Inventory Management at the National University Hospital of Iceland

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60 ECTS thesis submitted in partial fulfillment of a
Magister Scientiarum degree in Industrial Engineering

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Abstract

The main objective of this study is to investigate whether any of three selected MRP methods could reduce inventory and inventory related costs at NUHI's central storeroom. NUHI recently adopted the JIT/Kanban so an evaluation of their new system was made by comparing NUHI expenses with the consumer price index (CPI). However, the focus of this research was on NUHI's central storeroom, which services the JIT/Kanban system but itself uses a s,S inventory policy. Three Material Requirement Planning (MRP) lot-sizing techniques, The Economic Order Quantity (EOQ), The Silver-Meal heuristic (SM) and The Least Unit Cost heuristic (LUC) were compared to the central storerooms current system of choice. NUHI provided daily demand data for 60 items which were chosen with an ABC analysis. The data was analyzed and used as an input for an inventory simulator created to compare the four inventory control methods. Under simulation there the current s,S policy performed significantly best by returning the least total cost. The simulation also shows that the amount of money tied up in inventory can be reduced significantly by improving visibility and adjusting the service level. The research concludes that NUHI must define the goals and parameters of its supply chain in order to properly evaluate its supply chain system. Furthermore, a way to improve visibility and reduce inventory at the central storeroom is suggested. Also, all methods are discussed theoretically and a literature review presented with theoretical and case studies relevant to this research.

Útdráttur

Aðal markmið þessarar rannsóknar var að ákvarða hvort einhver þriggja MRP aðferða gætu bætt núverandi birgðastýringu á birgðastöð Landspítala – Háskólasjúkrahúss og minnkað tengdan kostnað. Landspítalinn tók Kanban í gagnið árið 2004 og var árangur þeirrar innleiðingar metinn með því að bera saman kostnað við rekstur spítalans við vísitölu neysluverðs. Rannsóknin einblíndi þó á birgðastöð spítalans sem þjónustar Kanban kerfið en notar s,S kerfi til að stjórna sínum lager. Þrjár MRP aðferðir, EOQ, Silver-Meal og Least Unit Cost voru bornar saman við núverandi kerfi birgðastöðvarinnar. Spítalinn veitti gögn sem innihéldu upplýsingar um daglega eftirspurn 60 vara inná birgðastöðina. Vörurnar voru valdar með ABC-greiningu. Gögnin voru greind og notuð sem inntak í birgðahermi sem notaður var til að bera saman aðferðirnar fjórar. Hermun leiddi í ljós að núverandi kerfi stóð sig áberandi best með því að skila lægstum kostnaði. Hermun sýndi einnig að peninginn sem bundinn er í lagerinn mætti minnka umtalsvert með því að auka gegnsæi vörukjeðjunnar og leyfa fleiri vantanir. Niðurlag rannsóknarinnar er að spítalinn þurfi að skilgreina markmið og mælistikur vörukeðjunnar sinnar svo að unnt sé að bera saman og meta árangur hennar. Einnig er bent á leið til að auka gegnsæi og minnka lager birgðastöðvarinnar. Allar aðferðir eru ræddar fræðilega, þá er yfirlit yfir fræðilegar rannsóknir sett fram ásamt rannsóknum úr heilbrigðisgeiranum sem tengjast þessari rannsókn.

To all the hardworking staff at NUHI who strive to keep us healthy

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1 Introduction

For many businesses or operations supply chain management is an integral part of becoming a successful one. The supply chain must be designed in such way that it meets the goals, needs and the nature of the operation it serves. The Council of Supply Chain Management Professionals (CSCMP) defines supply chain management as follows:

> "Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies. Supply Chain Management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance and information technology."(CSCMP 2011)

The definition above can be described as a market driven one. It focuses more on market based operations and although healthcare in other countries might fall into that category that is not the case in Iceland. Healthcare in Iceland is mainly funded by the government so it is a no-profit operation. Even though the definition from CSCMP above could be seen as a market driven one it could be argued that supply chain management is even more important for a no-profit operation like healthcare in Iceland.

Generally the supply chain is split into two parts; the external supply chain and the internal supply chain. For hospitals the external supply chain is relatively normal, i.e. it consists of a network of distributors, manufacturers and vendors and NUHI is no exception from that. Hospitals generally have a rather complex internal supply chain. The complexity lies in the many different wards that the hospital consists of. Many of whom have its own stock room or inventory. Each ward has its own needs and purpose so while one ward might only need simple, inexpensive easily accessible goods, another ward might need complex, high tech, expensive and exclusive goods or perhaps a mixture of both.

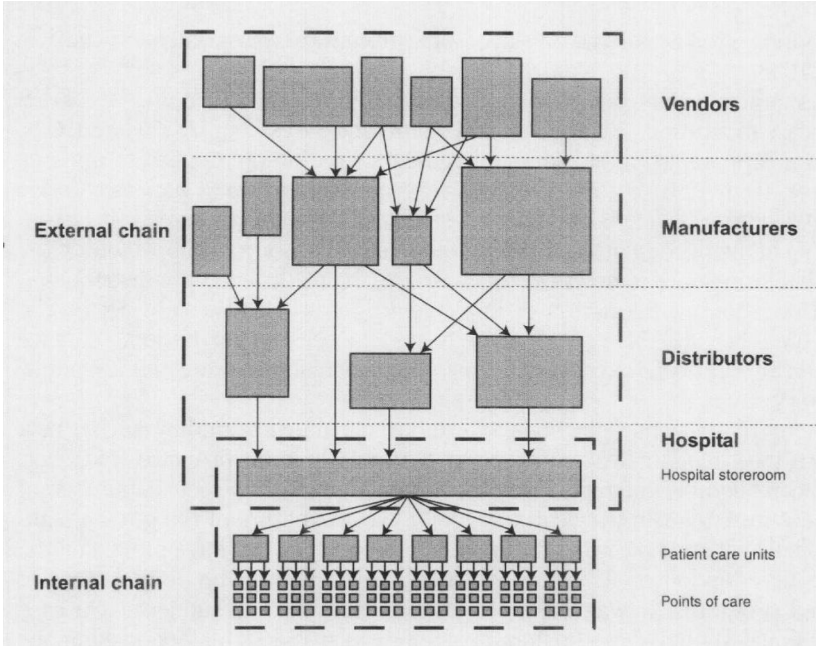

Figure 1.1 A typical supply chain for a hospital (Riverd-Royer et al. 2002)

As mentioned earlier a supply chain must be designed to meet the goals and nature of its operator. Across hospitals the goal is simply to maximize patient care. The hospital supply chain meets its goals by:

- Ensuring the availability of goods
- Minimizing storage space → maximizing patient care space
- Minimizing various inventory costs
- Reduce material handling time for all hospital staff

(DeScioli 2005)

Inventory management is the process of efficiently overseeing the constant flow of units into and out of an existing stock room. Countless inventory management methods exist and choosing the right method is vital. The method of choice usually takes into account the properties and nature of the physical activities surrounding the inventory (Lumsden 2006). The performance of a supply chain is often measured with regard to costs, including inventory costs (Beamon 1999). Thus, efficiently managing inventory enhances the supply chain performance.

The structure of this thesis is as follows: Chapter 2 introduces the current supply chain system at NUHI and NUHI's operational costs are discussed. Chapter 3 covers the theoretical background of this study. In chapter 4 the methodology used to conduct this study is discussed. In chapter 5 the inventory simulator created to compare and evaluate the inventory policies under consideration is discussed. Data analysis is also presented in chapter 5. In chapter 6 the simulation results are presented along with sensitivity analysis. Chapter 7 concludes the study and future research is suggested.

1.1 Problem formulation

As mentioned earlier the healthcare system in Iceland is mainly funded by the government. In fact since 1998 the health care system has accounted for a quarter of the government's total expenses, ranking it either as the biggest or second biggest expense factor. Governmental funding to NUHI has on average increased from year to year by 6% since 1998. However, in the wake of the credit crunch in 2008 the government was forced to cut back on funding to NUHI. As a result, in 2010 the funding to NUHI decreased from the previous year for the first time, at least since 1998.

NUHI has met these cut backs for example with layoffs, closing wards and reducing the number of beds. This in spite of growing needs towards NUHI in the form of increasing number of emergency visits and admissions. With increasing number of hospital visits the need for supplies is bound to follow suit. In fact supply usage has been an increasingly important factor in NUHI expenses, rising from 16% of total expenses in 2007 to 20% in 2010.

For that reason, this study focuses on reducing inventory related costs at NUHI's central storeroom by comparing lot sizing methods. In NUHI's supply chain the central storeroom corresponds to „Hospital Storeroom“ in figure 1.1. NUHI has recently adopted the JIT/Kanban system which is served by NUHI's central storeroom, however the central storeroom operates with a s,S policy developed over time by the central storeroom's employees (see section 2.3). The study seeks to answer the following research question.

- Can any of three selected Material Requirement Planning (MRP) methods reduce inventory and inventory related costs at the central storeroom?

In order to answer the question, an inventory simulator was developed in MathWorks – Matlab with data from NUHI's central storeroom as input. The simulator was used to compare three well known MRP methods to the s,S policy currently used at the central storeroom, based on total cost.

1.2 About the National University Hospital of Iceland

The National University Hospital of Iceland is by far the biggest piece in the Icelandic health care pie. The hospital was established March 3rd 2000 with the merger of the Icelandic State University Hospital (Landspítali) and the Reykjavík City Hospital (Borgarspítali). The main role of NUHI is threefold; service to patients, teaching and training of clinical staff and scientific research. NUHI runs several health care units around Reykjavík, including the two main hospitals at Hringbraut and in Fossvogur, the Bloodbank, Landakot Hospital, research labs and the laundry and central storeroom at Tunguháls.

With its approximately 5000 employees NUHI serves not only the Greater Reykjavík area but the country as a whole. NUHI offers services in just about every recognized specialty within the fields of medicine and nursing with emphasis on research, development and training. Some general statistics on NUHI can be seen in table 1.1.

Table 1.1 NUHI summary statistics. Data source (Guðmundsdóttir & Bjarnadóttir 2011)

NUHI summary statistics	
Emergency visits	91.482
Outpatient visits	325.805
Admissions	89.185
Number of births	3.420
Hospital beds	677

2 NUHI - Background

This chapter discusses the internal supply chain at NUHI. Since the current system was introduced fairly recently to NUHI the chapter briefly discusses how the system came about and how it differentiates from the old system. Firstly the development of the current system is discussed, then the flow of goods within NUHI is derived and the inventory management for NUHI and the central storeroom in particular is explained. Lastly, a discussion on NUHIs operational costs is presented.

2.1 Developing the current system

In 2002 NUHI hired AGR, a supply chain planning specialist firm, to observe its current supply chain system and suggest where improvements could be made. AGR focused on the flow of general supplies (this term will be derived in the next subchapter). At the time there were approximately 80 different wards within NUHI that had a stock room in some shape or form. Orders from these 80 wards went either straight to the distributors or through the central storeroom. Similarly the flow of general supplies went either through the central storeroom and on to the wards or straight from the distributors to the wards. See figure 2.1.

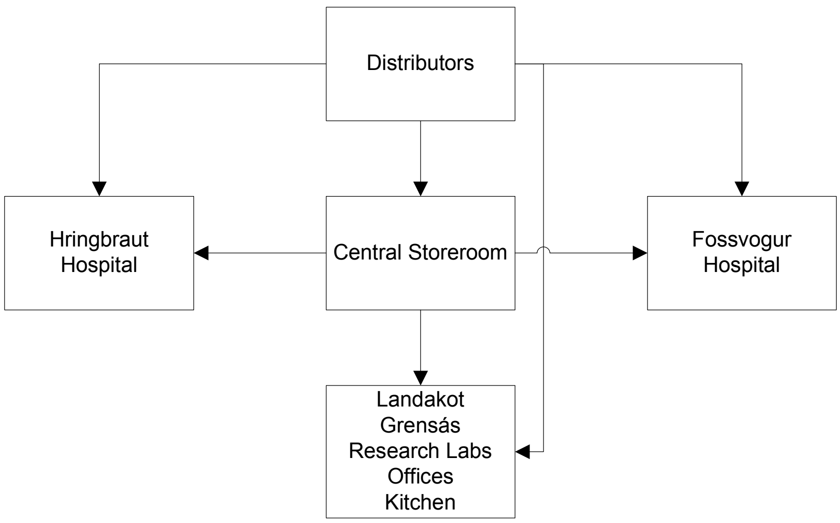

Figure 2.1 The flow of general supplies at NUHI in 2002

The personnel responsible for managing the stock rooms were mostly head nurses or head doctors so under this system staff trained in patient care or other healthcare related fields were spending a considerable amount of time figuring out when, where from and which supplies should be ordered. Furthermore according to talks the author made with various hospital staff there was no clear purchasing policy. This means for example that the stock room managers might purchase two or more different brands of items that served the same purpose just because doctors preferred one brand over the other. This caused unnecessarily high inventory levels and high purchasing and ordering costs.

After observing the ins and outs of the supply chain system and interviewing several NUHI employees, AGR made its recommendations a year later (AGR 2003). AGR wanted the new system to meet NUHIs needs and working environment. Some of the parameters they took into account when making their recommendations for a new supply chain management system were:

- Service level
- Holding costs
- Ordering costs
- Purchasing costs
- Delivery costs
- Floor space, buildings and facilities
- Active contracts with suppliers and distributors

They also wanted the transaction to the new system to be as smooth as possible, so that major reorganizing of how buildings and facilities are utilized wouldn't be necessary. AGR suggested several ways to improve the supply chain management system but the one they gave their best recommendations was a system based on the Kanban system which originates from the Toyota Motor Company. Implementing this system would mean that the basic setup would remain the same. However critical changes to the process of ordering and delivering general supplies to all 80 stock rooms would be required. Furthermore the responsibility on managing most of these stock rooms would move to the staff of the logistics department and from the staff of the wards in question. This meant that instead of managing inventory levels members of staff could focus on patient care or other tasks specialized to their training and/or department. This system is explained in further detail in the upcoming sections.

In 2004 NUHI began implementing this new system suggested by AGR and the system is now in full operation.

2.2 The flow of goods

All of the supplies used at NUHI can be divided into two main categories, general supplies and specialized supplies. In the former category there are supplies such as paper towels, catheters, injectors, plastic bags, batteries and so on. In the latter category are supplies that might only be used by one or two wards. The eye-surgical ward is an example of a ward that has a stock room which orders specialized goods. They might order such supplies as valves, needles and scalpels unique to eye surgery and lenses. Drugs and medicine also fall under specialized goods.

The solution AGR suggested that the supply chain should look more like the one shown in Figure 1.1. That is the central storeroom would serve as a stock room and distribution hub for the entire NUHI organization but only for general supplies. The central storeroom would receive orders from all other stock rooms and be responsible of fulfilling those orders within 24 hours. Since the central storeroom only handles general supplies, orders for specialized supplies are placed directly from the wards that use them at the distributor/manufacturer. AGR argued that this arrangement would reduce the number of orders placed at the distributors and therefore save money on ordering costs.

AGR also suggested that deliveries from the central storeroom to the two main hospitals should be reduced from three times a day to once a day. Deliveries to stock rooms located outside the two main hospitals would be in the hands of the laundry room vans as most stock rooms outside the two main hospitals only receive supplies once a week. This arrangement would reduce delivery costs and better utilize the current system at hand. Today however, there are two deliveries per day to the main hospitals and other units are delivered to three times a week.

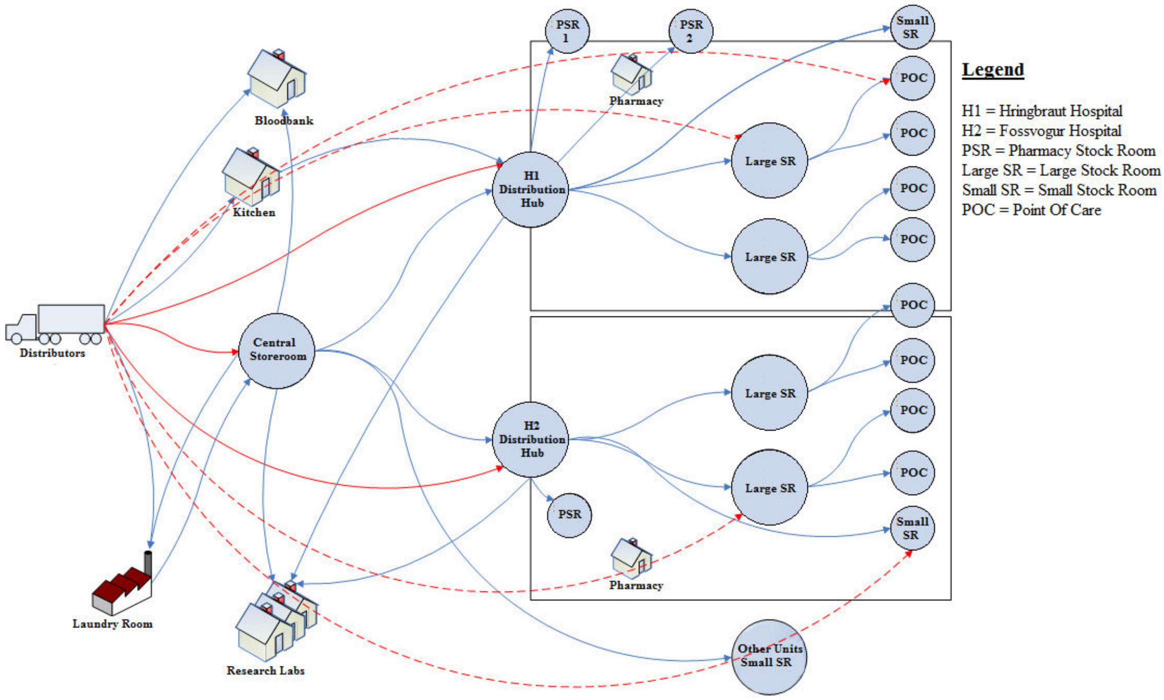

Figure 2.2 NUHIs internal supply chain (Bjarnason 2010)

Figure 2.2 describes the flow of goods within the NUHI network. General supplies are delivered from the central storeroom to all the arms of the NUHI network. In the case of the two big hospitals, which are represented by two boxes in the figure, the supplies from the central storeroom arrive at their respective distribution hubs where the supplies are sorted and passed on to the stock rooms in question. As seen in the figure, there are two types of stock rooms within the NUHI organization, small stock rooms and large stock rooms (Pharmacy stock rooms can be classified as large stock rooms). The principal difference between the two will be discussed in section 2.3. Other units which are not based in the two big hospitals such as research labs, the bloodbank and the laundry room receive their supplies directly to their respective stock rooms.

2.3 Inventory control at NUHI

As mentioned earlier AGR wanted to introduce Kanban to NUHIs inventory management. Today just about every stock room, small or large, within NUHI is controlled with Kanban.

Kanban will be explained in detail in section 3.3, however the Kanban system used around NUHI will be explained briefly here.

The Kanban system used at NUHI is a single card Kanban system where each stock item has two containers. Each container holds a quantity of units as defined by the corresponding Kanban tag (or ticket). The system dictates that units are picked only from one container at a time. When that container is fully drained it is a sign that the item needs replenishing. When an item needs replenishing the corresponding Kanban tag is placed on a Kanban post. An employee from the central storeroom will visit the stock room (the frequency of visits varies between stock rooms) and scan all the Kanban tags on the Kanban post. All Kanban tags have a barcode which when scanned sends information to the central storeroom on which stock room is ordering which item and in what quantity.

When the Kanban system was introduced the quantity of units each container would hold had to be determined for every item stored in every stock room. The general rule was that each container would hold supplies for one week divided by the number of scans each week. For example if an employee from the central storeroom would visit the stock room three times a week and the average usage of a given item is 9 units per week, each container for that item would hold 9/3 = 3 units.

As mentioned earlier, there are two types of stock rooms within NUHI small stock rooms and large stock rooms. The former, small stock rooms are either a small scale stock room or a just a simple shelve system where supplies are charged before they are used. Small stock rooms don't require a special employee managing it. When an item needs replenishing, any employee at the ward where the small stock room is located will place the corresponding Kanban tag on the Kanban post. A member of staff from the central storeroom will visit these stock rooms once a week and scan the Kanban tags

Even though there isn't a special employee which manages the small stock rooms, there is a member of staff (who works at the ward in question) responsible for overseeing the inventory. These personnel might for example foresee extra activity for any given item in the near future and therefore want to place an order for more units than the Kanban tag specifies.

On the other hand are large stock rooms where part of the supplies are not charged until they are used, so called consignment stock. These stock rooms are generally larger than small stock rooms and do require a stock room employee. The stock room employee is responsible for monitoring the inventory levels for all items in stock and placing the Kanban tags on the Kanban post. The surgical wards at Hringbraut and Fossvogur do for example require a stock room of this kind. The process of reordering supplies is similar to the one for small stock rooms. Again, a member of staff from the central storeroom will visit these stock rooms and scans the Kanban tags for the items that need replenishing from the central storeroom. However these visits occur more frequently, two or three times a week. Other items i.e. consignment items and special items are ordered directly from suppliers either domestic or foreign.

2.3.1 The central storeroom

Unlike other stock rooms at NUHI the central storeroom does not use the Kanban system. Instead they use a s,S policy to manage their purchasing policy. Inventory levels are overseen by a computer program that is updated when there is movement on any stocked item.

In order for the central storerooms suppliers to meet their requirements of a one day lead time they must receive the orders from the central storeroom before noon. As a result the first task at the central storeroom is to determine which items need replenishing. Every item has a min-max number. The min number determines the re-order point of the item and the max number determines the order up-to point. It takes one employee about three and a half hours to determine which items are to be ordered, calculate the quantity for each item and place an order at the correct supplier.

When being interviewed by the author, the central storeroom manager mentioned that the min-max number could change for any given item. When asked how a new min-max number is determined the reply was "just my touch" by which she meant that if she, or any employee, noticed an item lying in stock longer than normal or is frequently stocking out, the demand for that item was reviewed by viewing the sales history and the min-max number re-defined if necessary. The new min-max number is not calculated by any formula but the feel and experience of the central storeroom manager.

Figure 2.4 illustrates how an order is processed at the central storeroom. The general rule is that all orders are of equal importance so all orders are processed with the first come first serve rule. When it is time to process a particular order, a central storeroom employee receives the list of items requested. The items are listed in a specified order such that the employee follows a certain path around the stock room floor when picking the items for that order. The order is then packed and tagged and finally moved to the loading area where it is made available for the next delivery van.

