INVENTORY MANAGEMENT BY SIMULATION ANALYSIS: A CASE STUDY OF DAVIS & SHIRTLIFF COMPANY LIMITED

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DECLARATION

I, the undersigned declare that this is my original work and has not been submitted to any other college, institution or university other than University of Nairobi for academic credit.

Signed: ______________________ Date: 15th NOV 2008

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This project has been submitted for examination with my approval as the university supervisor

Signed: ______________________ Date: 19/11/08

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DEDICATION

To my parents, who sacrificed so much in their life to give us, their children, a very goo education.

AKNOWLEDGEMENT

There is no night so long and dark, that it will never give way to the light of day. To complete the journey in writing this project report involved literally sitting through some of the darkest nights that I have known. This work is as a result of many hands and minds and without the invaluable help of many people, it would never have seen the light of day.

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ABSTRACT

Many organizations face serious challenges when it comes to managing their inventory. This study was aimed at developing an inventory management model that could be used to optimize financial resources deployed in inventory. It was a case study of a water engineering company. The company carries stocks of high value equipment and hence the importance of instituting proper inventory management systems.

The model was developed through simulation analysis carried out on selected items from the company's inventory list. The selection of the items whose inventory simulation was carried out was based on an ABC analysis conducted on the product items. The Monte Carlo simulation method was applied using an electronic spreadsheet and both demand and lead time were treated as stochastic. The simulation was conducted over a period of 1000 weeks.

The study came up with an inventory model that will minimize the total inventory costs through simulation analysis while demonstrating how simulation technique can be effectively used to solve inventory management problems. For each product item whose demand and lead time was simulated, minimum cost inventory policies were determined in terms of the order quantities and reorder points.

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CHAPTER 1: INTRODUCTION

1.1 Background

Inventory is the stock of any item or resource used in an organization. An inventory system is the set of policies and controls that monitors the level of inventory and determines what levels should be maintained, when stock should be replenished and how large orders ought to be (Chase, Aquilano and Jacobs, 2003). Inventory management is receiving increased attention because stock assets form the largest proportion of an organisation's expenditure (Thierauf, 1975). In some organizations, inventory constitutes up to 60% of the value of current assets (Singh and Kongere, 2003).

Inventory is an important component of supply chain, and how well the whole supply chain is managed can be a source of a firm's competitive advantage. According to Chase et al (2003), the average cost of inventory across all manufacturing in the United States is 30 to 35% of its value. The costs of inventory carriage are due to obsolescence, insurance, opportunity cost, and so on. It follows therefore that if a firm improves its supply chain management such that it achieves a significant reduction in the size of inventory carried while at the same time meeting production and customer service requirements, the cost savings on the inventory go directly to improve the firm's profitability. Although not a core activity of most businesses, the financial implications of inventory management are critical to profitability. This lends importance to the area of inventory management. The components of inventory management include organizing incoming supplies, work in process inventory and final product (Mathews and Hendrickson, 2003).

Inventory management is an area characterised by varied problems such that it is difficult to consistently or logically classify them. Some of the major constrains that appear in inventory management are interactions among various products, storage capacity limitations, availability of funds, procurement methods, procurement sources, cooperation of suppliers and the nature of inventory (Kaffman, 1963). Due to the varied nature of inventory problems, many organizations struggle with issues relating to inventory management and use "gut feeling" to determine critical inventory parameters.

One of the issues organisations have faced when it comes to inventory management is bloated or high inventory levels. Too much inventory may be caused by poor forecasting, inadequate order and product specifications, ineffective production scheduling, poor quality, bottlenecks, long cycle times, and inappropriate performance metrics (Donovan, 2003), resulting into serious and costly business process and system problems like high cost of holding inventory and high working capital that can be very deeply rooted across the organisation. In one survey conducted by Donovan and Company, (Donovan, 2003) 82% of senior executives who responded said that inventory reduction was a major concern. Pressures to reduce inventories and therefore working capital requirements are increasing even in times of relatively lower interest rates. This is because of the many opportunities available for more efficient use of capital.

Another issue usually faced by organisations in trying to effectively manage inventory is long lead times (Donovan, 2003). This is especially a problem for organizations that import product from overseas. Long lead-times usually require long-range forecasts, which are by nature inaccurate. When actual customer-demand is not what is forecasted the results may be that unsold inventory quickly accumulates in expensive piles and expensive expediting is used to produce the needed products that are in short supply.

Throughout the end of the 1980's most software packages for distributors placed an emphasis on the ability to analyse sales and profits. In the early 1990's, many distributors recognised that they needed help in controlling and managing their largest asset, inventory (Schreibfeder, 1997). In response to this need, several computer software companies developed comprehensive inventory management modules and systems. The new packages included many new features designed to help distributors effectively manage warehouse stock. However, even after implementing new software, many distributors still felt they had not gained control of their inventory. They continued to face many of the same challenges they experienced with their old systems.

1.1.1 Inventory Management

The significant challenges faced by organizations in c
underscore the importance of inventory management. Inve
role in an organisation's operations and there is need to n
firm competitive advantage. Fisher (1997) argues that in
adversarial relations between supply chain partners as
industry practices which lead to lack of synchronizatio
members. The impact of these types of practices produc
the bull whip effect, whereby variability in demand fro
retailer causes a higher variability in demand from the re
and an even greater variability in the demand from
manufacturer (Chase et al, 2003).

Some organizations have adopted a continuous reple
smooth the flow of materials through their supply chain (C
involves establishment of electronic data interchange link
chain partners to enhance sharing of information. Us
wholesaler can forecast future demand and determine
replenishment based on upper and lower inventory limits
with retailers. This system enables both the wholesale
optimize their inventory holding while maintaining a h
service.

Aviv (2007) explored the potential benefits of collabor
partnerships in supply chains consisting of a manufacturer
that when the retailer is the dominant observer of market
yields a "win-win" outcome. Therefore, there are potentia
within a supply chain when it's trading partners sha
information.

Braglia and Zavanella (2003) have identified an indust
especially in the automotive industry known as Consignm
continuous exchange of information between the vendor

most radical application, it may lead to the suppression of the vendor's inventory as the vendor uses the buyer's warehouse to stock material, in the case where the warehouse is close to the buyer's production line such that material may be picked up whenever it is required. Their results show that consignment stocking policy is a strategic and profitable approach to stock management in uncertain environments where delivery lead times and market demand vary over time.

The practice of Just In Time (JIT) inventory management brought about by the management shift towards lean production has changed a paradigm of maintaining large inventories of parts and supplies to one where firms accept deliveries more frequently but maintain lower inventory levels (Mathews and Hendrickson, 2003). As opposed to holding huge inventories, deliveries are made via faster freight methods, e.g. truck or air instead of rail or water and this reduces the inventory in transit as well as on hand inventory.

Another emerging practice is virtual warehousing, where firms may actually hold no physical inventory of parts or supplies (Mathews and Hendrickson, 2003). The firms contract with partners or third party vendors who manage an overall level of inventory and guarantee that their customers will receive the necessary supplies when needed. Firms save money by outsourcing the activity of inventory management while the contracted firms centrally manage similar inventories of many companies at once.

Having seen the importance of inventory management to organisations, we now look at Simulation, as one of the methods that may be applied in inventory management.

1.1.2 Simulation

Legrande (1963) defines simulation as the exploration of alternative courses of action in a decision making situation and anticipation of the consequences of each one without actually trying each course of action. According to Render et al (2006), simulation involves trying to duplicate the features, appearance and characteristics of a real system. Simulation is widely used in business and management and involves building a mathematical model that comes as close as possible to representing the reality of the system. The problems tackled by simulation range from the very simple such as bank teller lines to the very complex such as analysis of a national economy. Simulation is also a very useful method in evaluating the effect of crisis situations and preparing for disasters. In such situations, simulation exercises provide the means to train people in an environment that is as realistic as possible (Haperen, 2001)

Though simulation is one of the oldest quantitative analysis tools, it has become more popular and useful in solving management problems with the advent of digital computers (Render et al., 2006). According to Saliby (1990), developments in computing have reduced the time taken in coding simulation programs and also processing times. New computer simulation systems or program generators such as CAPS by Clementson, DRAFT by Mathewson and more recently the VS6 system have made it easier to develop and code simulation programs. Processing time has been reduced by development of faster and more powerful computers. It is important to note however, that simulation does not guarantee optimal solutions and it is useful when a reasonably good estimate is being sought (Lelei, 1996).

1.1.3 Davis & Shirtliff Ltd

Davis & Shirtliff Ltd is a water engineering company which was started back in 1946 and has postured itself over the years as one of the leading water engineering firms in Eastern Africa. The pioneers who started the company just after World War II, Eddie Davis & Dick Shirtliff were two engineers from the British army. The organisation focussed on supply and installation of water related equipment and machinery and was heavily involved in large contracts and project work. However over the last ten years, the organization has adopted a changed strategy, by getting out of project work and concentrating on supply of water related equipment. Its main areas of expertise are supply and installation of surface pumping systems, borehole, pool, solar, power supply and water treatment equipment.

The company holds franchises of key world-renowned manufacturers of equipment in each of its product areas, and by so doing, it has managed to become dominant in the market in its areas of operation. The principal suppliers include Grundfos A/S of Denmark, Davey PTY and KSB Ajax of Australia, Pedrollo and Hanna of Italy, Lister and Certikin of UK, Yingli of China, So Safe and Tripplite of USA, Apex and Jainson of India and Sensus of France. In Kenya, the company now has branches in Mombasa, Kisumu, Eldoret and Nakuru. The company has subsidiaries in Uganda (Kampala), Tanzania (Dar es Salaam, Arusha and Zanzibar) Zambia (Lusaka and Kitwe) and recently in Rwanda (Kigali). The company's headquarters is in Nairobi, and the ownership is private being 100% Kenyan owned and run by local managers.

The organisational structure of the company is based on specialised and responsible business units and cost centres each with a focused role for which they are adequately resourced. The organisation has a total staff complement of 220 members in the entire group, 60% being at the head office in Nairobi.

According to Waweru (2000), in 1986 the water pumps engineering industry in Kenya was dominated by seven fabricators of pumps, ten assemblers and 18 large scale importers. Due to the competition and environmental turbulence that prevailed in the Kenyan economy in the decade of the 1990's, some of these firms have either folded up, changed ownership or diversified into other product areas. The major players in the Kenyan water engineering industry include Davis and Shirtliff limited, Baumann engineering limited, Switchgear and Controls limited, Johnson Pumps limited, Jos Hansen and Soehne (EA) limited, City Engineering Works limited, Kirloskar (K) limited, Karnataka Pumps (K) limited and Shakti Pumps limited. As the economic environment started to improve in Kenya, this has attracted new international entrants into the industry, such as Shakti Pumps and Karnataka Pumps of India. It is therefore important that organisations focus on competitiveness and efficiency in resource utilization, and therefore inventory management is an important issue in the water engineering industry. This is more so due to the high cost of the equipment held in stock.

1.2 Statement of the Problem

The strategy adopted by Davis and Shirtliff limited in stock holding i central stockholding in Nairobi from where the branches and subsic their stock. This means that the company commits a relatively high p its financial resources to inventory to service the regional demand. T of central stocking works well for the company since branches and do not have to duplicate stocks. However, because the equipment st high value, there is always the dilemma of a balance between too hig and too low stocks. High inventory sometimes puts a strain on cas overdraft while low inventory leads to lost sales and poor customer s strategy is supported by a well-organised and efficient logistics fu ensures deliveries are well handled and delivered on time. Bra subsidiaries therefore only keep minimum stocks for display purposes.

The main problem experienced by the company in inventory man periodic stock shortages. To put into perspective the nature of the pro by the company, an analysis of inventory held, sales and projected lo Grundfos Submersible Pumps was carried out for the financial y company 2004. A summary of the analysis is attached in appendix product items that make the whole range of submersible pumps offe company were analysed to determine the periods in the year during product was out of stock and the impact these stock shortages h company's financial performance in terms of lost sales. It was foun average monthly stock holding of the company was approximately million. During the year, the total sales were approximately KShs6 which is an average of KShs5.29million per month. Despite the financial resources tied up in inventory, the projected lost sales in the KShs12.95 million or an average of KShs1.08 million per month, re 20% of the total year sales. Clearly, this is a significant proport company's business and is a lost opportunity. A look at the monthly sto figures reveals that the inventory fluctuates widely between KShs5.1 KShs9.5 million.

The inventory management system used by the company is period based, w orders placed on a monthly basis. There is no alert system to warn when certain item stock level has reached a critical level requiring an order for that it to be raised. A stock out report generated weekly shows a list of items with ze stock balances and is circulated to the frontline staff to inform them that certa items have gone out of stock. Product shelf life is based on stock turn, which targeted at 4. This means that the company aims to hold 3 months stock of ea product. The sales history of each product is used to determine sales per mon which when multiplied with the total of the shelf life and lead time gives t quantity of each product that is targeted to be held in stock at any one tim During the monthly order review, the targeted stock quantities are compared w the quantities available in stock at that time and the differences taken to be t quantities that are suggested for order. The suggested order is further subject to the manager's judgement, taking into account cash flow, anticipated dema and stock reservations before a final decision on quantities to order is made.

The weakness with this system is that it does not take into account th stochastic nature of demand and lead time. Also lack of an alert system to gi an indication when items are approaching minimum stocking levels is a maj disadvantage of the system currently being used. Proper ordering and invento models based on projected sales, lead times and stock holding costs have n been established and as can be seen from the lost sales figures, instituting su a system would reduce the lost sales significantly. Lost sales negatively impa the company in several ways. Apart from the opportunity cost of lost busines stock outs are a source of customer dissatisfaction. Also, stock outs strengthe the company's competitors. Whenever the company does not have a product th the customer requires, the customer may choose to try the competitor's produc The company may then end up loosing a key customer and strengthening th competitor. Stock shortages also lead to costly expediting by sales staff in a attempt to meet customers' requirements. When a certain pump required by customer is not available, sales people put pressure on the supply department t breakdown some equipment and build up the required product to meet th customer's needs. In the process, expensive parts like pump shafts may be cu down and sometimes sold below cost.

For the strategy that has been adopted by the company to work well, it is important that the problem of stock shortages is dealt with and the inventory is optimised. As the organisation seeks to spread wider into new geographical areas, it must ensure that adequate stocks are held to cover the anticipated demand. On the other hand if too much stock is held this will put a strain on cash flow. The organisation has therefore got to stock enough but not too much. Proper inventory models need to be established and should be used to guide ordering and stock holding. If this is done, lost sales will be reduced and financial resources committed to inventory will be optimised.

Various studies carried out have identified inventory management problems faced by local companies. Odeny (1987) conducted a study on drugs inventory management at Kenyatta National Hospital. The findings of his study indicated that lack of computerised information systems contributed to poor inventory management of the drugs. Gathumbi (1997) carried out a similar study at Nairobi City Council Health Services and cited lack of computers and inability to implement inventory control models as the problems leading to poor inventory management. Kariuki (1993) studied drug inventory management at the University of Nairobi Health Clinics and found that proper inventory management was hampered by inadequate financial resources and poor records.

The findings from these studies may not be generalised to this study as they were conducted in the drugs industry while this study will focus on the engineering sector where equipment stocked is of very high value. Also, the studies conducted earlier did not come up with appropriate inventory models after identifying the problems faced in inventory management. By using simulation analysis, this study will go further and come up with an inventory model, which can be used to optimise financial resources and avoid shortages.

Lelei (1996) demonstrated the use of simulation technique in inventory management by using an electronic spreadsheet to determine safety stock. The objective of the simulation was minimization of total cost. In his model, the lead time variable was assumed to be deterministic. However, in most real life situations, lead time is stochastic. This study will treat both demand and lead time as stochastic and both their probability distributions will be determined using Monte Carlo random numbers.

The proposed study therefore intends to fill the gap in inventory management in equipment industry while demonstrating how simulation technique can be effectively used to solve inventory management problems.

1.3 Objectives of the Study

The objectives of this study are:
(i) To demonstrate how simulation analysis can be used to develop an inventory model for application in determining order quantities and ordering frequency.

(ii) To develop an inventory model that will minimise the total inventory costs.

