order amount	Cumulative Order	Actual Delivery	Expected Delivery	Cumulative of expected Delivery	The set of uniform random number using variable A = 0.3029, B = 0.4000	Simlated delivery	Simulated cumulative Delivery	Simulated closing stock
2	May-10	963	329	380	0	0	384	384	384	0.0000		384	634
3	Jun-10	634	341	341	2019	2019	347	347	731	0.3860	395	779	688
4	Jul-10	688	346	341	99	2117	0	0	731	0.3680	0	779	342
5	Aug-10	342	354	345	1087	3205	664	48	779	0.3537	354	1134	343
6	Sep-10	343	292	352	1161	4366	0	0	779	0.3319	316	1449	366
7	Oct-10	366	306	306	201	4567	1428	354	1134	0.3713	246	1695	306
8	Nov-10	306	318	306	1346	5913	500	316	1449	0.3400	315	2010	303
9	Dec-10	303	260	315	498	6411	0	246	1695	0.3580	285	2295	328
10	Jan-11	328	244	273	0	6411	0	315	2010	0.3891	199	2495	284
11	Feb-11	284	218	251	566	6977	96	285	2295	0.3848	190	2684	255
12	Mar-11	255	260	226	473	7450	192	196	2491	0.3902	222	2907	218
13	Apr-11	218	263	252	673	8123	0	193	2684	0.3941	294	3201	249
14	May-11	249	275	260	995	9118	500	222	2907	0.3821	283	3484	257
15	Jun-11	257	217	271	3186	12304	0	294	3201	0.3030	245	3729	285
16	Jul-11	285	216	230	537	12841	800	283	3484	0.3032	165	3893	233
17	Aug-11	233	219	219	321	13162	0	245	3729	0.3114	205	4098	219
18	Sep-11	219	306	219	193	13355	0	165	3893	0.3282	285	4383	198
19	Oct-11	198	335	285	2355	15709	504	205	4098	0.3051	410	4793	273
20	Nov-11	273	395	323	0	15709	768	285	4383	0.3441	612	5405	490
21	Dec-11	490	465	378	0	15709	675	410	4793	0.3360	0	5279	25

All important equations are applied on A-1 EM master table as follows:

1. Order amount (Column E, (1)) = Eq. (4.13) and the excel formula is

   =IF(((H8+H7+H6+I5)/J6)-F5>0,((H8+H7+H6+I5)/J6)-F5,0)

2. Expected-delivery amount, *scheme 2* (Column H,(2)) = Eq.(4.19) and the excel formula is **=IF((-B4+D4+D5)>0,(-B4+D4+D5),0)**

3. Generated-cumulative delivery amount (Column L,(3)) = Eq.(4.21) and the excel formula is **=J6*F6**

4. Generated delivery (Column K,(4)) = Eq.(4.22) and the excel formula is

   =IF((L6-L5)>0,(L6-L5),0)

5. Generated-closing stock = Eq.(4.20) and the excel formula is **=B6-C6+K6**

A – 3 Comparison for the number of mean closing stock from 20 months (May 2010 to Dec 2011) using 0 month of safety stock level obtained from simulated-order model.

Comparison of the mean- closing stock by **0 month - safety stock level comparing between Expected delivery equation Scheme 1 and 2**							
Alternatives of the uniform random number (B variable adjustment)	Order frequency	Expected delivery scheme	0< X= < 2000 (1)	0< X <= Actual closing stock (2)	T = negative stock (3)	0 < T < 2000 (4)	0 < T < Actual closing stock (5)
0.54020	1	1	893	758	0.05	18.49	13.63
		2	629	539	0.19	19.05	17.24
	2	1	1185	1004	0.00	17.04	9.67
		2	697	603	0.56	18.44	16.49
	3	1	1392	1117	0.01	13.75	5.78
		2	752	625	0.87	17.67	14.91
	4	1	1506	1143	0.00	9.77	3.52
		2	881	739	1.21	16.97	14.03
0.50000	1	1	830	722	0.09	19.26	15.10
		2	556	506	0.27	19.42	18.40
	2	1	1138	962	0.01	17.83	10.59
		2	640	568	0.66	19.05	17.56
	3	1	1353	1084	0.00	15.25	6.93
		2	709	602	0.97	18.37	15.94
	4	1	1490	1160	0.00	11.11	4.32
		2	813	721	1.47	17.64	15.57
0.40000	1	1	620	586	0.27	19.73	17.63
		2	360	360	0.58	19.42	19.42
	2	1	961	878	0.03	19.92	15.03
		2	457	455	1.10	18.90	18.85
	3	1	1247	1037	0.00	15.94	6.49
		2	517	490	1.58	18.42	17.44
	4	1	1424	1116	0.00	15.94	6.49
		2	623	610	2.52	17.47	17.20

Remark : X stands for mean value of the closing stock amount left at the end of each month for 20 months which are tested by matlab per 100 times.

: T stands for mean of the quantity of tested times from the closing stock left at the end of each month for 20 months which are tested by matlab per 100 times.

(1) = mean values of the closing stock are between 0 to 2000; which 2000 is the maximum number of the actual closing stock for 20 months

(2) = mean values of the closing stock are between 0 to less than each number of the actual closing stock for 20 months

(3) = mean of the tested-times quantities which the closing stock amount are negative number

(4) = mean of the quantity of tested times which the closing stock amount are between o to 2000

(5) = mean of the quantity of tested times which the closing stock amount are less than each number of the actual closing stock for 20 months

A – 4 Comparison for the number of mean closing stock from 20 months (May 2010 to Dec 2011) using 0.5 month of safety stock level obtained from simulated-order model.

Comparison of the mean- closing stock by **0.5 month- safety stock level comparing between Expected delivery equation Scheme 1 and 2**							
Alternatives of the uniform random number (B variable adjustment)	Order frequency	Expected delivery scheme	0< X= < 2000 (1)	0< X <= Actual closing stock (2)	T = negative stock (3)	0 < T < 2000 (4)	0 < T < Actual closing stock (5)
0.54020	1	1	1005	850	0.02	17.81	11.64
		2	751	652	0.1	18.78	16.44
	2	1	1300	1079	0	16.13	7.76
		2	808	691	0.16	18.35	15.58
	3	1	1479	1170	0	12.04	4.77
		2	840	695	0.35	17.4	13.99
	4	1	1496	1158	0	7.3	2.84
		2	928	764	0.49	16.22	12.88
0.50000	1	1	955	818	0.04	18.97	13.22
		2	691	619	0.18	19.37	17.59
	2	1	1255	1063	0.01	17.3	9.15
		2	760	665	0.19	19.22	16.88
	3	1	1441	1140	0	14.06	5.87
		2	799	676	0.38	18.19	15.05
	4	1	1493	1168	0	8.55	3.47
		2	900	755	0.63	17.5	14.17
0.40000	1	1	745	690	0.19	19.81	16.52
		2	483	481	0.45	19.55	19.45
	2	1	1083	958	0.03	19.87	12.94
		2	563	556	0.51	19.49	19.31
	3	1	1339	1088	0	13.63	5.53
		2	625	577	0.73	19.26	17.7
	4	1	1460	1150	0	13.63	5.53
		2	685	662	1.51	18.46	17.89

Remark : X stands for mean value of the closing stock amount left at the end of each month for 20 months which are tested by matlab per 100 times.

: T stands for mean of the quantity of tested times from the closing stock left at the end of each month for 20 months which are tested by matlab per 100 times.

(1) = mean values of the closing stock are between 0 to 2000; which 2000 is the maximum number of the actual closing stock for 20 months

(2) = mean values of the closing stock are between 0 to less than each number of the actual closing stock for 20 months

(3) = mean of the tested-times quantities which the closing stock amount are negative number

(4) = mean of the quantity of tested times which the closing stock amount are between o to 2000

(5) = mean of the quantity of tested times which the closing stock amount are less than each number of the actual closing stock for 20 months

A – 5 Comparison for the number of mean closing stock from 20 months (May 2010 to Dec 2011) using 1 month of safety stock level obtained from simulated-order model.

Comparison of the mean - closing stock by **1 month- safety stock level comparing between Expected delivery equation Scheme 1 and 2**							
Alternatives of the uniform random number (B variable adjustment)	Order frequency	Expected delivery scheme	0< X= < 2000 (1)	0< X <= Actual closing stock (2)	T = negative stock (3)	0 < T < 2000 (4)	0 < T < Actual closing stock (5)
0.54020	1	1	1141	953	0.02	17.28	10.27
		2	881	750	0.08	18.49	13.69
	2	1	1405	1150	0.02	14.41	6.24
		2	927	794	0.11	17.86	14.17
	3	1	1544	1180	0	10.13	3.71
		2	930	785	0.19	16.79	12.98
	4	1	1518	1125	0	5.67	2.27
		2	981	819	0.15	15.74	12.11
0.50000	1	1	1081	916	0.04	18.5	11.81
		2	822	714	0.11	19.21	15.07
	2	1	1371	1125	0	16.54	7.44
		2	885	771	0.06	18.81	15.47
	3	1	1525	1200	0	12.23	4.73
		2	900	764	0.21	17.77	13.93
	4	1	1533	1150	0	6.87	2.59
		2	962	810	0.27	16.72	13.14
0.40000	1	1	876	803	0.13	19.87	15.96
		2	609	573	0.3	19.7	17.6
	2	1	1212	1041	0.01	19.78	11.54
		2	684	666	0.24	19.74	18.8
	3	1	1431	1141	0	11.59	4.57
		2	751	678	0.46	19.48	16.79
	4	1	1509	1177	0	11.59	4.57
		2	790	742	0.62	19.28	17.5

Remark : X stands for mean value of the closing stock amount left at the end of each month for 20 months which are tested by matlab per 100 times.

: T stands for mean of the quantity of tested times from the closing stock left at the end of each month for 20 months which are tested by matlab per 100 times.

(1) = mean values of the closing stock are between 0 to 2000; which 2000 is the maximum number of the actual closing stock for 20 months

(2) = mean values of the closing stock are between 0 to less than each number of the actual closing stock for 20 months

(3) = mean of the tested-times quantities which the closing stock amount are negative number

(4) = mean of the quantity of tested times which the closing stock amount are between o to 2000

(5) = mean of the quantity of tested times which the closing stock amount are less than each number of the actual closing stock for 20 months

A – 6 Comparison for the number of mean closing stock from 20 months (May 2010 to Dec 2011) using 2 months of safety stock level obtained from simulated-order model

Comparison of the mean - closing stock by **2 month- safety stock level comparing between Expected delivery equation Scheme 1 and 2**							
Alternatives of the uniform random number (B variable adjustment)	Order frequency	Expected delivery scheme	0< X= < 2000 (1)	0< X <= Actual closing stock (2)	T = negative stock (3)	0 < T < 2000 (4)	0 < T < Actual closing stock (5)
0.54020	1	1	1368	1122	0.02	15	7.06
		2	1123	939	0.03	17.31	10.35
	2	1	1543	1190	0	10.05	3.66
		2	1142	954	0	16.86	9.65
	3	1	1529	1148	0	5.37	2.23
		2	1135	929	0.02	16	9.15
	4	1	1369	899	0	2.73	1.36
		2	1121	897	0.01	14.09	8.01
0.50000	1	1	1314	1096	0.01	16.95	8.91
		2	1066	897	0.04	18.49	11.81
	2	1	1529	1210	0	12.53	4.84
		2	1099	924	0	17.78	10.82
	3	1	1565	1193	0	7.23	2.75
		2	1103	904	0.03	16.62	9.93
	4	1	1447	998	0	3.67	1.64
		2	1116	912	0.04	15.43	9.22
0.40000	1	1	1124	1001	0.07	19.88	13.79
		2	857	786	0.14	19.86	16.08
	2	1	1433	1156	0	18.72	8.14
		2	931	839	0.1	19.84	14.92
	3	1	1529	1229	0	7.81	3.12
		2	1012	825	0.06	19.05	12.51
	4	1	1534	1169	0	7.81	3.12
		2	1004	881	0.31	19.18	14.26

Remark : X stands for mean value of the closing stock amount left at the end of each month for 20 months which are tested by matlab per 100 times.