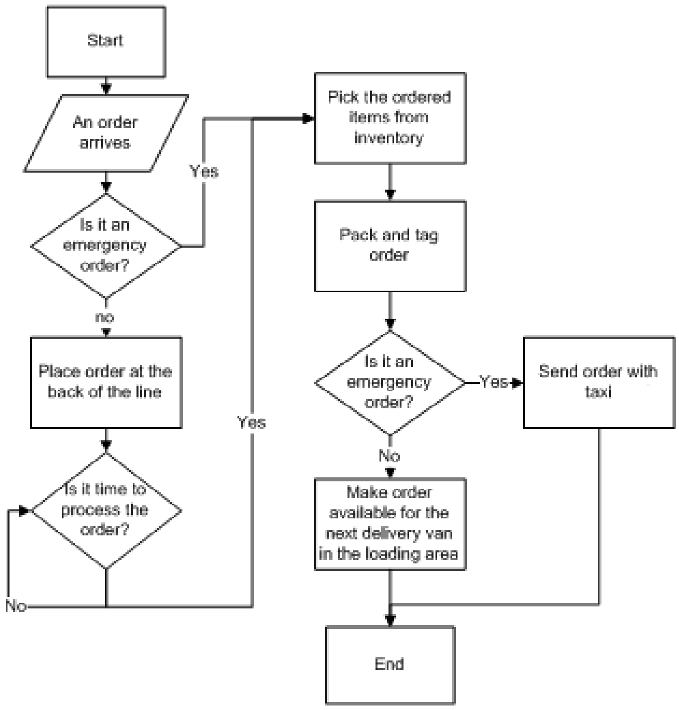

Figure 2.3 A flowchart on how an order is processed at the central storeroom

Even though the general rule is that all orders are of equal importance there might be some emergency cases where items are required right away. When such cases occur the order is processed right away and delivered by taxi. If an emergency order arrives during closing hours an on-call employee is called to open the central storeroom and process the order.

The central storeroom is split into sections with each section holding items of a similar sort. In other words, one section of the central storeroom will hold sterile supplies, another will hold office supplies and so on.

2.4 Possible improvements in the current system

A workgroup that consisted of several employees from NUHIs logistics department and a consultant from Intellecta (a consulting firm that specializes in operational management) released a report in March 2010 (Bjarnason 2010). The objective of the workgroup was to analyze the structure and performance of NUHIs supply chain and suggest potential improvements that could be implemented. The workgroups main findings were that the supply chain lacked the definition on its goals and purpose and ways to measure its performance were needed. They also mentioned that traceability was very poor and made things hard for analyzing the supply chains performance.

The workgroup mentioned several tasks that should be undertaken in order to improve the efficiency of NUHIs supply chain. Few of which are relevant to this thesis;

- Define the objectives and goals of the supply chain so that its efficiency could be determined more easily and all employees can better understand its purpose and significance.

- The supply chain's service level should be reviewed, which involves inventory levels, the frequency of supply deliveries and the flow of goods who may have significant impact on savings.

- Improve traceability so that money tied up in inventories and the depreciation of goods could be computed more accurately.

It should also be noted that when AGR recommended the current supply chain system should be implemented they identified the amount of money tied up in the central storeroom inventory and the central storerooms running costs as a potential flaw.

As discussed in chapter 5, these factors have not been addressed today. Cost factors have not been defined and NUHI has not a desired service level. Also, as mentioned in section 2.3 a specific protocol when defining the re-order and order up-to points at the central storeroom is not at hand. By not defining these factors, studies such as this becomes less effective and less focused.

2.5 Operational costs at NUHI

As mentioned earlier the health care system in Iceland is mostly funded by the government. In fact from 1998 to 2007 the health care system ranked as the biggest expense factor for the government, accounting for around 26% of total government expenditure each year. Since the credit crunch in 2008 the health care system has ranked number two behind economic affairs (DataMarket 2011). The operations that fall under NUHI are by far the biggest slice in the health care system cake so ensuring that the money provided to NUHI goes to good use is essential.

When the credit crunch hit Iceland in 2008 it was only natural that cutbacks were to be made in the government biggest expense factor. Like the case is for most health care units around Iceland the cutbacks have hit NUHI hard. According to NUHIs CEO, Björn Zoëga, NUHI has cut back in expenditure by 23% or 8,6 billion ISK since 2008. Furthermore NUHI has lost 11,5% of its staff, around 600 people due to layoffs (Mbl 2011; Visir 2011).

In October 2011 the government announced that further cutbacks in health care were due in 2012. The government allows for 630 million ISK cutbacks at NUHI in its budget for 2012. Björn Zoëga has announced that cutbacks will be met by closing wards and reducing the number of beds. A further cutback in personnel is planned with 85 positions dismissed in 2012. The doctors council at NUHI (læknaráð LSH) note that the two main hospitals that NUHI runs are the only health care units in Iceland that are always open and forbidden to reject any citizen service by law. They point out that in the first 8 months of 2011 NUHI has seen a 4% increase in emergency visits and 8% increase in patients that stay overnight. The doctors council states: „It is clear that NUHI will not be able to meet its growing needs“ (Mbl 2011).

During the last decade governmental funding to NUHI has increased on average by 6% each year or by 75% over the whole period (Fjármálaráðuneytið 2001-2011). An interesting measure on how NUHI performs financially is a comparison between the government's funds to NUHI and the consumer price index (CPI). While searching for data on this matter the author could not find a hospital price index (HPI) for Iceland. Therefore the author calculated a HPI from data on total funds provided to NUHI from the government.

Figure 2.4 displays a comparison between CPI (less housing) (Hagstofa Íslands 2011) and the calculated HPI. The figure shows that up until 2008 NUHI's expenses seem to outpace the inflation during the period but after 2008 the CPI exceeds the HPI. This is probably best explained by the necessary cut backs made at NUHI and the unusually high inflation in 2008 and 2009. It should be noted that some factors, such as the ISK exchange rate, might have different influences on the HPI than the CPI. Furthermore the population growth is not accounted for in the HPI and certainly plays some part in the increasing health care expenses. Indeed in the period 2005-2010 emergency visits have increased by 5%, outpatient visits have increased by 28% and hospital home services have increased by 107%. In contrast dayward visits decreased by 11% and the average length of stay decreased from 8,3 days to 7,5 days (Guðmundsdóttir & Heimisdóttir 2010; Guðmundsdóttir & Bjarnadóttir 2011).

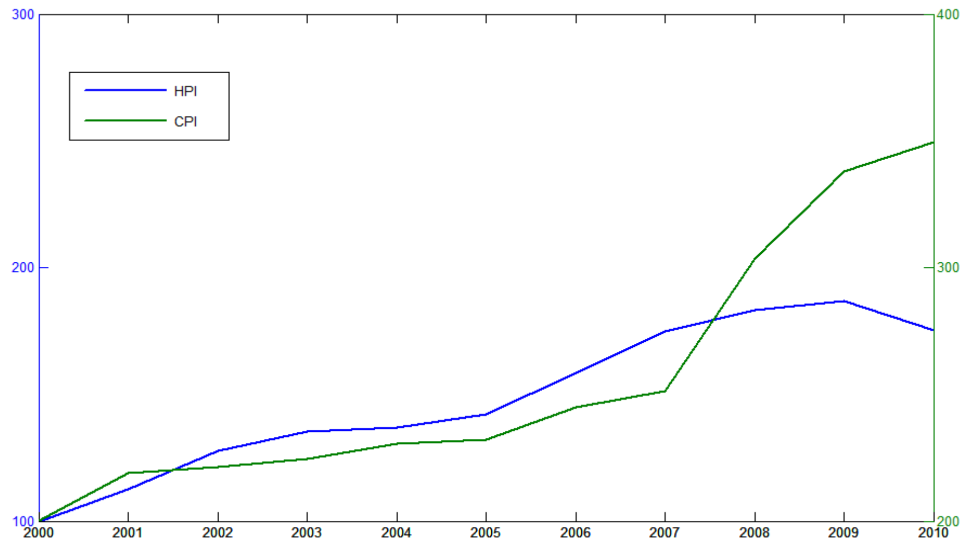

Figure 2.4 CPI vs. HPI. 2000-2010

Figure 2.5 displays the comparison between the HPI and the material price index (MPI). The MPI was calculated from data on NUHIs supply costs. The supply costs are defined as the purchasing cost of supplies bought by NUHI. Data on inventory related costs such as holding costs, ordering costs and labor costs were unavailable so they are excluded from the MPI. As shown in the figure the HPI outruns the MPI a little bit up until 2008. After 2008 there is a dramatic increase in the MPI compared to the HPI. Keeping in mind that a new supply chain system was introduced in 2004 a slightly better performance is perhaps in order.

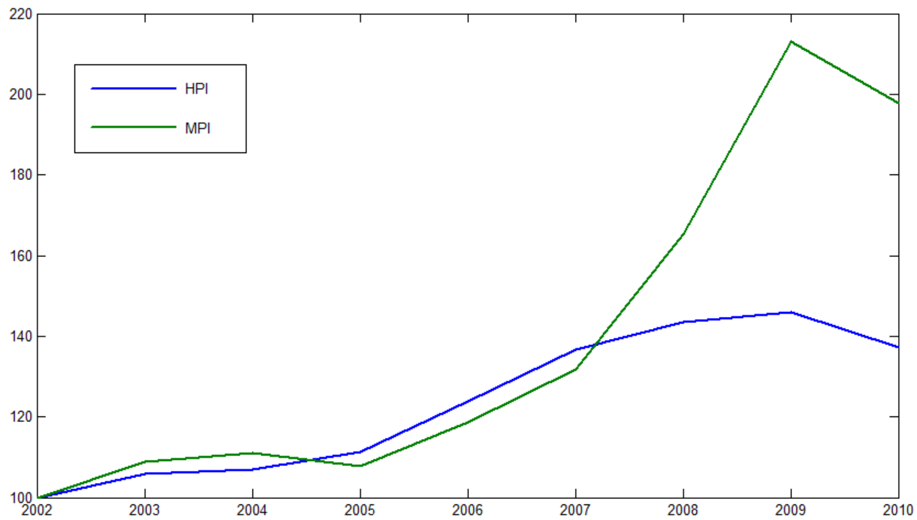

Figure 2.5 HPI vs. MPI. 2002-2010

Figure 2.6 displays the breakdown on supply purchasing costs for NUHI in 2010[1]. The total purchasing cost for NUHI was 6,2 billion ISK or around 20% of NUHIs total operating costs. Drugs and medicine and general medical supplies account for the vast

[1] The figure does not include S-labeled drugs. Since 2009 S-labaled drugs are not counted as expense for NUHI although NUHI does control the purchasing policy for them.

majority of the purchasing cost as shown in the figure. The supplies which go through the central storeroom account for around 735 million ISK, approximately 12% of the total purchasing costs. The central storeroom manages supplies in most categories shown in the figure below.

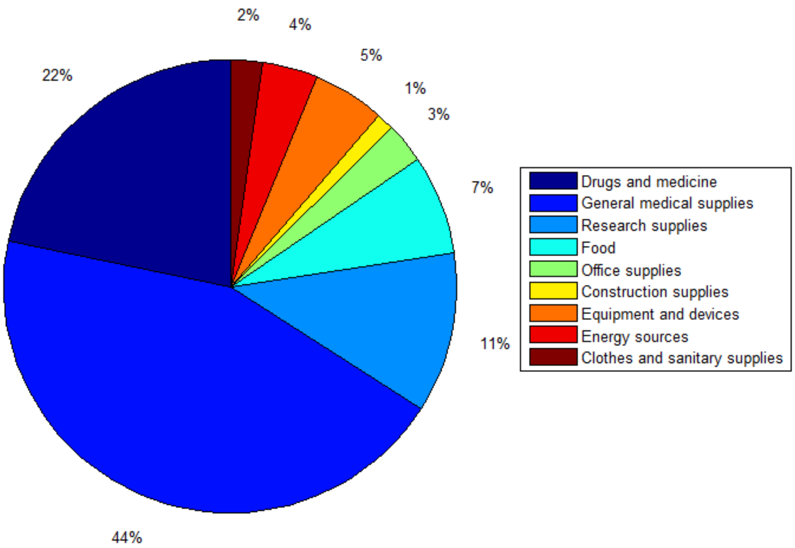

Figure 2.6 A breakdown on supply purchasing cost for NUH

It is clear that in the current economic environment it is critical for an organization such as NUHI to minimize expenses such as on inventory management. NUHI adopted a new supply chain system in 2004 to try and make its supply chain more efficient. Comparison on the CPI, HPI and MPI indicates that perhaps the new system is not performing as well as hoped for. However, data on other inventory related costs was not available and it should be noted that purchasing costs alone are not a good evaluation on how a supply chain system performs.

After all NUHI is not allowed to deny patients service and since the overall service required from NUHI has increased the past years supply usage is bound to follow suit. Without data on inventory related costs other than purchasing costs a conclusive evaluation on the new systems performance is not at hand.

Even though the central storeroom doesn't handle drugs and medicine, the second biggest category in figure 2.6, it does manage a broad selection of supplies. As a result the central storeroom is perhaps a good place to evaluate potential inventory policies that NUHI could benefit from adopting.

3 Literature review

The following chapter will put forward a literature review which introduces, discusses and compares the production control systems (PCS) under consideration and the tools used to carry out the inventory simulator presented in chapter 5. Although PCSs are originally intended for manufacturing and production they are frequently used for inventory and purchasing management. The application, pros and cons for each PCS are discussed through theoretical and case studies relevant to this study.

3.1 Inventory management

Inventory is one of the more visible aspects of any business. Raw materials, work in progress and finished goods all represent various forms of inventory. Inventory represents money tied up until it leaves the company as purchased product. Generally, an inventory is supposed to be kept at low level.

The motives for building inventories vary and consequently affect their character. The motives originate from the need for high functional guarantee and the customer needs to have access to products whenever they need them. The existence of an inventory can however be a sign that an operation is not stable. An integral part of the Japanese production philosophy is to remove all excess inventory, thus being able to reveal problems in the manufacturing process that were previously hidden (see section 3.2). Therefore in order to efficiently keep and manage the inventory, the motives behind it must be clear. Lumsden (2006) categories the motives behind keeping inventory into three main groups;

- Inventories due to process. One of the more important reasons for keeping inventory is to secure that the manufacturing processes between the arrival and shipping of goods is relieved from disruptions due to shortage of material.

- Inventories due to functions. Another way to define the motives behind the inventory is to start from its function within the company. It can be related to conditions that the company controls as well as conditions outside the company's main activities.

- Inventory in the flow. The third way to label the inventory is based on the manufacturing flow design. From this point of view one can follow the article flow through waiting before the process, waiting in the process, and waiting for transportation.

(Lumsden 2006)

Inventory management is the process of efficiently overseeing the constant flow of units into and out of an existing inventory or stock room. It involves balancing the costs of keeping inventory with the benefits of inventory. Inventory management can be split into two main segments, lot sizing and inventory layout. The former has to do with managing inventory levels. That is determining what points in time a particular item should be ordered and in what quantity. In other words, keeping inventory levels low enough in order to minimize money tied up in inventory and costs associated with keeping inventory, and high enough to meet the demand. There exist countless lot-sizing techniques and algorithms that take into account various constraints such as the item demand distribution, ordering costs, stockout costs, decay, size restrictions and criticality. Five selected lot sizing techniques will be discussed in the coming sections.

The latter has to do with determining the physical organization of a production system. The inventory layout is concerned with finding the most efficient arrangement of m groups of items (departments) with unequal area requirements within a facility. The objective of the inventory layout problem is to minimize the material handling costs inside a facility subject to two sets of constraints: 1. Department and floor area requirements and 2. department locational restrictions. The material handling cost is typically approximated with one or more of the following paramaters: interdepartmental flows, f_{ij} (the flow from department i to department j); unit cost values, c_{ij} (the cost to move one unit load one distance unit from i to j); and department closeness rating between, r_{ij} (the numerical value of a closeness rating between departments i and j) (Meller & Gau 1996).

Inventory management in healthcare is in essence no different from the traditional inventory management in production. It has to do with minimizing inventory related costs thus allowing resources in the form of money to be used in other areas. However, the nature of the hospital industry dictates that the motivation behind keeping inventory is making sure that disruptions and variations in demand do not cause shortages. Stocked items are generally not components or raw material which is then used in a value adding process but resources used to apply medical care on patients. As a result a better-safe-than-sorry approach to inventory control is often the case.

3.2 Toyota Production System

In 1973 an oil crisis, followed by a recession hit business and society all around the world. In 1974 Japan’s economy collapsed to a state of zero growth and companies all over the country were suffering. Toyota Motor Company (TMC) was one of the companies feeling the effects from the recession, however in the following years 1975-1977 a clear gap between Toyota’s profits and other companies’ profits was apparent. The reason for this gap was Toyota’s Production System (TPS). TPS was developed following World War II when excess inventories were a luxury that Japanese companies could not afford. Furthermore the productivity ratio between Japanese and American work forces was 1-to-9. TMC president, Toyoda Kiichiro felt that surely Japanese people were wasting something. He figured that by eliminating waste, productivity should rise by a factor of ten. This marked the start of the present TPS (Ohno 1988).

Spear & Bowen (1999) wrote an excellent article on how and why the TPS is so successful. After studying over 40 plants in the US, Europe and Japan during a 4 year period they found that the TPS could be broken down into four principal rules. In summary the four rules are;

1. All work shall be highly specified as to content, sequence, timing, and outcome.

2. Every custumer-supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses.

3. The pathway for every product and service must be simple and direct.

4. Any improvement must be made in accordance with the scientific method under the guidance of a teacher, at the lowest possible level in the organization.

(Spear & Bowen 1999)

The first rule implies that every activity that a worker or a machine undertakes is broken down into tasks and each task is specified to the tiniest detail. “When a car's seat is installed, for instance, the bolts are always tightened in the same order, the time it takes to turn each bolt is specified, and so is the torque to which the bolt should be tightened” (Spear & Bowen 1999). This rule is applied to all activities of people within the company, regardless of their hierarchical role. Even complex and rare activities such as shifting equipment within a manufacturing plant or launching a new model are subjected to this rule. By implementing this rule accurately, anomalies in any task or activity are detected and corrected immediately, thus reducing defected products and improving product quality.

The term Jidoka is used at Toyota and means “to make the equipment or operation stop whenever an abnormal or defective condition arises”. When a defect or an anomaly is detected during a task or activity and can’t be rectified during the tasks time span, the entire production line might be stopped. Jidoka is very important to TPS the reasons being two-fold. Firstly when the line stops it prevents other stations from manufacturing too much and secondly it ensures that rectifying the defect or anomaly is as easy as possible (Sugimori et al. 1977).

The second rule explains how people within the company connect with one another. The rule states that every connection must be standardized and direct, the form and quantity of the goods or services will be met in the expected time by the expected people. As a result, there are no gray zones in deciding who provides what to whom and when. The link between custumer and supplier within Toyota is kanban, cards that indicate a pre-defined request. The Kanban system is exploited further in section 3.3.

This rule also helps with improving product quality as workers and other members of staff are instructed to report any problems immediately to their supervisor. This prevents anyone to arbitrarily decide when the problem is big enough to justify a call for help, thus preventing problems to mount up and get solved much later when the cost could be much higher and the root of the problem unclear.

The third rule explains how the production line is constructed. The rule dictates that when work-in-progress flows through workstations in a production line the path it follows should not change unless the production line as a whole is redesigned. “To get a concrete idea of what that means, let's return to our seat installer. If he needs more plastic bolt covers, he orders them from the specific material handler responsible for providing him with bolt covers. That designated supplier makes requests to his own designated supplier at the off-line store in the factory who, in turn, makes requests directly to his designated supplier at the bolt cover factory's shipping dock. In this way, the production line links each person who contributes to the production and delivery of the product, from the Toyota factory, through the molding company, to even the plastic pellet manufacturer" (Spear & Bowen 1999). This rule also applies to the services and requests. That is the pathway for assistance is a clear chain with specific links from the worker to the plant manager.

These three rules might seem very strict and intolerant of any independent thought from the production line workers. The reason for these strict and unambiguous ways to manufacture is simple. By defining every step and break down the execution procedure the TPS performs an experiment every time an activity or task is performed. If the experiment results in a problem or an anomaly Toyota sees that as an opportunity to improve.

That brings up the fourth and final rule. Toyota encourages and expects workers at any level to improve their workstations. Improvements however must be made under the guidance of a teacher and using a scientific method. The teacher guides and trains the worker to frame problems better and to formulate and test hypotheses. It is critical that workers on any level and their supervisors realize that how they made changes was as important as what changes they made. This rule is the reason why two plants who manufacture essentially the same thing, for example might have a different production or organizational structure. The plants suffer different problems, thus come up with different solutions and therefore develop differently. The rule also helps the company to fully utilize its workers abilities instead of letting them go to waste.

Spear & Bowen believe that the reason for many companies inability to adopt the TPS is that they fail to grasp the idea and philosophy behind the production system. For example the TPS is constantly evolving with little improvements being made at every level. For example while some companies see the Kanban system as an integral part of TPS, Toyota doesn't. They only see the Kanban system as countermeasure until a better approach is found. By implying that something is a solution is saying that a better approach to a problem can't be found.

3.3 Just-in-Time, Kanban and Lean Management

Just-in-Time (JIT) and Lean Management are common production management terms used today. Some see them as synonyms for essentially the same thing. However, that is not strictly true. Although both JIT and Lean track their roots to TPS, in recent years lean manufacturing has come to encompass more than JIT. Today JIT is usually viewed just as a manufacturing tactic whereas lean manufacturing is a management strategy that is applicable to all organizations because it has to do with improving processes.

The term Lean Manufacturing was created in the USA by scholars trying to explain the TPS. Lean dictates that leaders in any organization must eliminate waste (or muda in Japanese) thus maximizing value. All organizations are composed of a series of processes to create value or reach its goals. To eliminate waste each process must be broken down into steps where value-adding steps are distinguished from non-value-adding steps. "In a perfect process, every step is valuable (creates value for the customer), capable (produces a good result every time), available (produces the desired output, not just the desired quality, every time), adequate (does not cause delay), flexible, and linked by continuous flow. Failure in any of these dimensions produces some type of waste" (Miller et al. 2005). Lean manufacturing is essentially a way to implement the TPS philosophy to any organization, not necessarily manufacturing firms.

As mentioned earlier JIT is today viewed as a manufacturing tactic, i.e. a way to move material and components through a manufacturing process and controlling inventory. “Most authors agree that the objectives of just-in-time (JIT) are to eliminate waste and to improve the flow of materials, so value is added throughout the transformation process. Once this is achieved, costs can be reduced, quality improved and the firm becomes more flexible: in short, JIT implementation, according to its supporters, results in competitive advantage“ (Waters-Fuller 1995). Sugimori et al. (1977) defines JIT as a production method where “all processes produce the necessary parts at the necessary time and have on hand only the minimum stock necessary to hold the processes together“. Today JIT is classified as a pull manufacturing system. Pull manufacturing systems are discussed in section 3.3.1.

The Kanban system was developed by Toyota as a visual way to implement JIT. The mechanics of Kanban are discussed in chapter 3.3.2. Kanban is NUHIs current method of choice for controlling inventory and since NUHI are not in the manufacturing business their implementation of JIT only involves the practice regarding purchasing. Waters-Fuller (1995) notes that most authors agree with the major JIT purchasing activities presented by Ansari and Modarress in 1988, some of which are;

- Small purchase lot sizes, delivered in exact quantities compared to traditional large batch delivery within 5 per cent volume either way
- Few suppliers, ideally one per component
- Supplier selection should take into account quality and delivery performance as well as price, rather than solely on price
- Quality inspection is performed at the supplier’s facility
- No annual rebidding compared to traditional frequent retendering

(Ansari & Modarress 1988)

Lean manufacturing and JIT are frequently used together to shape an organizations manufacturing and management policy and many success stories can be found on this matter. The use and application of lean will be discussed in section 3.5 but the remainder of section 3.3 will focus on JIT and Kanban in particular.

3.3.1 Pull Manufacturing

There are two fundamental philosophies for moving material through a manufacturing process, pull and push. The nature of push manufacturing systems will be discussed in section 3.4. Pull systems can be described in a sentence as systems where items are moved from one level to the next only when required. In a pull production system inventory is reduced and work in progress and the need for raw materials are comparable to the demand for the product. Figure 3.1 describes how a pull production works in principle. Each job in the pull system is withdrawn by its succeeding value adding work station from its current workstation. In other words, the job is pulled by the successive workstation to the end of the production line (Sendil Kumar & Panneerselvam 2006).