1.4 Importance of the Study

This study will benefit various groups as follows:
(i) Davis & Shirtliff Company
Development of an inventory model will optimise financial resources deployed in stock holding and lead to a reduction in lost sales due to stock outs.

(ii) Engineering Industry
Development of an inventory model for stock holding will help managers in the engineering industry to understand and apply inventory management techniques in optimisation of financial resources.

(iii) Academicians
The study aims to shed light in the area of inventory management as practised by local companies and hopefully stimulate further research into the aspects of inventory optimisation techniques among Kenyan Companies.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

An inventory consists of useable but idle resources such as men, machines, materials or money. When the resource involved is materials, the inventory is also called stock (Gupta and Hira, 2004). Though inventory of materials is an idle resource, almost all businesses must maintain it for efficient and smooth running of operations. An inventory system is the set of policies and controls that monitors levels of inventory and determines what levels should be maintained, when stock should be replenished and how large orders should be (Chase et al, 2003). It is necessary to monitor inventory because it takes up a significant proportion of an organization's resources (Singh and Kongere, 2003) which could be deployed to other use.

When attempting to explore the various issues that have been brought up in the literature on inventory management, it is first necessary to understand why an organisation needs to keep inventory. We will then look at the challenges that organisations face in inventory management and the techniques used in managing inventory. Finally, we will explore the Simulation method and its application in inventory management.

2.2 Inventory Management

It has been observed that between 1977 and 2000, the typical high – technology company in the U.S. doubled its inventory performance from 2.5 to 5.0 turns (Chase et al, 2003). Chase et al, (2003) argue that this has been made possible through steady improvement in the supply chain business processes and efficient use of information management systems. A key element in inventory management is availability of high quality information. The better the information on what is available and what is required, the less the inventory needed. This leads to better inventory management.

2.2.1 Necessity of Inventory

Inventory serves several important functions and adds a great deal of flexibility to the operation of an organisation. One of the major functions of inventory is to help in smoothening the running of the enterprise. It decouples the production from customers and vendors and simplifies the organisation thus reducing the coordination effort and improving efficiencies (Srivastava et al, 2004). Inventory also allows the organisation to provide service at short notice and this fetches customer goodwill. When the supply or demand for an item is irregular, storing certain amounts in inventory can be very important. The safety or buffer stock so maintained absorbs the demand variation. In absence of inventory, piecemeal purchasing may increase ordering costs. Inventory also acts as buffer stock when raw materials are received late (Render et al, 2006). When material is ordered from a vendor, delays can occur for a variety of reasons such as variation in shipping time, shortage of material at the vendor's plant or shipping of incorrect or defective material. In such situations, inventory held will ensure that production processes carry on despite the raw material delay. Process and movement inventories (pipeline stocks) are quite necessary in big enterprises where significant amounts of time are required to transport items from one location to another.

Keeping inventory usually means tying up capital that could be used in other ventures. Maintenance of inventory requires money to be spent on personnel, equipment, storage pace, and insurance e.t.c. Excess inventory is therefore not desirable and there is therefore the necessity to control or manage inventory.

2.2.2 Challenges of Inventory Management

In managing inventory, the basic concern of management is to develop inventory policies that will minimize the total operating cost of the firm (Srivastava et al, 2004). There are two basic decisions concerning inventory levels that must usually be made. The first is the quantity that should be ordered at any particular time if the time at which orders for goods are to be placed is fixed. The second involves determining both the order quantity and time at which the order should be placed.

Scientific inventory management can therefore be used to optimise financial resources and save money for the organisation. The process of scientific inventory management involves: (Hillier and Lieberman, 1980) 1) formulating a mathematical model describing the behaviour of the inventory system, 2) deriving an optimal inventory policy with respect to this model; and 3) using a computer to maintain a record of the inventory levels and to signal when and how much to reorder.

Few studies in this country have been conducted in the area of effective inventory management systems. Odeny (1987) conducted a case study of drugs inventory management at Kenyatta National Hospital. He cited lack of computerised information systems as one of the problems contributing to poor inventory management and consequent drug shortage.

Gathumbi (1997) carried out a case study of the Nairobi City Council Health Services on application of inventory models in drug inventory management. He found that the major factor hindering the application of inventory models is frustration by the ordering system. He also cited lack of computers to keep track of inventory levels and lack of awareness on how best to implement inventory models as constraining factors.

Kariuki (1993) carried out a case study on drug inventory management at the University of Nairobi Health Services. He found out that among the problems causing drug shortages at the University of Nairobi Health Clinics was inadequate financial resources, poor records on drug usage and unreliable suppliers.

The studies by Odeny (1987), Gathumbi (1997) and Kariuki (1993) are all in agreement on the need for inventory management information systems. Proper records can only be maintained if an organization invests in a suitable inventory management system. The quality of information that is available to manage and control inventory is only as good as the records that are maintained. However, when a good inventory management system has been maintained, the challenge to an organization's management team then becomes how this data can be used to ensure that the inventory is well managed. This would then involve using the available information to come up with inventory policies that optimize the use of inventory and minimize costs. Although Odeny (1987), Gathumbi (1997) and Kariuki (1993) are all in agreement on the need for computerised information systems in enhancing inventory management, they did not demonstrate how organizations can use this information to develop suitable inventory management policies.

Yobesh (1991) carried out a case study on inventory optimisation and determination of major inventory parameters for a raw material called hops used in beer manufacture at Kenya Breweries Ltd. He analysed 3-year data to determine inventory parameters that could be used to identify a suitable inventory model and develop a policy for the raw material hops, though he fell short of coming up with a model and inventory policy.

2.2.3 Inventory as Part of the Supply Chain

Identifying a suitable inventory model for a particular item is a complicated process due to the fact that inventory management is just one aspect of supply chain management. A supply chain can be viewed as a network of participating corporations working together to achieve global objectives which are generally minimizing total cost, through which material and products are acquired, transformed, and delivered to customers. Supply chain management is the act of optimizing all activities through the supply chain so that products and services are supplied in the right quantity at the right time (Chan and Chan, 2006).

In dealing with supply chains, complications can arise out of managing inventory of a wide selection of products where demand is hardly ever known precisely, and if a product is not stocked, a sale may be lost. In some cases, when a certain item is not in stock, customers may decide to buy another item, leading to demand substitution, if the items are interrelated (Smith and Agrawal, 1998). Smith and Agrawal (1998) have developed a method for determining the effect of substitution on the demand distributions for items and for jointly selecting stock levels for an assortment of interrelated items. By rigorous mathematical modelling employing probability distributions to predict demand, they have developed an inventory management methodology that incorporates the effect of product substitution on demand and customer service when determining optimal levels of inventory.

In a large supply chain such as those found in the computer and electronics or automotive industries, managers face the challenge of not knowing how to quantify the trade off between service levels and the investment in inventory required to support those service levels. The problem may be further complicated by the fact that sometimes supply chains are dynamic with products whose life spans are short, customer demand may be erratic or the required service levels may change. A model has been developed (Ettl et al, 2000) which optimizes the total expected inventory capital throughout the supply chain network while satisfying some given service level requirements. By modelling the demand data along a poisson distribution and relating this demand to performance measures such as on hand inventory, backorders and stock out probabilities, an optimized inventory model has been developed and implemented as computer software in the system. The system then generates the base stock levels at all stores in the network which minimize the total inventory capital while meeting required customer service levels.

Some of the problems experienced in inventory management will necessarily be linked to other activities of the supply chain, for example, delays in product shipment or delivery will affect inventory levels, as well as variation in demand from the forecasted levels. Tan and Karabati (2002) argue that inventory management is further complicated by the fact that organizational data systems capture information only on transactions that take place within a supply chain, leaving out the information on the actions that could not be transformed into transactions. As an example, a customer who could not buy a product from the shelves because the product was out of stock at the time of intention to buy does not have this information collected and recorded. In this case, the customer's demand is unobserved and will not be taken into account in influencing the company's inventory policy. Therefore, although standard procedure in developing inventory models is to use existing data and classical formulae, this approach may not always yield the desired results and there is need to employ other tools which take into account the input uncertainties encountered in real life systems.

2.2.4 Application of Heuristics in Inventory Management

While reviewing the available literature on the use of operations research in inventory management, Silver (1981) has remarked that a serious gap exists between theory and practice in many organizations. He has suggested that more attention should be devoted by analysts to formulating accurate models and seeking good solutions to them rather than getting the optimal solutions to mathematically interesting but possibly unrealistic formulations of inventory problems. In this regard, heuristic and simulation solution methods are worthy of more consideration. A lot of work has been done in the use of heuristic methods in developing solutions to inventory problems. Sandling et al, (1987) developed an inventory modelling system designed to help electric utility companies set long term fuel inventory strategies. The model was used by more than 50 companies, and provided a quantitative framework that helped to examine the trade offs involved in inventory decision making. The core of the model consists of a simulation sub model and two analytical sub models and addresses a wide range of issues that influence inventory policy such as supply and demand disruptions, fuel burn uncertainty, nonlinear supply and shortage costs, emergency management and seasonality.

Silver and Cao (2005) investigated an inventory system consisting of a central ware house (depot) and retailers (regional ware houses) whereby the system is replenished regularly by an outside supplier on a fixed cycle. Most of the stock is directly shipped to the retailer locations but some stock is sent to the central ware house. At the beginning of any one of the periods during the cycle, the central stock can then be completely allocated to the retailers. The issues that arise under this centralised control system are, first of all, how much of the inventory should be delivered to each regional sub warehouse; secondly, how much of the inventory should be retained at the central ware house and thirdly, when and how the centrally retained inventory should be allocated to the regional sub warehouses. A heuristic method was used to dynamically determine the appropriate period in which to do the allocation, bearing in mind that retailer inventory levels change with time. This dynamic heuristic was compared to an earlier published solution and the proposed heuristic was found to reduce the average shortages by 12% as compared to the earlier method. In this research study, we will therefore attempt to bridge the gap between theory and practice and will be focusing on simulation as a practical method of optimizing the use of inventory.

We now proceed to look at the techniques adopted in the classical approach to inventory management.

2.2.5 Inventory Management Techniques

Inventory costs are usually classified into three categories:

2.2.5.1 Ordering Costs

These are the costs of getting an item into the company stores. They are incurred each time an order is placed with the supplier. Ordering costs include those costs incurred on purchase requisitions, order processing and follow up actions as well as receiving goods, quality inspections and loading into the stores. Supplier payments and set up costs are also considered part of ordering costs. Ordering costs decrease with increase in order size.

2.2.5.2 Inventory Carrying or Holding Costs

Carrying or holding costs are those incurred because the firm has decided to maintain inventory. These costs may include Interest on funds invested in inventory, insurance premium paid on inventory, warehouse space costs or rent, heating, lighting or refrigeration. Costs due to obsolescence, depreciation, record keeping as well as administration are also part of holding costs. Ordering or holding costs are difficult to determine precisely because required records at times do not exist. The costs are calculated on an annual basis and expressed as a percentage of average inventory value. This percentage can be obtained by estimating total carrying costs at two different inventory levels. Holding costs increase with increase in order size.

2.2.5.3 Shortage Costs

These are costs associated (or loss incurred) with either delays in meeting demand or the inability to meet it at all.

As orderings costs decrease with increase in order size and inventory holding costs increase with increase in order size, the implication is that there is a certain order quantity which minimizes the total cost of ordering and holding inventory. The economic order quantity is defined as that size of order which minimizes total annual (or period) costs of ordering and carrying inventory (Srivastava et al, 2004). In developing a model for the economic order quantity, the following important assumptions are made (Render et al, 2006):

I. Demand is known and constant
II. The lead time or time between placement and receipt of orders is known and constant
III. The receipt of inventory is instantaneous, that is, the inventory from a certain order arrives at once in one batch
IV. Quantity discounts are not given
V. The only variable costs are the ordering costs, and inventory holding costs
VI. Stock outs or shortages are completely avoided.

The variables in the economic order quantity model are defined as follows (Render et al, 2006):

Q = Number of pieces to order
Q_0 = Economic order quantity (EOQ)
D = Annual demand in units for the inventory item
C_0 = Ordering costs of each order
C_h = Holding or carrying cost per unit per year

By expressing the total cost as a sum of purchasing, ordering and carrying costs, the economic order quantity is found by using differential calculus and minimizing the total cost function. Therefore, the economic order quantity formula is given as:

$$Q_o = \sqrt{\frac{2DC_o}{C_h}}$$

Having determined the optimum size of order to be placed, the question of when to order needs to be answered. The time between placement and receipt of an order is called the lead time or delivery time. Inventory must be available to meet the demand during this period. The reorder point or ROP, is the inventory level at which a new order should be placed so that the new inventory arrives just when the inventory level is reaching zero, and so a stock out does not occur. Therefore it can be stated that:

$$ROP = d \times L$$

Where d is the demand per day and L is the lead time for a new order in days.

The assumption that the demand is always known and constant is a simplification that helps in the analysis of the problem. In most cases, this assumption does not hold (Chase et al, 2003), and therefore safety stocks are maintained to provide a level of protection against stock outs. Safety stock is defined as the amount of inventory carried in addition to the expected demand. The amount of safety stock depends on the level of service desired. The fixed order quantity model is used to calculate the optimum order quantity and then the reorder point is set to cover the expected demand during the lead time plus a safety stock determined by the service level required. The uncertainty of demand is therefore taken care of by the safety stock. In this case the reorder point is then given as:

$$R = dL + z\sigma$$

Where

R = Reorder point in units
d = Average daily demand
L = Lead time in days
Z = number of standard deviations for a specified service probability
σ = standard deviation of usage during the lead time.

Braglia and Zavanella (2003) have developed a model known as the Consignment Stock model to deal with situations of uncertain or stochastic demand. In this model the vendor uses the buyer's warehouse to stock the inventory and has access to the final demand profile thus bypassing the filter determined by the buyer's orders. The buyer does not have to take care of ordering costs and only pays for goods when they are effectively used. This practice requires continuous flow of information between the vendor and buyer to minimize the costs to both parties. They compare this model with Hill's model which proposes a scenario where the vendor's production is organized in batches, and each batch is delivered to the buyer by a certain number of transport operations. Both parties incur material holding costs. Braglia and Zavanella (2003) contend that while the main strategic finding in Hill's model is that cooperation between the buyer and the vendor gives a far greater benefit than a non-collaborative relationship, Hill's approach only offers the lowest costs in a deterministic environment. Further, they show that the Consignment model yields lower costs in situations of uncertain demand.

Kandelin and Lin (1992) developed a computational prototype model by integrating various inventory reordering techniques to deal with different categories of items. The prototype uses the economic order quantity (EOQ) model, Just-In-Time (JIT) manufacturing systems and ABC method for classifying inventory. Integration of these techniques produced a model that can apply different inventory reorder techniques according to the classification of the item. Class A items, being the most critical and expensive, have the JIT type techniques used to manage their inventory levels. On the other hand, class C items are relatively inexpensive to order and hold, and only extremely simple reordering procedures are used. Class B items fall in between these two extremes and the EOQ model is justified for use. The computational model thus developed was flexible and could be used to manage different types of inventory.

We will now review some of the modules that are used in industry in controlling inventory of work in progress materials as well as finished products.

2.2.6 Inventory Management Modules

2.2.6.1 Material Requirements Planning (MRP) Systems

The main purposes of a basic MRP system are to control inventory levels, assign operating priorities for items and plan capacity to load the production system (Chase et al, 2003). The system is used to ensure that the right materials are at the right place at the right time. Like any other inventory management system, the objectives of MRP are to improve customer service, minimize inventory costs and maximize production operating efficiency. MRP systems are widely used in manufacturing firms. These systems are used to logically determine the number of parts, components and materials used to produce each item. MRP also provides the schedule specifying when each of the materials, parts and components should be ordered or produced. MRP systems are installed as computer programs controlling the entire process from order entry through scheduling, inventory control, finance, accounting and even accounts payable. MRP systems are based on the concept of dependent demand, whereby, the demand for a particular item is determined by the demand of a higher level item. For example, the demand for tyres in an automobile manufacturing plant is determine by the demand for cars. A bill of materials file which shows the sequence of everything that goes to the final product is maintained, as well as inventory file. This database contains specifications about every item, where it is purchased or produced and how long it takes.