: T stands for mean of the quantity of tested times from the closing stock left at the end of each month for 20 months which are tested by matlab per 100 times.

(1) = mean values of the closing stock are between 0 to 2000; which 2000 is the maximum number of the actual closing stock for 20 months

(2) = mean values of the closing stock are between 0 to less than each number of the actual closing stock for 20 months

(3) = mean of the tested-times quantities which the closing stock amount are negative number

(4) = mean of the quantity of tested times which the closing stock amount are between o to 2000

(5) = mean of the quantity of tested times which the closing stock amount are less than each number of the actual closing stock for 20 months

Appendix B – Godness of fit test for continuous uniform distribution with minimum of 0.3029 and maximum of 0.5402 (unif[0.3029,0.5402]).

$$\chi_0^2 = \sum_{i=1}^{k} \frac{(o_i - E_i)^2}{E_i} \tag{4.17}$$

The hypothesis-testing procedure [24] will be described as follow:

Hypothesis testing calculated by Matlab program provides the results as follows:

P- Value = 0.0593

St = chi2stat: 3.5556

df: 1

Edges: [0.3029 0.4215 0.5402]

O: [13 5]

E: [9 9]

A = 0.3029   B = 0.5402

Appendix – C The case application for EOQ model (Economic Order Quantity)

The case company has spare parts for repair service of Water treatment system, Electronic modules (EM). Suppose to adopt an EOQ model, all equations[23] are applied as follows:

$$EOQ = Q^* = \sqrt{\frac{2DC_O}{C_h}} \quad (A1)$$

$$C_O = \frac{D}{Q} C_o \quad (A2)$$

$$C_H = \frac{Q}{2} C_h \quad (A3)$$

$$E = \frac{D}{Q} \quad (A4)$$

$$T = \frac{Number\ of\ working\ day\ /\ year}{Expect\ number\ of\ order} \quad (A5)$$

$$\text{TC} = \frac{D}{Q} C_o + \frac{Q}{2} C_h + U \quad (A6)$$

where

Q = number of pieces to order

$EOQ = Q^*$ = optimal number of pieces to order

D = annual demand in units for the inventory item

C_o = ordering cost of each order

C_h = holding cost per unit per year

T = Time between the placing and reciept of an order

TC = Total cost

U = Total unit cost

E = expect number of order

The inventory cost is found and plugged into these equations (A1-A6) as follows:

$$EOQ = Q^* = \sqrt{\frac{2(5959)(428.66)}{(14.2)}} = 599.8 \approx 600 \text{ Units}$$

$$Holding\ cost\ for\ 20\ months = 14.2 \times 5{,}959 = 84{,}617.8 \text{ baht}$$

$$Total\ cost = \frac{5959}{600} 428.66 + \frac{600}{2} 14.2 + (1{,}361.85 x\ 5{,}959)$$

$$= 8{,}123{,}780.86 \text{ Baht}$$

$$E = \frac{5{,}959}{600} = 9.93 \approx 10$$

$$T = \frac{\text{22 days x 20 months}}{(10)} = 44 \text{ days} = 44/22 = 2 \text{ months}$$

Note that: All costs calculated from May 2010 to Dec 2011 are depicted at the end of this part.

EOQ model can give ordering policy as order quantity 600 units every two month to place an order. The total inventory cost obtains for total 20 months equal **8,123,780.86 Baht**. Although this cost could be lower cost than current situation of the case company. As the fact that the lead time and supply uncertainty it has met could violate EOQ model. According to EOQ model assumptions, one of them is stated that the lead time or the time between the placement of the order and the receipt of the order, is known and constant[23]. For this case, The EOQ gives time between orders that equal 2 months. Thus, this lead time period and its number of order quantity 600 units cannot be applied for the case. For example if we place order every two months with 600 units but the order may not arrive for next 2 months, moreover the order quantity expected to receive might not be as order placing. This will always cause stock out situation. Regarding the uncertain factors the company faces, EOQ or service level model adoptions are not possible for this case.

All relevant inventory cost and data related are available as follows:

1. Ordering cost = 428.66 Baht/One time ordering.

(Ordering cost/month comprised of 1.15% of product cost plus wage cost for operator, 413 baht/3 working hours/review an order period)

2. Holding cost = 0.71 baht /unit/month, in this case 20 months must be calculated as 0.71x20 = 14.2 baht/unit/20 months

(Holding cost /month comprised of Warehouse space rent 60,000 baht, warehouse insurance 887 baht, Inventory insurance 3,792 baht, Utilities (electric) cost 33,728 baht, Salary wage for warehouse operator (8500x3) 25,500 baht)

3. EM - demand rate (May 2010 – Dec 2011, 20 months) = 5,959 units
4. Unit price = 1,361.85 baht, Total unit cost = 1,361.85 x (demand for 20 months = 5,959) = 8,115,264.15 baht)

Appendix – D Random numbers generated by Matlab program from EM RDO in the form of continuous uniform distribution.

D- 1 Random number by variable A = 0.3029, B= 0.4000

0.385995	0.316311	0.389163	0.312168	0.307741	0.353791	0.370642	0.323609	0.348689	0.383981	0.349450	0.358161	0.350285	0.387994	0.399280
0.368034	0.352207	0.325541	0.306356	0.355906	0.314571	0.322677	0.340083	0.355624	0.348478	0.390149	0.387866	0.351240	0.399980	0.347162
0.353741	0.386081	0.386561	0.388953	0.394482	0.320164	0.367600	0.305781	0.308696	0.343077	0.393660	0.336747	0.393783	0.386819	0.344269
0.331915	0.340217	0.372009	0.326878	0.334115	0.371463	0.345922	0.348762	0.366795	0.351717	0.382317	0.306971	0.340699	0.306481	0.323603
0.371255	0.370452	0.387650	0.303766	0.381208	0.383625	0.344973	0.335270	0.389284	0.315080	0.371735	0.316721	0.314275	0.355789	0.321665
0.339954	0.363869	0.393980	0.382029	0.361296	0.306282	0.319916	0.397655	0.313545	0.315745	0.375067	0.310337	0.326245	0.399769	0.383760
0.358022	0.346633	0.316464	0.316542	0.379572	0.376486	0.321660	0.356834	0.345408	0.387423	0.390262	0.374805	0.369405	0.352519	0.373456
0.389111	0.348888	0.341148	0.388335	0.380501	0.395836	0.362755	0.385076	0.330110	0.361446	0.309235	0.347229	0.384392	0.387718	0.354338
0.384750	0.395116	0.398113	0.312161	0.307713	0.336193	0.329021	0.342523	0.398567	0.328661	0.335517	0.367787	0.397101	0.309719	0.383404
0.390173	0.311008	0.365509	0.337134	0.330399	0.364873	0.357245	0.347762	0.362010	0.386872	0.303321	0.370797	0.323793	0.398790	0.352603
0.394077	0.330071	0.389941	0.360521	0.366351	0.336206	0.394639	0.383134	0.327539	0.308542	0.383308	0.358379	0.376729	0.392495	0.356495
0.382079	0.346304	0.349725	0.359721	0.350446	0.323919	0.372275	0.399146	0.315777	0.347348	0.352172	0.363946	0.359616	0.357690	0.323610
0.303032	0.359953	0.304268	0.367732	0.397364	0.379240	0.368852	0.353775	0.355820	0.373027	0.338454	0.388131	0.342027	0.344795	0.359977
0.303200	0.388118	0.363382	0.365823	0.375578	0.373112	0.396056	0.392760	0.383280	0.335817	0.324907	0.367214	0.352425	0.335705	0.316762
0.311393	0.348450	0.325339	0.344980	0.358037	0.329975	0.378185	0.374659	0.384173	0.341858	0.354832	0.387903	0.351027	0.372882	0.307971
0.328217	0.345373	0.354114	0.316471	0.331929	0.359454	0.361910	0.357997	0.383818	0.354070	0.331009	0.348296	0.366148	0.304226	0.369249
0.305114	0.375355	0.373297	0.375912	0.327768	0.343780	0.394951	0.396968	0.322681	0.389730	0.309539	0.316624	0.375114	0.339221	0.361991
0.344079	0.348334	0.361880	0.326377	0.388985	0.311840	0.308691	0.382959	0.355763	0.378479	0.311151	0.309516	0.332220	0.392493	0.324229
0.336017	0.386486	0.360030	0.366060	0.346284	0.305233	0.328992	0.396078	0.387857	0.309636	0.309536	0.372253	0.311601	0.355963	0.342350