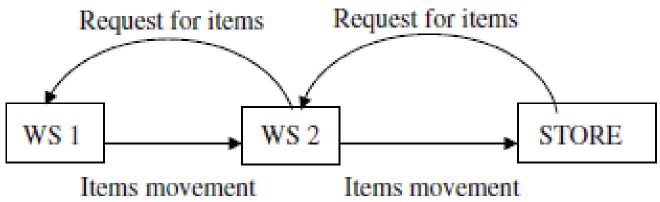

Figure 3.1 A schematic view of a pull production system with two value adding work stations and a store (Sendil Kumar & Panneerselvam 2006)

3.3.2 Mechanics of Kanban

The word kanban is Japanese for card or ticket. In the Kanban system tickets are used as a visual way to control the flow of items or material through a production line or in the case of NUHI, internal supply chain. In practice there are two main varieties of Kanban, a single card system and a two-card system. A Kanban system that operates in the single card system is sometimes referred to as a Production Order Kanban (POK) (Berkley 1992; Sharadapriyadarshini & Chandrasekharan 1997).

In both the single card system and the two-card system each workstation has an inbound buffer and an outbound buffer. The two-card system is used where workstations (WS) are not located close to each other so that each workstation has to have separate inbound and outbound buffers. NUHI uses a single card Kanban system and therefore will the single card system be exploited further.

The process for both single-card and two-card Kanban systems is in essence the same. The single-card system is used where WS_j and WS_{j+1} (see figure 3.2) are located close enough to each other so a single buffer mode is made available. In that case the input buffer for WS_{j+1} and the output buffer for WS_j are combined to create a single buffer. Figure 3.2 shows a schematic diagram of the single-card Kanban system.

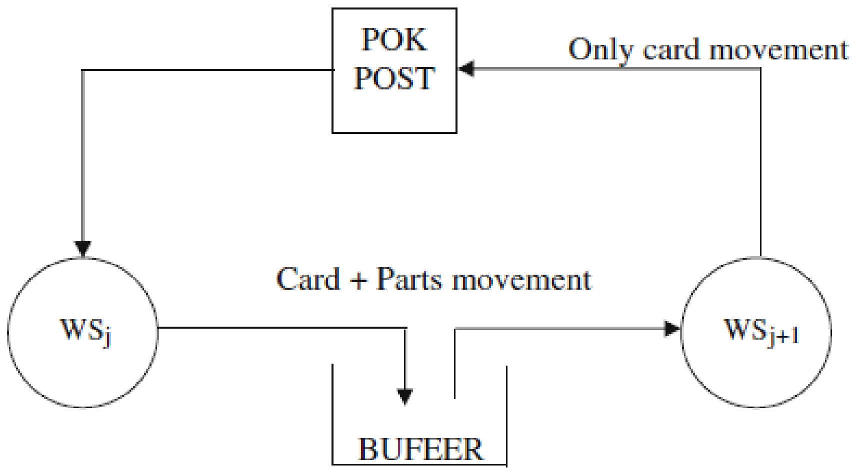

Figure 3.2 A schematic diagram of the single-card Kanban system (Sendil Kumar & Panneerselvam 2006)

When items stored in the buffer are required by WS_{j+1} for production, the POKs are detached from the items and placed at the POK post. When the POKs at the POK post reach a predetermined level, WS_j produces the number of items required. The POKs are consequently removed from the POK post and attached to the items before they are transferred to the buffer and the circle is complete.

The process for a single card Kanban system follows these steps;

1. When the number of tickets reaches a predetermined level at the POK post for WS_{j+1}, a worker takes these tickets along with a container from WS_{j+1} to the preceding WS_j workstation.

2. The preceding workstation WS_j consequently begins production on the items requested by the POKs.

3. When workstation WS_j has completed production on the items requested, a worker places the items in the container and transports the container along with the POKs to the buffer.

4. Repeat the process

The formula used to determine the number of Kanban tickets to be used within the system is called the Toyota formula (Berkley 1992; Nahmias 2009a). The formula was developed by Toyota Motor Company and is used today in their Kanban system. The Toyota formula is presented below.

$$K \geq \frac{DL(1+\alpha)}{C}$$

Where,

K = Number of Kanbans

D = Expected demand per unit time

L = Lead time

α = The safety factor

C = Container capacity

According to these literatures the lead time includes processing time, waiting time between processes, conveyance time and kanban collecting time. The safety factor determines the safety stock, sometimes referred to as buffer stock. The literatures mention that the values of α and C should be limited to the maximum of 10% of the expected demand. The ideal value for α is of course zero but in reality this would be difficult to obtain as the production line had to be perfectly balanced.

The formula implies that the maximum level of inventory is given by $KC \geq DL(1+\alpha)$. So when the value of K increases the stock of the parts also increases thus creating idle stock. Similarly, when the value of K decreases the stock of the parts decrease thus creating shortage. So to find the optimum amount of kanbans in the system, a trade-off between the above parameters is applied.

3.4 MRP systems

The output of any production system is the end product. The input of these systems is raw materials and components. The input is used in value adding operations to create the output. It is important to bear in mind that the end items, raw materials and components are defined in a relative sense. Hence an end item for one portion of a company may be raw materials for another. An entire manufacturing or production operation can therefore be seen as a composition of many production systems.

The master production schedule (MPS) is a specification of the exact amounts and timings of each of the end items in a productive system. The MPS is then broken down into a detailed schedule of production for each of the components that comprise an end item. The MPS is created with regard to firm custumer orders, forecasts on future demand and safety stock requirements. The materials requirements planning (MRP) systems are simply tools to accomplish the MPS as effectively as possible. Other inputs generally required for MRP systems are; bills of materials, on hand inventory and lead times. The output of MRP systems are requirements for raw materials and a detailed manufacturing schedule (Nahmias 2009b; Orlicky & Plossl 1994), see figure 3.3.

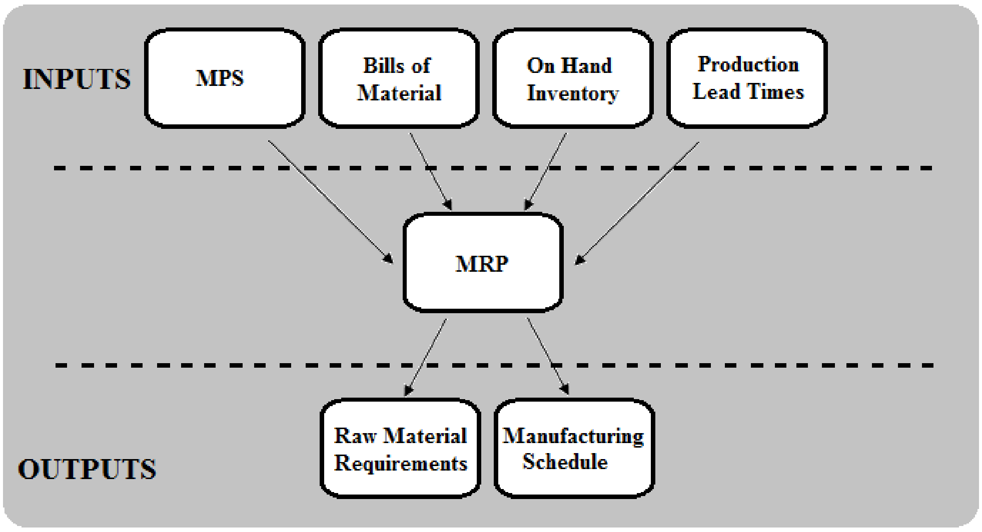

Figure 3.3 Schematic view of MRP systems

The major drawback with MRP systems is the integrity of the output data. MRP systems rely on forecasts and custumer orders through the MPS. Hence if the input data, MPS, turns out to be inaccurate then the output data is likely to be inaccurate as well, with additional manufacturing costs. Another drawback of MRP is that it does not take capacity restrictions into account in its calculations. However this is largely dealt with in material resource planning (MRPII) systems, computer based planning and scheduling systems.

There are almost countless different methods and variations that classify as MRP systems, three of which are under consideration in this study. The methods were chosen after reviewing reports and other literature, as well after suggestions from the thesis advisors. The three methods chosen are;

- Economic Order Quantity (EOQ)
- Silver Meal Heuristic (SM)
- Least Unit Cost (LUC)

In addition, s,S policies such as the one currently used at the central storeroom are discussed. In some cases the EOQ is not classified as a MRP system but a re-order point (ROP) system. Indeed EOQ was originally developed by Ford W. Harris in 1913 while MRP was originally developed by Joseph Orlacky in the 1960's. The principal difference is that ROP systems do not take into account the bills of material explosion calculus. Instead the depletion in the supply for each component or raw material is monitored and a replenishment order is released whenever an issue the supply to a predetermined quantity, ignoring its use in the assembly. This is irrelevant to this study since no items stored at NUHI's central storeroom require bills of material explosion calculus, and in any case ROP systems can easily be modified to take the bills of material into account.

3.4.1 Push Manufacturing

As mentioned in section 3.3 there are two fundamental philosophies for moving material through a manufacturing process, pull and push. Push manufacturing systems are older and a more traditional way of controlling a manufacturing process than pull systems. Although pull systems are starting to overcome push systems in popularity, the latter has still a lot to offer. This topic will be further explored in section 3.5.

A push manufacturing system is one in which production planning is done for all levels in the manufacturing process in advance. Figure 3.4 displays a schematic representation of a push manufacturing system. In push manufacturing system each workstation (WS_1 through WS_n in the figure) carries out its value adding operation and pushes the product on to the next workstation, regardless of the status of the succeeding workstation (Leiberman & Hillier 2005; Nahmias 2009b; Sendil Kumar & Panneerselvam 2006).

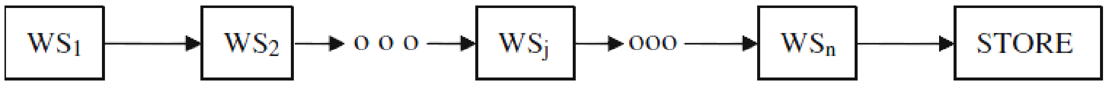

Figure 3.4 A schematic view of a push manufacturing system (Sendil Kumar & Panneerselvam 2006)

3.4.2 Economic Order Quantity

The Economic Order Quantity (sometimes referred to as the Wilson formula) is the level of inventory that minimizes total inventory holding costs and ordering costs. The model was developed by Ford W. Harris in 1913, but R. H. Wilson, a consultant who applied it extensively, is given credit for his in-depth analysis (Hax & Candea 1984). It is one of the oldest classical production scheduling models available, however it captures the essence of the problems faced by inventory management and is still widely used today.

The model determines the optimal number of units to order so that total costs associated with the purchase, delivery and storage are kept as low as possible for each item. The model describes the important trade-off between fixed order costs and holding costs. Furthermore the method determines the optimal point to order such that a stockout will not occur, called the re-order point. Just like in any MRP method there are some assumptions made that are perhaps not applicable in the real world. The most basic EOQ model makes the following assumptions (Harris 1913; Albright & Winston 2007; Nahmias 2009b; Leiberman & Hillier 2005);

- The company orders a single product from a supplier.
- Orders can be placed at any time (continuous review).
- The demand rate is known and constant.
- Lead time is known and constant.
- Shortages are not permitted.
- The ordering cost and unit price are fixed, independent of the size of the order.
- The holding cost is proportional to the average amount of inventory on hand.

In his original paper Harris did not present the EOQ formula as it is best known today. He did however present a differential equation that is easily solved by a simple calculus. The other literature referenced above present the basic EOQ formula as;

$$Q = \sqrt{\frac{2K\lambda}{h}}$$

Where,

Q = The economic order quantity

K = Setup/Ordering cost

λ = Demand per unit time

h = Holding cost

The re-order point is given by;

$$R = \lambda\tau$$

Where τ is the order lead time.

Figure 3.5 illustrates how an inventory is managed by the EOQ formula. As portrayed in the figure the function that describes the stock levels, I(t) takes the saw tooth shape. This is due to the assumption made on the demand rate. When the inventory level reaches a certain point, an order for Q items is placed which arrives when the inventory reaches zero. In reality though, the demand is not a constant. As a result of that, stockouts can occur.

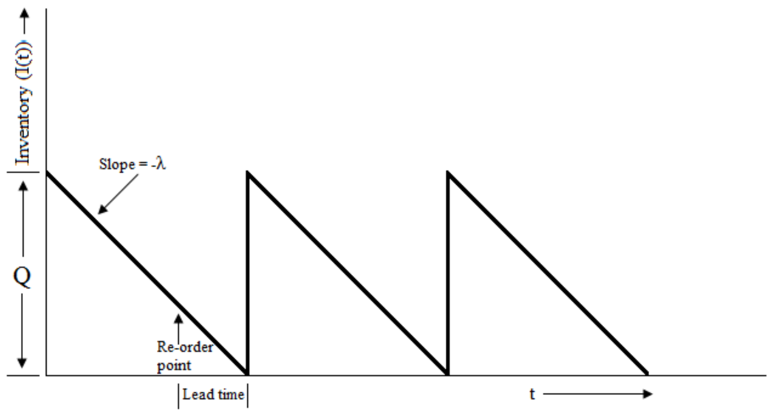

Figure 3.5 Inventory levels for the EOQ model

There exist several variations on the EOQ model that nullify some of the assumptions made in the basic model. Fazel et al. (1998) present an EOQ model that takes into account quantity discounts, thus nullifying the assumption that unit price is fixed. In his book, Production and Operations analysis (2009) Nahmias presents an algorithm to determine the order up-to point and the re-order point for items with uncertain normally distributed demand. The assumption that demand is known and constant is therefore nullified. Since only few of the items observed in this study have normally distributed demand this method was not an option. It should be noted that a search for a method in a similar mold that suited items which follow other distributions was not successful.

In some cases it might be in the organizations best interest to allow shortages. This might be the case in environments where the penalty for shortage is not too large. In the basic EOQ model this is not allowed. Albright and Winston present in their book (2007) an EOQ model where backlogging is accounted for. The method balances ordering and holding costs with penalty costs basically by moving the re-order point closer to the bottom of the saw tooth.

The EOQ model chosen for this study is in essence the basic EOQ model. However since a high inventory service level is required at NUHI replenishment orders are placed in the event of shortages. The model used in this study will be discussed in section 5.

3.4.3 s,S Inventory model

It was mentioned in section 2.3 that unlike other stock rooms at NUHI, the central storeroom controls its inventory level with a s,S policy. Under a s,S inventory policy, the points in time when a replenishment order is placed, is triggered through a re-order point, s. The order quantity however is a function of the inventory development over time, unlike in the EOQ model where the order quantity is a fixed number.

With the assumptions that the demand rate is known and constant, the lead time is known and constant and orders can be placed at any time (continuous review) the s,S policy is identical to a R,Q policy like the EOQ model. The principal difference in how the s,S and EOQ manage inventory can be seen when the first assumption is taken out of the equation, that is when the demand is stochastic. This is illustrated in figure 3.6. In the figure the same demand stream is managed by EOQ (left) and a s,S policy (right). As seen in the figure the order quantity varies in the s,S-policy as the order quantity is determined by a desired inventory level, S.

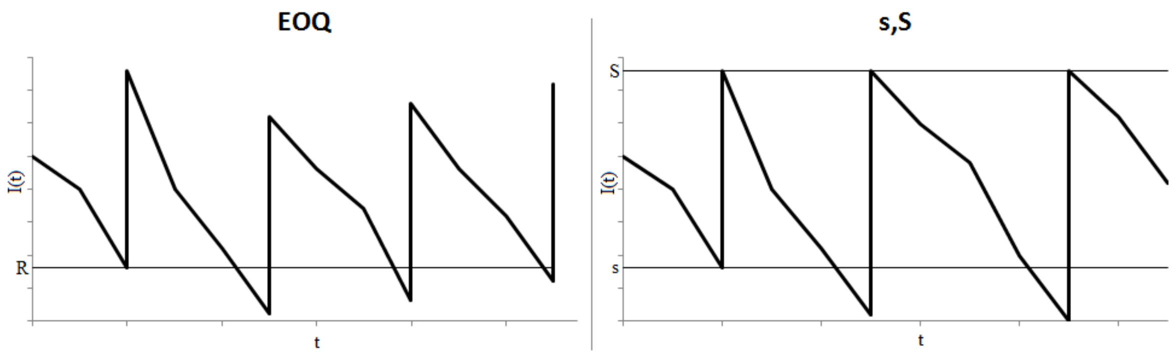

Figure 3.6 Order quantity varies when using a s,S policy (right) but is constant in the EOQ model (left)

Calculating the optimal (s,S) values is not as straightforward as calculating the (R,Q) values in the EOQ model. Nahmias (2009a) points out that determining the (s,S) values is extremely difficult, and for that reason few real operating systems use optimal (s,S) values. Silver et al. (1998) concur with Nahmias and note that the computational effort to find the best (s,S) values is substantial and as a result the (R,Q) policy may be the better choice, except perhaps when dealing with A-items (see ABC-analysis in section 3.8) (Silver et al. 1998). Nahmias also mentions that a common approximation of the (s,S) values is made by calculating the (R,Q) values as defined by the EOQ model, and set $s = R$ and $S = R + Q$.

In order to obtain (s,S) values closer to the optimal values, stochastic dynamic programming must be applied on algorithms that take into account the demand distribution, lead time variation, manufacturing restrictions, product decay and so on. These algorithms can be quite complicated and will not be discussed at length here. Iyer and Schrage (1992) do however summarize the classical approach to deriving operating s,S policies as follows;

1. Given a data set (e.g., a stream of demands), and a class of policies (e.g., any order point, order-up-to inventory policy)

2. Specify a distribution model to summarize the data

3. Fit a distribution model to the data, using some criterion such as least squares or maximum likelihood

4. From the class of policies, select the one which minimizes expected cost relative to the distribution fitted in (3).

(Iyer & Schrage 1992)

3.4.4 Silver Meal Heuristic

The Silver-Meal heuristic method was first described by Harlan Meal and Edward Silver in 1973. In order to use the method a requirement plan or forecast for the coming review periods is required. The first step when using the method is to determine the average cost per period as a function of the number of periods the current order is stop with the following formula;

$$C(j) = (K + hr_2 + 2hr_3 + \cdots + (j-1)hr_j)/j$$

(Nahmias 2009a; Silver & Meal 1973)

Where,

C(j) = Average setup and holding cost for the next j periods

K = Setup cost/Ordering cost

h = Holding cost

r_j = Expected demand for period j

j = Number of periods

Computation is stopped when the function above first increases, that is when the following conditions are met;

$$C(j) > C(j-1)$$

When the conditions are met an order is placed for $y = r_1 + r_2 + \cdots + r_{j-1}$ items. Consequently the process starts again in period j.

There are some variations existing on the SM method. Bergman and Silver (1993) present in their study a modified version on the SM method which takes into account purchasing discounts. They compare the method to other MRP known to work well in such environments. They note that “when flexibility of the method to operate in diverse environments and computational time are considered, the modified Silver-Meal heuristic may be the best procedure available“ (Bergman & Silver 1993).

Another variation on the method is presented by S.G. Johansen (1999) which includes the possibility of backlogging, whereas the original SM method excludes this option. In his SM method a replenishment order is placed if the net inventory is negative in the coming review period and if the replenishment order cost (determined by the SM formula) is less than the stock-out cost (Johansen 1999).

3.4.5 Least Unit Cost

The Silver-Meal Heuristic method minimizes the total cost per period by dividing the total cost over j periods by the number of periods, j. The Least Unit Cost heuristic (LUC) is an extended version of the SM method and works in a similar way. LUC minimizes the cost per unit of demand instead of the average cost per period. Just like when using the SM method a requirement plan or forecast for the coming review periods is required.

The method, which is one of the most commonly described methods in operations management textbooks has an advantage over SM where ordering costs are not constant as it can incorporate non-constant ordering costs (Tibben-Lembke 2002). The first step is to determine the average holding and setup cost per unit for a j-period order horizon with the following formula;

$$C(j) = (K + hr_1 + 2hr_2 + \cdots + (j-1)hr_j)/(r_1 + r_2 + \cdots + r_j)$$

(Nahmias 2009a; Tibben-Lembke 2002)

Where,

C(j) = Average holding and setup cost per unit for a j-period order horizon

K = Setup cost/Ordering cost

H = Holding cost

r_j = Expected demand for period j

Like in the SM method, computation is stopped when the function above first increases, or when the following conditions are met;

$$C(j) > C(j-1)$$

When the conditions are met an order is placed for $y = r_1 + r_2 + \cdots + r_{j-1}$ items. Consequently the process starts again in period j.

Earlier studies indicate that LUC performs best under conditions of low uncertainty (Christoph 1989), so good visibility within the supply chain and as a result accurate forecasting is required. A variation of the LUC method which takes purchasing discounts into account is presented by Benton & Whybark in their 1982 study. This variation is compared to several known MRP methods by Benton (1985) and Lee et al. (1993). Both studies show that LUC provides the best performance within the purchasing discount structure (Benton 1985; Lee et al. 1993).

A variation on LUC based on the SM variation presented by S.G. Johansen (1999) is used in this study. Like in his SM method a replenishment order is placed if the net inventory is negative in the coming review period and if the replenishment order cost (determined by the LUC formula) is less than the stock-out cost.

3.5 Comparing MRP and JIT/Kanban

There are of course many reports that discuss the pros and cons of MRP systems and JIT/Kanban. While searching through literature the thesis author picked out the literature most relevant to the thesis. The literature review begins with various theoretical studies on both MRP systems and JIT where they are compared and their pros and cons discussed. Finally a literature review on case studies within the health care industry is presented. The case studies presented all discuss the results on introducing either MRP systems or JIT/Lean to various hospital organizations.

3.5.1 Theoretical studies on MRP and JIT

Jin H. Im and Richard J. Shconberger discuss the characteristics and limitations of Kanban compared to traditional MRP methods in their journal article (1988). “The planning mechanism in kanban is similar to that in MRP; only independent demand is forecasted, while dependent demand is calculated based on the forecast through demand explosion, just as in MRP” (Im & Schonberger 1988). They state that one of Kanbans advantages is that it is only necessary to explode one day’s requirements for a month because it is the same for all days in the month and thus can be done manually. For MRP systems this is nearly impossible since time-phased explosion has to be made separately for each day.

Analogous to other literature (Nahmias 2009a; Fazel et al. 1998; Krajewski et al. 1987; Leiberman & Hillier 2005) they state Kanban is indeed a more flexible production system than MRP systems. They say that this is due to the fact the true flexibility of a manufacturing system has to be measured on the basis of a reaction time, which represents the total time from receiving a new order to finishing the order, an area where kanban is far superior to MRP systems. They do however concur with the other literature that ideal environment for kanban is a level, regularized production schedule where demand variations are no more than 10% from the predetermined daily production schedule. Thus concluding that kanban is a good technique for repetitive production, while MRP is usually better for a job shop.

Søren Glud Johansen performed a study (1999) where some well known lot sizing techniques are investigated by simulation. The lot-sizing techniques under consideration were; two Stochastic Dynamic Programming (SDP) techniques (s,S policies), the Silver Meal Heuristic method, Least expected period cost (Askin) and two Deterministic Dynamic Programming (DDP) methods. The focus of the study was to observe how the lot-sizing techniques in question behaved with regard to demand uncertainty and with change in setup costs. It should be noted that the term demand uncertainty refers to when the demand becomes firm (known) not how the demand evolves from period to period.