2.2.6.2 Just In Time (JIT) System

JIT is an integrated set of activities designed to achieve high volume production using minimum inventories of raw materials, work in progress and finished goods (Chase et al, 2003). Parts arrive at the next work station "Just in time" and are completed and move through the operation quickly. The system is based on the logic that nothing will be produced until it is needed, and need is created by actual demand for the product. JIT demands high levels of quality at each stage of the process, strong vendor relations, and a fairly predictable demand for the end product. Chase et al, (2003) have described JIT as practised in Japan as elimination of waste. Waste in Japan is defined by Fujio Cho of Toyota Motor

Corporation as anything other than the minimum amount of materials, equipment, parts and workers which are absolutely necessary for production. Under this definition, the seven types of waste identified are waste from over production, waste of waiting time, transportation waste, inventory waste, processing waste, waste of motion and waste from product defects. Clearly, this definition of waste does not allow for safety stocks, and hidden inventory in storage areas, transit systems and conveyors is a key target for inventory reduction.

2.2.6.3 ABC Analysis

The purpose of ABC analysis or classification is to divide all of a company's inventory items into three groups (group A, group B and group C) based on the overall inventory value or monetary volume of the items). It uses the Pareto principle of a few having the greatest importance and the many having little importance. Prudent management will therefore focus the most effort in managing those items representing the greatest monetary volume because this is where the greatest savings can be realised. It should be noted that monetary volume is not related to the unit cost of a particular item (Chase et al, 2003). An item may have a high monetary volume through a combination of either low unit cost and high usage or high unit cost and low usage.

A items constitute roughly the top 10-15% of the items accounting for approximately 70% of the company's business, B items the next 20-35% accounting for about 20% of the business and C items the last 50-70% which account for the balance 10% of the business (Render et al,2006; Chase, et al, 2003). Segmentation may not always occur very neatly and so it should be borne in mind that that the objective is to separate the important from the unimportant. The purpose of classifying the items into groups is establishing the appropriate degree of control over each item.

As class A items account for the greatest proportion of monetary volume of the organization, their inventory levels should be monitored very carefully. Great care should be taken in forecasting their demand and developing sound inventory

Simulation exercises in such circumstances provide a useful tool for assessing emergency planning requirements, identifying and developing new policy and procedures, and deriving requirements for any related aspects such as organizational structures, infrastructure, personnel and training. The technique of simulation analysis has been developed to study alternative courses of actions by building a model of a system and then conducting a series of repeated trial and error experiments to predict the behaviour of the system over a certain period of time.

In simulation, consequences of various courses of actions are explored without trying out the actions themselves before a decision is made. (Legrande, 1963). Legrande (1963) posits that in simulating, three basic elements are required. The first is a decision making situation, with various courses of actions. The second is a model which reflects how the environment will behave under a given decision. It must be able to predict the effects that a decision will produce in the environment and how the environment will react to the decision. The final element is a manipulative device that manipulates decision and model information in such a way that the effects of a given decision can be computed quickly and accurately.

Meier (1967) has observed that the use of many mathematical methods especially simulation techniques has been linked to the development of digital computers without which simulation is not practical due to the large amount of computational work involved.

A number of studies have been carried out demonstrating the use of simulation analysis in solving inventory management problems. Soriano and Gross (1969) investigated the savings that could be achieved on on-shelf inventory for a military overseas resupply system when resupply is performed by air rather than by sea. A simulation model describing a periodic inventory control procedure was utilized to study the effect of reducing mean lead time on safety stock levels required, in order to maintain given degrees of service. For this system, they found that reducing the mean lead time from 13 weeks (sea lift) to 2 weeks (air lift) would allow a reduction of approximately 3 weeks of supply in safety stock levels with a corresponding reduction in average on-shelf inventory of approximately 3 weeks supply.

Parker (1965) studied a selection of inventory accounts maintained by a large manufacturer of rocket engines. He developed a simulation model for two particular inventory accounts and tested its correspondence with the real world. Potential annual savings for various inventory items were thus determined.

Gessford (1962) used a simulation model to investigate potential cost savings in stocks of a raw material for a manufacturing plant. In this situation, the manufacturing plants required a steady supply of this basic raw material and the procurement department purchased this raw material from many suppliers within a few hundred kilometers of each plant and stored the material in stock piles. A computer simulation was used to evaluate the potential trade off between storage and transportation costs. The computer simulation technique was found useful in tracing out the effect of a specified inventory policy on certain cost and quantity characteristics of a widespread supply system.

The use of simulation analysis as a decision support technique is often advantageous over mathematical modeling in that it uses existing data and trends taken out of the system to explore the outcomes that could result from many alternative courses of action. It is then often found that a simulation study that is designed as decision support mechanism for a particular problem ends up providing more information over and above the original objectives.

Thinnes and Kachitvichyanukul (1989) developed a simulation model to predict the production output of a printed circuit board manufacturer. Model validation was carried out over 1 month by comparing the simulation results with actual outputs as well as the supervisor's predictions and found to yield reliable information. Once the supervisors developed confidence in the use of the model, they used it daily in assessing the impact of varying staffing strategies on output. Once a valid forecast was provided at the beginning of the production period, corrective measures could be taken at the earliest opportunity if the prediction does not meet the set target. The model was therefore used as a decision support tool in the operation and control of the production system. However, even though the simulation model was originally built to provide a more consistent means to predict circuit board manufacturing output, during the course of the project, it was also used to evaluate the effects of varying manning levels and equipment capacities on output so that better manpower allocations and capacity planning could be made.

Lelei (1996) demonstrated how safety stock could be determined by using a computer simulation model based on an electronic spreadsheet. He constructed a simulation model that was based on a "what if" approach and had its objective as total cost minimization for various levels of safety stock. In this model, data on storage cost per unit, shortage cost per unit of stock in short supply, ordering cost per order and number of units ordered and received into stock had to be obtained. Lelei (1996) has observed that storage and shortage costs are difficult to determine precisely, and in practice, these costs are usually rough estimates, obtained by careful study of stock related records as well as management judgment. Demand was treated as a random variable and its probability distribution was simulated using the Monte Carlo method of random numbers. The lead time was assumed to be deterministic in this case. It is observed however that in most real life situations, the lead time is usually stochastic and its probability distribution also aught to be simulated.

In this simulation analysis, a LOTUS 123 electronic spreadsheet was used. Lelei (1996) has highlighted the benefit of using an electronic spreadsheet for simulation, in that a program needs not be written to solve the problem. Formulas and functions can be used in the spreadsheet and it therefore lends itself to easy use by managers. It should be noted that as the objective of simulation analysis is to provide good solutions but not necessarily optimal ones, the use of electronic spreadsheets can be justified. Lelei (1996) has pointed this out and indicated that the results of the simulation analysis should be subjected to the decision maker's judgment. Lelei (1996) has recommended that further work in this area be carried out with a view to developing spreadsheet simulation models that will help decision makers improve customer service and reduce costs.

Simulation analysis is therefore a viable tool in solving inventory management problems. With the developments that have taken place over the years in computing ability, simulation has become an even more attractive tool to use in managing inventory. Our study will pick up on Lelei's work and will aim to develop an MS EXCEL spreadsheet based simulation model of an inventory management system. The model developed will be used to determine the order quantity and reorder point that will minimize the total inventory costs.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

The objective of this study as outlined earlier in chapter 1 was two fold. The first part was to carry out a simulation analysis and to develop an inventory model for application in determining order quantities and ordering frequency, and the second part was to ensure that the model developed minimizes the total inventory costs. The simulation analysis was carried out on selected items from the inventory list, the selection being based on an ABC classification of the items. The research study was therefore organized as follows.

3.2 Research Design

The research was a case study of Davis & Shirtliff Ltd, and was carried out as a desk research. An ABC classification was carried out on the inventory items, the classification being based on annual monetary sales volume. Class A items were taken as those whose monetary sales volume was approximately the top 50% and this criterion led to the top 20% of the items being selected. Class B items were taken as those accounting for the next 40% of the sales volumes while C items were taken as those whose sales volume accounted for the remaining 10%. The simulation analysis study focused only on class A items, as this is where much cost savings could be realized.

3.3 Data Collection Method

The data used for this study was all secondary, and was obtained from the stock records of Davis & Shirtliff Ltd, being taken out of Navision Enterprise Resource Planning (ERP) system. Ordering data was taken out of the order records and demand data was taken out of equipment sales and stocks records. The population was taken as the whole range of submersible borehole pumps offered by Davis & Shirtliff Ltd.

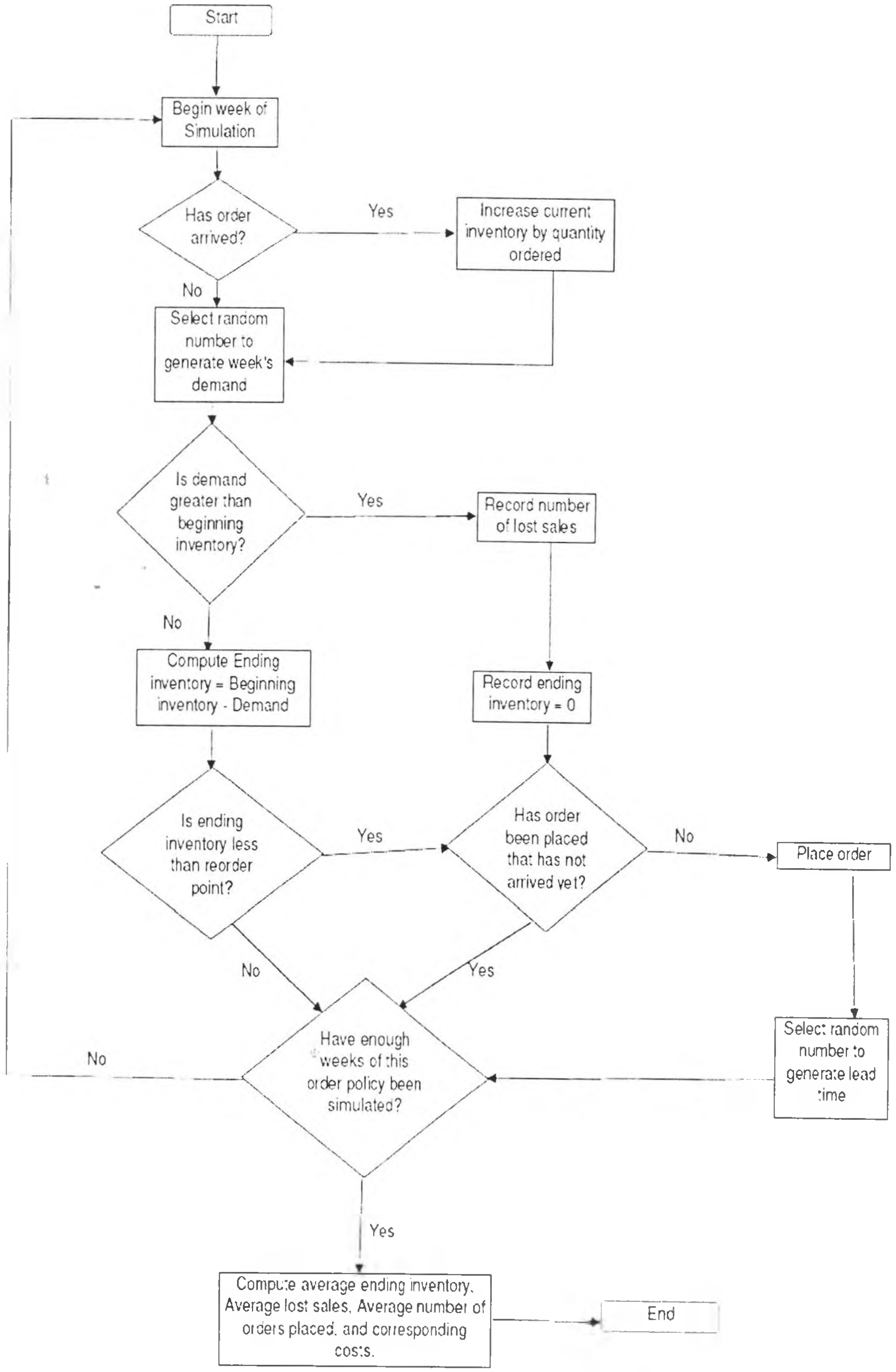
3.4 Data Analysis

The simulation analysis was conducted using an MS EXCEL electronic spreadsheet. The aim of this simulation experiment was to establish order quantity and reorder point for each particular product line that has been classified as an A item. Both the product demand and lead time were assumed to be probabilistic and were therefore determined using Monte Carlo random numbers. The random numbers were generated using MS EXCEL. Historical data from stock records was used to construct a probability distribution for the variable weekly demand. A cumulative probability distribution was then formed, and an interval of random numbers to represent each possible weekly demand was established. Similarly, a cumulative probability distribution for the variable lead time was constructed and random number intervals assigned for each possible lead time. For each product line, a series of simulation runs were carried out trying out various order quantities and reorder points, and each time the total inventory cost was calculated. Inventory costs were calculated as the sum of ordering, holding and stock out costs.

The simulation model was developed according to the diagram shown in Figure 3.1. To start the simulation experiment, initial values for the variables order quantity and reoder point had to be chosen and input. The simulation run was then conducted for a period of 1000 weeks in steps as follows:

1. Begin each simulated week by checking whether any ordered inventory has just arrived. If it has, increase the current inventory by the quantity ordered.
2. Generate a weekly demand from the demand probability distribution by selecting a random number. This random number is used to simulate a demand which is recorded.
3. The weekly ending inventory is then computed and recorded. Ending inventory equals beginning inventory minus demand. If on hand inventory is insufficient to meet the week's demand, satisfy as much as possible and then record the lost sales.

Figure 3.1: Simulation Flow Chart



4. Determine whether the week's ending inventory has reached the reorder point. If it has and if there are no outstanding orders, place an order. Lead time for the order is simulated by first choosing a random number, and then this random number is used to determine the lead time.

The results of the simulation for each set of variables of order quantity and reorder point were used to determine average ending inventory, average lost sales and average number of orders placed. These data were then used in working out the inventory costs of the policy being simulated.

In this manner, various other reasonable or possible inventory strategies were investigated for each product line and comparisons of total cost for each strategy made. The best strategy was selected as that which yielded the lowest total inventory cost.

CHAPTER 4: DATA ANALYSIS AND RESEARCH FINDINGS

4.1 Introduction

This chapter presents the findings and data analysis of the study carried out. At the first stage, a preliminary analysis on the stock items, ABC analysis was carried out to select the items whose inventory systems would be simulated. The analysis was based on monetary sales volume. Demand and lead times were then analysed and inventory parameters worked out before a model could be simulated on a spreadsheet.

4.2 ABC Analysis

The results of an ABC analysis conducted on a total number of 56 product items that make up the whole complement of the company's Borehole Pumps product range is presented in table 4.1. The classification was based on year 2007 product sales by value. For each product, the sales as a percentage of total sales were calculated. The sales data was tabulated, being sorted from the highest to the lowest sales value and cumulative sales were thus determined. It was found that the top 20% of the items contributed to approximately 54% of the total sales, and these items were classified as A items. The next 37% of the sales was contributed by 44% of the items and these items were classified as B items while the final 9% of the items was contributed by 36% of the items, these being classified as C items. Simulation analysis was carried out on the items classified as category A, as this is where much savings could be realized.

4.3 Demand and Lead Time Data Analysis

Eleven product items were identified as class A items. For these items, weekly demand data for the year 2007 was obtained from the stock records. The stock records are contained in the company's enterprise resource planning system (ERP), Navision. The data is presented in appendix 2. For the last 25 orders covering the years 2006, 2007 and part of 2008, lead time data was obtained and tabulated as shown in table 4.2. The mode of delivery for these orders was sea freight which reduces costs and enables the company to competitively price the products. It was observed that the lead time for these orders varied from 12 to 29 weeks. This wide variation is caused by periodic problems experienced at the Mombasa port, and also by transhipment of cargo from Europe to Africa.