0.350332	0.369167	0.358176	0.372098	0.368744	0.339760	0.338663	0.374984	0.326386	0.395359	0.332458	0.336992	0.337544	0.327073	0.336118
0.318423	0.337674	0.327056	0.339618	0.307996	0.333881	0.366560	0.393926	0.376680	0.355652	0.396864	0.308172	0.316878	0.340422	0.382242
0.367650	0.398731	0.333904	0.327070	0.380694	0.398646	0.393999	0.352748	0.331149	0.327312	0.389899	0.371715	0.385494	0.344792	0.354527
0.304640	0.311055	0.391339	0.327452	0.368789	0.372635	0.363143	0.326292	0.329839	0.359079	0.321351	0.399313	0.335707	0.383579	0.353501
0.314520	0.327205	0.388855	0.377399	0.394757	0.343020	0.330364	0.328143	0.303493	0.391793	0.303075	0.318676	0.329622	0.382973	0.378085
0.395351	0.381682	0.380055	0.307742	0.311790	0.312477	0.322823	0.376596	0.339284	0.389862	0.372012	0.313927	0.303484	0.346886	0.314578
0.397655	0.311097	0.392796	0.369442	0.391109	0.374226	0.345540	0.399354	0.345326	0.349751	0.387156	0.391540	0.380766	0.339852	0.363631
0.305902	0.354485	0.320265	0.363129	0.352416	0.364782	0.305546	0.337536	0.332447	0.345890	0.314388	0.349669	0.351198	0.392802	0.336560
0.350856	0.380640	0.353153	0.375403	0.362607	0.310070	0.387977	0.376002	0.331143	0.333171	0.306689	0.385610	0.355125	0.374836	0.335392
0.386670	0.374640	0.363782	0.397792	0.333591	0.314601	0.362140	0.313586	0.326448	0.308271	0.360985	0.381543	0.387466	0.374524	0.358695
0.326483	0.316655	0.391570	0.340178	0.310424	0.398213	0.322669	0.360873	0.393852	0.376093	0.361579	0.321034	0.373088	0.394846	0.386788
0.383908	0.345420	0.367371	0.328166	0.385495	0.351139	0.353384	0.344711	0.386424	0.315712	0.353046	0.326903	0.367771	0.352431	0.322180
0.381900	0.336922	0.340691	0.388102	0.316934	0.305076	0.308126	0.373853	0.341471	0.337460	0.303629	0.308162	0.320264	0.379791	0.368195
0.363973	0.349362	0.374755	0.381172	0.338874	0.308127	0.386618	0.328260	0.349452	0.341339	0.369795	0.362030	0.356353	0.346806	0.390468
0.303117	0.359937	0.382292	0.347675	0.363334	0.316579	0.345909	0.312106	0.357761	0.388884	0.394759	0.378369	0.396104	0.385357	0.322238
0.339771	0.317058	0.361193	0.311732	0.399762	0.389656	0.356112	0.346689	0.350442	0.304962	0.387720	0.352524	0.360774	0.340811	0.331863
0.390718	0.390808	0.311153	0.357691	0.353134	0.348131	0.357942	0.365051	0.329099	0.384860	0.313899	0.305595	0.381412	0.374596	0.351112
0.368962	0.365063	0.392461	0.321095	0.399079	0.357359	0.368966	0.315721	0.399004	0.330872	0.337329	0.399066	0.398498	0.397712	0.389310
0.339684	0.318721	0.308104	0.354527	0.324896	0.350912	0.338961	0.346869	0.320735	0.327208	0.326392	0.351541	0.388923	0.353712	0.351587

0.352105	0.393091	0.356011	0.347886	0.358648	0.370957	0.372566	0.311597	0.307970	0.307979	0.380265	0.371658	0.362198	0.368069	0.392127
0.339921	0.373987	0.342028	0.382595	0.350181	0.303505	0.315856	0.347025	0.358362	0.356968	0.313952	0.386346	0.371239	0.331950	0.361406
0.309205	0.375710	0.313294	0.395330	0.328361	0.339249	0.346186	0.367850	0.375499	0.372038	0.318322	0.378743	0.340122	0.354472	0.371078
0.337718	0.342451	0.373217	0.310306	0.359179	0.390435	0.352303	0.383619	0.333996	0.350276	0.337451	0.322689	0.373655	0.303042	0.375111
0.325646	0.326155	0.362489	0.371712	0.388186	0.333811	0.354411	0.379632	0.350764	0.362869	0.385217	0.399354	0.389055	0.388716	0.340293
0.322660	0.353475	0.378926	0.325711	0.308818	0.360877	0.386379	0.372104	0.324422	0.323658	0.359488	0.311991	0.308323	0.342166	0.327321
0.381918	0.324172	0.357919	0.341633	0.345709	0.331816	0.368707	0.348789	0.394103	0.365593	0.359818	0.366075	0.316321	0.332147	0.306469
0.341102	0.384696	0.381679	0.328935	0.311081	0.315039	0.381147	0.371704	0.349732	0.339860	0.392799	0.323794	0.386704	0.395201	0.348743
0.308102	0.367271	0.358905	0.383737	0.357590	0.340609	0.354484	0.395928	0.355334	0.312971	0.358740	0.326580	0.343852	0.347629	0.365537
0.339318	0.382156	0.394565	0.399551	0.355267	0.382297	0.395717	0.352011	0.324365	0.339556	0.303869	0.335884	0.342839	0.330831	0.329988
0.378152	0.379986	0.387518	0.365991	0.377478	0.398172	0.309374	0.332521	0.312216	0.328424	0.381491	0.322112	0.396033	0.311117	0.353184
0.318950	0.348450	0.352188	0.371254	0.325533	0.386599	0.355481	0.379591	0.308742	0.326329	0.362015	0.352114	0.375749	0.359430	0.326754
0.391476	0.332955	0.379495	0.393427	0.359933	0.311039	0.330249	0.325853	0.382474	0.363386	0.349500	0.395219	0.398155	0.317763	0.331788
0.333895	0.369664	0.348831	0.369671	0.347466	0.335692	0.349595	0.325651	0.377811	0.353676	0.328966	0.341216	0.325574	0.309997	0.366061
0.334922	0.398723	0.383377	0.358087	0.386501	0.325828	0.369400	0.348022	0.321902	0.343025	0.327961	0.359652	0.312244	0.359273	0.389454
0.322731	0.377661	0.334213	0.339880	0.367067	0.333759	0.323122	0.363042	0.389816	0.324048	0.349606	0.361795	0.340243	0.330769	0.386513
0.377397	0.383452	0.397684	0.364518	0.337262	0.398490	0.361952	0.362648	0.369346	0.386266	0.324975	0.372292	0.351476	0.338042	0.323283
0.309694	0.371461	0.329914	0.338169	0.336612	0.356135	0.334572	0.314807	0.366680	0.386504	0.307619	0.341889	0.358272	0.373280	0.341652
0.395148	0.360707	0.309972	0.342480	0.327536	0.375652	0.388430	0.314920	0.399066	0.330470	0.319333	0.386279	0.397731	0.386242	0.389113

0.355961	0.377035	0.315355	0.384933	0.396277	0.317646	0.387253	0.364129	0.339345	0.391209	0.318782	0.386633	0.393010	0.379199	0.306040
0.327304	0.307646	0.327458	0.382185	0.358305	0.339863	0.354228	0.398588	0.349544	0.308518	0.390878	0.389941	0.319357	0.392481	0.356991
0.306799	0.373388	0.388733	0.385069	0.357556	0.382621	0.391663	0.364488	0.336149	0.345309	0.310410	0.321253	0.388711	0.350704	0.372793
0.325561	0.370999	0.321958	0.338845	0.320054	0.319539	0.397469	0.361204	0.378361	0.358466	0.335772	0.367056	0.340561	0.383883	0.313621
0.337964	0.347458	0.314683	0.340112	0.352778	0.334941	0.359745	0.391182	0.340181	0.357768	0.359278	0.394294	0.340047	0.315654	0.323936
0.364408	0.359441	0.355693	0.386536	0.356157	0.396744	0.314453	0.358328	0.371992	0.382893	0.349045	0.397641	0.329258	0.376675	0.381650
0.398650	0.335826	0.333450	0.347946	0.318948	0.381191	0.392866	0.335469	0.349599	0.315144	0.381097	0.313381	0.387171	0.392789	0.316364
0.323015	0.319468	0.339996	0.358300	0.350857	0.324474	0.360535	0.395838	0.373703	0.332041	0.354439	0.320271	0.374900	0.383756	0.388532
0.376413	0.341662	0.379758	0.370414	0.354860	0.399978	0.388699	0.345617	0.393937	0.303106	0.324972	0.375390	0.346388	0.328088	0.392577
0.388962	0.392210	0.384384	0.396205	0.322204	0.309089	0.344117	0.361310	0.353125	0.395253	0.371791	0.307703	0.371806	0.323584	0.304139
0.348754	0.324849	0.368951	0.355947	0.363410	0.344214	0.361865	0.372837	0.390588	0.377308	0.317332	0.309822	0.394595	0.353617	0.339522
0.318331	0.337954	0.343383	0.364712	0.305455	0.342161	0.309771	0.368809	0.324087	0.375852	0.366803	0.350394	0.319807	0.341483	0.319195
0.381640	0.334415	0.365325	0.358334	0.333855	0.341768	0.392695	0.323559	0.387690	0.316384	0.364460	0.385425	0.326650	0.349422	0.355356
0.349169	0.311016	0.323687	0.392923	0.354654	0.313768	0.365246	0.310826	0.310929	0.336819	0.325166	0.399713	0.365134	0.399408	0.312771
0.314192	0.352680	0.362837	0.386772	0.334630	0.344101	0.313047	0.329552	0.348091	0.317595	0.320594	0.303327	0.381416	0.361595	0.306713
0.387932	0.383771	0.368461	0.319391	0.361373	0.362475	0.370892	0.387136	0.305029	0.351132	0.319053	0.355587	0.385762	0.394651	0.393517
0.364577	0.390738	0.361259	0.320252	0.338044	0.398841	0.341333	0.357214	0.381384	0.381420	0.317427	0.386537	0.341557	0.350522	0.397242
0.312346	0.373161	0.336527	0.326544	0.316001	0.324252	0.311144	0.348015	0.320301	0.364352	0.322587	0.391177	0.314114	0.345425	0.337946
0.391109	0.340089	0.338283	0.375898	0.391631	0.337281	0.323726	0.344682	0.318960	0.369744	0.395627	0.384984	0.310695	0.377925	0.365452

0.344368	0.386168	0.364902	0.307909	0.388838	0.341166	0.339321	0.347204	0.315069	0.305222	0.327190	0.325971	0.354408	0.342525	0.384526
0.395667	0.328131	0.360595	0.351851	0.384444	0.337786	0.383386	0.345866	0.338291	0.358726	0.363546	0.382286	0.310094	0.327073	0.348422
0.373224	0.388160	0.351316	0.377509	0.314373	0.311528	0.384637	0.347001	0.368562	0.307418	0.373612	0.342306	0.333178	0.366254	0.355841
0.359305	0.321181	0.358038	0.330378	0.342751	0.336077	0.367495	0.394687	0.339386	0.343928	0.351272	0.348179	0.389821	0.333999	0.320291
0.355359	0.376618	0.344314	0.324782	0.314574	0.356176	0.396130	0.324176	0.386742	0.348317	0.385418	0.395294	0.383956	0.312967	0.364506
0.371398	0.305977	0.310303	0.335068	0.358450	0.347619	0.394477	0.388581	0.331251	0.305097	0.321438	0.396602	0.303128	0.354903	0.396403
0.303388	0.365271	0.331116	0.346911	0.395086	0.365573	0.313843	0.304830	0.315860	0.309219	0.314954	0.377209	0.365064	0.318909	0.354753
0.378882	0.357943	0.357406	0.374500	0.327795	0.352763	0.365849	0.336085	0.368214	0.392616	0.303171	0.358687	0.380889	0.388682	0.349471
0.392898	0.339449	0.364397	0.352410	0.399016	0.381981	0.349586	0.377281	0.322571	0.354765	0.317752	0.391836	0.326702	0.367613	0.379965
0.303706	0.323538	0.393278	0.340042	0.336866	0.312336	0.309359	0.336186	0.387233	0.338516	0.354767	0.351006	0.309126	0.385216	0.311903
0.382971	0.379818	0.397841	0.390822	0.323148	0.347927	0.390074	0.362986	0.375837	0.338239	0.352483	0.319020	0.328452	0.376954	0.388426
0.377408	0.317023	0.311988	0.396627	0.367552	0.360171	0.351181	0.346888	0.343622	0.317598	0.340304	0.334554	0.312874	0.381261	0.303276
0.399722	0.350396	0.367154	0.363905	0.397412	0.321074	0.377794	0.303887	0.302922	0.317427	0.333059	0.331684	0.349869	0.364360	0.352569
0.325005	0.304147	0.361429	0.315720	0.363364	0.362260	0.308761	0.361071	0.317413	0.336963	0.303245	0.357111	0.343574	0.371882	0.368779
0.392188	0.321020	0.348908	0.362937	0.309070	0.307944	0.328385	0.361312	0.329489	0.335522	0.382060	0.309452	0.339923	0.369769	0.357834
0.365238	0.350016	0.337492	0.340091	0.339168	0.358803	0.366119	0.365958	0.387612	0.379029	0.364890	0.309598	0.389005	0.334064	0.349358
0.313127	0.384292	0.349079	0.399145	0.319043	0.384692	0.315873	0.336178	0.361281	0.350162	0.346434	0.319095	0.343736	0.354523	0.334022
0.328938	0.316597	0.368056	0.330751	0.325357	0.351423	0.364903	0.350799	0.334087	0.348032	0.326601	0.394896	0.330462	0.387687	0.361313
0.377069	0.373998	0.396082	0.371471	0.307969	0.345529	0.340278	0.371042	0.330505	0.315645	0.380909	0.381657	0.307578	0.308196	0.391567