When simulating, the backorder cost (stockout cost) and holding cost were based on the ending net stock in each period, however these two cost entities remained constant per unit in every simulation. Unit ordering cost was eliminated from the decision process. Lead time was constant, one period, for every simulation. The only variables were demand uncertainty and setup costs. The simulation results were that when demand uncertainty was low DDP returned the lowest inventory costs but when the demand uncertainty was high SDP performed the best (Johansen 1999). Table 3.1 displays Johansen's simulation results for an inventory with parameters like the inventory at NUHI's central storeroom, high demand uncertainty and short lead time. The first number in each column (K is setup cost) represents the total inventory costs for each method. It is obvious when K increases the SM method performs very well compared to the SDP methods.

Table 3.1 Simulation results from Johansen's study for high demand uncertainty (Johansen 1999)

	$K = 5$	$K = 10$	$K = 100$
SDP1 (exact)	3.118	4.429	14.065
SDP1 (simul.)	3.124 0.008 4764	4.445 0.012 3374	14.103 0.035 1062
SDP2 (simul.)	3.124 0.008 4764	4.445 0.012 3374	14.103 0.035 1062
Askin (simul.)	4.232 0.022 7500	5.898 0.040 3750	16.723 0.116 1154
SM (simul.)	3.160 0.009 5670	4.520 0.013 4104	14.110 0.033 1096
DDP1 (simul.)	3.164 0.009 5691	4.520 0.013 4104	14.176 0.035 1182
DDP2 (simul.)	3.160 0.009 5667	4.444 0.011 3231	14.112 0.033 1096

In the wake of Kanbans increasing popularity amongst U.S. manufacturers in the 80's, Lee J. Krajewski et al. did a study where Kanban was compared to several MRP methods using a manufacturing simulator. Both re-order point (ROP) methods and periodic review methods are compared to Kanban. The process of acquiring data for the study began by sending a detailed questionnaire to several manufacturing managers on what they thought to be the most significant factor to their respective manufacturing control systems. The questionnaire resulted in seven main factors. The simulation results indicated that inventory performance turned out to be one of the most significant factors, for both Kanban and MRP systems (Krajewski et al. 1987).

Each of the seven factors were given one ideal setting and one bad setting, several simulations were made with many settings combinations. The results of the simulation told the authors that Kanban performed better than periodic review MRP systems, however ROP systems performed just as well and sometimes better. "The conclusion is inescapable. The reason why kanban appears attractive is not the system itself. A reorder point system does just as well. The kanban system is merely a convenient way to implement a small lot strategy" (Krajewski et al. 1987). The authors also note that Kanban is sensitive to several factors. Low worker flexibility, high equipment failure rates and variation in demand are examples of such factors. They note that ROP systems are more flexible in that regard.

A comparison between JIT and the EOQ method was made by Farzane Fazel et al. (1998) with a slightly different approach. They developed a mathematical model that calculates the indifference point between the two systems. The indifference point is analyzed with various settings for parameters relevant to inventory purchasing policies. Figure 3.7 displays the indifference curves for different discount rates. The curve relevant to NUHIs purchasing policy is the one with no discount, furthest to the right. "The area to the right and above the curve represents the region in which EOQ is the less costly alternative and the region below and to the left of the curve represents the area where JIT is the preferred method" (Fazel et al. 1998). The figure indicates that when the ordering cost (k) increases compared to unit cost (P_E) and delivery cost (P_J) JIT will become favorable for a wider demand range.

Figure 3.8 is from the same study and illustrates the cost difference between EOQ and JIT for a given set of parameters. It indicates that for low levels of annual demand JIT is the favorable policy but when the annual demand increases the EOQ method becomes a better option.

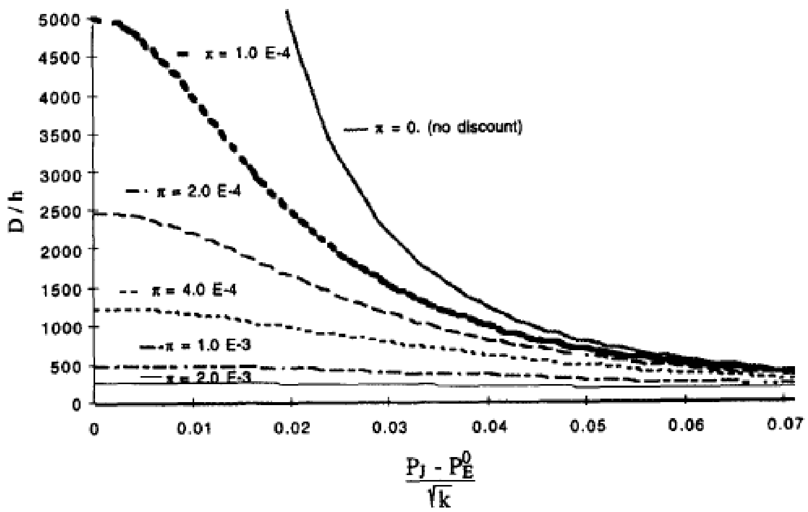

Figure 3.7 Indifference curves for different discount rates (Fazel et al. 1998)

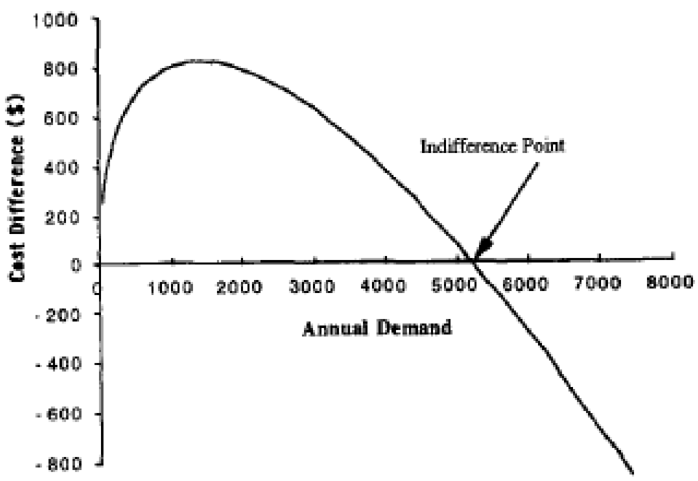

Figure 3.8 Cost difference between EOQ and JIT(Fazel et al. 1998)

The study concludes that the EOQ remains the better option for items with higher levels of annual demand. "Also, the lower the carrying cost, or the ordering cost associated with the EOQ model…the lower will be the point of indifference between JIT and EOQ" (Fazel et al. 1998). They suggest that since parameters vary from one product to the other, a combination of EOQ and JIT might prove to be the optimal solution.

3.5.2 MRP and JIT in healthcare – case studies

Derek T. DeScioli performed a case study in 2005 similar to this one. He created an inventory simulator based on daily demand data from two hospitals and used the simulator to compare four different inventory policies; 4-max policy, a base stock policy, an s,S inventory policy (the policy of choice for both hospitals) and EOQ. After simulating daily demand for inventories at 7 different wards within the hospitals he concluded that the optimal policy out of the four was the EOQ policy. It proved to be the most stable policy with an 99,8% service level while existing policies provided 98,6% service level. EOQ also reduced annual material management costs by 52% (DeScioli 2005).

He also concluded that the variations in the daily demand for the inventories at these two hospitals was severe and could be best described as intermittent. That is each stocked item has some periods with no demand at all and other periods with either small or large demand. DeScioli found that historically inventory policies were developed based on educated guesses and rules of thumb but together with automated point of use systems, the EOQ policy could counter these variations in demand. Furthermore supplies should be managed differently with regard to their criticality, annual cost and physical size and while "these distinctions seem obvious, they must be embedded into the supply chain policies and performance metrics".

Another case study which analyzes the inventory at a recently merged pediatric care center, South Texas Center for Pediatric Care (STC) illustrates the benefits of applying ABC-inventory analysis and the EOQ model to a multisite pediatric practice. After two independent pediatric care centers merged to become STC a cutback in supply costs was needed. An ABC analysis was performed which reflected that, unsurprisingly medical injectables or vaccines classified as A-items (ABC analysis is discussed in chapter 5.2) and accounted for an annual cost of $154,100 or 68,7% of the overall inventory costs (Burns et al. 2001).

STC applied the EOQ model only on the A-items which suggested that the optimal purchasing policy was ordering 25 lots of vaccines every 19 days. By implementing the policy suggested would result in a 30% reduction in inventory costs. The article also notes the flexibility represented by the EOQ formula, as an ordering cycle of 19 days was not feasible for STC. Table 3.2 displays the difference in cost between the ordering cycle suggested by the EOQ model and other feasible cycles that are close to the one suggested. The table shows that a feasible solution of a 14 day ordering cycle performs very good compared to the optimal solution.

Table 3.2 Vaccine inventory Policies for STC (Burns et al. 2001)

Inventory Policy	Quantity Ordered	Ordering Cost	Holding Cost	Cost of Policy
1 week	19	$1,774	$242	$2,016
2 weeks	38	887	484	1,371
EOQ (19 days)	52	648	662	1,310
4 weeks	76	444	968	1,412

There are several reports on successful implementations of JIT within the healthcare industry. The University of California, Los Angeles (UCLA), Medical center negotiated a deal with Owens & Minor, a medical supply distributor, to handle its JIT stockless program. The computer services at UCLA developed an electronic system so that medical employees could place an order directly to Owens & Minor. After a 3-year operating period UCLA reported 20,7% ($8,4 million) reduction in materiel expense over the period. A further $385.000 cost reduction per year was accomplished by implementing a total outsourced vendor based supply distribution system (North 1994).

Baxter Healthcare Corporation (BHC) in Deerfield, Illinois has a similar story to tell. BHC runs every kind of health care facility from big city hospitals to small rural clinics with nearly $9 billion in sales. BHC managed to improve supply-chain quality and create compelling economic value by integrating the ValueLink program. ValueLink is a stockless-JIT supply distribution service that provides a brand neutral material service by providing the product of choice necessary for its custumer. Two of the hospitals operated by BHC saved a combined $3,5 million in inventory reduction, $1,75 million in operating expense savings and just under 40.000 square feet in space savings by using the ValueLink program (Nathan & Trinkaus 1996). It should be noted that the article does not mention the time span for the reported savings.

The JIT-stockless inventory systems presented in the BHC and UCLA cases provide benefits to both the distributors and the two health care organizations. From the distributors stand point, under this program, the distributors have more visibility to the actual usage of the hospital and therefore suffer from less severe bull whip effect. The hospitals save money by reducing inventory costs, stock outs, labor costs and not to mention floor space. In some cases hospitals are able to convert store rooms into patient care units or even rent the space out.

There are also cases where JIT and Lean manufacturing was implemented with positive results. ThedaCare, Inc. based in Wisconsin and the Virginia Mason Medical Center (VMMC) are two examples of health care corporations that implanted not only JIT but Lean manufacturing as well. Over a two year period VMMC reported amongst other things a 53% reduction in inventory costs, 41% less floor space was needed and staff traveled 44% less distance. ThedaCare had similar success. In one year ThedaCare reported a $3,3 million savings in material handling, productivity increased significantly through time saved on paperwork, reduced patient waiting time and so forth.

These impressive results are a product of a complete change in the way management (and other employees) went about running the hospital. In both cases every minor process was reviewed and any non-value adding steps were eliminated, thus reducing waste. New strategic plans were developed to regain focus and set ambitious goals. Figure 3.9 displays the VMMC strategic plan pyramid. VMMC designed the system and its processes around the patients' needs, hence the patient is on the top of the pyramid. The pyramid also demonstrates VMMC vision on becoming the quality leader in health care and the methods used to reach these goals.

VMMC developed their own production system that was largely bases on TPS. Two things stand from their new system, "No-Layoff Policy" and "The Patient Safety Alert System". They found the No-Layoff Policy critical when implementing the new production system as it made their employee fully committed on the new system on engaging in improvement work rather than worry on improving themselves out of a job. This theory is backed by another paper about implanting a new production system[2], "people support was found to be crucial to achieving efficiency and coordination benefits" (Sum et al. 1995). The Patient Safety Alert System was developed to replicate the "stop the line system" at Toyota. The theory behind that system is that mistakes are not inevitable, but reversible and if you fix the mistake early enough your product will be without defects. At VMMC anyone can activate the safety alarm if they feel something is not right. The person who activates the alarm calls the patient safety department or other relevant managing staff and the appropriate actions are taken to access the situation and rectify any potential mistakes (Miller et al. 2005).

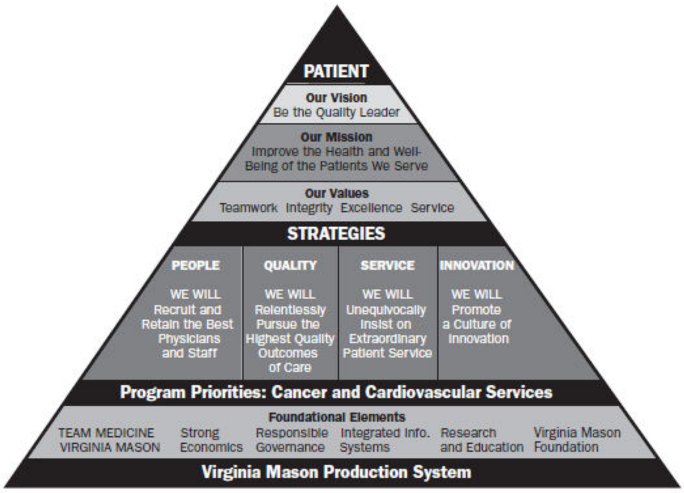

Figure 3.9 The Virginia Mason Medical Center strategic plan pyramid (Miller et al., 2005)

3.6 Automated Point of Use Systems

Automated Point of Use (APU) systems are a recent addition to hospital supply chain management. APU systems are devices that serve as automated supply cabinets. The devices are placed in the various wards throughout the hospital and only allow authorized users to pull inventory. Pull transactions are inputted directly on a computer attached to the device, thus keeping perpetual inventory records. The devices automatically place

[2]The system being implemented was an MRP system, not JIT.

replenishment orders based on the established re-order points and order quantity for each item. An example of an APU system can be seen in figure 3.10.

Figure 3.10 An APU system - OmniCell® (omnicell.com)

APU systems provide an effective inventory control system and allow for improved visibility into the entire hospital's inventory. That means a shortage in common supplies for one ward can be mitigated with excess inventory from another ward until the next replenishment arrives. It can also help with forecasting if the hospital has a storeroom, as is the case for NUHI. On the downside APU system are quite costly and slow down inventory deployment, as the users are required to identify themselves in order to pull supplies from the inventory.

In 1996 the Christ Hospital and Medical Center introduced APU systems to their newly built Hope Children's Hospital. The APU systems proved to be a instant success and today a total of 388 APU units are located around the hospital. In the first year the usage of APU systems resulted in 20% procedure savings. APU systems also proved reliable and accurate when assigning usage of supplies to patients, thus enabling accurate charging on patient care fees (Valestin 2001).

Duclos (1993) performed a study that contrary to the case study presented by Valestin (2001) demonstrated that point-of-use safety stock was much less effective than central store safety stock in preventing stock-outs. In his study, Duclos simulated emergency demand, a common characteristic in hospital demand. The study's conclusion are cause for concern and question the APU systems (Duclos 1993). However, Duclos did not account for the visibility between APU systems and the ability to utilize excess inventories where available.

3.7 Forecasting

Forecasting is an integral part in inventory management as well as in modeling. There are plenty of forecasting methods available and choosing the right one can be critical. The inventory simulator used in this study uses Croston's forecasting method for intermittent demand to create simulated demand data based on actual data provided by NUHI. The reason for why his method was chosen is discussed in chapter 5.

3.7.1 Forecasting with intermittent demand – Croston's method

J. D. Croston (1972) developed a forecasting method designed for stock items with intermittent demand and demonstrated its advantage over traditional forecasting methods such as exponential smoothing. Intermittent demand is described as an inventory pattern where there are some periods with no demand and some periods with either small or large demand. Figure 3.11 illustrates an item with demand best described as intermittent.

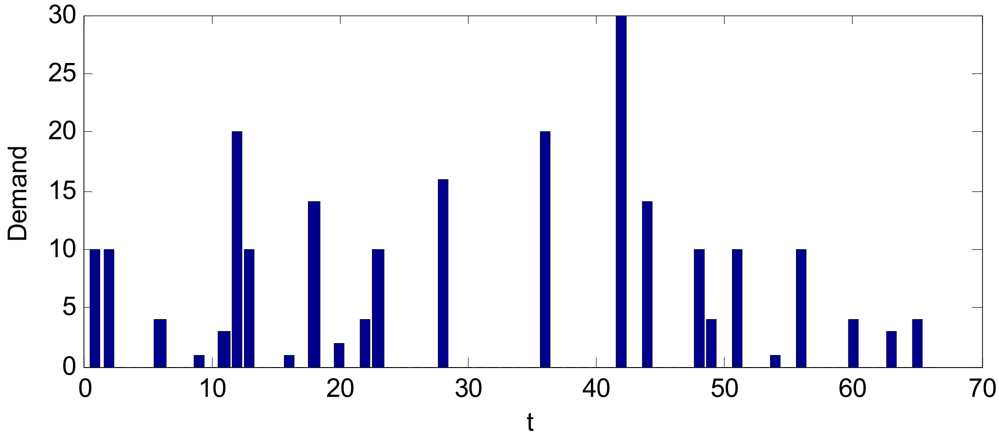

Figure 3.11 A stock item with intermittent demand

In his study, Croston showed that stocked items with intermittent demand could increase the stock replenishment levels and bias the estimates of average demand. "The improved system described makes separate estimates of demand size, and arrival of demand, thus eliminating the bias…It has the considerable advantage that the same forecasting system operates for intermittent and frequent demands as the system will behave in the standard way if a demand occurs every review interval" (Croston 1972).

In his paper, Croston presented several variations on his forecasting method, however his method for stochastic arrival and size of demand is used in this study and will be presented here. Croston's method segregates demand into two segments, the pick event itself and the quantity of each pick. The method dictates that the forecasted demand for next review period, *t*, is given by:

$$y_t = x_t \cdot z_t$$

where,

$$x_t = \begin{cases} 1, & prob(1/p) \\ 0, & prob(1-1/p) \end{cases}$$

with size of demand z_t following a predefined statistical distribution, where p is the average inter-arrival interval. The occurrence of a pick event p is therefore generated by a Bernoulli process with a constant probability $1/p$ that an order will be placed.

3.8 ABC analysis

While observing wealth distribution in the 19th century, economist Vilfredo Pareto noted that the vast majority of wealth was held by a small portion of the population. This Pareto effect is still with us today and is found elsewhere for example in multiproduct inventory systems. When products in such systems are ranked in a descending order of the dollar value of annual sales, the cumulative sales form a Pareto curve when plotted. This forms the basis of an ABC analysis a tool widely used in inventory management. The ABC analysis is also used for determining the importance of items with regard to annual costs, productivity and more.

The idea behind ABC analysis is that since products are unequally profitable to the organization their significance to the organization varies from one another. Therefore the inventory management system for these products should take into account their different significance and manage them differently. When performing ABC analysis one uses the Pareto curve to categorize the products into three (sometimes more) groups. Nahmias (2009) describes these groups as follows;

- A-items: Typically include the top 10-20 percent of all items and should account for about 70-80 percent of annual sales. These items are critically important and inventory levels should be monitored continuously. More sophisticated forecasting procedures might be carried out on these items and more care might be taken in the estimation of the various cost parameters required in calculating operating policies.

- B-items: Typically include 20-30 percent of the items in question and should account for 15-25 percent of annual sales. B-items are important to the organization, but of course less important than A-items. Inventory levels should be reviewed periodically and less sophisticated forecasting procedures might be used. Items could be ordered in groups rather than individually.

- C-items: Typically include the remaining 50-70 percent of all items and account for around 5-10 percent of annual sales. C-items are to be monitored at a minimum level. For very inexpensive C-items with moderate level of demand, large lot sizes are recommended to minimize the ordering frequency. For expensive C-items with very low demand, the best policy is to not hold any inventory.

The percentages mentioned above are not fixed thresholds for each class and can vary from one organization to the other, especially if the items in question are to be categorized into more than three groups.

3.9 Service level

The term service level generally refers to the probability that a demand is met. There are a number of different definitions of service, two of which will be discussed here. The two types of service are labeled type 1 (α) and type 2 (β), respectively. The former is an event-oriented service level. It measures the probability that all customer orders arriving within a given time interval will be completely delivered on time. A type 1 service level is appropriate when a shortage occurrence has the same consequence independent of its time or amount (Nahmias 2009b). Type 1 (α) service level is calculated by:

$$\alpha = 1 - \frac{\sum Orders\ fulfilled}{\sum Orders\ recieved}$$

Type 2 (β), sometimes referred to as fill rate, is a quantity-oriented service level, that measures the proportion of total demand which is delivered without delay from stock on hand (Nahmias 2009b). Type 2 service level is calculated with the following formula:

$$\beta = 1 - \frac{\sum Stockouts\ per\ review\ period}{\sum Demand\ per\ review\ period}$$

4 Methodology

The research presented in this paper is a case study in the field of operations management (OM). Case research has consistently been one of the most powerful research methods in operations management. “To cope with the growing frequency and magnitude of changes in technology and managerial methods, Operations Management (OM) researchers have been calling for greater employment of field-based research methods“ (Lewis 1998). Despite these calls Stuart et al. (2002) points out that the successful publication rate of such articles in top-tier journals has been less than stellar. “For example, Wacker (1998) assessed and classified the predominant research methodology of over 2000 OM articles published over the previous 5-year-period; only 8% of them were case based studies. A principal criticism from reviewers and associate editors is papers’’ lack of rigor in the case research process. (Stuart et al. 2002).

Stuart et al. (2002) present a five step case-based research model, see figure 4.1, and give guidance for each step in the process. A similar research model and guidance is given in Voss et al. (2002). These models and guidelines form the basis for methodology used in this case study.

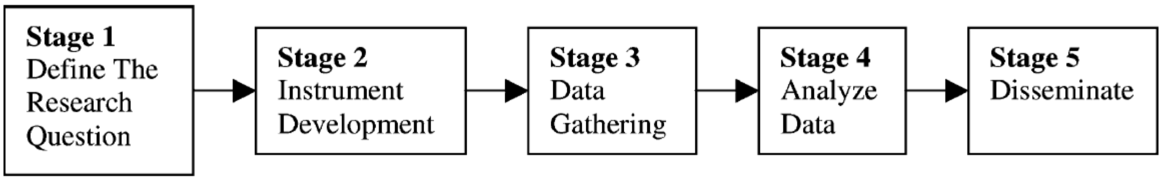

Figure 4.1 The five stage research model (Stuart et al. 2002)

The first stage involves defining the research question. Stuart et al. categorizes theories by their purpose. Each category considers the types of contribution to knowledge the proposed theory is likely to have and lays out some typical research questions for the given purpose. Stuart et al. presents six purpose categories one of which is theory extension/refinement, studies in this category typically expand the map of the theory. The main objective of this study is to investigate whether any of three selected MRP methods could reduce inventory and inventory related costs at NUHI’s central storeroom. Therefore the study presented here would fall under the category mentioned above and research questions were developed accordingly. The research question this study seeks to answer can be found in the introduction of this thesis.