Table 4.1: ABC Analysis

NO.	ITEM	YEAR 2007 SALES		% OF TOTAL VALUE	% CUMM SALES	% OF TOTAL NO.	CLASS
		QTY	VALUE (KShs)				
1	GRUNDFOS SP8A-50 7.5KW PUMP	61	9,711,280	10.3%	10.3%	1.8%	A
2	GRUNDFOS SP5A-44 4KW PUMP	70	8,091,623	8.5%	18.8%	3.6%	
3	GRUNDFOS SP8A-37 5.5KW PUMP	50	6,940,311	7.3%	26.1%	5.4%	
4	GRUNDFOS SP8A-25 4KW PUMP	57	4,535,338	4.8%	30.9%	7.1%	
5	GRUNDFOS SP17-20 11KW PUMP	24	4,279,770	4.5%	35.4%	8.9%	
6	GRUNDFOS SP14A-25 7.5KW PUMP	26	3,495,914	3.7%	39.1%	10.7%	
7	GRUNDFOS SP17-13 7.5KW PUMP	23	3,120,102	3.3%	42.4%	12.5%	
8	GRUNDFOS SP5A-25 2.2KW PUMP	85	3,090,880	3.3%	45.7%	14.3%	
9	GRUNDFOS SP5A-60 5.5KW PUMP	15	3,040,147	3.2%	48.9%	16.1%	
10	GRUNDFOS SQ 2-85 1KW PUMP	49	2,282,555	2.4%	51.3%	17.9%	
11	GRUNDFOS SP5A-33 3KW PUMP	49	2,217,668	2.3%	53.7%	19.6%	
12	GRUNDFOS SP3A-25 1.5KW PUMP	58	1,991,108	2.1%	55.8%	21.4%	B
13	GRUNDFOS SP17-27 15KW PUMP	8	1,980,675	2.1%	57.9%	23.2%	
14	GRUNDFOS SP14A-18 5.5KW PUMP	15	1,967,829	2.1%	59.9%	25.0%	
15	GRUNDFOS SP2A-48 2.2KW PUMP	16	1,944,000	2.1%	62.0%	26.8%	
16	GRUNDFOS SP2A-33 1.5KW PUMP	36	1,836,528	1.9%	63.9%	28.6%	
17	GRUNDFOS SP5A-8 0.75KW PUMP	155	1,719,708	1.8%	65.7%	30.4%	
18	GRUNDFOS SP2A-18 0.75KW PUMP	61	1,609,359	1.7%	67.4%	32.1%	
19	GRUNDFOS SP3A-45 3.0KW PUMP	16	1,596,000	1.7%	69.1%	33.9%	
20	GRUNDFOS SP17-10 5.5KW PUMP	13	1,524,409	1.6%	70.7%	35.7%	
21	GRUNDFOS SQ 3-65 1.05KW PUMP	24	1,516,833	1.6%	72.3%	37.5%	
22	GRUNDFOS SP3A-33 2.2KW PUMP	35	1,447,059	1.5%	73.9%	39.3%	
23	GRUNDFOS SQ 5-50 1KW PUMP	21	1,396,971	1.5%	75.3%	41.1%	
24	GRUNDFOS SP30-17 15KW PUMP	6	1,311,750	1.4%	76.7%	42.9%	
25	GRUNDFOS SP30-13 11KW PUMP	10	1,296,442	1.4%	78.1%	44.6%	
26	GRUNDFOS SQ 5-70 1.6KW PUMP	14	1,277,614	1.3%	79.5%	46.4%	
27	GRUNDFOS SP5A-17 1.5KW PUMP	48	1,261,691	1.3%	80.8%	48.2%	
28	GRUNDFOS SP46-12 18.5KW PUMP	6	1,251,256	1.3%	82.1%	50.0%	
29	GRUNDFOS SP14A-13 4KW PUMP	12	1,221,043	1.3%	83.4%	51.8%	
30	GRUNDFOS SP2A-65 3.0KW PUMP	7	1,196,050	1.3%	84.7%	53.6%	
31	GRUNDFOS SP2A-23 1.1KW PUMP	22	1,048,876	1.1%	85.8%	55.4%	
32	GRUNDFOS SP5A-12 1.1KW PUMP	49	974,177	1.0%	86.8%	57.1%	
33	GRUNDFOS SP8A-15 2.2KW PUMP	17	914,584	1.0%	87.8%	58.9%	
34	GRUNDFOS SP3A-18 1.1KW PUMP	38	887,190	0.9%	88.7%	60.7%	
35	GRUNDFOS SQ 2-115 1.7KW PUMP	10	876,296	0.9%	89.6%	62.5%	
36	GRUNDFOS SP2A-9 0.37KW PUMP	78	858,743	0.9%	90.5%	64.3%	
37	GRUNDFOS SQ 3-105 1.73KW PUMP	8	812,000	0.9%	91.4%	66.1%	C
38	GRUNDFOS SP3A-60 4KW PUMP	7	800,800	0.8%	92.2%	67.9%	
39	GRUNDFOS SP60-10 18.5KW PUMP	5	764,823	0.8%	93.0%	69.6%	
40	GRUNDFOS SP8A-44 7.5KW PUMP	5	736,500	0.8%	93.8%	71.4%	
41	GRUNDFOS SP30-21 18.5KW PUMP	3	674,376	0.7%	94.5%	73.2%	
42	GRUNDFOS SP3A-12 0.75KW PUMP	27	621,222	0.7%	95.2%	75.0%	
43	GRUNDFOS SP17-7 4KW PUMP	8	607,700	0.6%	95.8%	76.8%	
44	GRUNDFOS SP30-26 22KW PUMP	2	547,400	0.6%	96.4%	78.6%	
45	GRUNDFOS SQ 2-35 0.4KW PUMP	15	523,757	0.6%	97.0%	80.4%	
46	GRUNDFOS SP17-17 9.2KW PUMP	3	474,000	0.5%	97.5%	82.1%	
47	GRUNDFOS SP8A-10 1.5KW PUMP	12	416,576	0.4%	97.9%	83.9%	
48	GRUNDFOS SP14A-7 2.2KW PUMP	9	358,901	0.4%	98.3%	85.7%	
49	GRUNDFOS SP8A-30 5.5KW PUMP	3	342,000	0.4%	98.6%	87.5%	
50	GRUNDFOS SP30-8 7.5KW PUMP	3	304,063	0.3%	99.0%	89.3%	
51	GRUNDFOS SQ 7-40 1.7KW PUMP	3	255,453	0.3%	99.2%	91.1%	
52	GRUNDFOS SP17-24 13KW PUMP	1	217,000	0.2%	99.5%	92.9%	
53	GRUNDFOS SQ 7-30 1.05KW PUMP	2	152,100	0.2%	99.6%	94.6%	
54	GRUNDFOS SP8A-21 4KW PUMP	3	146,792	0.2%	99.8%	96.4%	
55	GRUNDFOS SQ 3-30 0.63KW PUMP	3	106,433	0.1%	99.9%	98.2%	
56	GRUNDFOS SQ 5-25 0.5KW PUMP	3	103,200	0.1%	100.0%	100.0%	
	TOTAL		94,676,875	100.0%			

Table 4.2: Lead time data

	ORDER NUMBER	ORDER DATE	FREIGHT	LEAD TIME (WEEKS)
1	1884	9/Nov/05	SEA40'	14
2	1964	11/Jan/06	SEA-40'	13
3	2000	7/Feb/06	SEA-40'	17
4	2038	8/Mar/06	SEA 40'	14
5	2096	5/May 06	SEA-40'	14
6	2170	10/Jul/06	SEA - 40'	12
7	2263	5/Sep/06	SEA - LC	19
8	2300	11/Oct/06	SEA-20'	15
9	2299	11/Oct 06	SEA-LC	15
10	2338	7/Nov 06	SEA-LC	14
11	2376	6/Dec/06	SEA-LC	12
12	2387	20 Dec 06	SEA-LC	14
13	2374	6/Dec/06	SEA-LC	15
14	2406	6 Jan/07	SEA 20'	21
15	2466	8 Feb/07	SEA 40'	21
16	2481	26 Feb 07	SEA 20'	19
17	2596	4/May 07	SEA 20'	20
18	2690	6 Jul/07	SEA 20'	12
19	2548	4 Apr 07	SEA 40'	28
20	2690	7 Jul 07	SEA 20'	29
21	2884	8 Nov 07	SEA 40'	22
22	2918	5/Dec/07	SEA 20'	25
23	3005	29 Jan/08	SEA 20'	17
24	3074	7/Mar/08	SEA 20	21
25	3162	3/May/08	SEA 2*40'	18

LEADTIME	FREQUENCY
12	3
13	1
14	5
15	3
16	0
17	2
18	1
19	2
20	1
21	3
22	1
25	1
28	1
29	1
	25

4.4 Inventory Cost Parameters

Before a simulation analysis of each product item could be carried out, it was necessary to determine the inventory cost parameters that affect the total inventory costs. Total costs were obtained as a summation of ordering costs, holding costs and shortage costs. The parameters are summarised in table 4.3.

Ordering costs comprise mainly of the costs of staff time and effort expended in raising and processing orders, following up with the supplier and receiving product into the ware house. The staff involved in this exercise includes the CEO and Managing director, the General Manager supply, the Stores Manager and the procurement assistant. To determine the ordering cost, the proportion of time spent on orders for each of the staff members in question had to be estimated. Grundfos orders account for 25% of all the orders raised in the company and this was also taken into consideration. The Total annual staff cost was determined by adding up the total monthly cost of each of the staff members involved in order processing and annualizing it. The other component of ordering cost is the cost of order receiving.

Table 4.3: Inventory cost parameters

1) ANNUAL ORDERING COSTS

(i) STAFF COSTS

	ANNUALIZATION FACTOR	12	
ITEM	PROPORTION PER MONTH	MONTHLY COST (KShs)	TOTAL MONTHLY COST (KShs)
Executive Time	10%	2.000.000	200.000
Supply General Manager	30%	580.000	174.000
Stores Manager	10%	220.000	22.000
Procurement Assistant	100%	106.000	106.000
TOTAL			502.000
Proportion of Grundfos Orders	25%		
ANNUAL GRUNDFOS ORDER COSTS			1.506.000

(ii) ORDER RECEIVING

	ANNUAL NO. OF ORDERS	12	
ITEM	COST (KShs)	QUANTITY	TOTAL COST (KShs)
OFF LOADING COSTS	4.000	1	4.000
TOTAL			4.000
ANNUAL COSTS			48.000

TOTAL ANNUAL ORDERING COSTS	1.554.000
COST PER ORDER	129.500

2) ANNUAL HOLDING COSTS

(i) RECORD KEEPING AND ADMINISTRATION (STAFF) COSTS

	ANNUALIZATION FACTOR	12	
ITEM	PROPORTION PER MONTH	MONTHLY COST (KShs)	TOTAL MONTHLY COST (KShs)
Supply General Manager	30%	580.000	174.000
Stores Manager	90%	220.000	198.000
Stores Assistant Manager	100%	78.000	78.000
Stores Clerks (3No.)	100%	201.000	201.000
Stores Labourers (3No.)	100%	105.000	105.000
TOTAL			756.000
ANNUAL COSTS			9.072.000
Proportion of Grundfos SP's Inventory	6%		
ANNUAL ADMINISTRATION AND RECORD KEEPING COSTS			544.320

(ii) WAREHOUSING

	ANNUALIZATION FACTOR	12	
ITEM	PROPORTION OF STORE	MONTHLY COST (KShs)	TOTAL MONTHLY COST (KShs)
WAREHOUSE RENT	10%	100.000	10.000
ANNUAL COSTS			120.000

(iii) INTEREST ON FUNDS INVESTED IN INVENTORY

ITEM	PROPORTION OF GRUNDFOS SP's INVENTORY	ANNUAL COST (KShs)	TOTAL ANNUAL COST (KShs)
Overdraft Interest	6%	24.000.000	1.440.000
ANNUAL COSTS			1.440.000
TOTAL ANNUAL HOLDING COSTS			2.104.320

AVERAGE NUMBER OF UNITS HELD IN STOCK	400
ANNUAL HOLDING COST PER UNIT (KShs)	5.261
WEEKLY HOLDING COST PER UNIT (KShs)	101

3) SHORTAGE COSTS PER ITEM

	ITEM	GROSS SELLING (KShs)	AVERAGE DISCOUNT	NETT SELLING (KShs)	COST PRICE (KShs)	SHORTAGE COST (KShs)
1	GRUNDFOS SP6A-50 7.5KW PUMP	267.000	15%	226.950	112.000	114.950
2	GRUNDFOS SP5A-44 4KW PUMP	192.000	15%	163.200	84.000	79.200
3	GRUNDFOS SP8A-37 5.5KW PUMP	231.000	15%	196.350	89.000	107.350
4	GRUNDFOS SP6A-25 4KW PUMP	142.000	15%	120.700	66.000	54.700
5	GRUNDFOS SP17-20 11KW PUMP	294.000	15%	249.900	127.000	122.900
6	GRUNDFOS SP14A-25 7.5KW PUMP	270.000	15%	229.500	97.000	132.500
7	GRUNDFOS SP17-13 7.5KW PUMP	226.000	15%	193.800	88.000	105.800
8	GRUNDFOS SP5A-25 2.2KW PUMP	64.000	15%	54.400	18.000	36.400
9	GRUNDFOS SP5A-60 5.5KW PUMP	314.000	15%	266.900	123.000	143.900
10	GRUNDFOS SQ 2-85 1KW PUMP	110.000	15%	93.500	52.000	41.500
11	GRUNDFOS SP5A-33 3KW PUMP	77.000	15%	65.450	25.000	40.450

This cost comprises the cost of hiring a fork lift and a few labourers. The cost is incurred each time an order is received, and it was determined that approximately 12 orders are received annually. The annual ordering costs are obtained as the sum of annual staff costs and receiving costs and the cost per order is determined as the annual ordering costs divided by the total number of orders per year.

Holding costs comprise of the costs of staff involved in record keeping and administration, warehouse rental costs and the cost of funds invested in inventory. The staff involved in record keeping and stores administration includes the General Manager supply, Stores Manager, Assistant Stores Manager, 3 stores clerks and 3 manual labourers. In order to determine the total cost of record keeping and administration, the proportion of time spent on this task by each of the staff members in question had to be estimated. Grundfos Borehole Pumps account for 6% of the total company inventory and this was also taken into account. The warehouse rental cost allocated to the Borehole Pumps product range was based on the proportion of stores space allocated to this product. The annual cost of funds invested in inventory was taken as interest on the overdraft used to fund inventory. The proportion of this interest allocated to the Borehole Pumps product range was based on the proportion of the inventory of this product range to the total Company inventory. The average number of units held in stock at any time also had to be estimated. The total annual holding cost was calculated as the sum of record keeping and administration costs, warehousing costs and interest on funds invested in inventory. To obtain the annual holding cost per unit, the total annual holding cost was divided by the average number of units held in stock. The weekly holding cost per unit was determined as the annual holding cost per unit divided by 52 weeks per year.

Shortage costs were determined for each of the items for which simulation was to be carried out. For each item, the shortage cost was taken as the profit realised when the item is sold, or the loss incurred when the item is out of stock and is therefore not sold. The shortage cost was therefore calculated as the net discounted price less the cost of the item. This data was obtained from the Navision enterprise resource planning (ERP) system.

From table 4.3, the inventory cost parameters used in the simulation analysis were: Ordering cost per order, KShs129,500.0; and weekly holding cost per unit, KShs101.0. The shortage cost used in simulation analysis for each product item is shown in the table alongside each item.

4.5 Inventory Model Simulation

The purpose of the simulation model is to enable a "what if" evaluation of the total inventory cost for various inventory policies. For each inventory policy an order quantity and reorder level have to be specified. The inventory policy can be stated as 'Place an order for "order quantity" whenever the inventory level goes down to "reorder level"'.

The method used in this study is Monte Carlo simulation. Monte Carlo simulation requires random numbers to be assigned to probabilistic variables being simulated to reflect the frequency of their occurrence. In this study, the quantity to order and reorder level are the controllable inputs while demand and lead time are the uncontrollable variables which are determined using Monte Carlo random numbers. Before random numbers could be assigned, a probability distribution of the variable had to be constructed. Random numbers were assigned to the data based on their cumulative probabilities.

