Master's degree thesis

LOG952 Logistics

Product Variety on Inventory at Hospitals

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Preface and Acknowledgement

This thesis is submitted in partial fulfilment of the requirements for the Masters of Science degree in Engineering Logistics at Molde University College – Specialized University in Logistics, Norway. It is written through the spring semester 2016.

Even though many types of research have been done on the topic of product variety, its focus does not include hospitals. This research explores the topic on product variety in inventory at hospitals. With modesty, I submit my thesis within this field, with the hope to explore the impact of product variety on inventory at hospitals.

I would like to express my gratitude to my supervisor Associate Professor Bjørn Jæger for his thoughtful advice and constant feedbacks. I appreciate his encouragement and grateful for his inspiration that helped me to realize the thesis.

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Agaraoli Aravazhi

Summary

The main purpose of the study is to explore the influence of product variety on inventory at hospitals. The part of the study involves in understanding the behavior of product substitution for the different types of products such as sterile and non–sterile product. The potential product reduction and the corresponding impact on cost are studied. An additional study of the impact on product variety when the cost per order varies is done. The study includes the impact of product reduction in the Hospital's Central Storeroom on the subsequent level, the Nursing Units.

The current replenishment system for products is a homegrown ad-hoc system used in both the Hospital's Central Storeroom and the Nursing Units. A new model is developed for the Hospital's Central Storeroom for exploring all the possible combinations of products that can be substituted by similar products within a product group. At the Nursing Units, a new two-bin replenishment system is suggested. The impact of the product variety decision at the Hospital's Central Storeroom on the Nursing Units is studied.

Results were calculated for two cases, a simple baseline case when substitution is based on the functionality of the product only, and one case where the substitution is based on both functionality and the cost of each product. Overall, the results show 13.6 % reduction in total number for the baseline case. When including cost considerations, the effect is reduced to approximately 11% in average reduction of product variety, and an average reduction in cost of NOK 3.6 Million among all the scenarios.

When the cost per order variable changes there is an effect on the product reduction. For the Hospital's Central Storeroom, a cost reduction of NOK 3.6 million approximately is achieved. Among the Nursing Units, the results vary a lot depending on what products that can be substituted with each unit and product group. 54% of these units reduce their costs, and 46 % have a higher cost. In total it will be a slight increase, 1.25% (NOK 45,000) of cost savings made at Hospital's Central Storeroom. In conclusion, the total effect for both the Hospital's Central Storeroom and all the Nursing Units is NOK 3.56 million.

In conclusion, product variety on inventory at the hospital has a significant effect on the inventory level, making it an excellent study area of study for future research considering other issues like medical personnel preference, coordinated replenishment within and across hospitals, automated replenishment, floor space, and so on.

Keywords: *Product Variety, substitution effect, inventory management, hospital*

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1. INTRODUCTION

One of the key challenges of healthcare is to provide high–quality care at a very affordable cost. In Norway, the preliminary estimates of providing healthcare in 2015 constitute 9.9% (NOK 311 billion) of the Gross Domestic Product (GDP) whereas in 2012 the share was only 8.8% (NOK 260 billion) (Statistics Norway 2016). This data shows the increase in expenditure by the healthcare sector. In any system, there is the simultaneous presence of two major supply chain such as internal supply chain and external supply chain. Figure 1-1 below represents a typical hospital supply chain. Hospital's Central Storeroom and Nursing Units of the internal supply chain of the hospital are considered for the thesis. Since these are the echelons which manage and uses the logistics within hospitals.