Although it is important to keep focus on the original objective developing, modifying or abandoning the research questions when the research process is started is not uncommon (Voss et al. 2002). Indeed that was the case for this study. Originally the study was intended to compare a single MRP method to NUHIs current method of choice.

The second stage involves developing the study protocol and site selection. The literature suggests that the site selected for the case study must be likely to have easy access to any desired data. The site must consider the parameters that define the population being researched and truly represent the population. There are is no upper or lower limit on how many sites should be chosen. However with fewer sites the study is more likely to provide depth in the analysis but less external validity. As mentioned in chapter 2 there are many stock rooms located within the NUHI organization. Originally the idea was to gather data from three stock rooms but the focus turned to the central storeroom early on. The central storeroom manages supplies for the entire organization and has easily accessed data on the supply demand.

For most case-based OM studies interviews are an integral part of the process. When conducting this study no formal interviews where undertaken. However there were visits to the central storeroom and informal conversations with a few NUHI employees. Halldór Ólafur Sigurðsson, Purchasing Mgr. purchasing dept, Nanna Ólafsdóttir, central storeroom manager purchasing dept and Erlín Óskarsdóttir surgical ward manager at Hringbraut Hospital provided the author information through informal conversations. In those cases the date of the conversation was documented and the name of the interviewee also notes on key points were taken and documented. When data collected from visits and informal talks was used for writing this thesis, verification and feedback was acquired by running the report by the people in question.

The information gathered by these visits and informal discussion along with data provided by the central storeroom manager were used to analyze and model the current situation and to populate the proposed systems. In order to answer the research questions, an inventory simulator was created in Mathworks-Matlab using the data analysis as an input. The inventory simulator is used to determine how each policy under consideration performs with simulated daily demand for 60 months.

Gathering data is the third stage in the research model. Stuart et al. and Voss et al. both note that the data must be reliable and the methods chosen to gather the data should be consistent throughout the course of the research. "Such methods can include interviews, questionnaires, direct observations, content analysis of documents, and archival research"(Voss et al. 2002).

NUHI provided data in order to conduct an ABC analysis. A subset of 60 items were selected for further analysis. The central storeroom manager provided daily demand data for all desired items along with purchase costs and current re-order and order up-to points. Data on other inventory related costs was not available so estimations on these factors had to be made. These estimations are discussed in chapter 5. A number of official statistical documents and archival research regarding NUHI were sent to the author from NUHI. Other statistical data was acquired by going through the databases available on the official web pages for Statistics Iceland and DataMarket. Lastly a literature review was conducted to build on others shoulders and form a theoretical basis for the study.

The study protocol calls for documentation on how the literature review was conducted. The author searched for literature in known OM journals and Google Scholar with several key words. The journals chosen are all OM journals and contain material relevant to the thesis. However, the key words were in some cases tweaked if the literature found by the original key words presented a slightly different wording of some key phrases. In many cases the literature referenced in this thesis was found by conducting a backward reference search. The journals and key words used for the literature search procedure are as follows;

Journals

- International Journal of Operations & Production Management
- Hospital Materiel Management Quarterly
- Production and Inventory Management Journal
- Journal of Operations Management
- International Journal of Production Economics
- Production and Operations Management

- Key words
  - Inventory management, kanban, JIT, MRP, EOQ, LUC, SM, heuristic, s,S inventory policy, Wilson formula, short lead time, uncertain demand, health care supply chain, Toyota Production System, Lean manufacturing

The fourth stage involves analyzing the data gathered in the third step. "As reviewers for a variety of journals, the authors have noted three specific weaknesses in the data analysis section of case research paper submissions: the inability to extract significant patterns, the inability to simplify from descriptive information and the inability to think laterally" (Stuart et al. 2002). These common weaknesses were kept in mind when conducting the data analysis for this study.

Since the data analysis for this study is mainly based on statistics the process was fairly straightforward. The daily demand data for each item was analyzed and a relevant statistical distribution found to describe the demand pattern. This demand analysis was conducted through a built-in Matlab tool. Consequently, simulated demand was created for each item which was used to run the inventory simulator for 60 months.

Furthermore, the financial data gathered was used to create two indexes, the hospital price index (HPI) and the material price index (MPI). The HPI was calculated from the overall running costs of NUHI and the MPI was calculated from data on NUHIs supply costs. The supply costs are defined as the purchasing cost of supplies bought by NUHI. The MPI was compared to the consumer price index (CPI) and the MPI in order to evaluate NUHIs current supply chain system.

The five case-based steps used in this study are summarized as follows;

1. The main objective of this study is to investigate whether any of three selected MRP methods could reduce inventory and inventory related costs at NUHI's central storeroom. The research question is presented in the introduction of this thesis.

2. Instruments needed to answer the research question are in the form of case study to analyze the current situation and model to calculate alternatives. The case supplies data for the current system and to populate the proposed systems. The data analysis was used to develop an inventory simulator in Mathworks-Matlab. The simulator was used to determine how each inventory policy under consideration would

perform with simulated daily demand for 60 months. When data collected from visits and informal talks was used for writing this thesis, verification and feedback was acquired by running the report by the personnel in question.

3. Data gathering is three-folded. Firstly, observation through visits to the central storeroom along with informal conversations with key-personnel, secondly, financial data gathered from a number of official statistical documents, archival research at NUHI and the official web pages for Statistics Iceland. Thirdly, a literature review to build on others shoulders. Lastly, the central storeroom manager provided daily demand data for 60 items, which were chosen after conducting an ABC analysis. Included in the data were purchase costs and current re-order and order up-to points. Data on other inventory related costs was not available so estimations on these factors had to be made.

4. The daily demand data received for the subset of 60 items was analyzed and a relevant statistical distribution was found for each item and verified through a built-in Matlab tool. Consequently, simulated demand was created for each item which was used to run the inventory simulator for 60 months. A HPI (hospital price index) was made for the overall performance of the hospital and compared to inflation (CPI - consumer price index). The material price index (MPI) was calculated from data on NUHIs supply costs. The supply costs are defined as the purchasing cost of supplies bought by NUHI. A sensitivity analysis was performed on all cost factors.

5. Dissemination is being done by writing this thesis and presenting the results in an open lecture at the University of Iceland.

5 Developing the inventory simulator

This chapter discusses the development and mechanics of the inventory simulator created and used to compare the current policy used at the central storeroom, EOQ, SM and LUC for this study. Daily demand data was simulated based on the actual data provided by NUHI. The nature of the actual data is discussed, the simulated data is also discussed and validated and the selection of items is explained.

5.1 The mechanics of the inventory simulator

An inventory simulator was created in Matlab to compare the four inventory management policies. The Matlab code for the simulator can be found in Appendix A. The simulator consists of four independent inventories, each being managed with one of the policies under consideration. This section will explain how the simulator works for each of the four policies. The inventory simulator has the following restrictions and assumptions for all policies;

- Simulations spans 1320 working days ~ 5 years.
- All order arrivals and order quantities are stochastic and independent.
- If an item stocks out, a replenishment order is placed right away. The number of units stocked out is added to the optimal order quantity.
- Replenishments are assumed to be available before orders arrive the next working day.
- All items have a base order quantity. The base order quantity dictates the number of units each packaging holds.
    - All replenishment orders for a given item must be a multiple of the respective base order quantity.

The inventory policies will be evaluated based on total cost. The total cost for each policy is the cumulative cost for each item during the simulation. The total cost for each item is given by the formula;

$$TC = I \cdot h \cdot C + O + S \cdot n_s + C \cdot n_o$$

Where,

TC = The total cost for the item during the day (ISK)

I = Number of units in stock at the end of the day

C = Unit price (ISK)

h = Internal interest rate (%)

O = Ordering cost (ISK)

S = Stockout cost (ISK)

n_s = The number of units that could not be delivered

n_o = The number of units ordered

Three cost factors; holding cost, ordering cost and stockout cost all had to be estimated. A discussion on the cost estimations can be found in section 5.7.

5.1.1 The simulation process

As mentioned earlier, the inventory simulator consists of four independent inventories, each being managed with one of the policies under consideration. The simulation process for the four inventories is essentially the same. Figure 5.1 is a flowchart that describes the process skeleton used for all four inventories. As seen in the figure, each inventory is essentially a double for-loop with i*j = 1.320*60 = 79.200 iterations. A step by step explanation on the flowchart can be found below the figure, where each numbered step is explained in detail and the principal differences between the simulated inventories is presented.

It should be noted that the simulator is designed to simulate any number of items through any number of days. The simulator will however be explained with regard to the needs and settings of this study.

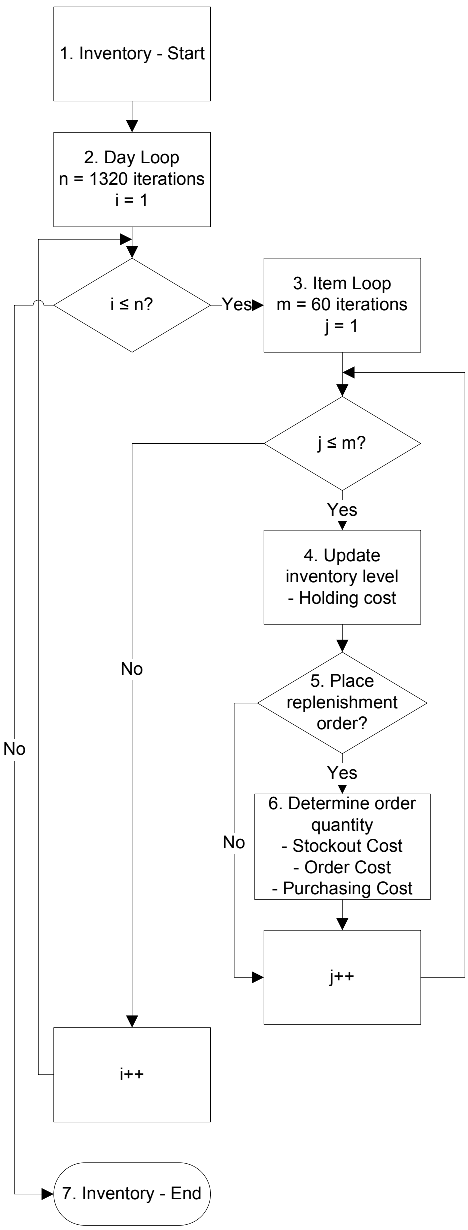

Figure 5.1 Flowchart describing the simulation process for all inventories

1. This step involves initiating the inventory level for all items as well as the value for the following constants; holding cost, order cost and penalty cost. For the EOQ inventory this step also involves calculating the re-order point (R) and order-quantity (Q) for each item. The R,Q points are calculated with the formulas displayed in section 3.4.2. The average demand per working day (λ) is calculated from the actual data (see inputs) provided by NUHI. The R,Q points remain as constants throughout the simulation.

    a. *Inputs:* All inventories require the following inputs; simulated demand, unit price for each item and the base order quantity for each item. The SM and LUC inventories also require a forecast for each item as an input. The re-order and order up-to points for each item are required for the s,S inventory and the actual data is required for the EOQ inventory. This will be discussed further after the process diagram has been explained.

   b. *Outputs:* Each inventory has 6 outputs, total cost and five 1320x60 matrixes. The five matrixes hold information on inventory level, holding cost, purchasing cost, penalty cost and order cost for each item each day.

2. Here the actual simulation starts. The program enters the day loop. Each iteration within this loop represents one working day, 1320 iterations in total.

3. The program enters the item loop. Each iteration within this loop represents one item within the inventory. Since there are 60 items under consideration, there are 60 iterations in total. Steps 4-6 all occur within the item loop.

4. In step 4 the demand for item j at time i is retrieved from the simulated demand. The demand quantity is subtracted from the inventory level and a new inventory level determined. If the inventory level is positive the holding cost is calculated and added to the appropriate outputs. In the case of the SM and LUC inventories, this step also involves updating the period counter. The period counter is used to count how many review periods have gone by since an order was placed for item j (see step 5).

5. In step 5 a decision is made whether the inventory level for item j needs replenishing.

   a. *EOQ and s,S*: In the case of the re-order point (ROP) inventories this is simply decided by comparing the inventory level with the respective re-order point. If the inventory level is beneath the re-order point the program enters step 6. If not the program enters next iteration.

   b. *SM and LUC*: In the case of SM and LUC a replenishment order is placed for item j, if either of the following conditions is met; 1. The stock level is equal to or less than zero. 2. The number of review periods the last order was intended to cover has passed. If either condition is met the program enters step 6. If not the program enters next iteration.

6. If the program enters this step a replenishment order is for item j is placed at time i. As mentioned earlier, the order quantity must be a multiple of the base order quantity for the given item. In the s,S inventory this is ensured with a while-loop that adds the base order quantity to the inventory in every iteration and breaks when the inventory level has reached the order up-to point. In the other three inventories this is ensured by calculating the modulo operator between the base order quantity and the desired order quantity (lot size + number of stocked out units) thus calculating the distance to the next viable order quantity. When the order quantity has been determined, the order cost, purchasing cost and penalty cost (if necessary) are calculated and added to the total cost and the respective output matrixes. Lastly the inventory level is updated for next iteration in the day loop. The process for calculating lot sizes in the SM and LUC inventories is explained in figure 5.2.

7. When the program has been through all iterations, the program ends returning the desired outputs.

As mentioned in section 2.3 the re-order and order up-to points in the central storeroom's s,S system can change. However, only the feeling and experience of the central storeroom manager determines when and how the re-order and order up-to points are redefined. As a result the re-order and order up-to points were kept as constants for all items.

It should also be noted that the author experimented with letting the EOQ inventory calculate new re-order and order quantity points for each item on regular intervals. This was done by using the simulated data as new historical data as the simulation progressed. This proved to be unsuccessful as the EOQ inventory gave better results when the re-order and order quantity points remained as constants. The reason is likely to be that the simulated data was after all modeled after the actual data and variations in the simulated demand are not describing new behavior in the demand patterns.

As mentioned in step 1 the SM and LUC inventories require a forecast for each item as an input. This is not to be confused with the simulated demand. The thinking behind this is that when using SM and LUC in real life a forecast is required in order to determine the lot size for the coming review periods. Since both the arrival of an order and the order quantity is assumed to be stochastic, a demand forecast was created with the same method the simulated demand was created (see section 5.4). Originally the Matlab-program created a new forecast when needed however in order to save simulation time a forecast was created for the whole simulation period and taken into the program as an input.

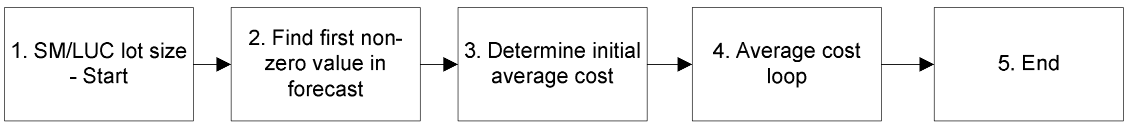

Figure 5.2 The process when determining a new lot size in the SM and LUC inventories

Figure 5.2 describes the process within the Matlab-function when calculating lot sizes with SM or LUC. Below a step by step explanation is presented.

1. Both SM and LUC take in holding cost, ordering cost, unit price, a 4 week forecast and the current inventory level for item j as inputs. They both return the lot size for item j and the number of review periods the lot size is intended to cover.

2. Since the demand is intermittent, and several items ordered very rarely the optimum lot size could be calculated as zero units. With all orders arrivals viewed as stochastic it is anticipated that the forecasted demand will not accurately predict when orders arrive for the most intermittent items. The two methods were therefore forced to calculate a lot size larger than zero by locating the first non-zero element within the forecast and compare the cost functions from that point. This is done with a built in Matlab function that returns the index number of the first non-zero element in an array.

3. The algorithm for both SM and LUC is in essence the same and dictates that a cost function, as defined by the respective methods is compared between iterations. In

step 3 the cost function is calculated if a lot size that is only intended to cover one review period is ordered.

4. The program now enters a for-loop that runs from the first non-zero element in the forecast to the end of the forecast. As the formulas in sections 3.4.3 and 3.4.4 show, when calculating the respective cost functions, a new term is added to both numerator and denominator every iteration. Therefore, in every iteration the Matlab program calculates the new term for the numerators and denominators separately and simply adds them to the old numerator/denominator. Iterations are stopped when the cost function in current iteration returns a bigger value than the cost function calculated in the previous iteration.

5. The program finally subtracts the current inventory level (if positive) from the calculated lot size and returns the resulting lot size and the number of periods the lot size is intended to cover.

5.2 ABC analysis

The central storeroom manages the inventory level for over 6000 different items so an ABC analysis could proof to be a useful tool. Since NUHI is not selling manufactured products, the most important items are the ones which cost NUHI the most.

Cost figures for all the items purchased by the storeroom in the year 2010 were provided by NUHI and analyzed. 3.613 different items were purchased in the period which means that around 2500 items that the central storeroom manages where not at all purchased in that year. The percentages shown in the figure and table below are with regard to the number of items purchased so the approximately 2500 items that weren't purchased are unaccounted for in these figures. The reason for that being they don't contribute anything to the costs of NUHI and aren't really on the central storerooms radar anyway.

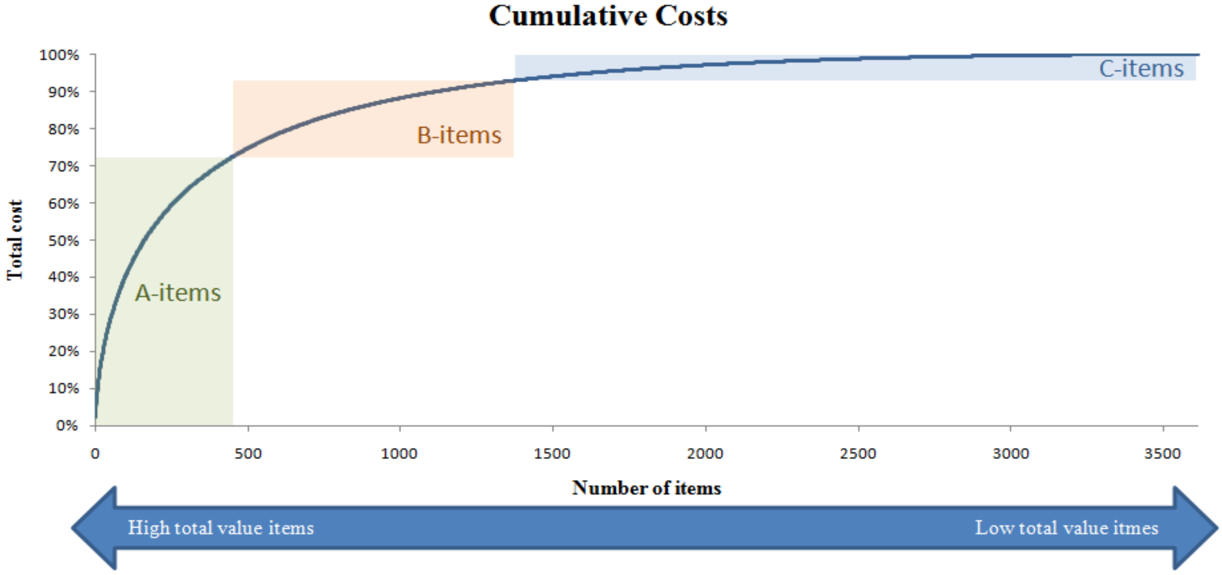

Figure 5.3 ABC analysis for the central storeroom inventory

In figure 5.3 the results of the ABC analysis for the central storeroom are shown. The ABC analysis was carried out with the guidelines mentioned in section 3.8 in mind. Firstly the products were ranked in a descending order by ISK value of annual cost, then the cumulative cost was plotted to form a Pareto curve. Finally all the items were categorized into three groups.

Since there are so many different items to work with the difference in ISK value of annual cost between two items that are closely ranked is marginal so it was tricky to determine which items went in which group. However, the line must be drawn somewhere and with percentages proposed by the guidelines mentioned earlier in mind, the A-group consists of items that contribute at least 0,05% of the total annual purchasing cost. The B-group consists of items that contribute between 0,01% and 0,05% and the C-group are those items who contribute below 0,01% of the total annual purchasing cost.

Table 5.1 ABC analysis - summary

Class	No. of items	% of total items	Cumulative cost
A	453	12,54%	72,56%
B	931	25,77%	20,47%
C	2.229	61,69%	6,97%
Total	3.613	100,00%	100,00%

5.3 The data provided by NUHI

The top 60 items in class A were chosen to compare the four inventory policies for this study. Data on daily demand during a 100 day period for the 60 items were provided by the central storeroom manager. The cumulative cost for these 60 items is just over 30% of annual costs. The data provided is the main input for the inventory simulator that was developed for this study. The data showed when an order was placed for any particular item and what quantity was requested. Included in the data were also unit prices and current re-order and order up-to points. Each item has a base order quantity determined by the item packaging from the central storerooms suppliers. Data on this matter was also provided.

In many cases the unit price changed during the 100 day period in question. For each item the most recent unit price was used to calculate inventory related costs throughout the simulation. The changes in unit price build on factors that are hard to simulate and irrelevant to this study. Hence the unit price for each item was considered a constant.

5.4 Data analysis and forecasting

Firstly it should be mentioned that in some cases the central storeroom receives orders during closing hours, on weekends or holidays. These orders are carried out when the central storeroom opens. The inventory simulator focuses on when items are picked from the central storeroom inventory, so the first step was to import the data into Matlab and move orders received during closing hours to the next working day. This effectively reduced the number of data points from 100 to 66 points.

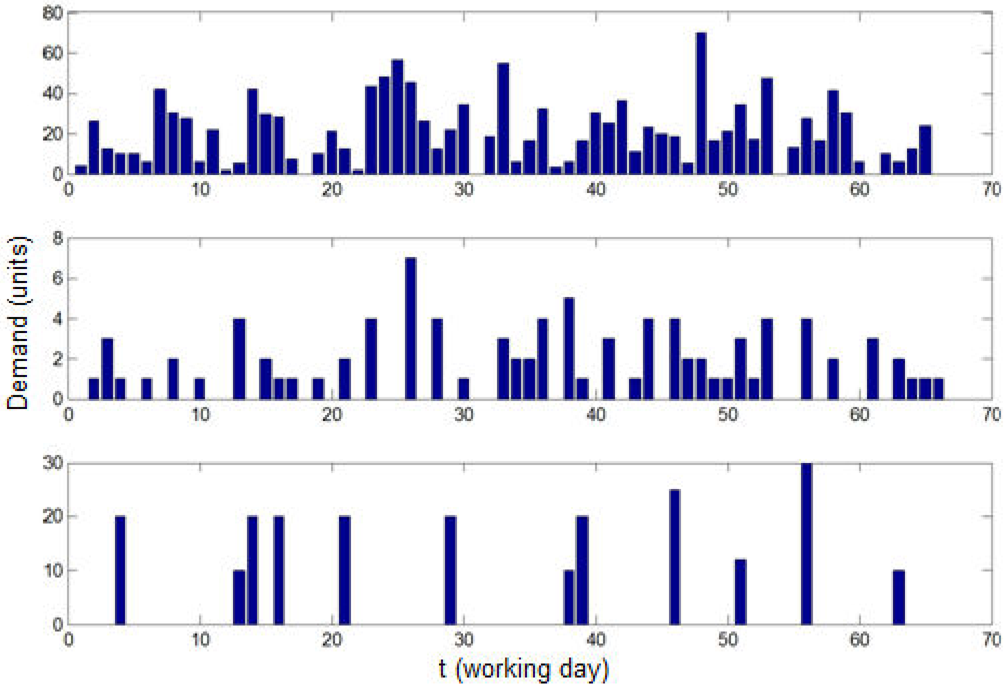

Figure 5.4 Daily demand for three different items

In figure 5.4 the daily demand (working days only) for three items is shown. As illustrated in the figure the nature of the 60 items under consideration is very diverse. Some items are relatively inexpensive and used in large quantities and some are relatively expensive but used seldom. The figure indicates that the demand can be best described as intermittent and therefore could Croston's forecasting method for intermittent demand prove useful.