4.5.1 Demand Probability Distribution

From each item's historical demand data obtained from the stock records, the relative frequency or probability for each possible weekly demand was obtained by dividing the frequency of observation by the total number of observations. The weekly demand data obtained for each product item was for the year 2007. This data was converted to a probability distribution by assuming that past demand rates will hold for the future. A cumulative probability is the probability that a variable (weekly demand in this case) will be less than or equal to a particular value. The weekly demand probability distribution for one of the product items, SP8A-50, is shown in table 4.4. The weekly demand and frequency are as obtained from the demand data.

Table 4.4: Demand probability distribution for Grundfos SP8A-50

WEEKLY DEMAND	FREQUENCY	PROBABILITY	PROB RANGE (LOWER)	CUMM PROB	DEMAND
0	16	0.31	0	0.31	0
1	14	0.27	0.31	0.58	1
2	14	0.27	0.58	0.85	2
3	5	0.10	0.85	0.94	3
4	1	0.02	0.94	0.96	4
5	1	0.02	0.96	0.98	5
6	0	0.00	0.98	0.98	6
7	1	0.02	0.98	1.00	7
	52				

The cumulative probability at each weekly demand is obtained by adding the cumulative probability at the immediate lower demand to the probability of that demand when the demand data has been sorted in ascending order. The last column showing demand has been added for ease of reference when employing the "VLOOKUP" MS EXCEL function to determine demand at every week. The weekly demand probability distributions for all the product items that were simulated are as shown in appendix 3.

4.5.2 Lead Time Probability Distribution

The lead time probability distribution was constructed in a similar manner to the demand probability distribution. The order lead time data as obtained from the order records was used to construct a frequency table as shown in table 4.2. The probability of each possible lead time was then calculated by dividing the frequency of observation at that lead time with the total number of observations. The cumulative probability was then determined at every lead time by adding the probability at that lead time to the cumulative probability at the immediate lower lead time when the lead time data has been sorted in ascending order. The lead time probability distribution of the orders is shown in table 4.5. The last column showing lead time has been added for ease of reference when employing the "VLOOKUP" MS EXCEL function to determine lead time whenever an order is placed.

Table 4.5: Lead Time Probability distribution

LEADTIME (WEEKS)	FREQUENCY	PROBABILITY	PROB RANGE (LOWER)	CUMM PROB	LEADTIME
12	3	0.12	0.00	0.12	12
13	1	0.04	0.12	0.16	13
14	5	0.20	0.16	0.36	14
15	3	0.12	0.36	0.48	15
16	0	0.00	0.48	0.48	16
17	2	0.08	0.48	0.56	17
18	1	0.04	0.56	0.60	18
19	2	0.08	0.60	0.68	19
20	1	0.04	0.68	0.72	20
21	3	0.12	0.72	0.84	21
22	1	0.04	0.84	0.88	22
25	1	0.04	0.88	0.92	25
28	1	0.04	0.92	0.96	28
29	1	0.04	0.96	1.00	29
TOTAL	25	1.00			

4.5.3 Simulation Worksheet

The controllable inputs that must be set before simulation begins are the order quantity and the reorder point. Initially, a beginning inventory value must also be set, though this value is of little significance in a long simulation and the inventory values will even out to be largely dependent on the order quantities and the reorder points.

The simulation was configured to run for 1000 weeks. The first column indicates the week number. The second column enables a decision to be made, as to whether an order has been received or not, as may be expected on that particular week. Depending on whether an order has been received, the third column is updated with the number of orders received. The initial condition is that there is no pending order received and therefore the number of orders received in week 1 is zero. From week 2 onwards, order arrival is determined by the pending orders expected. The fourth column indicates the number of units received and is a formula multiplying the number of orders received with the quantity per order. For each policy that is to be tested, the order quantity and the reorder level are fixed. The fifth column shows the current inventory which is determined by adding the end inventory from the previous week to the units received in the current week, if an order was received, and returns the end inventory at the end of the previous week as the current inventory if no order was received in the current week.

To simulate demand for the week in question, first a random number has to be generated. The random number is generated using the MS EXCEL random number function. Two separate table columns running alongside the main simulation worksheet have been used for demand simulation. The first table is labelled Demand Simulation (Dynamic). In its first column, random numbers are generated by the spreadsheet generator whenever the spreadsheet is recalculated using F9 or Enter. In the second column, the demand for each random number generated is obtained from the demand probability distribution table using the VLOOKUP function. In this dynamic table, the demand is always changing whenever random numbers are regenerated. To allow for comparison of various inventory policies, it is necessary that the same set of random numbers is used. For this reason, a second table labelled Demand Simulation (Static) has been used. The second table contains data of random numbers and demand data that have been copied as values from the dynamic simulation table. The sixth column of the main simulation worksheet refers to the static demand simulation table to obtain the random number for the particular week's demand. The corresponding week's demand is then obtained from the static demand table using the VLOOKUP function, and is entered in the seventh column.

Once the demand for a particular week has been determined, the end inventory can be worked out. The end inventory is calculated and entered in column eight. If the demand exceeds the current inventory, the end inventory is recorded as zero; otherwise, it is calculated as the current inventory less the demand. The ninth column shows the number of pending units, as a result of orders that have been placed but have not yet been delivered. This is important in helping to decide whether future orders should be placed. As there are no orders expected in the first week, pending orders in the first week must be entered as zero. Thereafter, from the second week onwards, pending orders are determined by a formula. The formula counts all the orders placed in the previous weeks.

multiplies them by the order quantity and subtracts the total sum of units received up to the current week.

The tenth column is a record of all the lost sales and is useful in determining the cost of lost sales. Lost sales are determined by whether or not the current inventory is enough to satisfy the week's demand. If the current inventory is less than the weeks demand, lost sales are calculated as the demand less the current inventory, otherwise lost sales are entered as zero.

The eleventh column helps in making a decision as to whether an order should be placed. There are two conditions that should be fulfilled before an order can be raised. The first is that the end inventory should be less than the reorder point, and the second is that there should be no pending units. In the first week, no pending units can be expected, and so only the first condition has been formulated. From the second week onwards, the formula has captured both of these conditions, and depending on the result, the output returned is "order" or "no".

The twelfth column shows the random number for lead time if an order is to be raised. To simulate an order, first a random number for lead time has to be generated. As in the case for demand simulation, two separate tables running alongside the main simulation worksheet have been used. The first table is labelled Lead time Simulation (Dynamic) and the second one is labelled Lead time Simulation (Static). In the dynamic simulation table, random numbers for each week are generated by the worksheet random number generator. The lead time is then obtained from the table of lead time probability distribution using the VLOOKUP function. The lead time so obtained will change each time the spreadsheet is recalculated. To enable comparison of various policies, it is necessary to use the same set of random numbers. The second table labelled Lead time simulation (Static) has been obtained by copying the contents of the dynamic simulation table as values. The random number in column twelve of the main simulation worksheet refers to the random number from the static lead time simulation table in the same week. The lead time is also obtained from the static lead time simulation table using the VLOOKUP function, and entered in column thirteen. If the indication from column eleven is that no order will be raised, the random number returns “none” in column twelve and the lead time returns “0” in column thirteen. The fourteenth and fifteenth columns are useful in determining when the orders that have been raised are expected to arrive, to ensure that they arrive at the time that they are expected. The fourteenth column indicates whether or not an order has been raised and is therefore expected. If the lead time is zero, an order has not been raised and is therefore not expected, otherwise an order is expected. If an order is expected, the arrival week, which is entered in column fifteen, is calculated as the current week plus the lead time. Where an order is not expected, the arrival week works out as the same as the current week and this value is of no consequence.

Where an order is expected on a certain arrival week, the order must be credited as “yes” on the first column of order arrival on the week in which the order was expected to arrive. The simulation system must check in columns fourteen and fifteen of all the previous weeks to see if there are any expected orders whose delivery week matches the current week. This process is carried out from week 2 to week 1000. A macro subroutine labelled “update order arrival” written as part of the simulation worksheet in visual basic is run each time a new inventory policy is being tested. It updates columns one and two with order arrival and number of orders arrived in each week from week 2 to week 1000. The macro subroutine is attached as appendix 4. Whenever the macro is to be run to update order arrival, it is first necessary to change the worksheet references in the program to the current worksheet. The worksheets have been named according to the product whose inventory model is being simulated.

Tables 4.6 and 4.7 show the demand simulation and lead time simulation data extracted from the simulation worksheet for the first 30 weeks respectively. The dynamic random numbers are generated by the worksheet random number generator, while the static random numbers have been copied as values only from the dynamic random number columns. The static random numbers are then used to generate demand and lead time from the demand and lead time probability distribution tables respectively. Table 4.8 shows a part of the simulation worksheet for Grundfos SP5A-44 model up to week number 105, with order quantity 80 and reorder point 50.

Table 4.6: Demand Simulation using dynamic and static random numbers

WEEK	DEMAND SIMULATION (DYNAMIC)		DEMAND SIMULATION (STATIC)	
NO.	RANDOM NO.	DEMAND	RANDOM NO.	DEMAND
1	0.100885099	0	0.726149658	2
2	0.610131033	2	0.038760333	0
3	0.695417712	2	0.119824612	0
4	0.614662142	2	0.048294972	0
5	0.034620782	0	0.536588631	1
6	0.024901856	0	0.012043304	0
7	0.670945565	2	0.668630885	2
8	0.182654522	0	0.843818257	2
9	0.515317889	1	0.47546703	1
10	0.244978783	0	0.967707544	5
11	0.362415428	1	0.687859013	2
12	0.418576509	1	0.439265205	1
13	0.937523414	3	0.528419433	1
14	0.135393417	0	0.917152601	3
15	0.026541803	0	0.777162667	2
16	0.708273067	2	0.254979333	0
17	0.644185083	2	0.637866375	2
18	0.268653428	0	0.623613427	2
19	0.848914976	3	0.790577602	2
20	0.977763715	5	0.037811091	0
21	0.543993988	1	0.51567156	1
22	0.28213199	0	0.057586958	0
23	0.43248092	1	0.406264605	1
24	0.712329597	2	0.612363119	2
25	0.070653089	0	0.153948973	0
26	0.49595488	1	0.809006952	2
27	0.413347355	1	0.879033636	3
28	0.927203312	3	0.754336273	2
29	0.626615684	2	0.040514007	0
30	0.210250039	0	0.856586853	3

Table 4.7: Lead time Simulation using dynamic and static random numbers

LEADTIME SIMULATION (DYNAMIC)		WEEK NO.	LEADTIME SIMULATION (STATIC)	
RANDOM NO.	LEADTIME		RANDOM NO.	LEADTIME
0.919973831	25	1	0.068673491	12
0.837269856	21	2	0.01254057	12
0.691081639	20	3	0.275828591	14
0.247557894	14	4	0.403468613	15
0.470239291	15	5	0.448052765	15
0.311431674	14	6	0.016314968	12
0.249756091	14	7	0.713587136	20
0.801167426	21	8	0.750292558	21
0.83061905	21	9	0.180829304	14
0.447645885	15	10	0.78382071	21
0.855524058	22	11	0.244570407	14
0.037647595	12	12	0.283975137	14
0.042955136	12	13	0.270325264	14
0.283849302	14	14	0.182533385	14
0.679318196	19	15	0.848009073	22
0.202758179	14	16	0.407505688	15
0.142232591	13	17	0.593544772	18
0.219619815	14	18	0.790551832	21
0.053235625	12	19	0.875880904	22
0.170928085	14	20	0.589725372	18
0.551909276	17	21	0.866454335	22
0.472567544	15	22	0.71354061	20
0.481263149	17	23	0.623362207	19
0.14682868	13	24	0.145302683	13
0.411158555	15	25	0.650127354	19
0.592604681	18	26	0.497899096	17
0.839891729	21	27	0.636252365	19
0.636991934	19	28	0.804216138	21
0.80176026	21	29	0.489761003	17
0.051991086	12	30	0.397406362	15

Table 4.8: Sample Simulation Worksheet for SP5A-44 up to 105 weeks

ORDER QUANTITY	80	REORDER POINT	50	BEG INVENTORY	3

WEEK	ORDER ARRIVAL?	NO. OF ORDERS ARRIVED	UNITS RECEIVED	CURRENT INVENTORY	RANDOM NO.	DEMAND	END INVENTORY	PENDING UNITS	LOST SALES	TO ORDER?	RANDOM NO.	LEAD TIME	COMMENTS	ARRIVAL WEEK
1	NO	0	0	3	0.568995416	1	2	0	0	ORDER	0.069673	12	EXPECTED	13
2	NO	0	0	2	0.359134573	1	1	80,	0	NO	NONE	0	NOT EXPECTED	2
3	NO	0	0	1	0.593421479	1	0	80	0	NO	NONE	0	NOT EXPECTED	3
4	NO	0	0	0	0.565610037	1	0	80	1	NO	NONE	0	NOT EXPECTED	4
5	NO	0	0	0	0.674070723	2	0	80	2	NO	NONE	0	NOT EXPECTED	5
6	NO	0	0	0	0.107970006	0	0	80	0	NO	NONE	0	NOT EXPECTED	6
7	NO	0	0	0	0.260644606	0	0	80	0	NO	NONE	0	NOT EXPECTED	7
8	NO	0	0	0	0.290829402	0	0	80	0	NO	NONE	0	NOT EXPECTED	8
9	NO	0	0	0	0.770098096	3	0	80	3	NO	NONE	0	NOT EXPECTED	9
10	NO	0	0	0	0.865056259	3	0	80	3	NO	NONE	0	NOT EXPECTED	10
11	NO	0	0	0	0.859245265	3	0	80	3	NO	NONE	0	NOT EXPECTED	11
12	NO	0	0	0	0.104414768	0	0	80	0	NO	NONE	0	NOT EXPECTED	12
13	YES	1	80	90	0.666541578	1	79	0	0	NO	NONE	0	NOT EXPECTED	13
14	NO	0	0	79	0.998523835	5	74	0	0	NO	NONE	0	NOT EXPECTED	14
15	NO	0	0	74	0.023636486	0	74	0	0	NO	NONE	0	NOT EXPECTED	15
16	NO	0	0	74	0.094430176	0	74	0	0	NO	NONE	0	NOT EXPECTED	16
17	NO	0	0	74	0.630577697	1	73	0	0	NO	NONE	0	NOT EXPECTED	17
18	NO	0	0	73	0.995229165	5	68	0	0	NO	NONE	0	NOT EXPECTED	18
19	NO	0	0	68	0.345916233	0	68	0	0	NO	NONE	0	NOT EXPECTED	19
20	NO	0	0	68	0.897087013	4	64	0	0	NO	NONE	0	NOT EXPECTED	20
21	NO	0	0	64	0.11742732	0	64	0	0	NO	NONE	0	NOT EXPECTED	21
22	NO	0	0	64	0.147302685	0	64	0	0	NO	NONE	0	NOT EXPECTED	22
23	NO	0	0	64	0.338895593	0	64	0	0	NO	NONE	0	NOT EXPECTED	23
24	NO	0	0	64	0.157410801	0	64	0	0	NO	NONE	0	NOT EXPECTED	24
25	NO	0	0	64	0.019392875	0	64	0	0	NO	NONE	0	NOT EXPECTED	25
26	NO	0	0	64	0.67396952	2	62	0	0	NO	NONE	0	NOT EXPECTED	26
27	NO	0	0	62	0.209442408	0	62	0	0	NO	NONE	0	NOT EXPECTED	27
28	NO	0	0	62	0.474494376	1	61	0	0	NO	NONE	0	NOT EXPECTED	28
29	NO	0	0	61	0.573563041	1	60	0	0	NO	NONE	0	NOT EXPECTED	29
30	NO	0	0	60	0.430580865	1	59	0	0	NO	NONE	0	NOT EXPECTED	30
31	NO	0	0	59	0.495810761	1	58	0	0	NO	NONE	0	NOT EXPECTED	31
32	NO	0	0	58	0.953294319	5	53	0	0	NO	NONE	0	NOT EXPECTED	32
33	NO	0	0	53	0.84362401	3	50	0	0	ORDER	0.12337	13	EXPECTED	46
34	NO	0	0	50	0.897423584	4	46	80	0	NO	NONE	0	NOT EXPECTED	34
35	NO	0	0	46	0.208871154	0	46	80	0	NO	NONE	0	NOT EXPECTED	35
36	NO	0	0	46	0.69178279	2	44	80	0	NO	NONE	0	NOT EXPECTED	36
37	NO	0	0	44	0.5401087	1	43	80	0	NO	NONE	0	NOT EXPECTED	37
38	NO	0	0	43	0.391665488	1	42	80	0	NO	NONE	0	NOT EXPECTED	38
39	NO	0	0	42	0.822944647	3	39	80	0	NO	NONE	0	NOT EXPECTED	39
40	NO	0	0	39	0.620101342	1	38	80	0	NO	NONE	0	NOT EXPECTED	40
41	NO	0	0	38	0.295203374	0	38	80	0	NO	NONE	0	NOT EXPECTED	41
42	NO	0	0	38	0.066654295	0	38	80	0	NO	NONE	0	NOT EXPECTED	42
43	NO	0	0	38	0.292845206	0	38	80	0	NO	NONE	0	NOT EXPECTED	43
44	NO	0	0	38	0.657081375	1	37	80	0	NO	NONE	0	NOT EXPECTED	44
45	NO	0	0	37	0.250834253	0	37	80	0	NO	NONE	0	NOT EXPECTED	45
46	YES	1	80	117	0.05807777	0	117	0	0	NO	NONE	0	NOT EXPECTED	46
47	NO	0	0	117	0.66976056	1	116	0	0	NO	NONE	0	NOT EXPECTED	47
48	NO	0	0	116	0.921399277	4	112	0	0	NO	NONE	0	NOT EXPECTED	48
49	NO	0	0	112	0.874711983	4	108	0	0	NO	NONE	0	NOT EXPECTED	49
50	NO	0	0	108	0.793364162	3	105	0	0	NO	NONE	0	NOT EXPECTED	50
51	NO	0	0	105	0.239402329	0	105	0	0	NO	NONE	0	NOT EXPECTED	51
52	NO	0	0	105	0.47576089	1	104	0	0	NO	NONE	0	NOT EXPECTED	52
53	NO	0	0	104	0.338663983	0	104	0	0	NO	NONE	0	NOT EXPECTED	53
54	NO	0	0	104	0.644269735	1	103	0	0	NO	NONE	0	NOT EXPECTED	54
55	NO	0	0	103	0.971935234	5	98	0	0	NO	NONE	0	NOT EXPECTED	55