0.369781	0.375186	0.344697	0.395991	0.377437	0.398390	0.388176	0.365202	0.376364	0.331443	0.394494	0.354633	0.394459	0.306518	0.318156
0.317214	0.384401	0.343315	0.372019	0.323879	0.389931	0.390520	0.379258	0.384782	0.305508	0.331037	0.337337	0.312279	0.397650	0.363604
0.378401	0.328382	0.373663	0.319107	0.306207	0.386960	0.317682	0.330977	0.377682	0.311960	0.339464	0.377969	0.385035	0.353619	0.370771
0.341648	0.352833	0.342369	0.345894	0.345289	0.380673	0.321600	0.351243	0.397928	0.380375	0.313946	0.388511	0.391202	0.391225	0.311238
0.390125	0.346282	0.395321	0.364364	0.393869	0.356788	0.379704	0.382370	0.313713	0.371977	0.396587	0.374180	0.304001	0.340113	0.354478
0.332714	0.336032	0.391454	0.393200	0.328349	0.343572	0.308794	0.360687	0.341359	0.378969	0.344897	0.342365	0.353750	0.388780	0.389180
0.308828	0.384381	0.395282	0.354298	0.358222	0.315244	0.340752	0.354987	0.350679	0.363483	0.311111	0.361566	0.366049	0.327662	0.328502
0.324211	0.398300	0.336497	0.363731	0.337813	0.366464	0.332027	0.335028	0.327961	0.383048	0.372489	0.365151	0.340298	0.391169	0.325698
0.310943	0.363730	0.331083	0.369008	0.305506	0.386791	0.374189	0.342875	0.306489	0.306301	0.352109	0.315277	0.365947	0.389762	0.384431
0.395183	0.320502	0.388999	0.392542	0.351491	0.329564	0.313019	0.379998	0.397512	0.342272	0.334757	0.351080	0.376973	0.341596	0.351017
0.304490	0.314845	0.323294	0.317740	0.383203	0.384480	0.379859	0.336226	0.373436	0.327143	0.376067	0.333047	0.358799	0.363589	0.317695
0.314034	0.359215	0.315608	0.342295	0.328047	0.309770	0.378903	0.347819	0.317267	0.349595	0.384076	0.359080	0.364259	0.358014	0.325308
0.304105	0.334801	0.353442	0.333241	0.307355	0.339681	0.354596	0.338616	0.317261	0.388429	0.327536	0.394524	0.329914	0.389757	0.366787
0.323896	0.328941	0.390820	0.370278	0.326832	0.328939	0.327501	0.368886	0.371338	0.330154	0.354793	0.344356	0.384448	0.323695	0.357562
0.304010	0.356328	0.341986	0.389386	0.367057	0.317749	0.309790	0.358031	0.339894	0.361077	0.345155	0.306117	0.344346	0.303275	0.331237
0.365282	0.320428	0.323850	0.350544	0.334886	0.364170	0.363666	0.366188	0.310320	0.305447	0.318213	0.393148	0.364231	0.388404	0.363326
0.353100	0.368782	0.310546	0.381145	0.366937	0.333620	0.305297	0.350587	0.342793	0.317970	0.361207	0.392716	0.383830	0.325730	0.372414
0.326742	0.308307	0.393500	0.334597	0.304163	0.396030	0.308924	0.341590	0.316784	0.383873	0.393926	0.337692	0.329135	0.326676	0.330159
0.321713	0.306207	0.361439	0.356293	0.372624	0.351321	0.315485	0.349264	0.380475	0.321824	0.313363	0.328145	0.341818	0.365133	0.342932

0.378987	0.390201	0.346390	0.303782	0.321840	0.333615	0.371787	0.382363	0.360950	0.391757
0.368643	0.355803	0.366136	0.360815	0.371392	0.378970	0.399283	0.393996	0.381768	0.390385
0.317447	0.390399	0.319359	0.362039	0.320431	0.397320	0.393416	0.302932	0.381996	0.323702
0.370542	0.307932	0.354504	0.392127	0.353619	0.359846	0.311855	0.365082	0.311584	0.356020
0.315427	0.381415	0.364442	0.374130	0.331658	0.378448	0.395489	0.303614	0.373907	0.379095
0.394751	0.335419	0.304269	0.332141	0.347836	0.373559	0.318707	0.313233	0.390664	0.321780
0.388971	0.325105	0.348573	0.351020	0.392740	0.366111	0.397131	0.313270	0.346812	0.375423
0.352907	0.382755	0.388962	0.327968	0.323863	0.367434	0.360869	0.338546	0.309764	0.349077
0.368871	0.336714	0.313972	0.374060	0.302998	0.394056	0.326226	0.326166	0.326328	0.359534
0.397747	0.318967	0.345871	0.314237	0.390931	0.354856	0.309726	0.336510	0.373964	0.328199
0.315082	0.305632	0.366942	0.375341	0.368932	0.341589	0.332034	0.327138	0.306832	0.311136
0.375943	0.395666	0.331522	0.381531	0.352902	0.368001	0.381895	0.340484	0.344121	0.331849
0.383207	0.368956	0.395181	0.375262	0.353593	0.345676	0.310349	0.343783	0.355355	0.391953
0.378777	0.386461	0.370315	0.335637	0.312893	0.315802	0.337319	0.365052	0.395517	0.348587
0.321435	0.394086	0.322981	0.359638	0.399697	0.345547	0.315718	0.379371	0.323185	0.329065
0.344521	0.368947	0.356767	0.348435	0.337756	0.356076	0.318259	0.329116	0.314196	0.376984
0.304304	0.391982	0.388278	0.311373	0.363611	0.341268	0.308934	0.384851	0.365648	0.377878
0.334485	0.327825	0.357068	0.383368	0.341096	0.341572	0.371049	0.374799	0.313427	0.304968
0.315980	0.388894	0.375952	0.369505	0.303644	0.375856	0.311297	0.383114	0.398398	0.388347

D - 2 Random number by variable A = 0.3029, B= 0.5000

0.463482	0.452251	0.357305	0.371882	0.334866	0.474120	0.385143	0.336208	0.429895	0.496008	0.492725	0.481023	0.314651	0.381594	0.362317
0.481432	0.449371	0.436869	0.341649	0.459453	0.319542	0.312687	0.430841	0.377524	0.389401	0.410675	0.478501	0.437317	0.406747	0.441087
0.327929	0.380208	0.432020	0.352389	0.364240	0.381697	0.480825	0.447122	0.462863	0.324802	0.405616	0.368764	0.311263	0.385051	0.434235
0.482926	0.432095	0.334951	0.424322	0.407074	0.354120	0.489118	0.430571	0.407920	0.353765	0.348547	0.440623	0.316982	0.432367	0.409162
0.427538	0.336641	0.326354	0.396185	0.335549	0.460593	0.399649	0.391777	0.372028	0.383459	0.399262	0.341888	0.405717	0.426674	0.440497
0.322125	0.442062	0.401128	0.372212	0.421551	0.387932	0.399332	0.410715	0.487977	0.420154	0.425902	0.308920	0.321965	0.360450	0.434273
0.357792	0.309174	0.492066	0.466656	0.354732	0.482389	0.369464	0.361305	0.475548	0.354582	0.436758	0.449557	0.464157	0.387978	0.338010
0.410690	0.357482	0.369990	0.418256	0.431819	0.338742	0.480301	0.449679	0.411336	0.421720	0.380856	0.401454	0.464039	0.305953	0.328132
0.491625	0.312000	0.418256	0.411251	0.438744	0.354896	0.375679	0.340143	0.425590	0.443081	0.375322	0.397493	0.445293	0.496859	0.499819
0.493080	0.322045	0.347013	0.483679	0.450361	0.331586	0.324818	0.438263	0.418607	0.346606	0.497631	0.481221	0.332438	0.335849	0.336628
0.333966	0.465204	0.450975	0.359239	0.391702	0.329719	0.456688	0.339070	0.343846	0.326043	0.310338	0.423105	0.432908	0.323835	0.309326
0.494204	0.439851	0.353179	0.452144	0.319421	0.474237	0.379718	0.375528	0.362276	0.361375	0.477367	0.424642	0.405115	0.376302	0.413512
0.491558	0.365400	0.402624	0.451460	0.348031	0.417160	0.350537	0.426209	0.395719	0.365731	0.482909	0.472296	0.494673	0.341949	0.476716
0.398568	0.490189	0.440688	0.377886	0.482919	0.411277	0.382511	0.456683	0.348329	0.386503	0.459828	0.461662	0.430816	0.399417	0.434794
0.460635	0.309689	0.478497	0.414818	0.332934	0.331471	0.321911	0.318890	0.469313	0.402999	0.322356	0.416572	0.460645	0.369814	0.340434
0.330866	0.389377	0.491976	0.317851	0.465669	0.471032	0.328912	0.486082	0.341288	0.319755	0.354515	0.338954	0.392344	0.490466	0.375613
0.386029	0.378105	0.410756	0.313534	0.409007	0.425507	0.488578	0.455793	0.347429	0.354635	0.368999	0.350191	0.388124	0.484297	0.393709
0.483391	0.453783	0.330223	0.407520	0.499238	0.372073	0.491354	0.398847	0.336547	0.460780	0.436874	0.477632	0.465569	0.313283	0.496381
0.459044	0.459634	0.332326	0.456474	0.318308	0.404061	0.416274	0.388808	0.347773	0.308659	0.329815	0.308552	0.319352	0.448332	0.333727