In figure 5.5 the items are sorted by the average inter-arrival interval, p. The average inter-arrival interval is defined as the average number of review periods between orders for any given item. If an item has a p-value of 1.25 the item is picked from the inventory on 4 times (5/1.25 = 4) per working week on average. Similarly if an item has a p-value of 2.5 the item is picked 2 times per working week on average. As shown in figure 5.5, 25 out of the 60 items under consideration are ordered at least 4 times per working week ($p<1.25$). This means that just under 60% of the items are ordered less than 4 times per working week. This demonstrates that the demand is indeed intermittent and that Croston's method is an appropriate forecasting method for the items in question.

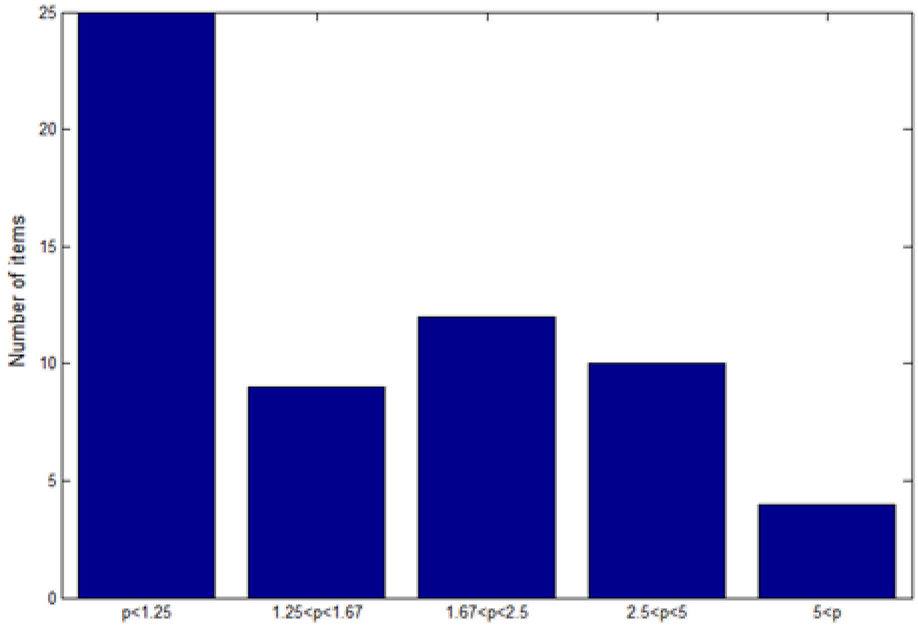

Figure 5.5 Items sorted by the average inter-arrival interval

As mentioned earlier the nature of the items under consideration is very diverse. Therefore the demand data for each item had to be analyzed individually in order to create fairly accurate simulated data. As Croston's method dictates (see section 3.6) the daily demand data was analyzed in two parts, the likelihood of a pick and the quantity of each pick. The likelihood of a pick is calculated from the average inter-arrival interval. In order to determine the quantity of each pick, the non-zero values from the daily demand data had to be statistically analyzed in order to determine the distribution the demand follows. The tool used to carry out this statistical analysis was MathWorks Matlab and two of its built in functions; hist.m and probplot.m.

A histogram for each item was created using hist.m and the resulting figure used to guess the appropriate statistical distribution. The guess was consequently verified using the function probplot.m. The function creates probability plot for the specified distribution, comparing the distribution of the data to the specified distribution. The function uses midpoint probability plotting positions. The i^{th} sorted value from a sample of size N is plotted against the midpoint in the jump of the empirical CDF (cumulative distribution function) on the y-axis. The plot includes a reference line useful for judging whether the data follow the specified distribution. The data set follows the specified distribution if the data points don't wander off from the line.

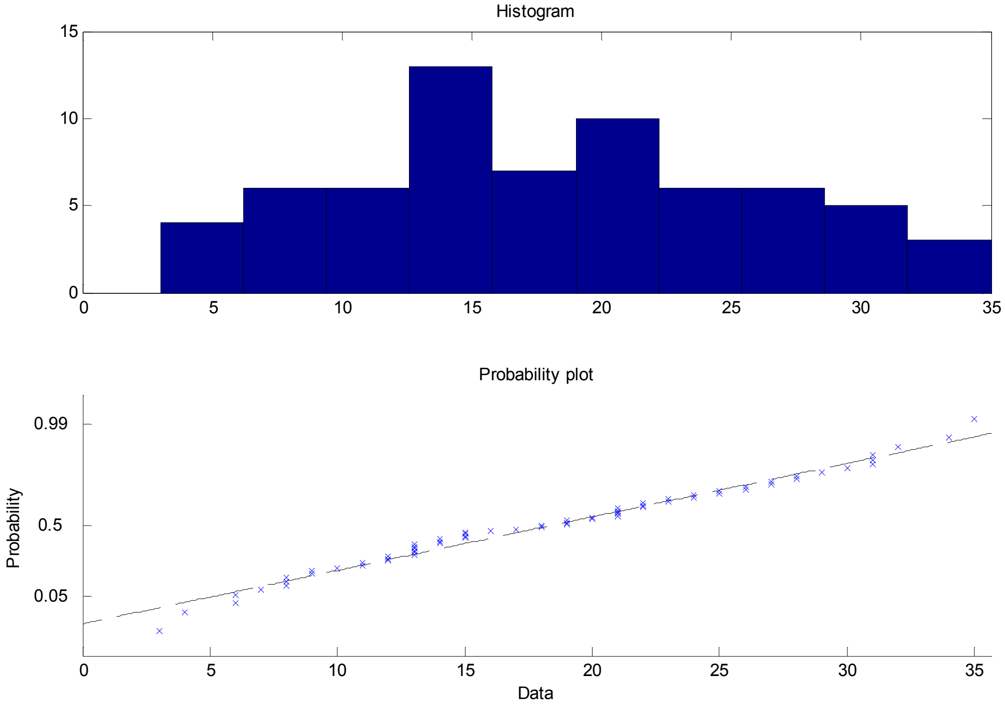

Figure 5.6 A histogram and a probability plot for one of the items

Figure 5.6 displays a histogram and a probability plot for one of the items under consideration. It can be seen that the histogram resembles a normal probability curve. The probability plot confirms that this particular item follows the normal distribution as the data points stay on the reference line. In those cases where the data set could not be statistically connected to a specified distribution, a distribution that gave simulated data closest to the actual data was chosen.

For each item a dataset of 1320 (amounts to around 5 years daily demand) simulated data points was created. The reason for creating 1320 data points was simply that the number is statistically big enough and small enough to provide fast simulation times. The datasets were created using built in Matlab functions. The distribution for any given item determined which functions were used to create simulated data for that particular item. The functions were;

- Exponentially distributed items
  - expfit.m - estimates the mean of an exponentially distributed data
  - exprnd.m - generates random numbers from the exponential distribution with mean calculated from expfit.m
- Normally distributed items
  - normfit.m - estimates the mean and standard deviation of a normally distributed data

- o normrnd.m - generates random numbers from the normal distribution with the mean and standard deviation calculated from normfit.m

- Uniformly distributed items
  - o unifrnd.m - generates random numbers from a uniformly distributed data with lower limit A and upper limit B

- Poisson distributed items
  - o poissfit.m - estimates the mean paramater for poisson distributed data
  - o poissrnd.m - generates random numbers from the Poisson distribution with mean parameter calculated from poissfit.m

5.5 Model validation

The inventory simulator is set to run for 1320 working days (~60 months) so demand for each of the 60 items was simulated as mentioned in the previous subchapter. The simulated demand was compared to the actual 3 month data provided by NUHI. The results can be seen in table 5.2.

Table 5.2 Demand model validation

Demand characteristics - 3 months

	Actual data	Simulation	Percentage	Std deviation	CV
Total units	381.837	389.688	2,05%	12.756	0,034
Total value	62.002.611	63.349.825	2,17%	1.405.010	0,022
Average no. of picks	43,15	43,26	0,25%	0,30	0,007

To validate the model, three measurements were analyzed. First, the total demand measured in units, was compared. The cumulative demand for the 60 items were 381.837 units in the data provided by NUHI. The simulated demand had on average 284.173 units with a coefficient of variation (CV) of 0,034 which was within 1,2% of the actual data. Secondly, the total demand, measured in ISK was compared. The actual data cumulated 75.360.984 ISK while the simulated data cumulated on average 76.817.600 ISK with a CV of 0,031 which was 1,93% from the actual data.

Lastly the average number of picks from inventory was compared to ensure the model accurately reflected the intermittent nature of the demand. In the actual data each item was on average picked 43,15 times over the course of the three months. In the simulated demand each item was picked on average 43,26 times with an CV of 0,007 which is 0,25% from the actual data.

Table 5.2 compares the demand characteristics for the 60 items as a whole. In order to determine whether any item was modeled inaccurately, the percentile variation for each of the three measurements in table 5.2 was analyzed for each of the 60 items. The results can be seen in table 5.3.

Table 5.3 Percentile variation in the simulated demand

	Percentile variation			
	Mean	**Median**	**Min**	**Max**
Total units/value	4,15%	3,35%	0,00%	11,09%
Number of picks	1,75%	0,92%	0,00%	9,57%

Since each item is analyzed individually the percentile variation for total units and total value is the same for any given item, as a result these two measurements are displayed as one. As seen in table 5.3 the total units/value in the simulated demand was on average 4,15% from the actual data with a median of 3,35% and 11,09% from the actual data at the most. When looking at the number of picks, the simulated demand was on average 1,75% from the actual data with a median of 0,92% and 9,57% at the most.

For both total units/value and the number of picks the item that had the maximum percentile variation from the actual data was an item that was relatively expensive and ordered in low quantities.

Given the high accuracy displayed in table 5.2 and the acceptable accuracy displayed in table 5.3 the model was confirmed to accurately display the nature of demand for the 60 items under consideration.

5.6 Modeling issues

When looking at the analysis in the previous subchapter the simulated demand does accurately display the nature of the actual demand. There are however some limitations to the model. Firstly since only non-zero demand was taken into account when determining the appropriate distribution function for each item, there were only 66 data points available, at best. In some cases it was hard to determine which distribution function to use and statistically verify that the selected distribution function was the one to use. It is also clear that data that covers only 3 months is not enough to identify seasonal trends in demand. As a result the simulated demand only reflects the three months included in the data.

In some cases the difficulties in determining which distribution best suited the data resulted in little variation in the simulated demand. The simulated demand could therefore not accurately emulate the actual demand variation. This is illustrated in figure 5.7. In the figure the first 18 non-zero values in the simulated demand are plotted against all 18 non-zero values from the actual data for one of the items. As seen in the figure the simulated demand doesn’t capture the variation in the actual demand, although it should be noted that the simulated demand variation is a bit better than illustrated in the figure. This particular item was one of three items which was best simulated with a poisson distribution. The simulated demand for poission distributed items did not manage to emulate the actual demand variation.

It should be stressed that this was not the general trend as in most cases the simulated demand captured the actual demand variation adequately well in most cases. This is illustrated in figure 5.8.

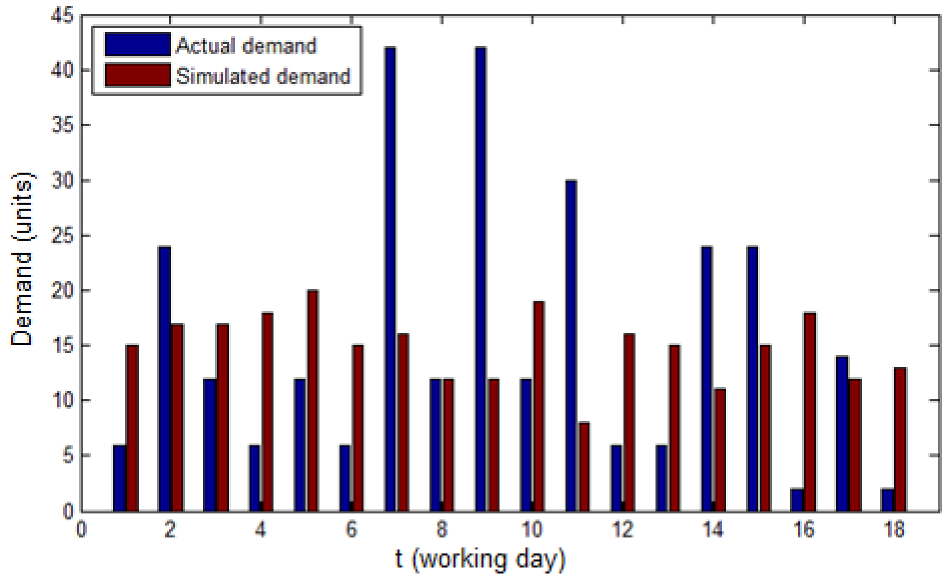

Figure 5.7 Actual demand vs. simulated demand for one of the items – simulated data doesn't capture the demand variation

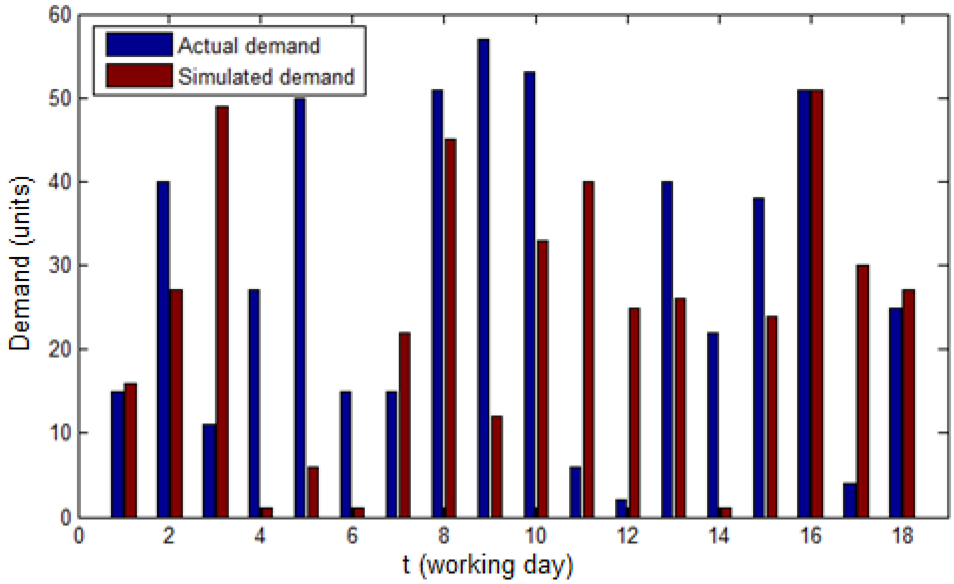

Figure 5.8 Actual demand vs. simulated demand for one of the items – simulated data captures the demand variation

Another issue was that in some cases the demand could be viewed as cyclical, an example of this can be seen in figure 5.9. For this particular item the general trend is that an order is placed every 5 review periods, with few exceptions. This behavior can't be captured by Croston's forecasting method used in this study. Since this behavior is currently not accounted for at the central storeroom, simulating this cyclical behavior was deemed irrelevant and all arrivals are assumed to be stochastic.

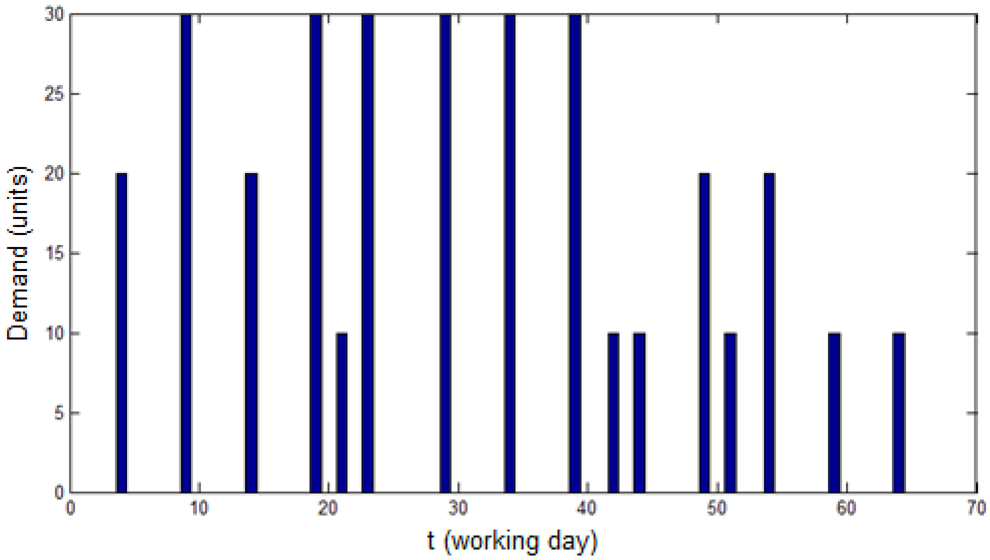

Figure 5.9 Item with a cyclical demand behavior – only ordered in the multiple of 10 every 5 review periods

Figure 5.9 also illustrates two other issues with the data. First, there are only three order quantity values, 10, 20 and 30. If this demand would be simulated with a uniform distribution it would result in inacurate results. As a result, items with this kind of demand pattern were simulated in the same way as the order arrival. That is, the average inter-arrival interval for each demand quantity was calculated and simulated using a bernoulli process.

The other issue is that if the first half of the demand data is looked at on order for 10 units arrives against 5 orders for 30 units. On the other hand when the data is looked at as a whole there are 6 orders both for 10 units and 30 units. This suggests that data over a three month period is possibly not enough to accurately simulate the demand patterns for the items under consideration.

5.7 Cost estimations

Since NUHI has not defined holding cost, stockout cost and ordering cost, no data was available on this matter. These three cost parameters had to be estimated and the following subchapters will discuss the estimations and the criteria behind the estimations. A sensitivity analysis was performed for all three cost parameters which can be found in chapter 6.

5.7.1 Holding cost

Holding cost is money spent to keep and maintain a stock of goods in storage. In this study, the annual holding cost is assumed to be 20% of the unit cost for all products. The internal interest rate value of 20% was chosen simply because it was frequently used in other studies and textbooks, the value was also suggested by the thesis advisor. Since the review period and lead time for every item at the central storeroom is just a single working day it is appropriate to convert the annual interest rate into daily interest rate. If it is assumed that there are 250 working days each year the daily interest rate is given by

$$(1 + r_a) = (1 + r_d)^n => r_d = (1 + r_a)^{\frac{1}{n}} - 1 = (1 + 0{,}2)^{\frac{1}{250}} - 1 = 0.073\%$$

The holding cost was only calculated for working days even though items lying in stock during weekends and holidays do bear holding cost. However this method was chosen since the annual interest rate is only divided by the number of working days in a year resulting in a higher daily interest rate than if it would be divided by 360 days. Therefore the annual holding cost should level out.

5.7.2 Order cost

The order cost is the fixed cost coupled with placing an order for a single line item, regardless of the quantity of that item. In this study ordering cost is defined as the man-hours to determine which items need to be ordered and to place the order at the appropriate supplier. NUHI provided data on this matter and it turns out that it takes a single employee about 3,5 hours every day to complete the task of placing orders. On average the central storeroom orders around 120 items each working day. Hence the ordering cost is set as the cost in employing a single person for 3,5 hours divided by the number of order lines ordered. The ordering cost was calculated as 80 ISK per item.

Since some of the items under consideration in this study are ordered more frequently than other items, it could be argued they should have higher ordering costs. However, since all the items under consideration are ordered fairly frequently the difference would be measured in a few ISK and therefore deemed negligible. As a result the ordering cost is set as a constant for all items.

5.7.3 Stockout cost

Stockout costs are economic consequences of not being able to meet an internal or external demand from the inventory. The central storeroom only handles internal demand. Such stockout costs could for example consist of delays and labor time wastage.

The stockout cost was set as the 7% of the unit cost for each item that was unavailable when requested. For example if there is a shortage of 5 units for any item the stockout cost is calculated as five times 7% of the unit cost. NUHI has not defined a desired service level for its stock rooms or individual items. It is therefore hard to estimate the stockout cost. When determining the percentage value the author balanced holding cost (as estimated above) with stockout cost for several items. In essence it was determined through trial and error. The percentage value was set as relatively high compared to holding cost as the nature of the hospital industry dictates that stockouts can potentially be serious.

By setting the stockout cost as a function of the unit price results in higher stockout cost for rare and expensive items. Shortages for such items are potentially more serious as the ward requesting the item is unlikely to find a similar item elsewhere in the hospital. Similarly when shortages for relatively inexpensive and common items occur they result in lower stockout costs.

5.8 Service level

When calculating and comparing the service level for each of the four inventory policies, this study uses a type 2 service level. As mentioned in section 3.9 type 2 service level is a quantity oriented service that measures the proportion of total demand which is delivered without delay from stock on hand. Type 2 service level was chosen as the inventory simulator simulates the total demand for a given item each review period. That is the quantity of individual orders is unknown. The service level is calculated for each item with the formula presented in section 3.9.

6 Simulation results and analysis

Four inventory policies were simulated and compared. They included the s,S policy currently used at NUHI's central storeroom, EOQ, SM and LUC. A model was developed in Mathworks Matlab to capture the mechanics of each of the four inventory policies. The model generated demand for 1320 consecutive working days and tracked and stored data on inventory levels, stockouts and inventory related costs. Each inventory policy worked with the same simulated demand and had the same initial inventory level.

This chapter will put forward and analyze the simulation results and compare the total costs and service level for each inventory policy. Also, a sensitivity analysis for all estimated cost factors is presented. Lastly, experimentations with the model assumptions are conducted.

6.1 Cost comparison and analysis

The four inventory policies were compared and evaluated as defined by the total cost-equation in displayed in section 5.1. Cost comparison on the four inventory policies can be seen in table 6.1 below. When the total cost is compared the two ROP policies, s,S and EOQ perform slightly better than the other two methods.

Table 6.1 Average annual inventory cost. All values in ISK.

Policy	Purchasing cost	Stockout cost	Holding cost	Order cost	Total cost	Total cost - Purc.cost	Hold. cost + Order cost
s,S	254.178.035	418.565	879.535	255.792	255.731.926	1.553.892	1.135.327
EOQ	253.905.667	1.463.885	486.509	258.816	256.114.878	2.209.210	745.325
SM	253.907.007	2.596.563	461.303	348.832	257.313.706	3.406.699	810.135
LUC	253.927.020	2.311.124	478.017	324.704	257.040.867	3.113.846	802.721

Perhaps predictably the purchasing cost accounts for the vast majority of the total cost and the variance in purchasing cost between policies is minute. It should be noted that the reason for the minute difference in purchasing cost is due to different inventory levels for each policy at the end of the simulation. With the purchasing cost accounting for the vast majority of the total cost a comparison where the purchasing cost has been removed was made and can be seen in the column to the right of total cost in table 6.1. The comparison in that case leads to a different conclusion as SM, LUC and EOQ perform significantly worse than the s,S policy currently used at the central storeroom. The EOQ policy does however perform significantly better than SM and LUC.