ORDER QUANTITY 80 REORDER POINT 50 BEG INVENTORY 3

WEEK	ORDER ARRIVAL?	NO. OF ORDERS ARRIVED	UNITS RECEIVED	CURRENT INVENTORY	RANDOM NO.	DEMAND	END INVENTORY	PENDING UNITS	LOST SALES	TO ORDER?	RANDOM NO.	LEAD TIME	COMMENTS	ARRIVAL WEEK
56	NO	0	0	98	0.604967276	1	97	0	0	NO	NONE	0	NOT EXPECTED	56
57	NO	0	0	97	0.554173339	1	96	0	0	NO	NONE	0	NOT EXPECTED	57
58	NO	0	0	96	0.144159732	0	96	0	0	NO	NONE	0	NOT EXPECTED	58
59	NO	0	0	96	0.921484968	4	92	0	0	NO	NONE	0	NOT EXPECTED	59
60	NO	0	0	92	0.392663303	1	91	0	0	NO	NONE	0	NOT EXPECTED	60
61	NO	0	0	91	0.434927947	1	90	0	0	NO	NONE	0	NOT EXPECTED	61
62	NO	0	0	90	0.596936826	1	89	0	0	NO	NONE	0	NOT EXPECTED	62
63	NO	0	0	89	0.755797626	2	87	0	0	NO	NONE	0	NOT EXPECTED	63
64	NO	0	0	87	0.418017254	1	86	0	0	NO	NONE	0	NOT EXPECTED	64
65	NO	0	0	86	0.271031718	0	86	0	0	NO	NONE	0	NOT EXPECTED	65
66	NO	0	0	86	0.148145189	0	86	0	0	NO	NONE	0	NOT EXPECTED	66
67	NO	0	0	86	0.018097526	0	86	0	0	NO	NONE	0	NOT EXPECTED	67
68	NO	0	0	86	0.289499395	0	86	0	0	NO	NONE	0	NOT EXPECTED	68
69	NO	0	0	86	0.010179512	0	86	0	0	NO	NONE	0	NOT EXPECTED	69
70	NO	0	0	86	0.560957249	1	85	0	0	NO	NONE	0	NOT EXPECTED	70
71	NO	0	0	85	0.612014231	1	84	0	0	NO	NONE	0	NOT EXPECTED	71
72	NO	0	0	84	0.092649535	0	84	0	0	NO	NONE	0	NOT EXPECTED	72
73	NO	0	0	84	0.247444374	0	84	0	0	NO	NONE	0	NOT EXPECTED	73
74	NO	0	0	84	0.062573024	0	84	0	0	NO	NONE	0	NOT EXPECTED	74
75	NO	0	0	84	0.253851854	0	84	0	0	NO	NONE	0	NOT EXPECTED	75
76	NO	0	0	84	0.993124318	5	79	0	0	NO	NONE	0	NOT EXPECTED	76
77	NO	0	0	79	0.516789309	1	78	0	0	NO	NONE	0	NOT EXPECTED	77
78	NO	0	0	78	0.591460442	1	77	0	0	NO	NONE	0	NOT EXPECTED	78
79	NO	0	0	77	0.904399353	4	73	0	0	NO	NONE	0	NOT EXPECTED	79
80	NO	0	0	73	0.893509958	4	69	0	0	NO	NONE	0	NOT EXPECTED	80
81	NO	0	0	69	0.510276847	1	68	0	0	NO	NONE	0	NOT EXPECTED	81
82	NO	0	0	68	0.50360302	1	67	0	0	NO	NONE	0	NOT EXPECTED	82
83	NO	0	0	67	0.307374928	0	67	0	0	NO	NONE	0	NOT EXPECTED	83
84	NO	0	0	67	0.973069957	5	62	0	0	NO	NONE	0	NOT EXPECTED	84
85	NO	0	0	62	0.271287296	0	62	0	0	NO	NONE	0	NOT EXPECTED	85
86	NO	0	0	62	0.932125814	5	57	0	0	NO	NONE	0	NOT EXPECTED	86
87	NO	0	0	57	0.426202933	1	56	0	0	NO	NONE	0	NOT EXPECTED	87
88	NO	0	0	56	0.441523462	1	55	0	0	NO	NONE	0	NOT EXPECTED	88
89	NO	0	0	55	0.497107567	1	54	0	0	NO	NONE	0	NOT EXPECTED	89
90	NO	0	0	54	0.354424564	1	53	0	0	NO	NONE	0	NOT EXPECTED	90
91	NO	0	0	53	0.714910266	2	51	0	0	NO	NONE	0	NOT EXPECTED	91
92	NO	0	0	51	0.46291997	1	50	0	0	ORDER	0.013773	12	EXPECTED	104
93	NO	0	0	50	0.067029876	0	50	80	0	NO	NONE	0	NOT EXPECTED	93
94	NO	0	0	50	0.805976973	3	47	80	0	NO	NONE	0	NOT EXPECTED	94
95	NO	0	0	47	0.264807515	0	47	80	0	NO	NONE	0	NOT EXPECTED	95
96	NO	0	0	47	0.826542563	3	44	80	0	NO	NONE	0	NOT EXPECTED	96
97	NO	0	0	44	0.238091075	0	44	80	0	NO	NONE	0	NOT EXPECTED	97
98	NO	0	0	44	0.940794492	5	39	80	0	NO	NONE	0	NOT EXPECTED	98
99	NO	0	0	39	0.561830888	1	38	80	0	NO	NONE	0	NOT EXPECTED	99
100	NO	0	0	38	0.811401787	3	35	80	0	NO	NONE	0	NOT EXPECTED	100
101	NO	0	0	35	0.276323169	0	35	80	0	NO	NONE	0	NOT EXPECTED	101
102	NO	0	0	35	0.714009542	2	33	80	0	NO	NONE	0	NOT EXPECTED	102
103	NO	0	0	33	0.649117381	1	32	80	0	NO	NONE	0	NOT EXPECTED	103
104	YES	1	80	112	0.236014327	0	112	0	0	NO	NONE	0	NOT EXPECTED	104
105	NO	0	0	112	0.401895016	1	111	0	0	NO	NONE	0	NOT EXPECTED	105

The simulation worksheet shows that for this particular order policy, expected orders are due to arrive in weeks 13, 46, and 104, from the last two columns of the table, columns 14 and 15. Inspection of columns 2, 3, and 4 at those weeks shows that the orders are indicated to have arrived when they were due, and the units received at each arrival week are equivalent to the order quantity. This validates the simulation model and confirms that the model can now be used to test various ordering policies. A summary of the spreadsheet formulas and functions used in the simulation worksheet is given in table 4.9

Table 4.9: Spreadsheet formulas and functions

FORMULAR	APPLICATION	CELL OF ENTRY	RANGE COPIED TO
+IF(C23="YES".$C$21*D23.0)	Calculate units received	E23	E24:E1022
+IF(C23="YES".+E23+$H$21.$H$21)	Calculate current inventory. first week	F23	
+IF(C24="YES",+E24+I23.I23)	Calculate current inventory. subsequent weeks	F24	F25:F1022
+U23	Obtain Demand Random number	G23	G24:G1022
+VLOOKUP(G23.$U$23:$V$1022,2.FALSE)	Generate Week's demand	H23	H24:H1022
+IF(H23>F23.0.F23-H23)	Calculate end inventory	I23	I24:I1022
=(+COUNTIF($L$23:L23,"ORDER")*$C$21)-SUM($E$23:E24)	Calculate Pending units	J24	J25:J1022
+IF(F23<H23.H23-F23.0)	Calculate lost sales	K23	K23:K1022
+IF(I23<=$F$21."ORDER"."NO")	Determine if to order. first week	L23	
+IF(I24<=$F$21,+IF(J24>0,"NO"."ORDER")."NO")	Determine if to order. subsequent weeks	L24	L25:L1022
+IF(L23="ORDER".+VLOOKUP(B23.$Z$23:AB1022.2.FALSE)."NONE")	Obtain Lead time Random number	M23	M24:M1022
+IF(M23="NONE".0.+VLOOKUP(M23.$AA$23:AB1022.2.FALSE))	Generate order lead time	N23	N24:N1022
+IF(N23=0."NOT EXPECTED"."EXPECTED")	Determine if there is an expected order or not	O23	O24:O1022
+N23+B23	Determine order arrival week	P23	P24:P1022
+RAND()	Dynamic Random number generator - demand	R23	R24:R1022
+VLOOKUP(R23.$E$5:$G$12,3.TRUE)	Obtain demand from probability distribution table	S23	S24:S1022
+RAND()	Dynamic Random number generator – lead time	X23	X24:X1022
+VLOOKUP(X23.$L$5:$N$18,3.TRUE)	Obtain lead time from probability distribution table	Y23	Y24:Y1022

4.5.4 Order Policy Total Cost

Having validated the inventory simulation model, the information obtained from the simulation run is then used to determine the total cost of each policy simulated. The inventory total cost parameters are applied on the information generated from the simulation run. Table 4.10 shows a sample of the parameters used to determine the total inventory cost of any given order policy.

Table 4.10: Policy total cost determination; SP5A-44 Order Quantity 80, Reorder point 50

AVE INVENTORY	TOTAL NO. OF ORDERS	AVE LOST SALES	
62.476 Units/Week	0.017 Orders/Week	0.012 Units/Week	52.00 Weeks/Year

TOTAL COST PARAMETERS

HOLDING COST PER ITEM PER WEEK	101.00
COST PER ORDER	129,500.00
COST PER LOST SALE (PROFIT)	79,200.00
WEEKLY INVENTORY COST	**9,461.98**
ANNUAL INVENTORY COST	**492,022.75**

The average inventory in units per week is determined as the summation of all the end inventories divided by 1000 weeks. The orders per week are determined as the total number of orders that have arrived divided by 1000 weeks. The average lost sales per week are determined as the summation of all lost sales divided by 1000 weeks. Total cost parameters are obtained from table 4.3 of inventory cost parameters. The holding cost is the average inventory times the holding cost per unit per week while the ordering cost is the cost per order times the number of orders per week and the cost of lost sales is the cost per lost sale times the average lost sales per week. The weekly inventory cost is the summation of these three costs, and the annual inventory cost is the weekly cost times 52 weeks per year. The weekly total inventory cost was used to compare various ordering policies for each of the inventory items which were simulated.

4.6 Simulation Results

For each inventory item under investigation, various inventory policies were simulated and the results obtained are as shown in table 4.11. It is observed that for each product model, simulation was first tested with lower values of order quantities. As the order quantities were increased, the total costs decreased to a minimum. Above a critical value of order quantity, the total inventory cost was observed to increase. The lowest cost was obtained by varying the reorder quantities for the critical order quantity determined. In this way, the inventory cost policy that yielded the lowest inventory cost was determined. The variation of the total inventory costs with order quantities is shown graphically in figure 4.1

A summary of the minimum cost inventory policies for each of the product items that were investigated is presented in table 4.12.

Figure 4.1: Variation of Total Inventory Costs with Order Quantity for SP5A-44

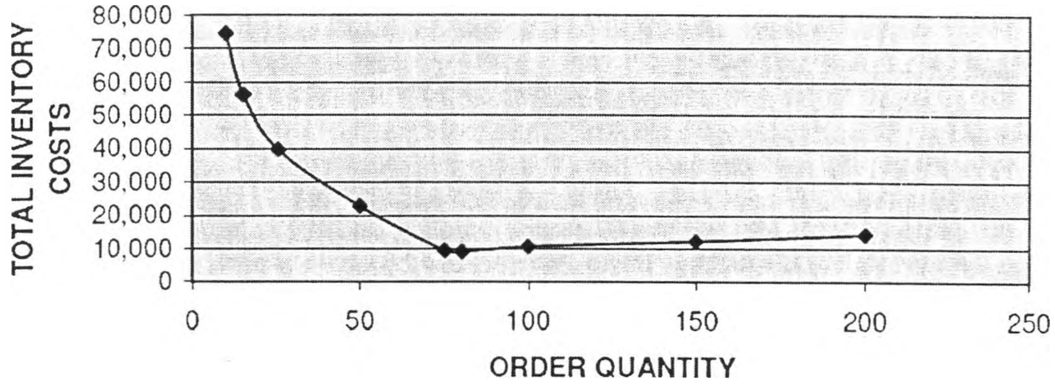
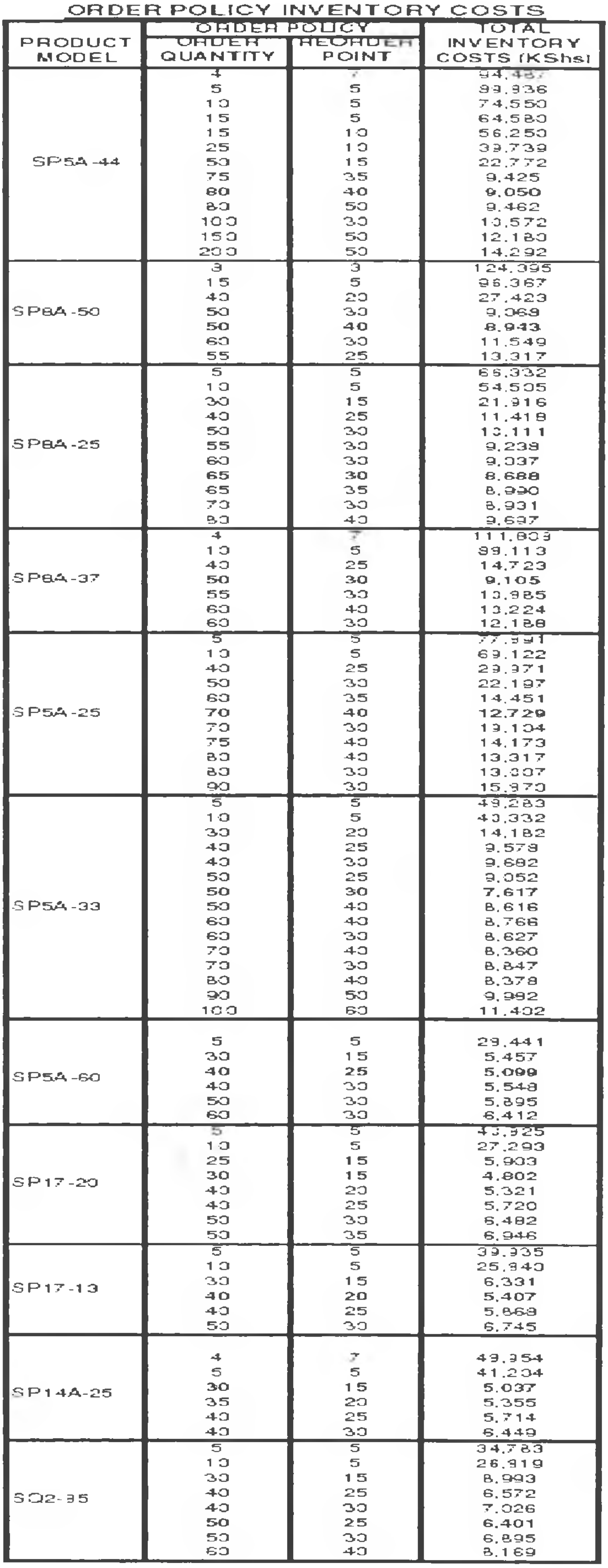


Table 4.11: Product Inventory Policy Costs.