0.326673	0.386251	0.358286	0.483442	0.416471	0.417661	0.455057	0.448033	0.467183	0.470575	0.426277	0.331778	0.425291	0.413085	0.337524
0.419092	0.321473	0.389641	0.303127	0.437591	0.409480	0.486765	0.380697	0.454441	0.413386	0.433172	0.340166	0.415978	0.471243	0.344083
0.347482	0.420869	0.406800	0.394049	0.410634	0.474365	0.494627	0.437601	0.335866	0.486126	0.446734	0.311307	0.313165	0.371467	0.481306
0.378708	0.395719	0.393058	0.386539	0.386811	0.355088	0.340749	0.441668	0.472796	0.440213	0.478467	0.428098	0.486440	0.390812	0.436020
0.417807	0.440072	0.475436	0.393747	0.429920	0.365592	0.330272	0.390078	0.498004	0.417768	0.496512	0.358456	0.446519	0.313591	0.395235
0.352531	0.440848	0.405008	0.454698	0.430545	0.326397	0.440134	0.306759	0.404293	0.463615	0.454476	0.409057	0.448329	0.337808	0.482681
0.360146	0.428754	0.488888	0.366459	0.436734	0.488140	0.321392	0.368112	0.477192	0.476154	0.417503	0.439917	0.315397	0.433539	0.323401
0.424529	0.309523	0.428592	0.457572	0.428214	0.430138	0.406457	0.386531	0.418800	0.497814	0.485871	0.401276	0.472493	0.368106	0.449847
0.355187	0.316462	0.491661	0.395804	0.489194	0.397402	0.407431	0.356170	0.333402	0.303003	0.417236	0.408506	0.487071	0.479992	0.448018
0.465385	0.365893	0.350343	0.309949	0.344081	0.428909	0.472631	0.341739	0.342293	0.473478	0.306247	0.390646	0.496925	0.326188	0.413643
0.496583	0.407533	0.436164	0.337565	0.442699	0.410264	0.398465	0.464861	0.383111	0.423637	0.326721	0.327327	0.472197	0.497717	0.339205
0.446832	0.431891	0.359875	0.445159	0.349461	0.430485	0.380450	0.387638	0.450470	0.498019	0.472940	0.399549	0.457734	0.409330	0.420610
0.370678	0.383242	0.435313	0.396224	0.326433	0.410100	0.435239	0.477880	0.465623	0.406906	0.398355	0.471026	0.404087	0.442233	0.362018
0.418020	0.464518	0.439912	0.333001	0.422600	0.445018	0.449002	0.380002	0.458602	0.397414	0.469421	0.475151	0.337905	0.499900	0.329336
0.324141	0.444489	0.316301	0.370136	0.391622	0.405884	0.405402	0.454492	0.365681	0.460846	0.344174	0.356175	0.381462	0.359635	0.344804
0.481533	0.493821	0.353119	0.422616	0.393315	0.498759	0.371434	0.381108	0.408164	0.347808	0.411757	0.343988	0.329298	0.384602	0.479293
0.476280	0.407626	0.347058	0.340693	0.433369	0.346001	0.332464	0.462258	0.320629	0.401074	0.427050	0.414257	0.308988	0.394520	0.316983
0.464081	0.366986	0.434530	0.448444	0.454723	0.323753	0.418419	0.451726	0.324917	0.480458	0.309205	0.429105	0.488005	0.453476	0.350694
0.354289	0.323720	0.469330	0.350766	0.371928	0.324521	0.354569	0.377285	0.329763	0.416166	0.424060	0.385096	0.362287	0.464168	0.313495

0.392789	0.406595	0.437660	0.343438	0.324533	0.407601	0.497622	0.373778	0.335140	0.484448	0.427307	0.311780	0.497860	0.433455	0.457204
0.322939	0.446726	0.328934	0.379428	0.486944	0.324348	0.336492	0.412945	0.434166	0.459527	0.372885	0.445437	0.316095	0.351025	0.439646
0.499091	0.442300	0.445349	0.411656	0.339849	0.427421	0.353711	0.449256	0.479184	0.416704	0.499409	0.371380	0.488055	0.361144	0.304832
0.368355	0.456909	0.324651	0.348027	0.355364	0.327833	0.381109	0.386536	0.404714	0.389631	0.347084	0.433108	0.306483	0.436963	0.469097
0.361507	0.359660	0.326058	0.429426	0.460152	0.329371	0.317484	0.387526	0.441403	0.353676	0.431498	0.378561	0.437685	0.406939	0.484692
0.315129	0.439398	0.429186	0.398391	0.399007	0.322333	0.437735	0.327512	0.333173	0.451109	0.422144	0.426550	0.457374	0.384025	0.454855
0.361684	0.412620	0.367709	0.332829	0.454462	0.330894	0.382211	0.307716	0.490826	0.347971	0.379226	0.307167	0.408179	0.421680	0.311308
0.312036	0.381054	0.431766	0.457019	0.380953	0.336062	0.496617	0.360096	0.409508	0.315551	0.330925	0.482373	0.477404	0.450828	0.377440
0.402520	0.315040	0.450554	0.322730	0.356696	0.341581	0.382170	0.365483	0.436876	0.454141	0.307854	0.460690	0.480094	0.417914	0.441725
0.452977	0.456673	0.417846	0.360860	0.310239	0.365475	0.425234	0.431742	0.310107	0.435194	0.385901	0.449907	0.426272	0.411658	0.446687
0.427284	0.369438	0.448760	0.349686	0.435606	0.365268	0.333326	0.491512	0.462394	0.443868	0.339186	0.463165	0.330074	0.417922	0.347105
0.320618	0.422710	0.349184	0.407535	0.387567	0.345782	0.378063	0.487333	0.450453	0.429450	0.445950	0.378450	0.345829	0.403780	0.355931
0.318838	0.449001	0.447760	0.320934	0.391938	0.352380	0.334660	0.393149	0.326589	0.385494	0.375898	0.424566	0.338800	0.319179	0.435554
0.456094	0.323559	0.494205	0.382788	0.423103	0.478895	0.452324	0.350298	0.406386	0.379919	0.468771	0.416330	0.311143	0.444727	0.397014
0.481302	0.328107	0.473772	0.323565	0.314608	0.441505	0.474596	0.453464	0.367122	0.463761	0.447617	0.407373	0.323978	0.499242	0.425835
0.408106	0.411214	0.319897	0.325031	0.365146	0.412436	0.372038	0.452563	0.410605	0.365465	0.415449	0.357116	0.424401	0.372779	0.349503
0.324414	0.398539	0.375125	0.457511	0.455204	0.339252	0.438019	0.448882	0.381519	0.463446	0.337758	0.351905	0.488107	0.494335	0.337811
0.465667	0.478413	0.375669	0.360369	0.440167	0.344691	0.360877	0.449481	0.384715	0.458426	0.491600	0.391918	0.372763	0.371185	0.466423
0.369539	0.460375	0.437919	0.421856	0.327603	0.318145	0.407487	0.323777	0.338523	0.470881	0.355195	0.347782	0.383835	0.477638	0.454060

0.479480	0.443545	0.448571	0.402195	0.332905	0.359260	0.359393	0.383066	0.359064	0.325968	0.331778	0.402207	0.387708	0.306767	0.404797
0.322431	0.424774	0.490968	0.399399	0.371492	0.410056	0.460742	0.434352	0.435593	0.463474	0.427298	0.432685	0.439639	0.388673	0.336614
0.311605	0.370562	0.309192	0.475766	0.326879	0.496999	0.479524	0.486937	0.433830	0.366929	0.472272	0.464408	0.489202	0.466931	0.487890
0.412743	0.487391	0.373239	0.372504	0.477167	0.443960	0.420672	0.462738	0.327107	0.351432	0.494919	0.407735	0.457472	0.424588	0.419284
0.455159	0.327493	0.433509	0.391485	0.321482	0.468261	0.477140	0.398404	0.383182	0.370449	0.415412	0.342729	0.441968	0.405418	0.389749
0.364383	0.446898	0.358384	0.492812	0.486211	0.388296	0.488909	0.452055	0.357159	0.376949	0.499379	0.392362	0.324450	0.473168	0.488552
0.338177	0.430321	0.348309	0.311237	0.381547	0.395660	0.411139	0.385100	0.444156	0.410626	0.412003	0.387241	0.379755	0.322156	0.432181
0.369708	0.467114	0.443063	0.494670	0.312243	0.413417	0.446465	0.494439	0.358755	0.413654	0.404497	0.493309	0.419367	0.481877	0.391978
0.344320	0.381401	0.426003	0.340193	0.370382	0.355938	0.416579	0.497630	0.479541	0.380917	0.368077	0.425113	0.393444	0.324190	0.468404
0.403451	0.450690	0.419309	0.434389	0.447959	0.450532	0.307997	0.473223	0.465819	0.381372	0.387653	0.439961	0.312822	0.404800	0.407880
0.481544	0.467522	0.433072	0.418487	0.459532	0.402216	0.390911	0.379549	0.379774	0.404479	0.399835	0.444844	0.347974	0.331116	0.412071
0.426861	0.366457	0.312273	0.435965	0.410301	0.430386	0.430286	0.392530	0.401037	0.432499	0.316901	0.371273	0.467319	0.413152	0.436941
0.322912	0.411751	0.371645	0.374057	0.438155	0.363557	0.405629	0.351522	0.439846	0.490325	0.477873	0.404799	0.305984	0.303803	0.375273
0.379937	0.495886	0.391859	0.425157	0.479035	0.330243	0.376283	0.457510	0.467354	0.445275	0.315639	0.412625	0.473137	0.454013	0.350064
0.313665	0.411169	0.350382	0.462778	0.313699	0.396635	0.487609	0.476907	0.423058	0.381756	0.388872	0.333745	0.318287	0.470181	0.417006
0.401703	0.368026	0.443835	0.306696	0.362752	0.374341	0.466401	0.482993	0.416181	0.466862	0.465829	0.413681	0.434768	0.483605	0.473763
0.387992	0.424998	0.471654	0.319431	0.312004	0.458237	0.470255	0.412938	0.367163	0.329378	0.380663	0.439846	0.401492	0.497431	0.383076
0.499519	0.373981	0.358385	0.495033	0.341428	0.456696	0.376326	0.420937	0.392861	0.314818	0.423816	0.386954	0.345867	0.402462	0.325096
0.462867	0.452008	0.446990	0.431281	0.444845	0.434664	0.419817	0.332244	0.443589	0.319505	0.464254	0.467729	0.415565	0.356397	0.390382