When the purchasing cost has been taken out of the equation, it is obvious from table 6.1 that the poor performance shown by EOQ, SM and LUC is due to high stockout costs. In table 6.2 the service level for each policy can be found. Also displayed in the table is the average amount of ISK tied up in each inventory. The service level displayed in the table is the average service level with the service level for each item calculated as defined in section 5.8.

Table 6.2 Service level and money tied up in inventory

Policy	Service Level	ISK tied up in inv. (ISK)
s,S	97,8%	4.563.796
EOQ	92,0%	2.524.435
SM	86,0%	2.393.644
LUC	88,1%	2.480.374

As seen in the table the current s,S policy performs significantly better in terms of service however, the high service level comes at a cost since the amount of ISK tied up in the inventory is much higher than for the other three policies. Interestingly the EOQ policy returns significantly better service level than SM and LUC with similar amount of ISK tied up in the inventory.

A closer look at the stockout data reveals why the amount of ISK tied up in the s,S inventory is so extravagant compared to the other inventories. In table 6.3 a comparison on service level distribution between s,S and EOQ can be seen. The s,S inventory has 13 items with 100% service level and a total of 36 items with a service level of 99% or better. Keeping up such a high service level will obviously mean that more items are kept in stock and drive the money tied up in the inventory upwards.

Table 6.3 A comparison on service level distribution

Policy	100%	100%>SL>99%	99%>SL>98%	98%>SL>91%	SL<91%
s,S	13	23	7	14	3
EOQ	0	1	6	35	18

In order to determine why the EOQ, SM and LUC inventory policies return such poor service level the 60 items were categorized by three criteria; unit price, annual demand in units and average inter-arrival interval. This analysis might give indication on whether there is any trend in performance far any inventory policy.

For each criterion items were sorted into 4 groups with each group consisting of 15 items. Items were sorted in a descending order for unit price and annual demand. In the case of the average inter-arrival interval items were sorted in an ascending order. Tables 6.4-6.6 display a cost comparison and a service level comparison between the four policies. The total cost displayed in the tables is the total annual cost without purchasing cost and the service level displayed is the average service level within the group.

Table 6.4 Items sorted by unit price

	s,S		EOQ		SM		LUC	
	Total cost (ISK)	Serv. level	Total cost (ISK)	Serv. level	Total cost (ISK)	Serv. level	Total cost (ISK)	Serv. level
Group I	550.164	97,2%	740.194	91,2%	1.015.887	85,6%	982.895	86,5%
Group II	428.540	97,6%	800.229	88,2%	1.121.384	84,7%	1.051.099	86,1%
Group III	295.239	98,7%	334.251	94,2%	636.954	87,1%	552.776	90,0%
Group IV	279.950	97,8%	334.536	94,5%	632.474	86,7%	527.076	89,9%
Total	1.553.892		2.209.210		3.406.699		3.113.846	

Table 6.5 Items sorted by annual demand

	s,S		EOQ		SM		LUC	
	Total cost (ISK)	Serv. level	Total cost (ISK)	Serv. level	Total cost (ISK)	Serv. level	Total cost (ISK)	Serv. level
Group I	322.951	98,1%	376.449	95,1%	760.756	86,9%	655.709	89,5%
Group II	412.184	97,7%	658.374	92,3%	1.150.588	84,6%	1.032.255	87,6%
Group III	292.991	98,3%	441.891	92,6%	672.223	86,4%	637.537	88,0%
Group IV	525.766	97,1%	732.497	88,1%	823.132	86,2%	788.345	87,4%
Total	1.553.892		2.209.210		3.406.699		3.113.846	

Table 6.6 Items sorted by average inter-arrival interval

	s,S		EOQ		SM		LUC	
	Total cost (ISK)	Serv. level	Total cost (ISK)	Serv. level	Total cost (ISK)	Serv. level	Total cost (ISK)	Serv. level
Group I	370.089	98,7%	429.119	96,4%	1.023.935	88,0%	937.460	89,7%
Group II	292.824	97,9%	338.246	94,7%	620.830	87,0%	526.742	90,0%
Group III	357.935	98,6%	622.083	92,3%	923.641	85,4%	811.877	88,2%
Group IV	533.044	96,1%	819.763	84,6%	838.292	83,8%	837.768	84,6%
Total	1.553.892		2.209.210		3.406.699		3.113.846	

When the tables above are analyzed it is clear that with current cost estimations, the practice of minimizing the cost per unit of demand, as is the case in the LUC policy, works better instead of minimizing the average cost per period, as practiced by the SM policy. It is interesting to note that Group III and IV in table 6.4 are only slightly better managed with the s,S policy rather than EOQ. Even though EOQ has significantly less service level in those groups and the stockout is set relatively high. This suggests that the money tied up in the s,S policy is perhaps more than is necessary.

The most obvious trend in tables 6.4-6.6 can be seen in table 6.6. In terms of service level the EOQ policy performs better with items that are ordered more frequently. This does not have to come as a surprise when the formulas and assumptions behind the EOQ model are looked at and compared to the demand patterns for the items with the biggest average inter-arrival interval. The EOQ model assumes that demand is known and constant, the re-order point can therefore be calculated as the average demand per unit time multiplied with the lead time.

Figure 6.1 displays the actual demand pattern for the item that had the worst service level within the EOQ inventory. The average demand per review period is calculated as 4 units and the optimal order quantity is calculated as 22 units. It is therefore clear that the assumptions made in the EOQ model do not hold for the demand pattern shown by many of the items.

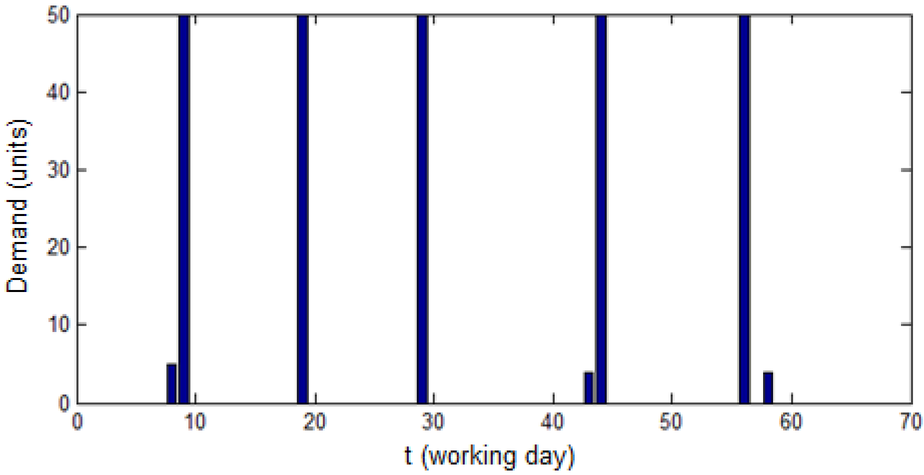

Figure 6.1 Item with an average demand of 4 units and a common order quantity of 50 units

Table 6.6 also indicates the reason for the poor performances showed by the SM and LUC policies. SM and LUC are lot sizing techniques that calculate optimal lot sizes based on expected demand. Since the inventory simulator assumes that all order arrivals are stochastic as well as order quantity, a forecasting method where the only input is statistical data was on past demand was used. Such forecasts tend to provide inaccurate forecasts and that is the case for SM and LUC. The items in the first group in table 6.6 are ordered more frequently and over several review periods the forecasted demand better predicts the simulated demand. However, the demand variation is still too much for the forecasting method to prepare the SM and LUC inventories for spikes in the demand. This is illustrated in figure 6.2.

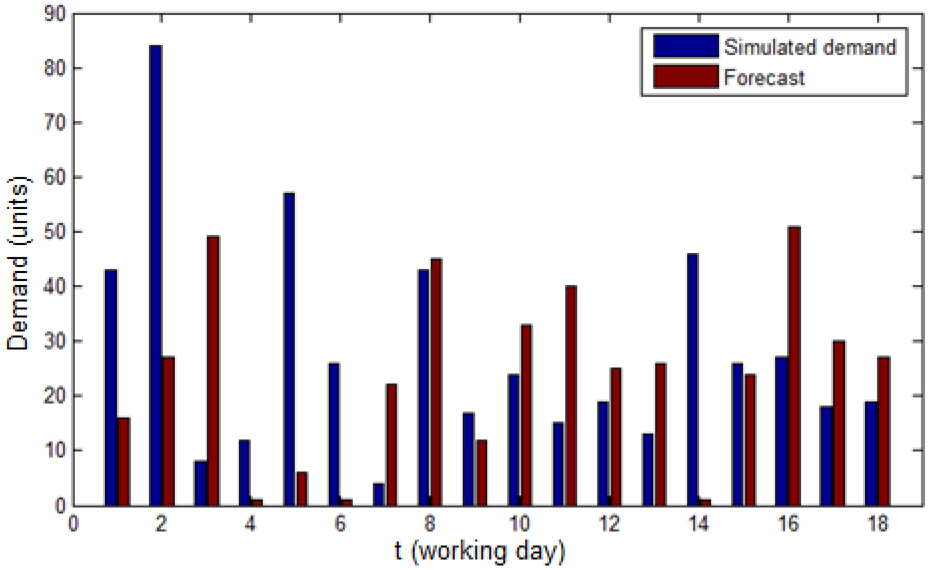

Figure 6.2 Forecast fails to accurately predict order quantity

If the first 8 review periods are looked in figure 6.2, it is clear that the forecast fails to accurately predict the order quantity. This results in too small lot-sizes thus ultimately stocking out. As a result SM and LUC fail to meet the service level EOQ and s,S provide. With the cost parameters on the current setting the savings in holding and setup cost are completely outweighed by the stockout cost.

Figure 6.3 illustrates the general trend in how the four policies manage their respective inventories. The figure shows the inventory level for each inventory policy during a 3 month period for one of the items. The figure illustrates how SM and LUC have a tendency of ordering too few units, hence being vulnerable to big orders and as a result, stockouts. The figure also shows that the s,S inventory provides 100% service level while the EOQ policy has on average less inventory and allows stockouts on occasion.

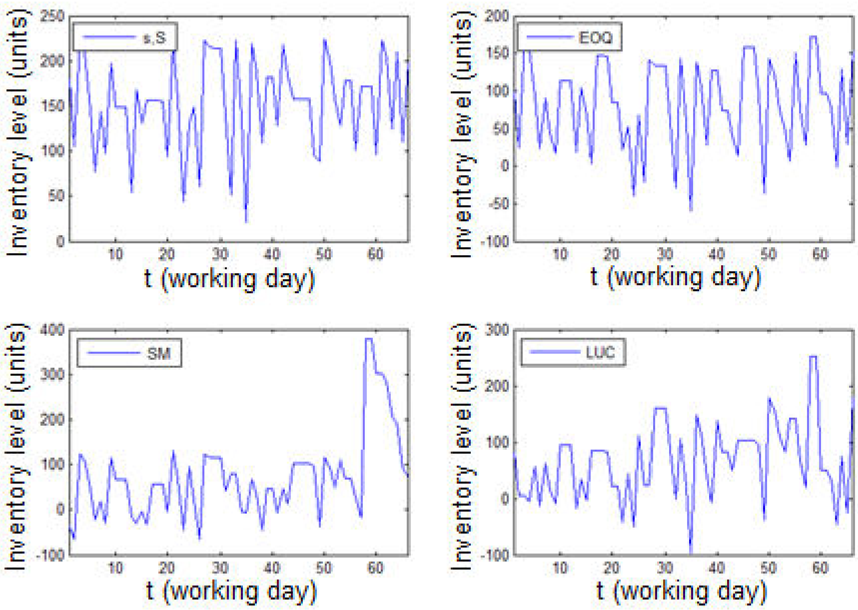

Figure 6.3 A comparison on inventory level for one of the items

6.2 Sensitivity analysis

A sensitivity analysis was performed for the three estimated cost factors, holding cost (annual interest rate), order cost and stockout cost. The results can be seen in figure 6.3 below. The figure displays the change in total cost, without purchasing cost, with regard to change for any given cost factor. In the cases of order cost and stockout cost the lowest value was calculated as 50% of the original estimation made in section 5.7 and the highest as 150% of the original estimation. These values are represented on the horizontal-axis at the bottom of each graph. In the case of holding cost, the lowest value was calculated as 5% annual internal interest rate and the highest as 50% annual internal interest rate. These values are represented on the horizontal-axis at the top of each graph.

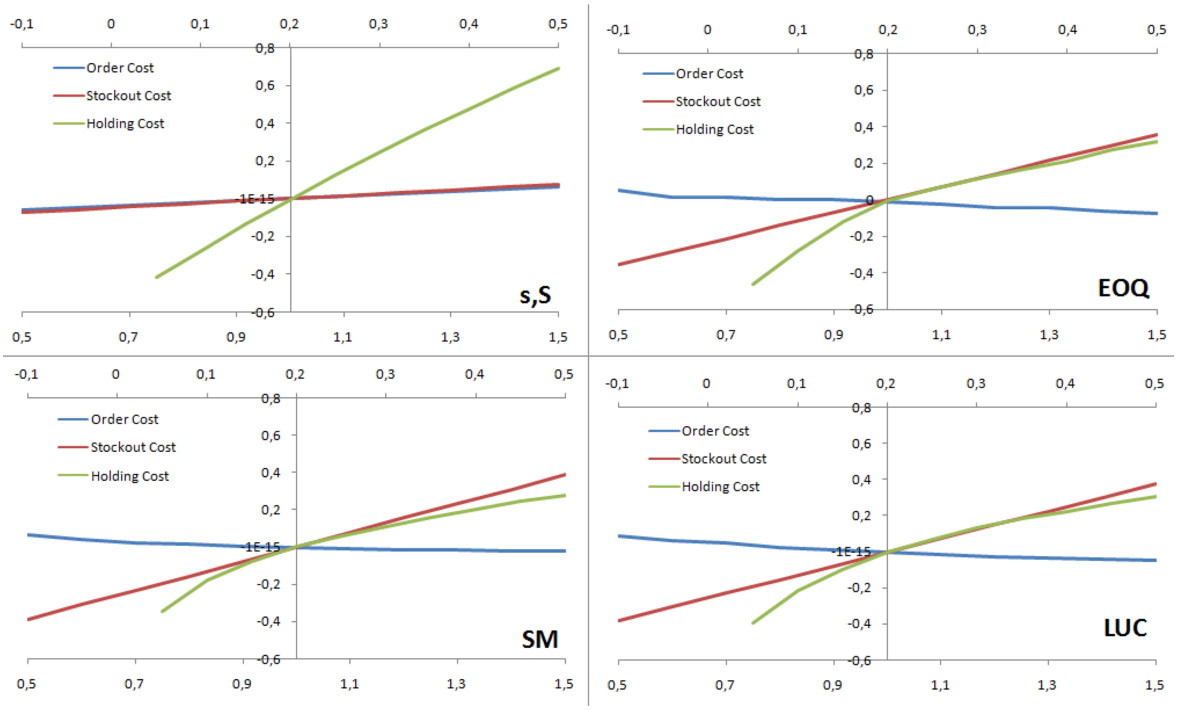

Figure 6.4 Sensitivity analysis for all policies

In the top left corner of figure 6.4 the senitivity analysis for the s,S policy can be found. As seen the s,S policy is the most sensitive with regard to holding cost. This is unsurprising due to high inventory levels within the s,S inventory. The sensitivity lines for all cost factors are linear since the re-orders and order up-to points in the s,S policy are fixed and do not take into account the cost facturs when calculating lot sizes.

The sensitivity analysis for the EOQ policy can be seen in the top right corner in figure 6.4. The EOQ policy is least sensitive with regard to order cost, conversely the EOQ policy is relatively sensitive with regard to stockout cost and holding cost. The sensitivity with regard to stock out cost is unsurprising as the EOQ returns a poor service level. The change in total cost with regar to stockout cost is linear since the EOQ policy does not take the stockout cost into consideration when calculating lot-sizes. The reason behind the sensitivity with regard to holding cost is due to the fact that lot-sizes becom smaller with increasing holding cost and a s a result the inventory becomes more sensitive to big orders. In other wors, high stockout cost is the reason for the sensitivity with regard to holding cost.

In the bottom left corner in figure 6.4 the sensitivity analysis for the SM policy can be found. The story for the SM policy is the same as for the EOQ policy. Again the order cost is the least significant cost factor and, due to a poor service level the stockout cost the most significant. Like the EOQ policy, SM is also relatively sensitive with regard to holding cost, the reason again being smaller lot-sizes with rising holding cost and as a more stockouts.

Lastly, in the bottom right corner in figure 6.4 the sensitivity analysis for the LUC policy can be seen. Again, the sensitivity analysis tells a similar story to the ones for the EOQ and SM policies. The order cost is the least significant cost factor with the stockout cost the most significant due to a poor service level. As is the case for SM and EOQ the relatively high sensitivity with regard to holding cost is in escence due to the high stockout cost. As more stockouts occur with smaller lot-sizes.

6.3 Experimentations

Since none of the cost factors used to evaluate the inventory polices are defined by NUHI, they all had to be estimated. Even though there is logic behind the estimations, a more focused approach can be acquired by simply comparing the amount of money tied up in inventory for each policy and service level. Therefore the focus in this section will be on that as well as addressing the limitations for SM, LUC and EOQ mentioned in section 6.1. It is anticipated that by addressing these limitations, the policies in question will return better service levels. Since poor service levels resulted in high stockout costs, the inventory policies in question will become a more feasible option.

In table 6.3 it was shown that 36 of the 60 items in the s,S inventory have a service level of 99% or better. Keeping up such a high service level forces higher inventory levels and as a result more money tied up in inventory. This was demonstrated in table 6.2. Inventory levels can be greatly reduced if a target service level is set for the inventory and allowing most items to stock out on occasion. To demonstrate this, a simple heuristic method was created for the EOQ inventory.

The heuristic method alternatively raised the re-order and order quantity points by multiplying them with a factor of 10% in each iteration. The method stores the re-order and order quantity points for each item and changes them for the most improved items in each iteration. The items with the worst service level improve faster than the ones already with a good service level so the method forces the inventory to spread stockouts more evenly on all items. The method therefore addresses the issues the EOQ inventory had with its assumptions not applying for the current demand patterns.

Table 6.7 Service level and ISK tied up in inventory for a modified EOQ policy

Service Level	93,0%	94,4%	95,0%	96,0%	97,0%	97,8%
ISK in inv. (ISK)	2.690.173	2.794.846	2.890.150	3.149.328	3.548.519	3.909.163

Table 6.7 displays the results of the heuristic method. The average service level is shown with the corresponding amount of ISK tied up in inventory. The service level furthermost to the right matches the service level provided by the s,S inventory but reduces the average amount of ISK tied up in inventory by approximately 15%. The EOQ inventory with a target service level of 97% reduces the amount of money tied up in inventory by approximately 25%. For these two target service levels the minimum service level for each item was set as 94%. In table 6.8 the service level distribution for these two inventories can be found. If compared to table 6.3 it is clear that by spreading stockouts on all items the inventory level will decrease.

Table 6.8 A comparison on service level distribution for a modified EOQ policy

Policy	100%	100%>SL>99%	99%>SL>98%	98%>SL>94%
EOQ – 97,0	1	3	10	46
EOQ – 97,8	1	18	13	28

The main issue with the SM and LUC policies was that the forecasting they operated with was not accurate enough. In other words, the forecasting method lacked visibility. One possible way to rectify this is to introduce safety stock to these two methods. However it is much more effective to simply increase the visibility. Therefore the assumptions of the model were changed and the SM and LUC methods were given visibility of 1-7 review periods. In other words, if the visibility was set as 3 review periods, the forecast used to calculate lot sizes had its first 3 review periods precisely accurate while the forecast for periods 4-20 were created as before. The results can be seen in table 6.9.

Table 6.9 The performance of SM and LUC with better visibility

		SM	**LUC**
1 review period	Total cost (ISK)	3.476.824	2.947.150
	ISK in inventory	2.086.708	2.335.248
	Service level	85,2%	88,6%
3 review periods	Total cost (ISK)	2.127.104	1.897.581
	ISK in inventory	1.867.038	2.207.065
	Service level	90,6%	92,6%
5 review periods	Total cost (ISK)	1.160.685	1.198.689
	ISK in inventory	1.777.221	2.114.376
	Service level	96,2%	96,3%
7 review periods	Total cost (ISK)	863.166	937.306
	ISK in inventory	1.723.995	2.054.020
	Service level	98,4%	98,1%

Table 6.9 clearly illustrates the importance of better visibility when conducting forecasts. Not only will more accurate forecasts decrease the amount of stockouts thus reducing total costs but it will also reduce the amount of money tied up in inventory. The reason for that is that with better visibility the need for barricading the inventory with high inventory levels against big orders becomes unnecessary. It is also interesting to note that with better visibility the SM method performs better than LUC. With the current cost parameter estimations the LUC method tends to create lot sizes for more periods, which is unnecessary with good visibility.

Improving visibility can be a tall order especially with the amount of stock rooms the central storeroom services. However, after looking through the data NUHI provided there are several items, twelve to be exact, that are ordered only by three wards or even fewer. It is more plausible that visibility could be increased for those items. Therefore a final experiment was conducted where two inventories were created where these items were controlled with the SM method with a 5 review periods visibility. All other items were controlled with the EOQ inventory furthermost to the right in table 6.7 or the s,S policy. The results can be seen in table 6.10. As seen in the table, by combining SM with the ROP policies not only improves the service level but also greatly reduces the amount of ISK tied up in inventory.

Table 6.10 Service level and ISK tied up in inventory for a s,S-SM and EOQ-SM inventory

	s,S-SM	**EOQ-SM**
Service level	98.6%	98.2%
ISK in inv.	3.638.938	3.042.804

7 Conclusion, discussion and future research

This chapter will conclude the study by answering the research question put forward in the introduction of this thesis and discussing the simulation results. The conclusion is followed by a discussion on the assumptions behind the simulation results. Finally recommendations are proposed and future research suggested.

7.1 Conclusion

In the introduction of this thesis the following research question was put forward:

- Can any of three selected Material Requirement Planning (MRP) methods reduce inventory and inventory related costs at the central storeroom?

In order to answer the question an inventory simulator was developed Mathworks-Matlab. The inventory simulator was used to compare the three proposed MRP methods, EOQ, SM and LUC to the central storerooms current method of choice, a s,S policy. The main input for the simulator was daily demand data for 60 A-class items stocked at the central storeroom. The data was provided by NUHI and spanned roughly 3 months. The methods under consideration were compared based on the average amount of ISK tied up in inventory and total cost. The total cost was defined as the sum of purchasing cost, stockout cost, holding cost and order cost. All cost factors, except purchasing cost, had to be estimated as NUHI has not defined these factors.

Under simulation the three proposed methods did not reduce inventory and inventory related costs compared to the method currently used at the central storeroom. Simulation showed that the three proposed methods reduced significantly the amount of ISK tied up in inventory compared to the s,S policy. However, the reduction came at a cost as the three proposed methods provided a significantly worse service level compared to service level provided by the s,S policy. The poor service level resulted in high stockout costs for all three proposed methods, as the stockout cost was deliberately set relatively high due to the nature of the hospital industry. The high stockout costs resulted in a significantly worse performance by the three proposed methods compared to the s,S policy with regard to total cost. On a further note the SM and LUC policies performed significantly worse than the EOQ policy while tying up a slightly less amount of ISK in inventory.