ORDER POLICY INVENTORY COSTS

PRODUCT MODEL	ORDER POLICY		TOTAL INVENTORY COSTS (KShs)
	ORDER QUANTITY	REORDER POINT	
SP5A-44	4	7	94,487
	5	5	93,936
	10	5	74,550
	15	5	64,580
	15	10	56,250
	25	10	39,739
	50	15	22,772
	75	35	9,425
	80	40	9,050
	80	50	9,462
	100	30	10,572
	150	50	12,180
	200	50	14,292
SP8A-50	3	3	124,395
	15	5	96,367
	40	20	27,423
	50	30	9,069
	50	40	8,943
	60	30	11,549
	55	25	13,317
SP8A-25	5	5	66,332
	10	5	54,505
	30	15	21,916
	40	25	11,418
	50	30	10,111
	55	30	9,239
	60	30	9,037
	65	30	8,688
	65	35	8,990
	70	30	8,931
	80	40	9,697
SP8A-37	4	7	111,809
	10	5	99,113
	40	25	14,723
	50	30	9,105
	55	30	10,985
	60	40	10,224
	60	30	12,188
SP5A-25	5	5	77,991
	10	5	69,122
	40	25	29,971
	50	30	22,197
	60	35	14,451
	70	40	12,729
	70	30	19,104
	75	40	14,173
	80	40	13,317
	80	30	13,007
	90	30	15,970
SP5A-33	5	5	49,283
	10	5	40,332
	30	20	14,182
	40	25	9,578
	40	30	9,682
	50	25	9,052
	50	30	7,617
	50	40	8,616
	60	40	8,766
	60	30	8,627
	70	40	8,360
	70	30	8,847
	80	40	8,378
	90	50	9,992
	100	60	11,402
SP5A-60	5	5	29,441
	30	15	5,457
	40	25	5,099
	40	30	5,548
	50	30	5,895
	60	30	6,412
SP17-20	5	5	43,925
	10	5	27,293
	25	15	5,903
	30	15	4,802
	40	20	5,321
	40	25	5,720
	50	30	6,482
	50	35	6,946
SP17-13	5	5	39,935
	10	5	25,940
	30	15	6,331
	40	20	5,407
	40	25	5,868
	50	30	6,745
SP14A-25	4	7	49,354
	5	5	41,204
	30	15	5,037
	35	20	5,355
	40	25	5,714
	40	30	6,449
SQ2-35	5	5	34,783
	10	5	26,919
	30	15	8,993
	40	25	6,572
	40	30	7,026
	50	25	6,401
	50	30	6,895
	60	40	8,169

Table 4.12: Minimum Cost Inventory Policies

MODEL	INVENTORY POLICY ORDER QUANTITY	REORDER POINT	TOTAL INVENTORY COSTS (KShs)
GRUNDFOS SP8A-50 7.5KW PUMP	50	40	8,943
GRUNDFOS SP5A-44 4KW PUMP	80	40	9,050
GRUNDFOS SP8A-37 5.5KW PUMP	50	30	9,105
GRUNDFOS SP8A-25 4KW PUMP	65	30	8,688
GRUNDFOS SP17-20 11KW PUMP	30	15	4,802
GRUNDFOS SP14A-25 7.5KW PUMP	30	15	5,037
GRUNDFOS SP17-13 7.5KW PUMP	40	20	5,407
GRUNDFOS SP5A-25 2.2KW PUMP	70	40	12,729
GRUNDFOS SP5A-60 5.5KW PUMP	40	25	5,099
GRUNDFOS SQ 2-85 1KW PUMP	50	25	6,401
GRUNDFOS SP5A-33 3KW PUMP	50	30	7,617

CHAPTER 5: DISCUSSIONS, CONCLUSIONS, AND RECOMMENDATIONS

The objective of this research was to develop an inventory model that would minimise the total inventory costs through simulation analysis. The study demonstrated how simulation analysis could be employed in optimizing inventory. For all the inventory products that were identified as category A through ABC analysis, minimum cost inventory policies were established after simulating the inventory management system over a period of 1000 weeks. In section 1.2, it was observed that the current system of ordering used by the Company is period based, whereby orders are placed monthly. A product shelf life of three months is targeted, though there is no alert system to warn when stock levels are approaching minimum quantities and need to be replenished. An inventory model based on projected sales, lead times and stock holding costs has not been established.

Another weakness of the system currently in use is that it does not take into account the stochastic nature of demand and lead time. As a result, frequent stock outs are experienced, and there has been no effort to quantify the losses resulting from such stock outs. The simulation model that was developed took into account holding costs, ordering costs and shortage costs and sought to minimize the total inventory costs. By trying out various inventory policies, it was observed that the total costs started from a high figure at low order quantities and reorder levels and as the order quantities were gradually increased, the total inventory costs reduced until they stabilized at a minimum, at a critical ordering policy. These optimum inventory policies should therefore be adopted for the products whose inventory systems were simulated.

The simulation model in this research was based on an MS EXCEL electronic spreadsheet. Although modern simulation languages have been developed, electronic spreadsheets lend themselves to easy use by managers because a program needs not be written, and the spreadsheet formulas can be used, albeit with minor programming using the macros. It was felt that demonstrating the power of electronic spreadsheets in carrying out simulation analysis would encourage managers to adopt these techniques. It should be borne in mind that each run of a stochastic simulation model produces only estimates of a model's true characteristics for a particular set of input parameters. Since the simulation is based on a "what if" approach, many different inventory policies should be tried out with different independent sets of random numbers, before an optimum policy is settled on.

In carrying out this research a number of problems were encountered. One of the problems observed was the wide variation in lead time data on which the probability distribution of lead time was based. Such wide variations ranging from 12 to 29 weeks were noted to be caused by delays at the sea port of Mombasa due to inefficient and inconsistent operation of the container terminal. If the problems at the port are addressed, lead times may change significantly and it would be prudent to carry out the simulation again. Another cause of long lead times is the issue of transhipment of containers from Europe destined to Africa. Due to the higher traffic of ships from Europe going to high demand regions such as china, less priority has been placed on cargo destined for African ports. Cargo going to Africa is consolidated at transhipment ports such as Salala, and this process increases the lead time. With shorter lead times, it is expected that the simulation model would yield lower order quantities.

It is quite difficult to accurately determine inventory parameters. At best, these parameters are estimates, for example, determination of ordering costs per order requires that the time spent by various staff members on ordering be estimated, and this can not be accurately determined and is fairly subjective. It therefore calls upon the manager to use their own judgement to obtain meaningful results.

In this inventory model, demand probability distribution was based on historical demand. The historical demand is however distorted by periods of stock outs. If products were readily available all the time from stock, it would be expected that the demand recorded would be higher.

This research achieved the set objective of developing an inventory model that would minimize total inventory costs by simulation analysis. It made a contribution to the management of inventory in the water engineering industry and developed an approach that if adopted by companies could result in more efficient utilization of financial resources employed in inventory. Further research should be conducted across the various engineering companies in the water industry to understand the techniques or methods that are currently employed in inventory management and should build in the aspect of service levels.

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APPENDICES

7.1 Appendix 1: Lost Sales Analysis

DAVIS AND SHIRTLIFF LTD														
MONTH	GRUNDFOS SP PUMPS LOST SALES SUMMARY REPORT - 2004												CUMM VALUES	AVERAGE VALUES
	Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04		
Total No. of Stock Items	51	51	51	51	51	51	51	51	51	51	51	51		51
Stock Value Held (KShs)	9 456 063	9 093 395	7 633 396	6 653 508	9 428 649	8 907 641	7 693 719	7 346 768	5 127 147	9 133 874	8 544 684	8 933 163		8 204 751
Total Sales Value (KShs)	5 640 600	6 227 135	2 603 502	4 244 056	5 031 907	5 546 456	5 288 302	6 628 052	4 939 119	6 478 655	5 743 609	4 867 600	63 439 497	5 286 625
No. of Items out of Stock	6	6	11	11	5	6	8	5	14	6	7	9		8
Lost Sales Value (KShs)	568 900	799 900	1 579 200	1 431 300	731 600	532 100	961 700	501 900	3 223 000	734 800	643 500	1 246 300	12 954 400	1 079 533
% Loss of sales	10%	13%	56%	34%	15%	10%	18%	8%	65%	11%	11%	26%	20%	20%

	ITEM	ITEMS OUT OF STOCK (0 if out of stock, otherwise 1)												Unit Sales/Mth	Unit Cost (KShs)	Selling Price (Kshs)	Sales Value/Mth	No Of Mths out of Stock	CUMM Year Lost Sales (KShs)
		Dec-03	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04						
1	GRUNDFOS SP 2A-9 0.37KW PUMP	1	1	1	1	1	1	1	1	1	1	1	1	5.3	11 752.51	26 000	137 800	0	-
2	GRUNDFOS SP 2A-18 0.75KW PUMP	1	1	0	0	1	1	0	1	1	1	1	0	4.3	19 674.76	52 000	223 600	4	894 400
3	GRUNDFOS SP 2A-23 1.1KW PUMP	1	1	1	0	1	1	1	1	0	1	1	1	2	21 694.60	69 000	138 000	2	276 000
4	GRUNDFOS SP 2A-33 1.5KW PUMP	1	1	1	1	1	1	1	1	1	1	1	1	1	20 861.45	70 000	70 000	0	-
5	GRUNDFOS SP 2A-48 2.2KW PUMP	0	0	0	1	1	1	1	1	1	1	1	1	0.5	67 189.95	192 000	96 000	3	288 000
6	GRUNDFOS SP 2A-65 3.0KW PUMP	1	1	1	1	1	1	1	1	1	1	1	1	0.2	79 430.30	242 000	48 400	0	-
7	GRUNDFOS SP 3A-12 0.75KW PUMP	1	1	0	0	0	1	1	1	0	1	0	1	1.6	17 147.36	40 000	64 000	5	320 000
8	GRUNDFOS SP 3A-18 1.1KW PUMP	1	1	0	0	1	1	0	1	1	1	1	0	2.1	20 545.22	50 000	105 000	4	420 000
9	GRUNDFOS SP 3A-25 1.5KW PUMP	1	1	1	1	0	1	0	0	0	1	1	1	2.8	23 584.65	59 000	165 200	4	660 800
10	GRUNDFOS SP 3A-33 2.2KW PUMP	1	1	1	0	1	1	1	1	1	1	1	1	1.8	29 966.73	61 000	109 800	1	109 800
11	GRUNDFOS SP 3A-45 3.0KW PUMP	1	1	1	1	1	0	0	1	1	1	1	0	0.7	70 880.26	150 000	105 000	3	315 000
12	GRUNDFOS SP 3A-60 4KW PUMP	1	1	1	1	1	1	0	0	1	1	1	0	0.3	84 961.45	176 000	52 800	3	158 400
13	GRUNDFOS SP 5A-6 0.75KW PUMP	1	1	1	1	1	1	1	1	1	1	1	0	6.7	12 916.53	28 000	187 600	1	187 600
14	GRUNDFOS SP 5A-12 1.1KW PUMP	0	1	0	0	1	1	1	1	1	1	1	1	2.6	17 847.50	39 000	101 400	3	304 200
15	GRUNDFOS SP 5A-17 1.5KW PUMP	1	0	0	1	1	1	1	1	1	1	1	1	1.9	19 500.53	49 000	93 100	2	186 200
16	GRUNDFOS SP 5A-25 2.2KW PUMP	1	0	0	1	1	1	1	1	1	1	1	1	4.1	22 499.93	62 000	254 200	2	508 400
17	GRUNDFOS SP 5A-33 3KW PUMP	1	1	1	0	1	1	1	1	1	1	1	1	2.3	23 603.41	75 000	172 500	1	172 500
18	GRUNDFOS SP 5A-44 4KW PUMP	1	1	1	1	1	1	1	1	0	1	1	1	2.9	74 451.67	186 000	539 400	1	539 400
19	GRUNDFOS SP 5A-60 5.5KW PUMP	1	1	1	1	1	1	1	1	0	1	1	1	0.7	114 885.60	305 000	213 500	1	213 500
20	GRUNDFOS SP 8A-10 1.5KW PUMP	1	1	1	1	1	1	1	1	1	1	1	1	0.7	27 334.03	67 000	46 900	0	-
21	GRUNDFOS SP 8A-15 2.2KW PUMP	0	0	0	1	1	1	1	1	1	1	1	1	1.4	34 913.70	92 000	128 800	3	386 400
22	GRUNDFOS SP 8A-25 4KW PUMP	1	1	1	1	1	1	1	1	0	1	1	1	2.5	52 006.48	138 000	345 000	1	345 000
23	GRUNDFOS SP 8A-37 5.5KW PUMP	1	1	1	1	1	1	1	1	1	1	1	1	2.5	82 287.74	216 000	540 000	0	-
24	GRUNDFOS SP 8A-50 7.5KW PUMP	1	1	1	1	1	1	1	1	1	1	1	1	4.8	106 600.15	259 000	1 243 200	0	-
25	GRUNDFOS SP 14A-13 4KW PUMP	1	1	1	1	1	1	1	1	1	1	1	0	0.5	55 253.05	141 000	70 500	1	70 500
26	GRUNDFOS SP 14A-16 5.5KW PUMP	1	1	1	1	1	1	1	1	1	1	1	1	0.4	62 706.94	204 000	81 600	0	-
27	GRUNDFOS SP 14A-25 7.5KW PUMP	1	1	1	1	1	1	1	1	1	0	1	1	0.8	85 900.28	261 000	208 800	1	208 800
28	GRUNDFOS SP 14A-7 2.2KW PUMP	1	1	1	1	1	1	0	1	1	1	1	1	0.5	31 909.90	81 000	40 500	1	40 500
29	GRUNDFOS SP 17-10 5.5KW PUMP	0	1	1	1	1	1	1	0	0	1	1	1	0.5	83 706.15	188 000	94 000	3	282 000
30	GRUNDFOS SP 17-13 7.5KW PUMP	1	0	0	0	1	1	1	1	0	1	1	1	0.4	95 765.15	221 000	88 400	4	353 600
31	GRUNDFOS SP 17-20 11KW PUMP	1	1	1	1	1	1	1	1	0	1	1	1	2.3	120 824.78	268 000	616 400	1	616 400
32	GRUNDFOS SP 17-27 15KW PUMP	1	1	0	1	1	1	1	1	0	1	1	1	0.8	165 330.53	357 000	285 600	2	571 200
33	GRUNDFOS SP 17-7 4KW PUMP	1	1	1	1	1	0	1	1	1	1	1	1	0.3	62 339.95	128 000	38 400	1	38 400
34	GRUNDFOS SP 30-8 7.5KW PUMP	1	1	1	1	1	1	1	1	1	0	0	1	0.6	82 845.70	184 000	110 400	2	220 800
35	GRUNDFOS SP 30-13 11KW PUMP	1	1	1	1	1	1	1	1	1	1	1	1	0.2	114 652.50	256 000	51 200	0	-
36	GRUNDFOS SP 30-17 15KW PUMP	1	1	1	1	1	1	1	0	0	0	0	1	0.3	145 167.05	330 000	99 000	4	396 000
37	GRUNDFOS SP 30-21 18.5KW PUMP	1	1	1	1	0	1	1	1	1	1	1	1	0.7	139 811.45	407 000	284 900	1	284 900
38	GRUNDFOS SP 30-26 22KW PUMP	0	1	1	1	1	1	1	1	1	0	0	0	0.2	208 745.30	476 000	95 200	4	380 800
39	GRUNDFOS SP 46-12 18.5KW PUMP	1	1	1	1	1	1	1	1	1	1	1	1	0.1	121 222.52	335 000	33 500	0	
40	GRUNDFOS SP 60-10 18.5KW PUMP	1	1	1	1	1	1	1	0	0	0	0	1	0.3	141 853.00	303 000	90 900	4	363 600
41	GRUNDFOS SQ 3-105 1.73KW PUMP	1	1	1	0	0	0	0	1	0	0	0	1	0.9	54 036.64	145 000	130 500	7	913 500
42	GRUNDFOS SQ 3-30 0.63KW PUMP	1	1	1	1	1	1	1	1	1	1	1	1	0.1	21 753.70	81 000	8 100	0	
43	GRUNDFOS SQ 3-65 1.05KW PUMP	1	0	0	0	1	1	0	1	1	1	1	1	1.3	44 051.25	107 000	139 100	4	556 400
44	GRUNDFOS SQ 7-30 1.05KW PUMP	1	1	1	1	1	0	1	1	1	1	1	1	0.1	44 616.90	117 000	11 700	1	11 700
45	GRUNDFOS SQ 2-115 1.7KW PUMP	1	1	1	1	0	0	1	1	1	1	1	1	0.6	50 861.48	145 000	87 000	2	174 000
46	GRUNDFOS SQ 2-35 0.4KW PUMP	1	1	1	1	1	1	1	1	1	1	1	1	2.2	29 312.40	67 000	147 400	0	-
47	GRUNDFOS SQ 2-85 1KW PUMP	1	1	1	1	1	1	1	1	0	1	1	0	3.3	41 755.53	107 000	353 100	2	706 200
48	GRUNDFOS SQ 5-25 0.5KW PUMP	1	1	1	1	1	1	1	1	1	1	1	1	0.3	20 760.63	67 000	20 100	0	-
49	GRUNDFOS SQ 5-50 1KW PUMP	0	1	1	1	1	1	1	1	1	1	0	0	0.5	41 028.69	107 000	53 500	3	160 500
50	GRUNDFOS SQ 5-70 1.6KW PUMP	1	1	1	0	1	0	1	1	1	1	1	1	1.1	52 929.59	145 000	159 500	2	319 000
51	GRUNDFOS SQ 7-40 1.7KW PUMP	1	1	1	1	1	1	1	1	1	1	1	1	0.2	56 721.59	152 000	30 400	0	
																			12 954 400