0.330544	0.346495	0.365582	0.487319	0.435404	0.496012	0.429500	0.366157	0.468120	0.391866	0.462352	0.412992	0.341970	0.409888	0.350418
0.354172	0.398035	0.422862	0.464269	0.387951	0.359039	0.346511	0.403699	0.418148	0.378320	0.373168	0.452032	0.341349	0.409355	0.468734
0.320011	0.377012	0.482299	0.446440	0.439767	0.420169	0.467884	0.314846	0.489772	0.458539	0.317336	0.499109	0.367320	0.364220	0.471857
0.387534	0.406137	0.482083	0.337552	0.353512	0.492542	0.494299	0.445933	0.314929	0.374701	0.419384	0.492595	0.476415	0.316940	0.492828
0.353610	0.355106	0.419503	0.373929	0.304823	0.339517	0.469720	0.412597	0.418133	0.407826	0.482298	0.408362	0.395754	0.338768	0.399262
0.361548	0.316373	0.368450	0.340111	0.407813	0.340948	0.402632	0.407237	0.359095	0.443168	0.341091	0.492879	0.382522	0.321228	0.346323
0.386640	0.388900	0.471039	0.303136	0.357968	0.370238	0.357866	0.466490	0.466046	0.474668	0.388120	0.325690	0.338227	0.394254	0.347486
0.326396	0.337166	0.390097	0.365266	0.489402	0.486774	0.450058	0.472161	0.340543	0.367685	0.450559	0.313040	0.493875	0.304739	0.408701
0.400478	0.308046	0.481148	0.440795	0.481560	0.379901	0.349599	0.458418	0.390123	0.431038	0.310623	0.362887	0.383210	0.483252	0.453112
0.442133	0.491067	0.309440	0.426138	0.380298	0.356751	0.491593	0.365545	0.380441	0.495040	0.489421	0.417256	0.469348	0.429584	0.371405
0.350908	0.387771	0.407841	0.409938	0.307799	0.332849	0.425153	0.392030	0.465818	0.317873	0.453420	0.407553	0.424181	0.303180	0.393809
0.457637	0.492423	0.444122	0.389434	0.435240	0.381170	0.421212	0.451164	0.436311	0.418601	0.413044	0.480528	0.377130	0.308889	0.428911
0.317503	0.453172	0.338240	0.359552	0.467906	0.376758	0.336920	0.324554	0.343819	0.384477	0.339135	0.409442	0.475793	0.343989	0.483707
0.380534	0.304348	0.369231	0.401777	0.494383	0.328743	0.320707	0.324530	0.365598	0.363831	0.401046	0.388043	0.457594	0.392574	0.334746
0.303569	0.436936	0.339898	0.453001	0.314121	0.388647	0.353212	0.356094	0.329274	0.354902	0.404967	0.409860	0.394542	0.327984	0.443952
0.346395	0.442043	0.366352	0.453171	0.391659	0.320937	0.472124	0.406306	0.435245	0.452453	0.498865	0.443317	0.463335	0.304604	0.416772
0.303156	0.430055	0.382500	0.416441	0.417705	0.424043	0.482471	0.494610	0.415442	0.499057	0.471391	0.306187	0.479983	0.446207	0.388303
0.340187	0.411760	0.411022	0.450264	0.438236	0.305064	0.440798	0.442922	0.336361	0.339673	0.492590	0.460762	0.387503	0.372696	0.477184
0.330984	0.345889	0.312506	0.430135	0.444700	0.415890	0.445833	0.364368	0.332003	0.456864	0.436719	0.330989	0.368796	0.456726	0.380371

0.496251	0.341026	0.477416	0.405989	0.343844	0.449713	0.488240	0.381558	0.481210	0.497090	0.409374	0.367086	0.448932	0.313928	0.470023
0.327939	0.451597	0.383264	0.367016	0.346121	0.478766	0.304050	0.421049	0.477213	0.413173	0.308866	0.427113	0.402789	0.463902	0.457595
0.348675	0.371148	0.310071	0.466856	0.367116	0.350717	0.423192	0.460683	0.389425	0.486911	0.440144	0.348292	0.342305	0.407151	0.356281
0.307558	0.385411	0.449966	0.462609	0.321812	0.328444	0.460792	0.323609	0.456978	0.444880	0.405336	0.417195	0.387100	0.439756	0.347801
0.422625	0.333592	0.333417	0.412684	0.450239	0.347261	0.348821	0.464806	0.332162	0.398304	0.314535	0.421782	0.336149	0.344765	0.366174
0.324741	0.464325	0.331264	0.354730	0.450431	0.371888	0.486690	0.468678	0.425066	0.428853	0.478326	0.421136	0.451059	0.409980	0.466407
0.383210	0.426072	0.422335	0.437040	0.409984	0.359484	0.453339	0.372773	0.354269	0.477853	0.367983	0.391285	0.375502	0.441367	0.464952
0.477152	0.448470	0.353058	0.348953	0.369546	0.485708	0.465793	0.387667	0.390739	0.342071	0.348174	0.309882	0.488532	0.491413	0.415382
0.410937	0.461588	0.366791	0.392861	0.466953	0.313014	0.415930	0.415688	0.469252	0.380827	0.325359	0.404173	0.306285	0.390519	0.415608
0.375631	0.316150	0.382093	0.378698	0.411812	0.419715	0.459118	0.441033	0.341572	0.498458	0.364183	0.383264	0.466307	0.319732	0.359274
0.343965	0.490301	0.382996	0.409058	0.491632	0.335007	0.367754	0.449241	0.362789	0.382204	0.347924	0.324196	0.426401	0.314202	0.440699
0.389810	0.400972	0.379018	0.498365	0.478877	0.468150	0.346944	0.452279	0.398157	0.432761	0.431409	0.393541	0.409087	0.426965	0.459842
0.491366	0.451739	0.423092	0.451754	0.373167	0.335926	0.364471	0.379597	0.369483	0.480556	0.315940	0.391769	0.431115	0.459827	0.389937
0.327346	0.449228	0.335794	0.496148	0.410596	0.401884	0.418110	0.387516	0.460282	0.499090	0.357188	0.411530	0.446119	0.439134	0.390849
0.395687	0.466716	0.339973	0.349176	0.371231	0.499868	0.466476	0.491396	0.497534	0.431638	0.358447	0.461645	0.321524	0.370960	0.394682
0.471794	0.333747	0.321551	0.407079	0.425654	0.372951	0.360150	0.415833	0.334248	0.324273	0.476361	0.441038	0.475870	0.489518	0.357899
0.311452	0.393036	0.366600	0.313038	0.459915	0.312179	0.382243	0.470380	0.349589	0.310018	0.390478	0.474818	0.305731	0.405430	0.436016
0.439219	0.424728	0.454588	0.452080	0.449912	0.345013	0.472811	0.357368	0.441311	0.424726	0.451891	0.313187	0.360907	0.490897	0.481012
0.495858	0.486633	0.349045	0.421550	0.327643	0.381314	0.424065	0.425560	0.376905	0.414684	0.421810	0.346199	0.338361	0.317406	0.481970

0.331624	0.440526	0.323560	0.487842	0.483700	0.467228	0.463913	0.389067	0.480640	0.342287
0.418212	0.308681	0.472081	0.353245	0.403389	0.460672	0.340245	0.377766	0.385587	0.422607
0.317360	0.406946	0.440515	0.407986	0.494913	0.483814	0.327280	0.495990	0.373487	0.409934
0.464980	0.309222	0.447521	0.491082	0.341784	0.329963	0.464718	0.381542	0.399279	0.334894
0.445384	0.465930	0.431120	0.355673	0.324815	0.402383	0.428630	0.389661	0.353350	0.304014
0.485387	0.369911	0.404657	0.352192	0.361509	0.382717	0.306077	0.333807	0.486039	0.454960
0.399999	0.469787	0.367231	0.485744	0.381034	0.337111	0.479493	0.367161	0.394898	0.453640
0.431977	0.351400	0.433336	0.316418	0.385831	0.416269	0.404480	0.364802	0.352965	0.385893
0.478343	0.417512	0.326072	0.361912	0.364292	0.422386	0.410225	0.479206	0.387893	0.314098
0.409043	0.487716	0.332035	0.419501	0.439656	0.345167	0.422430	0.351588	0.441369	0.418351
0.358523	0.312319	0.306796	0.342970	0.321008	0.405379	0.452782	0.364135	0.382199	0.337226
0.495261	0.313539	0.492962	0.428233	0.382152	0.497869	0.471489	0.383488	0.338741	0.446509
0.310079	0.306964	0.494160	0.460259	0.361080	0.399462	0.378363	0.442449	0.471667	0.408209
0.367203	0.437219	0.327313	0.401785	0.363311	0.439860	0.319584	0.331211	0.418046	0.352779
0.494681	0.420890	0.395027	0.431175	0.323706	0.383991	0.447546	0.474638	0.376532	0.483652
0.374848	0.325375	0.432334	0.459783	0.419943	0.309754	0.368335	0.319290	0.346596	0.452340
0.363833	0.459840	0.360096	0.348898	0.358626	0.360617	0.468415	0.393909	0.346064	0.477734
0.326732	0.424678	0.451619	0.421325	0.333494	0.460864	0.376167	0.308890	0.405832	0.316460
0.483397	0.316739	0.412905	0.325066	0.303030	0.371196	0.466141	0.451356	0.388328	0.339073

D - 3 Random number by variable A = 0.3029, B= 0.5402

0.496234	0.482712	0.368401	0.385951	0.341386	0.509041	0.401917	0.343001	0.455797	0.535394	0.531441	0.517353	0.317048	0.397644	0.374435
0.517844	0.479245	0.464193	0.349552	0.491384	0.322937	0.314683	0.456935	0.392744	0.407044	0.432657	0.514316	0.464732	0.427928	0.469271
0.333034	0.395975	0.458355	0.362482	0.376751	0.397768	0.517115	0.476538	0.495488	0.329269	0.426566	0.382197	0.312969	0.401807	0.461022
0.519644	0.458445	0.341488	0.449087	0.428321	0.364567	0.527098	0.456610	0.429340	0.364139	0.357857	0.468712	0.319854	0.458773	0.430835
0.452959	0.343523	0.331138	0.415211	0.342208	0.492756	0.419382	0.409904	0.386128	0.399889	0.418915	0.349840	0.426688	0.451918	0.468560
0.326046	0.470445	0.421162	0.386349	0.445750	0.405275	0.419000	0.432705	0.525725	0.444069	0.450989	0.310147	0.325854	0.372188	0.461067
0.368988	0.310454	0.530647	0.500056	0.365303	0.518997	0.383041	0.373217	0.510761	0.365123	0.464059	0.479469	0.497047	0.405331	0.345171
0.432675	0.368614	0.383674	0.441783	0.458113	0.346052	0.516483	0.479616	0.433452	0.445955	0.396756	0.421555	0.496904	0.306575	0.333278
0.530116	0.313856	0.441784	0.433349	0.466451	0.365500	0.390522	0.347739	0.450613	0.471672	0.390093	0.416786	0.474335	0.536418	0.539982
0.531868	0.325949	0.356011	0.520550	0.480436	0.337436	0.329288	0.465872	0.442206	0.355520	0.537348	0.517591	0.338463	0.342569	0.343507
0.340302	0.498307	0.481176	0.370730	0.409814	0.335189	0.488054	0.346447	0.352197	0.330763	0.311855	0.447621	0.459424	0.328105	0.310636
0.533222	0.467783	0.363434	0.482584	0.322791	0.509183	0.395385	0.390341	0.374386	0.373301	0.512950	0.449472	0.425963	0.391273	0.436073
0.530036	0.378148	0.422964	0.481760	0.357236	0.440464	0.360253	0.451359	0.414650	0.378546	0.519623	0.506846	0.533787	0.349913	0.512167
0.418080	0.528388	0.468791	0.393180	0.519635	0.433382	0.398748	0.488048	0.357595	0.403555	0.491834	0.494043	0.456906	0.419103	0.461695
0.492807	0.311074	0.514311	0.437644	0.339059	0.337298	0.325789	0.322151	0.503254	0.423415	0.326324	0.439756	0.492818	0.383462	0.348090
0.336570	0.407014	0.530540	0.320900	0.498866	0.505324	0.334217	0.523443	0.349118	0.323193	0.365042	0.346308	0.410586	0.528722	0.390444
0.402984	0.393444	0.432754	0.315702	0.430649	0.450514	0.526449	0.486977	0.356511	0.365187	0.382480	0.359836	0.405507	0.521295	0.412230
0.520204	0.484557	0.335796	0.428858	0.539283	0.386181	0.529791	0.418416	0.343409	0.492981	0.464199	0.513269	0.498747	0.315400	0.535843
0.490891	0.491601	0.338327	0.487796	0.321451	0.424694	0.439397	0.406329	0.356925	0.309834	0.335304	0.309704	0.322707	0.477994	0.340015