With demand uncertainty high at the central storeroom inventory, the results are along the same lines as those of Johansen (1999) who concluded that s,S policies perform better than SM with high demand uncertainty. However the results come in contrast with the findings of DeScioli (2005) who concluded that the EOQ policy would return a 99% service level for items with intermittent demand.

The reason behind the poor service provided by the EOQ policy was that one of the key assumptions in the EOQ model does not apply for many of the items under consideration.

The assumption is that demand is known and constant. However, since the average demand quantity per review is in many cases much lower than a common order quantity, the EOQ model has a tendency to underestimate the optimal amount of units to keep in stock. This results in vulnerability towards spikes in demand and as a result too many stockouts.

In the case of SM and LUC the poor service level provided was a result of inaccurate forecasts. In order to calculate lot-sizes these methods require a demand forecast. With one of the assumptions of the inventory simulator being that all orders and order quantities are stochastic and independent, the forecasting method was not provided with a visibility into future demand. This resulted in inability to accurately predict when spikes in demand would occur and as a result frequent stockouts.

A sensitivity analysis on the three estimated cost factors showed that the SM, LUC and EOQ methods were most sensitive with regard to stockout cost and holding cost. The sensitivity towards the stockout cost is unsurprising as the three methods return poor service levels. The sensitivity towards the holding cost is essence due to stockout cost as well since all three methods keep fewer units in stock with increasing holding cost, thus being vulnerable to spikes in demand. Furthermore, the sensitivity analysis illustrated that the s,S policy is very sensitive with regard to holding cost, which suggests that inventory levels are perhaps too high.

A further analysis on service level showed that this was the case as 39 items out 60 in the s,S inventory had a service level of 99% or better. In order to keep up such high service level a relatively large safety stock is required, thus binding more money in the inventory at any given time. By experimenting with the assumptions of the inventory simulator and the assumptions made in the EOQ model, it was illustrated that by adjusting the service level for each item, an average service level equal to the one provided by the s,S policy can be acquired while reducing the amount of money tied up in inventory by 15%. Also, it was shown that by improving visibility the SM and LUC methods performed very well, providing high service level and greatly reducing the amount of ISK tied up in inventory.

7.2 Discussion

In the introduction of this document the four goals the hospitals supply chain uses to maximize patient care were mentioned. These four goals can however not be achieved simultaneously as they are inherently conflicting. For example one can easily maximize product availability by stocking large amounts of inventory but that inherently requires more storage space and ties up more money in inventory. So which goal is the most important?

There are several product characteristics which will impact the decision on the appropriate supply chain and inventory control; unit price, physical size, demand, variability and criticality. These characteristics also define the weighting of each of the supply chain goals. One characteristic is particularly relevant to this study and that is criticality. Criticality determines the desired service level and stockout cost. The main objective of this study was to compare and evaluate three MRP methods to the one used at the central storeroom by comparing total inventory related costs. None of the cost factors used to calculate total cost are defined by NUHI so cost comparison becomes less focused and perhaps a bit of a stab in the dark.

The central storeroom manages a wide spectrum of items or over 6.000 different line items. The items vary from printing paper to surgical equipment. As a result the stockout cost was not a fixed value for all items but set as moderately high for all items or 7% of the unit price. However, the simulation results show that 39 out of the 60 items under consideration have a 99% service level or better. That suggests that stockouts are strictly avoided for those items and perhaps the stockout cost should be set higher. That also suggests that ensuring product availability is the supply chain goal with the highest priority. But should that be the case?

The demand pattern for the items under consideration is very different from one item to the other and there is also high demand uncertainty. The demand uncertainty is a result of a behavior that is perhaps a bit strange. Take for example the bottom item in figure 5.5, for that item there are many periods with no units ordered and some periods with demand for 10, 20 or 30 units. This resembles a demand pattern that is common for multi-echelon inventories.

Multi-echelon inventories often experience some periods where there is a spike in demand and other periods with no demand. This happens since the multi-echelon inventory, in this case the central storeroom, doesn't receive orders that demonstrates true usage pattern of the supplies. Multi-echelon inventories receive orders when other inventories, which the multi-echelon inventory serves, reach their safety stock. This also means that shortage at the multi-echelon inventory doesn't demonstrate true shortage within the supply chain system.

To give indication on whether this multi-echelon theory stood on valid grounds, the author visited one of the wards that the central storeroom receives orders from and uses the Kanban system. That visit confirmed this suspicion as the actual usage was much more stable than the daily demand suggested. In the case of the bottom item in figure 5.5 the actual usage was a fairly stable 2-3 units per working day and that the reason for why they placed an order at the central storeroom for 20 units is that they reached their re-order point and needed to stock up. This therefore explains why the performance of the EOQ model in this study is not as good as the one presented by DeScioli (2005).

This demand pattern was the root of the main problem the SM and LUC methods had, which was their poor service level. They used a forecasting method based on a method developed by J. D. Croston for intermittent demand. Since the forecasting method is based on statistical information, Croston's method is very good for modeling demand over the course of several weeks or perhaps months. The method however, fails at predicting accurately when spikes occur and therefore increase the likelihood of either too big lot sizes or crucially too small lot sizes. This actually confirms one of the drawbacks with MRP methods as mentioned in chapter 3.3; "Hence if the input data, MPS, turns out to be inaccurate then the output data is likely to be inaccurate as well, with additional manufacturing costs".

After a literature review on multi-echelon inventories it seems that inventory related costs for such inventories are reduced for example with better visibility within the supply chain or with time-series analysis. These methods should better formulate the demand by not only predicting that a spike in demand will occur but crucially, predict fairly accurately when the spikes occur.

It was illustrated that with a better visibility the SM and LUC methods perform much better than only with a forecast based only on statistical information. Table 6.8 shows that with better visibility the service level will not only increase but the amount of money tied up in inventory will drop as well. This is a similar trend that organizations look to when adopting the JIT/Kanban. Krajewski (1987) noted that the reason for Kanbans increasing popularity was that it was a convenient way on adopting small lot sizes. With so much demand variation at the central storeroom, perhaps the combination of better visibility and SM/LUC is the key for reducing inventory at NUHI's central storeroom.

When the Kanban system was introduced at NUHI the general rule was that each container would hold supplies for one week divided by the number of scans each week. Therefore, depending on the number of scans each week, the stock rooms will hold supplies for two weeks (if scanned once a week) and four days (if scanned three times a week).

The author received information on the order frequency for items in a stock room where scans occur three times a week. The most common order frequency was once a month or once a fortnight. Only a handful of items are ordered three times a week. This suggests that the stock room holds too much stock, in fact the stock room manager noted that there was not room in the stock room for all the supplies she had received. This also suggests that the actual demand for items varies from week to week and perhaps another inventory policy is better suited for these stock rooms. This speculation does however need a closer look in order to provide an informed recommendation.

If the author were to repeat the research, a slightly different approach to the problem at hand would be undertaken. The demand for fewer items would be taken into account but the usage would be monitored at the actual point of use. In other words the author would take into account the multi-echelon nature of the central storeroom inventory. This would allow for more accurate demand forecasts and give the SM and LUC methods a better chance in competing with the ROP policies.

7.2.1 The research process

For many reasons the research process for this study was not ideal. However the author did gain invaluable experience by falling into many pitfalls along the way. A more structural and scientific approach to the process would have been necessary. Creating a realistic time-schedule and sticking to it would have helped keep the research focused and on track. Lastly, the author should have been more critical and question more the information and data he was given. That would minimize the likelihood of misunderstandings and provide a more insightful report.

7.3 Recommendations

The Kanban system was adopted at NUHI in 2004 and a comparison with the Price Consumer Index indicated that the impact expected from the Kanban system is perhaps not as positive as hoped for. A conclusive evaluation on the Kanban systems performance could however not be acquired as NUHI does not defined inventory related costs such as stockout cost, holding cost and setup cost. Nor does it have a desired service level. These factors could vary from one item to the other as some are more critical, some expire sooner than others and so on.

To be conclusively able to evaluate the performance of their system, both the Kanban system and the s,S policy used at the central storeroom, NUHI must define these factors. Also, a process protocol when re-defining the re-order and order up-to points in the s,S could help result in a better inventory performance.

It seems that the multi-echelon nature of the central storeroom is tackled with the practice of adjusting the re-order and order up-to points. However, the simulation results suggest that this practice results in too much inventory. That is in accordance with AGR’s concerns when proposing the new system as they identified the money tied up in the central storeroom inventory as a potential flaw.

Simulation showed that improving visibility seems to be the key for reducing the money tied up in the central storeroom inventory. Improving visibility enables the central storeroom to know when an order will be placed for a given item, thus removing the need for keeping it in stock. NUHI should experiment with combining better visibility, by improving information flow, with lot-sizing methods such as SM and LUC. Items that are ordered by only a few wards could prove to be a good place to start.

Simulation has also shown that by adjusting the service level, the money tied up in inventory can be reduced significantly. However without information on criticality and desired service level this can not be conclusively demonstrated. Nonetheless, since the shortages at the central storeroom don’t demonstrate true shortage within NUHI’s supply chain, the central storeroom should adjust the service level for A-class items.

7.4 Future research

A research where the central storeroom inventory is modeled as a multi-echelon inventory could prove beneficial. There exist several multi-echelon modeling techniques who aim at removing noise from demand patterns. This is done for example with time-series diagnosis and improving data integrity by improving data flow. If the demand patterns could be modeled more accurately and improve visibility that would lead to more accurate demand forecasts. MRP methods such as SM and LUC could then prove to be ideal lot sizing methods for the central storeroom inventory.

The Kanban system originates from the Toyota Production System (TPS). It is well documented (Spear & Bowen 1999) that there is more to TPS than Kanban. Should NUHI decide to stick with the Kanban system a research to determine whether NUHI could benefit from adopting other aspects of TPS, such as Jidoku, is perhaps in order. There are examples of Hospitals adopting large proportions of TPS with great success (Sum et al. 1995) so NUHI might want to consider developing a similar production system. Also, if possible, a JIT-stockless system as presented by Nathan and Trinkaus (1996) and North (1994) could prove beneficial.

Finally, in order to reduce inventory at the wards NUHI should look into the use of Automated Point of Use systems. One of the advantages of Kanban is the visual control the tickets provide. APU systems provide this visual control through a computer and have proved to be useful as put forward by Valestin (2001). APU systems could perhaps be used for items with most demand variation while the more stable items stay in the Kanban system.

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Appendix A

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Inventory Simulator designed for calculating inventory related costs
% for the s,S policy used at NUHI's central storeroom
% Copyright © Eymundur Sveinn Leifsson, 2012
%
% Inputs:
% simdata = simulated daily demand
% minmax = array that contains re-oder and order up-to points for
%          s,S, base order quantity and unit-price
% adata = actual daily demand data
%
% Outputs:
% costss = total cost for the s,S policy
% iss,hss,oss,puss and pess = inventory level, holding cost, order cost
%                             purchasing cost and penalty cost for each
%                             review period respectively.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [costss,iss,hss,oss,puss,pess] = ss(simdata,minmax,adata)
   mult = minmax(:,3);
   uprice = minmax(:,4); setupcost = 80; interest = 0.00073;
   [fjd,fjv] = size(gogn); %number of days and items in the original data
   fjs = length(simdata); %number of simulated days
   costss = 0; %Total Cost for the s,S policy
   %re-order and order up-to points for each item
   min = minmax(:,1); maxi = minmax(:,2);
   %initiating putputs
   iss = zeros(fjs,fjv);
   hss = zeros(fjs,fjv); oss = hss; puss = hss; pess = hss;
   ilevelss = simdata(1,:); %initial inventory level
   for i = 1:fjs
      for j = 1:fjv
         demand = simdata(i,j); %demand for item j on day i
         ilevelss(j) = ilevelss(j) - demand;
         iss(i,j) = ilevelss(j); %inventory level for item j after day i
         if ilevelss(j) > 0
            iss(i,j) = ilevelss(j)*uprice(j)*interest; %holding cost
            costss = costss + iss(i,j); %update total cost
         end
         if ilevelss(j) < 0
            pess(i,j) = abs(ilevelss(j))*uprice(j)*0.07; %penalty cost
            costss = costss + pess(i,j);
         end
         if ilevelss(j) <= min(j)
            oss(i,j) = setupcost;
            % determine order quantity
            while ilevelss(j) < maxi(j)
               ilevelss(j) = ilevelss(j) + mult(j);
               puss(i,j) = puss(i,j)+mult(j)*uprice(j); %purchasing cost
            end
            costss = costss + puss(i,j) + oss(i,j);
         end
      end
   end
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Inventory Simulator designed for calculating inventory related costs
% for the EOQ-model
% Copyright © Eymundur Sveinn Leifsson, 2012
%
% Inputs:
% simdata = simulated daily demand
% minmax = array that contains re-oder and order up-to points for
%          s,S , base order quantity and unit-price
% adata = actual daily demand data
%
% Outputs:
% coste = total cost for the EOQ-model
% ie,he,oe,pue and pee = inventory level, holding cost, order cost
%                              purchasing cost and penalty cost for each
%                              review period respectively.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [coste,ie,he,oe,pue,pee] = eoqinv(simdata,minmax,adata)
   mult = minmax(:,3);
   uprice = minmax(:,4); setupcost = 80; interest = 0.00073;
   [fjd,fjv] = size(gogn); %number of days and items in the original data
   fjs = length(simdata); %number of simulated days
   coste = 0;
   %retrieve re-order and order quantity
   QR = eoq(adata,uprice,mult,setupcost,interest);
   Q = QR(:,1); R = QR(:,2);
   %arrays that keep track of inventory level,holding cost,order cost,
   %purchasing cost and penalty cost for each item
   ie = zeros(fjs,fjv); he = ie; oe = ie; pue = ie; pee = ie;
   ilevele = simdata(1,:); %initial inventory level for all items
   for i = 1:fjs
      for j = 1:fjv
         demand = simdata(i,j); %demand for item j on day
         ilevele(j) = ilevele(j) - demand;
         ie(i,j) = ilevele(j); %inventory level for item j after day i
         shortage = 0;
         if ilevele(j) > 0
            he(i,j) = ilevele(j)*uprice(j)*interest; %holding cost
            coste = coste + he(i,j); %update total cost
         end
         if ilevele(j) < 0
            pee(i,j) = abs(ilevele(j))*uprice(j)*0.07; %penalty cost
            coste = coste + pee(i,j);
            shortage = abs(birgdire(j));
         end
         if ilevele(j) <= R(j)
            oe(i,j) = setupcost;
            order = shortage + Q(j); %optimal order quantity
            % find a viable order quantity
            module = mod(order,mult(j));
            if module ~= 0
               order = order + (mult(j)-module);
            end
            ilevele(j) = ilevele(j) + order;
            pue(i,j) = order*uprice(j);  % purchasing cost
            coste = coste + pue(i,j) + oe(i,j);
         end
      end
   end
   %%
```

```
    % The EOQ-model
    % Inputs:
    % adata = actual daily demand data provided by NUHI
    % uprice = unit price for all items
    % mult = base order quantity for all items
    % setupcost = order cost
    % interest = holding cost interest
    % Outputs:
    % QR = re-order and optimal order quantity for all items
    %%
    function QR = eoq(adata,uprice,mult,setupcost,interest)
       QR = zeros(length(uprice),2);
       k = setupcost;
       for l = 1:length(uprice)
          lambda = ceil(mean(adata(:,l)));
          Q = ceil(sqrt((2*k*lambda)/(interest*uprice(l))));
          R = ceil(lambda*1.0);
          QR(l,1) = Q; QR(l,2) = R;
       end
    end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Inventory Simulator designed for calculating inventory related costs
% for the Silver-Meal Heuristic
% Copyright © Eymundur Sveinn Leifsson, 2012
%
% Inputs:
% simdata = simulated daily demand
% minmax = array that contains re-oder and order up-to points for
%          s,S , base order quantity and unit-price
% adata = actual daily demand data
% forec = daily demand forecast for entire simulation
%
% Outputs:
% costsm = total cost for the Silver-Meal heuristic
% ism,hsm,osm,pusm and pesm = inventory level, holding cost, order cost
%                             purchasing cost and penalty cost for each
%                             review period respectively.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [costsm,ism,hsm,osm,pusm,pesm] =
silvermeal(simdata,minmax,adata,forec)
   mult = minmax(:,3);
   uprice = minmax(:,4); setupcost = 80; interest = 0.00073;
   [fjd,fjv] = size(adata);%number of days and items in the original data
   fjs = length(simdata); %number of simulated days
   % initiating outputs
   costsm = 0;
   ism = zeros(fjs,fjv); hsm = ism; osm = ism; pusm = ism; pesm = ism;
   % initiating variables
   periods = ones(fjv,1); %number of periods a order is intended to cover
   count = zeros(fjv,1);   %number of periods since order was last placed
   ilevelsm = simdata(1,:); %initial inventory level for all items
   for i = 1:fjs
      for j = 1:fjv
         demand = simdata(i,j); %demand for item j on day i
         ilevelsm(j) = ilevelsm(j) - demand;
         ism(i,j) = ilevelsm(j); %inventory level for item j after day i
         count(j) = count(j) + 1;
         if ilevelsm(j) > 0
            hsm(i,j) = ilevelsm(j)*uprice(j)*interest;
            costsm = costsm + hsm(i,j);
```

```
      end
      if (ilevelsm(j) <= 0 || count(j,1) == periods(j,1))
         osm(i,j) = setupcost;  %order cost
         costsm = costsm + osm(i,j);
         fore = forec(i+1:i+20,j); %retrive forec. for next 20 periods
         % retrieve optimal lot size and the number of periods
         % the lot size is intended to cover
         [lots,nrp]=sm(fore,setupcost,interest,uprice(j),ilevelsm(j));
         periods(j,1) = nrp;
         if ilevelsm(j) < 0
            pesm(i,j) = abs(ilevelsm(j))*uprice(j)*0.07;
            costsm = costsm + pesm(i,j); %penalty cost
            lots = lots + abs(ilevelsm(j));
         end
        % find a viable lot size
         module = mod(lots,mult(j));
         if module ~= 0
            lots = lots + (mult(j)-module);
         end
         pusm(i,j) = lots*uprice(j); % purchasing cost
         costsm = costsm + pusm(i,j);
         ilevelsm(j) = ilevelsm(j) + lots;
         count(j,1) = 0;
      end
   end
end
%%
% The Silver-Meal Heuristic Algorithm
% Inputs:
% fore = 20 day forecast
% k = ordering cost
% h = holding cost
% uprice = unitprice for item j
% ilevel = inventory level for item j at time i
% Outputs:
% lots = optimal lot size
% nrp = number of periods the lot size is intended to cover
%%
function [lots,nrp] = sm(fore,k,h,uprice,ilevel)
   ind = find(fore);
   index = ind(1); % find first non-zero element in forecast
   cold = k; % initial cost function
   numerator = k; % numerator in cost function
   if index == 1;
      f = 2;
   else
      f = index+1;
   end
   for m = f:length(fore)
      term = (m-1)*h*uprice*fore(m); % new term for numerator
      denom = m; % denominator in cost function
      numerator = numeratore + term;
      cnew = numerator/denom; % new cost function
      if cnew > cold
         lots = sum(fore(1:m-1));
         nrp = m-1;
         break
      elseif (m == length(fore) && cnew < cold)
         lots = sum(fore);
         nrp = m;
```

```
            break
         else
            cold = cnew;
         end
      end
      %subtract current inventory level (if positive) from optimal lots.
      if ilevel > 0
         lots = lots - ilevel;
      end
   end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Inventory Simulator designed for calculating inventory related costs
% for the Least Unit Cost Heuristic
% Copyright © Eymundur Sveinn Leifsson, 2012
%
% Inputs:
% simdata = simulated daily demand
% minmax = array that contains re-oder and order up-to points for
%          s,S , base order quantity and unit-price
% adata = actual daily demand data
% forec = daily demand forecast for entire simulation
%
% Outputs:
% costluc = total cost for the Least Unit Cost Heuristic
% ilc,hlc,olc,pulc and pelc = inventory level, holding cost, order cost
%                              purchasing cost and penalty cost for each
%                              review period respectively.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [costluc,ilc,hlc,olc,pulc,pelc] =
leastuc(simdata,minmax,adata,forec)
   mult = minmax(:,3);
   uprice = minmax(:,4); setupcost = 80; interest = 0.00073;
   [fjd,fjv] = size(adata);%number of days and items in the original data
   fjs = length(simdata); %number of simulated days
   %initiating outputs
   kostluc = 0;
   ilc = zeros(fjs,fjv); hlc = ilc; olc = ilc; pulc = ilc; pelc = ilc;
   %initiating variables
   periods = ones(fjv,1); %number of periods a order is intended to cover
   count = zeros(fjv,1); %number of periods since order was last placed
   ilevelluc = simdata(1,:); %initial inventory level for all items
   for i = 1:fjs
      for j = 1:fjv
         demand = simdata(i,j); %demand for item j on day i
         ilevelluc(j) = ilevelluc(j) - demand;
         ilc(i,j) = ilevelluc(j); %inventory level for item j after day i
         count(j) = count(j) + 1;
         if ilevelluc(j) > 0
            hlc(i,j) = ilevelluc(j)*uprice(j)*interest;
            costluc = costluc + hlc(i,j);
         end
         if (ilevelluc(j) <= 0 || count(j,1) == periods(j,1))
            olc(i,j) = setupcost; %order cost
            costluc = costluc + olc(i,j);
            fore = forec(i+1:i+20,j); %retrive forec. for next 20 periods
            % retrieve optimal lot size and the number of periods
           % the lot size is intended to cover
            [lots,nrp]=luc(fore,setupco,interest,uprice(j),ilevelluc(j));
            periods(j,1) = nrp;
            if ilevelluc(j) < 0
```

```
            pelc(i,j) = abs(ilevelluc(j))*uprice(j)*0.07;
            costluc = costluc + pelc(i,j); %penalty cost
            lots = lots + abs(ilevelluc(j));
         end
         % find a viable lot size
         module = mod(lots,mult(j));
         if module ~= 0
            lots = lots + (mult(j)-module);
         end
         pulc(i,j) = lots*uprice(j); % purchasing cost
         costluc = costluc + pulc(i,j);
         ilevelluc(j) = ilevelluc(j) + lots;
         count(j,1) = 0;
      end
   end
end
%%
% The Least Unit Cost Algorithm
% Inputs:
% fore = 20 day forecast
% k = ordering cost
% h = holding cost
% uprice = unitprice for item j
% ilevel = inventory level for item j at time i
% Outputs:
% lots = optimal lot size
% nrp = number of periods the lot size is intended to cover
%%
function [lot,nrp] = luc(fore,k,h,uprice,ilevel)
   ind = find(spain);
   index = ind(1); % find first non-zero element in forecast
   cold = k/fore(index); % initial cost function
   numerator = k; % numerator in cost function
   if index == 1;
      f = 2;
   else
      f = index+1;
   end
   for m = f:length(fore)
      term = (m-1)*h*uprice*fore(m); % new term for numerator
      denom = sum(fore(1:m)); % denominator in cost function
      numerator = numerator + term;
      cnew = numerator/denom; % new cost function
      if cnew > cold
         lot = sum(fore(1:m-1));
         nrp = m-1;
         break
      elseif (m == length(fore) && cnew <= cold)
         lot = sum(fore);
         nrp = m;
         break
      else
         cold = cnew;
      end
   end
   % subtract current inventory level (if positive) from optimal lots.
   if birgdir > 0
      lot = lot - birgdir;
   end
end
```