7.2 Appendix 2: Demand Data

SP8A-50

Week No.	Demand
1	0
2	2
3	1
4	0
5	0
6	5
7	1
8	1
9	1
10	1
11	0
12	7
13	0
14	2
15	2
16	1
17	2
18	2
19	0
20	1
21	2
22	0
23	3
24	2
25	1
26	2
27	1
28	0
29	2
30	3
31	0
32	2
33	1
34	1
35	3
36	0
37	0
38	1
39	0
40	2
41	0
42	1
43	2
44	3
45	0
46	2
47	0
48	3
49	0
50	4
51	1
52	2

DEMAND	FREQUENCY
0	16
1	14
2	14
3	5
4	1
5	1
6	0
7	1
	52

SP8A-37

Week No.	Demand
1	0
2	1
3	0
4	0
5	0
6	1
7	0
8	1
9	1
10	0
11	0
12	5
13	2
14	0
15	1
16	1
17	1
18	1
19	3
20	2
21	2
22	0
23	1
24	1
25	1
26	2
27	0
28	1
29	2
30	1
31	2
32	0
33	2
34	1
35	1
36	2
37	0
38	0
39	1
40	0
41	4
42	0
43	2
44	2
45	3
46	1
47	0
48	1
49	2
50	1
51	0
52	7

DEMAND	FREQUENCY
0	17
1	19
2	11
3	2
4	1
5	1
6	0
7	1
	52

SP8A-25

Week No.	Demand
1	0
2	0
3	0
4	0
5	0
6	1
7	3
8	0
9	1
10	0
11	0
12	7
13	0
14	1
15	2
16	3
17	0
18	0
19	1
20	1
21	4
22	4
23	1
24	0
25	1
26	4
27	1
28	1
29	2
30	2
31	2
32	3
33	1
34	1
35	1
36	3
37	2
38	1
39	0
40	1
41	1
42	1
43	1
44	2
45	0
46	1
47	4
48	3
49	1
50	2
51	1
52	0

DEMAND	FREQUENCY
0	15
1	20
2	7
3	5
4	4
5	0
6	0
7	1
	52

SP5A-25

WEEK NO.	DEMAND
1	1
2	2
3	0
4	1
5	6
6	3
7	7
8	3
9	1
10	0
11	3
12	1
13	0
14	7
15	3
16	3
17	3
18	3
19	2
20	6
21	2
22	4
23	2
24	6
25	1
26	0
27	0
28	0
29	3
30	2
31	2
32	0
33	1
34	6
35	1
36	0
37	3
38	5
39	1
40	2
41	1
42	0
43	1
44	0
45	2
46	3
47	1
48	2
49	4
50	2
51	2
52	1

DEMAND	FREQUENCY
0	10
1	12
2	11
3	10
4	2
5	1
6	4
7	2
	52

SP5A-44

WEEK NO.	DEMAND
1	1
2	4
3	1
4	0
5	1
6	1
7	5
8	0
9	0
10	2
11	0
12	4
13	3
14	0
15	0
16	0
17	4
18	0
19	0
20	2
21	1
22	0
23	0
24	5
25	1
26	1
27	5
28	2
29	1
30	1
31	1
32	3
33	0
34	5
35	1
36	3
37	0
38	3
39	1
40	0
41	1
42	3
43	1
44	1
45	2
46	2
47	1
48	0
49	0
50	1
51	0
52	0

WEEKLY DEMAND	FREQUENCY
0	18
1	17
2	5
3	5
4	3
5	4
TOTAL	52

SP5A-33

Week No.	Demand
1	0
2	1
3	2
4	0
5	0
6	1
7	2
8	1
9	0
10	2
11	2
12	6
13	0
14	0
15	2
16	2
17	0
18	0
19	1
20	0
21	0
22	2
23	5
24	6
25	1
26	1
27	0
28	1
29	2
30	2
31	2
32	0
33	3
34	1
35	0
36	6
37	1
38	1
39	0
40	1
41	1
42	1
43	1
44	0
45	0
46	1
47	0
48	3
49	2
50	1
51	1
52	0

DEMAND	FREQUENCY
0	18
1	17
2	11
3	2
4	0
5	1
6	3
	52

SP17-20

Week No.	Demand
1	0
2	1
3	2
4	0
5	0
6	0
7	1
8	1
9	0
10	1
11	0
12	0
13	1
14	0
15	0
16	0
17	0
18	1
19	1
20	1
21	0
22	0
23	0
24	0
25	1
26	0
27	1
28	0
29	3
30	0
31	1
32	1
33	1
34	0
35	0
36	0
37	1
38	0
39	1
40	0
41	1
42	0
43	2
44	1
45	1
46	0
47	1
48	1
49	0
50	0
51	0
52	2

DEMAND	FREQUENCY
0	28
1	20
2	3
3	1
	52

SP17-13

Week No.	Demand
1	3
2	0
3	0
4	0
5	2
6	0
7	0
8	0
9	1
10	2
11	0
12	3
13	0
14	0
15	0
16	0
17	0
18	2
19	2
20	0
21	0
22	0
23	0
24	3
25	0
26	0
27	0
28	2
29	0
30	0
31	0
32	1
33	0
34	0
35	1
36	0
37	1
38	1
39	0
40	0
41	2
42	0
43	0
44	0
45	0
46	0
47	0
48	0
49	2
50	1
51	1
52	0

DEMAND	FREQUENCY
0	35
1	7
2	7
3	3
	52

SP14A-25

Week No.	Demand
1	0
2	0
3	1
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	3
13	0
14	1
15	1
16	1
17	1
18	0
19	0
20	1
21	0
22	1
23	0
24	0
25	2
26	0
27	0
28	2
29	0
30	0
31	0
32	1
33	1
34	2
35	0
36	0
37	3
38	0
39	0
40	0
41	0
42	0
43	2
44	1
45	2
46	4
47	0
48	0
49	0
50	0
51	0
52	0

DEMAND	FREQUENCY
0	34
1	10
2	5
3	2
4	1
	52

SP5A-60

Week No.	Demand
1	0
2	0
3	0
4	0
5	0
6	2
7	0
8	1
9	1
10	0
11	0
12	0
13	0
14	0
15	0
16	1
17	0
18	0
19	0
20	1
21	1
22	1
23	0
24	0
25	0
26	0
27	6
28	1
29	0
30	0
31	0
32	0
33	1
34	0
35	0
36	1
37	0
38	0
39	0
40	0
41	1
42	1
43	0
44	1
45	0
46	0
47	0
48	1
49	1
50	0
51	0
52	0

DEMAND	FREQUENCY
0	36
1	14
2	1
3	0
4	0
5	0
6	1
	52

SQ2-85

Week No.	Demand
1	2
2	0
3	2
4	0
5	0
6	4
7	3
8	0
9	0
10	2
11	0
12	2
13	1
14	1
15	2
16	1
17	1
18	0
19	0
20	0
21	0
22	2
23	0
24	1
25	0
26	2
27	1
28	2
29	2
30	1
31	0
32	3
33	2
34	0
35	4
36	0
37	0
38	1
39	0
40	0
41	0
42	2
43	3
44	0
45	0
46	2
47	0
48	2
49	0
50	0
51	0
52	0

DEMAND	FREQUENCY
0	26
1	8
2	13
3	3
4	2
	52

7.3 Appendix 3: Demand Probability Distributions

SP8A-50

WEEKLY DEMAND	FREQUENCY	PROBABILITY	PROB RANGE (LOWER)	CUMM PROB
0	16	0.31	0	0.31
1	14	0.27	0.31	0.58
2	14	0.27	0.58	0.85
3	5	0.10	0.85	0.94
4	1	0.02	0.94	0.96
5	1	0.02	0.96	0.98
6	0	0.00	0.98	0.98
7	1	0.02	0.98	1.00
	52			

SP5A-44

WEEKLY DEMAND	FREQUENCY	PROBABILITY	PROB RANGE (LOWER)	CUMM PROB
0	18	0.35	0	0.35
1	17	0.33	0.35	0.67
2	5	0.10	0.67	0.77
3	5	0.10	0.77	0.87
4	3	0.06	0.87	0.92
5	4	0.08	0.92	1.00
	52	**1.00**		

SP5A-25

WEEKLY DEMAND	FREQUENCY	PROBABILITY	PROB RANGE (LOWER)	CUMM PROB
0	10	0.19	0	0.19
1	12	0.23	0.19	0.42
2	11	0.21	0.42	0.63
3	10	0.19	0.63	0.83
4	2	0.04	0.83	0.87
5	1	0.02	0.87	0.88
6	4	0.08	0.88	0.96
7	2	0.04	0.96	1.00
	52			

SP17-13

WEEKLY DEMAND	FREQUENCY	PROBABILITY	PROB RANGE (LOWER)	CUMM PROB
0	35	0.67	0	0.67
1	7	0.13	0.67	0.81
2	7	0.13	0.81	0.94
3	3	0.06	0.94	1.00
	52			

SP5A-33

WEEKLY DEMAND	FREQUENCY	PROBABILITY	PROB RANGE (LOWER)	CUMM PROB
0	18	0.35	0	0.35
1	17	0.33	0.35	0.67
2	11	0.21	0.67	0.88
3	2	0.04	0.88	0.92
4	0	0.00	0.92	0.92
5	1	0.02	0.92	0.94
6	3	0.06	0.94	1.00
	52			

SO2-85

WEEKLY DEMAND	FREQUENCY	PROBABILITY	PROB RANGE (LOWER)	CUMM PROB
0	26	0.50	0	0.50
1	8	0.15	0.50	0.65
2	13	0.25	0.65	0.90
3	3	0.06	0.90	0.96
4	2	0.04	0.96	1.00
	52			

SP5A-60

WEEKLY DEMAND	FREQUENCY	PROBABILITY	PROB RANGE (LOWER)	CUMM PROB
0	36	0.69	0	0.69
1	14	0.27	0.69	0.96
2	1	0.02	0.96	0.98
3	0	0.00	0.98	0.98
4	0	0.00	0.98	0.98
5	0	0.00	0.98	0.98
6	1	0.02	0.98	1.00
	52			

SP14A-25

WEEKLY DEMAND	FREQUENCY	PROBABILITY	PROB RANGE (LOWER)	CUMM PROB
0	34	0.65	0	0.65
1	10	0.19	0.65	0.85
2	5	0.10	0.85	0.94
3	2	0.04	0.94	0.98
4	1	0.02	0.98	1.00
	52			

SP17-20

WEEKLY DEMAND	FREQUENCY	PROBABILITY	PROB RANGE (LOWER)	CUMM PROB
0	28	0.54	0	0.54
1	20	0.38	0.54	0.92
2	3	0.06	0.92	0.98
3	1	0.02	0.98	1.00
	52			

SP8A-25

WEEKLY DEMAND	FREQUENCY	PROBABILITY	PROB RANGE (LOWER)	CUMM PROB
0	15	0.29	0	0.29
1	20	0.38	0.29	0.67
2	7	0.13	0.67	0.81
3	5	0.10	0.81	0.90
4	4	0.08	0.90	0.98
5	0	0.00	0.98	0.98
6	0	0.00	0.98	0.98
7	1	0.02	0.98	1.00
	52			

SP8A-37

WEEKLY DEMAND	FREQUENCY	PROBABILITY	PROB RANGE (LOWER)	CUMM PROB
0	17	0.33	0	0.33
1	19	0.37	0.33	0.69
2	11	0.21	0.69	0.90
3	2	0.04	0.90	0.94
4	1	0.02	0.94	0.96
5	1	0.02	0.96	0.98
6	0	0.00	0.98	0.98
7	1	0.02	0.98	1.00
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7.4 Appendix 4: Macro Subroutine “Update Order Arrival”

```
Sub UpdateOrderArrival()
    Dim Roww  As Integer
    Dim Roww2 As Integer
    Dim Order As Boolean

    Dim NoOfOrders As Integer
    Order = False

    'Dim DAY1 As Integer
    For Roww = 23 To 1022
     Order = False
      If i >= 1 Then
         Set DAY1 = Worksheets("SQ2-85").Cells(Roww, 2)
           NoOfOrders = 0
           For Roww2 = 23 To Roww - 1
               Set ARRIVALDAY = Worksheets("SQ2-85").Cells(Roww2, 16)
               If (DAY1 = ARRIVALDAY) And (Worksheets("SQ2-85").Cells(Roww2, 15) = "EXPECTED") The
                Order = True
                NoOfOrders = NoOfOrders - 1
               End If
           Next Roww2

        If Order = True Then
           Worksheets("SQ2-85").Cells(Roww, 3).Value = "YES"
           Worksheets("SQ2-85").Cells(Roww, 4).Value = NoOfOrders
        Else
           Worksheets("SQ2-85").Cells(Roww, 3).Value = "NO"
           Worksheets("SQ2-85").Cells(Roww, 4).Value = 0
        End If

      End If
    i = i - 1
    Next Roww

End Sub
```