0.331521	0.403251	0.369583	0.520265	0.439634	0.441068	0.486091	0.477633	0.500690	0.504774	0.451440	0.337668	0.450253	0.435558	0.344586
0.442790	0.325261	0.407332	0.303173	0.465062	0.431217	0.524266	0.396564	0.485349	0.435921	0.459742	0.347767	0.439041	0.505578	0.352483
0.356574	0.444930	0.427991	0.412639	0.432607	0.509337	0.533731	0.465075	0.342589	0.523496	0.476070	0.313021	0.315258	0.385452	0.517693
0.394170	0.414650	0.411447	0.403598	0.403925	0.365732	0.348468	0.469970	0.507448	0.468219	0.514275	0.453632	0.523874	0.408742	0.463170
0.441243	0.468049	0.510626	0.412275	0.455826	0.378379	0.335855	0.407859	0.537797	0.441196	0.536001	0.369787	0.475811	0.315771	0.414068
0.362654	0.468983	0.425834	0.485659	0.456580	0.331190	0.468124	0.307546	0.424973	0.496394	0.485391	0.430709	0.477990	0.344928	0.519349
0.371822	0.454423	0.526822	0.379423	0.464031	0.525922	0.325163	0.381413	0.512740	0.511490	0.440877	0.467862	0.317946	0.460184	0.327582
0.449336	0.310874	0.454228	0.489119	0.453772	0.456089	0.427578	0.403589	0.442439	0.537569	0.523189	0.421340	0.507083	0.381406	0.479818
0.365851	0.319228	0.530161	0.414753	0.527190	0.416677	0.428751	0.367035	0.339623	0.303024	0.440555	0.430046	0.524634	0.516111	0.477616
0.498524	0.378741	0.360020	0.311386	0.352480	0.454610	0.507248	0.349661	0.350327	0.508269	0.306930	0.408542	0.536498	0.330938	0.436230
0.536086	0.428874	0.463344	0.344635	0.471213	0.432161	0.417956	0.497894	0.399470	0.448262	0.331580	0.332309	0.506726	0.537452	0.346609
0.476188	0.458200	0.371495	0.474173	0.358958	0.456507	0.396267	0.404920	0.480568	0.537815	0.507621	0.419262	0.489313	0.431038	0.444618
0.384502	0.399628	0.462320	0.415258	0.331233	0.431964	0.462231	0.513568	0.498811	0.428118	0.417824	0.505316	0.424724	0.470652	0.374075
0.441500	0.497482	0.467857	0.339141	0.447013	0.474004	0.478801	0.395728	0.490358	0.416691	0.503384	0.510283	0.345045	0.540079	0.334727
0.328474	0.473367	0.319035	0.383849	0.409718	0.426888	0.426308	0.485411	0.378486	0.493060	0.352592	0.367041	0.397485	0.371207	0.353350
0.517967	0.532760	0.363362	0.447033	0.411756	0.538706	0.385412	0.397059	0.429633	0.356967	0.433959	0.352368	0.334682	0.401266	0.515270
0.511642	0.428986	0.356065	0.348401	0.459979	0.354792	0.338494	0.494760	0.324245	0.421098	0.452371	0.436970	0.310230	0.413207	0.319856
0.496955	0.380057	0.461377	0.478129	0.485689	0.328006	0.441980	0.482080	0.329408	0.516672	0.310491	0.454846	0.525758	0.484187	0.360442
0.364771	0.327966	0.503274	0.360528	0.386007	0.328931	0.365107	0.392456	0.335242	0.439267	0.448771	0.401861	0.374400	0.497060	0.315656

0.411122	0.427744	0.465146	0.351707	0.328945	0.428956	0.537337	0.388235	0.341715	0.521476	0.452681	0.313591	0.537624	0.460083	0.488676
0.327026	0.476060	0.334243	0.395037	0.524481	0.328722	0.343344	0.435389	0.460939	0.491472	0.387159	0.474509	0.318786	0.360840	0.467536
0.539106	0.470731	0.474403	0.433837	0.347384	0.452818	0.364074	0.479106	0.515139	0.439916	0.539489	0.385347	0.525819	0.373024	0.305226
0.381706	0.488321	0.329087	0.357231	0.366064	0.332918	0.397060	0.403595	0.425479	0.407320	0.356096	0.459664	0.307214	0.464306	0.502995
0.373460	0.371237	0.330781	0.455233	0.492225	0.334770	0.320459	0.404786	0.469651	0.364032	0.457727	0.393992	0.465175	0.428158	0.521769
0.317623	0.467238	0.454942	0.417867	0.418608	0.326296	0.465236	0.332532	0.339347	0.481337	0.446464	0.451769	0.488881	0.400571	0.485847
0.373673	0.434998	0.380928	0.338933	0.485374	0.336603	0.398387	0.308698	0.529155	0.357163	0.394793	0.308038	0.429651	0.445906	0.313023
0.313899	0.396994	0.458050	0.488452	0.396872	0.342826	0.536127	0.371761	0.431252	0.318132	0.336641	0.518978	0.512996	0.480998	0.392644
0.422838	0.317515	0.480669	0.326774	0.367668	0.349470	0.398338	0.378248	0.464201	0.484987	0.308865	0.492873	0.516234	0.441372	0.470040
0.483586	0.488036	0.441290	0.372682	0.311736	0.378238	0.450185	0.458021	0.311576	0.462176	0.402830	0.479890	0.451435	0.433840	0.476013
0.452653	0.383009	0.478510	0.359229	0.462673	0.377989	0.339532	0.529981	0.494924	0.472620	0.346587	0.495852	0.335616	0.441381	0.356121
0.324231	0.447147	0.358624	0.428876	0.404836	0.354528	0.393393	0.524949	0.480547	0.455261	0.475126	0.393859	0.354584	0.424355	0.366747
0.322089	0.478800	0.477305	0.324613	0.410098	0.362472	0.341137	0.411556	0.331420	0.402340	0.390787	0.449380	0.346122	0.322499	0.462610
0.487339	0.327772	0.533223	0.399081	0.447619	0.514790	0.482800	0.359966	0.427493	0.395628	0.502602	0.439465	0.312824	0.473654	0.416209
0.517688	0.333248	0.508623	0.327780	0.316996	0.469775	0.509615	0.484173	0.380220	0.496570	0.477133	0.428681	0.328277	0.539288	0.450908
0.429564	0.433306	0.323363	0.329545	0.377842	0.434777	0.386139	0.483088	0.432572	0.378226	0.438404	0.368174	0.449182	0.387031	0.359008
0.328802	0.418045	0.389855	0.489045	0.486267	0.346666	0.465578	0.478656	0.397554	0.496190	0.344868	0.361900	0.525882	0.533380	0.344931
0.498864	0.514210	0.390511	0.372090	0.468164	0.353215	0.372701	0.479377	0.401402	0.490147	0.530087	0.410074	0.387012	0.385112	0.499774
0.383131	0.492493	0.465457	0.446118	0.332641	0.321254	0.428818	0.328035	0.345789	0.505142	0.365861	0.356936	0.400342	0.513277	0.484891

0.515495	0.472231	0.478282	0.422447	0.339025	0.370755	0.370915	0.399416	0.370519	0.330673	0.337668	0.422461	0.405005	0.307556	0.425579
0.326414	0.449631	0.529326	0.419081	0.385482	0.431911	0.492935	0.461163	0.462657	0.496224	0.452670	0.448320	0.467527	0.406167	0.343490
0.313380	0.384362	0.310475	0.511024	0.331770	0.536587	0.515547	0.524473	0.460534	0.379988	0.506817	0.497349	0.527199	0.500386	0.525620
0.435146	0.525019	0.387585	0.386701	0.512710	0.472730	0.444693	0.495338	0.332044	0.361330	0.534083	0.429117	0.488998	0.449407	0.443022
0.486213	0.332509	0.460148	0.409553	0.325272	0.501987	0.512677	0.417883	0.399557	0.384226	0.438360	0.350852	0.470332	0.426327	0.407463
0.376923	0.476268	0.369700	0.531546	0.523599	0.405713	0.526847	0.482477	0.368226	0.392052	0.539453	0.410609	0.328845	0.507896	0.526417
0.345373	0.456309	0.357570	0.312937	0.397587	0.414579	0.433215	0.401865	0.472966	0.432597	0.434255	0.404443	0.395431	0.326084	0.458548
0.383334	0.500607	0.471651	0.533783	0.314148	0.435957	0.475746	0.533505	0.370147	0.436244	0.425218	0.532144	0.443122	0.518381	0.410147
0.352768	0.397412	0.451111	0.347799	0.384145	0.366755	0.439765	0.537346	0.515568	0.396829	0.381371	0.450039	0.411911	0.328532	0.502160
0.423959	0.480833	0.443051	0.461208	0.477545	0.480642	0.309036	0.507962	0.499047	0.397376	0.404939	0.467916	0.314846	0.425583	0.429292
0.517980	0.501098	0.459622	0.442062	0.491478	0.422473	0.408862	0.395182	0.395453	0.425197	0.419606	0.473795	0.357168	0.336871	0.434337
0.452144	0.379420	0.314185	0.463104	0.432206	0.456388	0.456267	0.410810	0.421052	0.458932	0.319757	0.385218	0.500853	0.435639	0.464280
0.326994	0.433952	0.385667	0.388571	0.465741	0.375928	0.426581	0.361439	0.467777	0.528552	0.513561	0.425582	0.306612	0.303987	0.390034
0.395650	0.535247	0.410003	0.450092	0.514959	0.335819	0.391250	0.489044	0.500896	0.474313	0.318238	0.435004	0.507859	0.484834	0.359684
0.315861	0.433251	0.360067	0.495386	0.315902	0.415753	0.525282	0.512397	0.447565	0.397839	0.406407	0.340036	0.321426	0.504299	0.440279
0.421854	0.381310	0.472580	0.307470	0.374959	0.388912	0.499748	0.519724	0.439285	0.500303	0.499059	0.436276	0.461664	0.520462	0.508612
0.405347	0.449901	0.506072	0.322803	0.313861	0.489919	0.504388	0.435381	0.380270	0.334778	0.396523	0.467777	0.421600	0.537108	0.399428
0.539621	0.388479	0.369702	0.534220	0.349287	0.488064	0.391302	0.445011	0.411210	0.317249	0.448478	0.404098	0.354630	0.422768	0.329624
0.495493	0.482420	0.476378	0.457465	0.473795	0.461538	0.443663	0.338228	0.472284	0.322892	0.497163	0.501347	0.438544	0.367308	0.408225

0.336183	0.355387	0.378366	0.524932	0.462430	0.535398	0.455321	0.379059	0.501818	0.410011	0.494873	0.435446	0.349938	0.431710	0.360109
0.364629	0.417438	0.447329	0.497181	0.405298	0.370489	0.355406	0.424257	0.441654	0.393702	0.387500	0.482448	0.349190	0.431067	0.502557
0.323501	0.392127	0.518889	0.475717	0.467682	0.444087	0.501533	0.317282	0.527886	0.490282	0.320281	0.539128	0.380459	0.376726	0.506317
0.404796	0.427193	0.518629	0.344620	0.363835	0.531221	0.533336	0.475106	0.317382	0.389345	0.443142	0.531285	0.511804	0.319804	0.531565
0.363953	0.365754	0.443285	0.388416	0.305216	0.346985	0.503744	0.434971	0.441635	0.429227	0.518888	0.429871	0.414692	0.346084	0.418916
0.373510	0.319121	0.381819	0.347700	0.429211	0.348708	0.422974	0.428517	0.370556	0.471776	0.348881	0.531626	0.398762	0.324966	0.355180
0.403719	0.406440	0.505332	0.303184	0.369200	0.383972	0.369077	0.499855	0.499321	0.509701	0.405501	0.330338	0.345432	0.412886	0.356579
0.331188	0.344155	0.407881	0.377986	0.527440	0.524277	0.480072	0.506684	0.348221	0.380898	0.480676	0.315109	0.532826	0.305115	0.430280
0.420379	0.309095	0.517504	0.468919	0.517999	0.395605	0.359124	0.490137	0.407912	0.457173	0.312198	0.375122	0.399589	0.520036	0.483749
0.470530	0.529445	0.310773	0.451273	0.396084	0.367734	0.530078	0.378322	0.396257	0.534229	0.527463	0.440580	0.503297	0.455423	0.385378
0.360700	0.405081	0.429245	0.431769	0.308798	0.338957	0.450088	0.410209	0.499046	0.320927	0.484120	0.428898	0.448917	0.303237	0.412350
0.489197	0.531078	0.472925	0.407084	0.462232	0.397134	0.445342	0.481404	0.463522	0.442200	0.435508	0.516757	0.392270	0.310110	0.454612
0.320481	0.483821	0.345448	0.371106	0.501561	0.391822	0.343859	0.328970	0.352164	0.401115	0.346526	0.431173	0.511055	0.352370	0.520584
0.396369	0.304644	0.382759	0.421944	0.533437	0.334014	0.324339	0.328942	0.378386	0.376258	0.421063	0.405409	0.489145	0.410863	0.341241
0.303705	0.464273	0.347444	0.483615	0.316410	0.406135	0.363474	0.366943	0.334653	0.365508	0.425785	0.431675	0.413234	0.333100	0.472720
0.355267	0.470422	0.379293	0.483819	0.409762	0.324616	0.506639	0.427396	0.462238	0.482955	0.538834	0.471956	0.496057	0.304952	0.439997
0.303209	0.455989	0.398735	0.439598	0.441120	0.448751	0.519096	0.533710	0.438396	0.539065	0.505756	0.306857	0.516101	0.475436	0.405722
0.347792	0.433963	0.433075	0.480320	0.465839	0.305505	0.468923	0.471480	0.343186	0.347173	0.531278	0.492959	0.404758	0.386932	0.512731
0.336711	0.354657	0.314466	0.456085	0.473621	0.438935	0.474986	0.376904	0.337939	0.488266	0.464013	0.336717	0.382236	0.488100	0.396171

0.535686	0.348802	0.513010	0.427015	0.352194	0.479657	0.526042	0.397601	0.517577	0.536697	0.431090	0.380178	0.478717	0.316178	0.504109
0.333046	0.481925	0.399655	0.380093	0.354936	0.514635	0.304284	0.445147	0.512765	0.435664	0.310083	0.452448	0.423162	0.496740	0.489146
0.358011	0.385068	0.311533	0.500296	0.380214	0.360470	0.447726	0.492864	0.407072	0.524441	0.468135	0.357550	0.350342	0.428413	0.367168
0.308508	0.402240	0.479961	0.495183	0.325669	0.333653	0.492995	0.327833	0.488403	0.473837	0.426229	0.440507	0.404273	0.467669	0.356959
0.447044	0.339852	0.339641	0.435076	0.480290	0.356309	0.358187	0.497828	0.338131	0.417762	0.316908	0.446029	0.342930	0.353304	0.379079
0.329195	0.497249	0.337049	0.365301	0.480521	0.385958	0.524175	0.502490	0.449982	0.454542	0.514106	0.445251	0.481277	0.431820	0.499755
0.399590	0.451194	0.446694	0.464398	0.431825	0.371025	0.484022	0.387024	0.364746	0.513536	0.381257	0.409312	0.390310	0.469608	0.498004
0.512691	0.478160	0.363288	0.358346	0.383139	0.522993	0.499016	0.404955	0.408654	0.350060	0.357408	0.311306	0.526393	0.529862	0.438323
0.432972	0.493953	0.379822	0.411210	0.500413	0.315077	0.438983	0.438692	0.503181	0.396720	0.329940	0.424828	0.306975	0.408390	0.438595
0.390464	0.318852	0.398245	0.394158	0.434025	0.443540	0.490980	0.469206	0.349459	0.538343	0.376682	0.399654	0.499635	0.323165	0.370772
0.352341	0.528523	0.399332	0.430710	0.530125	0.341556	0.380981	0.479088	0.375004	0.398378	0.357107	0.328539	0.451590	0.316507	0.468804
0.407536	0.420975	0.394543	0.538231	0.514769	0.501854	0.355928	0.482746	0.417586	0.459247	0.457619	0.412028	0.430745	0.452269	0.491852
0.529805	0.482096	0.447606	0.482114	0.387498	0.342662	0.377029	0.395240	0.383063	0.516790	0.318600	0.409894	0.457265	0.491833	0.407689
0.332331	0.479073	0.342503	0.535562	0.432561	0.422072	0.441607	0.404773	0.492381	0.539104	0.368260	0.433686	0.475329	0.466920	0.408787
0.414612	0.500127	0.347534	0.358614	0.385168	0.540041	0.499839	0.529841	0.537231	0.457896	0.369776	0.494022	0.325322	0.384842	0.413402
0.506241	0.340038	0.325355	0.428327	0.450691	0.387238	0.371827	0.438866	0.340642	0.328632	0.511740	0.469212	0.511148	0.527580	0.369116
0.313197	0.411419	0.379592	0.315106	0.491939	0.314072	0.398426	0.504539	0.359112	0.311470	0.408340	0.509881	0.306308	0.426341	0.463167
0.467023	0.449575	0.485525	0.482507	0.479896	0.353602	0.507466	0.368477	0.469541	0.449573	0.482278	0.315285	0.372738	0.529240	0.517340
0.535213	0.524107	0.358456	0.445750	0.332690	0.397307	0.448778	0.450577	0.391999	0.437483	0.446062	0.355030	0.345594	0.320364	0.518493

0.337482	0.468596	0.327774	0.525562	0.520575	0.500744	0.496753	0.406641	0.516891	0.350321
0.441731	0.309861	0.506587	0.363513	0.423885	0.492851	0.347862	0.393036	0.402452	0.447022
0.320309	0.428167	0.468583	0.429420	0.534076	0.520713	0.332252	0.535373	0.387884	0.431765
0.498038	0.310511	0.477017	0.529463	0.349714	0.335482	0.497722	0.397581	0.418937	0.341420
0.474445	0.499181	0.457271	0.366436	0.329284	0.422673	0.454273	0.407356	0.363640	0.304241
0.522606	0.383579	0.425411	0.362245	0.373462	0.398997	0.306725	0.340111	0.523392	0.485973
0.419803	0.503825	0.380352	0.523037	0.396970	0.344089	0.515510	0.380268	0.413661	0.484384
0.458304	0.361292	0.459939	0.319175	0.402745	0.439391	0.425199	0.377427	0.363176	0.402820
0.514126	0.440888	0.330798	0.373948	0.376813	0.446756	0.432115	0.515165	0.405228	0.316382
0.430692	0.525411	0.337977	0.443283	0.467549	0.353788	0.446809	0.361519	0.469610	0.441898
0.369867	0.314240	0.307590	0.351143	0.324701	0.426280	0.483352	0.376624	0.398373	0.344227
0.534495	0.315709	0.531726	0.453795	0.398316	0.537634	0.505874	0.399925	0.346051	0.475799
0.311544	0.307793	0.533169	0.492353	0.372946	0.419157	0.393755	0.470911	0.506088	0.429687
0.380318	0.464615	0.332292	0.421954	0.375632	0.467793	0.322987	0.336985	0.441531	0.362952
0.533796	0.444955	0.413816	0.457338	0.327950	0.400530	0.477048	0.509665	0.391550	0.520518
0.389522	0.329959	0.458733	0.491780	0.443815	0.311153	0.381681	0.322633	0.355508	0.482820
0.376261	0.491849	0.371761	0.358280	0.369991	0.372389	0.502173	0.412470	0.354867	0.513392
0.331593	0.449516	0.481952	0.445479	0.339734	0.493082	0.391110	0.310111	0.426826	0.319226
0.520211	0.319562	0.435341	0.329587	0.303056	0.385125	0.499435	0.481634	0.405751	0.346451

AUTHOR BIOGRAPHY

NAME	Mr. Natthanun Jangsetthagul
DATE OF BIRTH	September 22, 1969
ADDRESS	15/1053 D-Condo, Ramkhamhaeng Road, Huamark, Bangkapi Bangkok, 10240.
EDUCATIONAL BACKGROUND	1992 Bachelor degree in Business Administration (Marketing): The University of Thai Chamber of Commerce, Bangkok.

EXPERIENCES

1992-1994	Thai International Fast Food CO., LTD Assistant Manager
1994-2001	Entertain Golden Villages CO., LTD Manager
2001-2002	Ake- Chai distribution system CO., LTD Department Manager
2004-Present	Amway (Thailand) Ltd Shop Manager