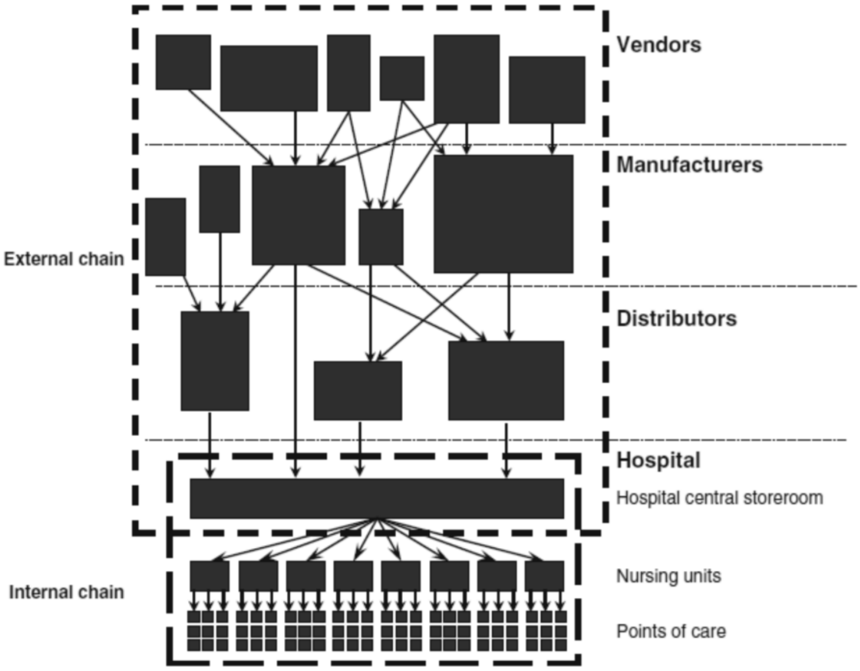


Figure 1-1: Typical supply chain of a hospital
Source: Rivard-Royer, Landry, and Beaulieu (2002)

The significant factor in the operating expense of a hospital is their logistics which constitutes 25 – 30% of the budget (Varghese et al. 2012). The healthcare logistics have a unique characteristic of using a large number of different products. An example for this can be found in the research done by Ramani (2006) at the Gujarat Cancer Research Institute, India, which uses about 2,000 items ranging from medicines to plastic wares. The products used in healthcare are perishable and durable, medical and non-medical as well as highly critical and non-critical by nature. These products are purchased either low volume or high volume and differs based on costs as low cost and high cost (DeScioli 2005). In general, these variations in the products have created both opportunities and issues for the firms. It is commonly referred by the term *product variety* (Blecker, Kersten, and Meyer 2005). Therefore, the thesis is built to explore the impact of product variety on inventory at hospitals focusing on the echelons Hospitals' Central Storeroom and Nursing Units.

The study of product variety has been carried out in different fields such as design (Fujita, Sakaguchi, and Akagi 1999), manufacturing (Hu et al. 2008), retail (Wan, Evers, and Dresner 2012, Nishino et al. 2014, Syam and Bhatnagar 2015) and so on. For example, the number of variants of shampoo Head and Shoulders produced by Procter & Gamble Co. reduced from 26 to 15 (Schwartz 2000). Also, retailers such as Walgreen Co. has reduced superglues types to 11 from 25 and Kroger Co. strips 30% of cereal varieties. Manufacturers such as ConAgra Foods, Campbell Soup has also done their product variety study (Brat, Byron, and Zimmerman 2009).

Each of the fields mentioned above outlines the product variety differently. Product variety in design terms it as product variety design or product variety deployment (Fujita, Sakaguchi, and Akagi 1999). The variety present in the existing product line is referred as the spatial variety and if the variety exists based on generations of a product is referred as the generational variety (Martin and Ishii 2002). In manufacturing, the variety is discussed based on the product attributes and the type of production process (Taylor and Ulrich 2001). In retail, the discussion of product variety is mostly based on the sale of different brands of a similar product (Jayaraman, Srivastava, and Benton 1998). When it comes to hospitals, the product variety can be understood as either the services they offer or the inventory used by them. In this study, the focus is on product variety on inventory at hospitals. So, wherever the term product variety is used, it refers to the inventory at hospitals.

1.1 Research Objectives and Questions

This research seeks to contribute to the understanding of the influence of product variety in hospitals based on different characteristics.

1.1.1 Research Objective – 1

In product variety studies, the focus is given on finding the optimum number of product variants for the firms (Jayaraman, Srivastava, and Benton 1998). In words it seems simple but in reality, it becomes complex. For example, if a person has to select from two product variants then three different options are created such as product 1 or product 2 or both of them. During the situation of three product variants, seven options are created, and it increases exponentially as the number of variants increases. Thus generating the problem to be complex in nature.

During this product selection process between variants, there occur few situations where the demand for eliminated products has to be substituted with the products selected. Each of these products differs based on their attributes. Due to which when the substitution occurs, the factor to convert the demand of one product to another varies. Therefore, the initial focus is to understand the behaviour of the substation effect during the product variety study.

The strategical decisions on product variety in firms depend on either decrease in spending or increasing the profit (Fujita, Sakaguchi, and Akagi 1999, Wan, Evers, and Dresner 2012, Nishino et al. 2014). In this thesis, we define two different cost functions namely the logistics cost and total cost. Here, the logistics cost is defined to constitute the cost factors such as order cost, inventory holding cost, and stock – out cost whereas the total cost constitutes the cost factors of logistics cost and the product cost. The product selection process is based on the comparison of values generated by the cost functions.

The cost functions have many input variables, and one such variable is the cost per order. This variable has a direct impact on the order cost and the order quantity generating an indirect impact on the cost factors such as inventory holding cost and stock – out cost. Thus, making it an important variable in the cost function. Therefore, the focus is set to study the optimal number of variants and the resultant cost impact when the variable cost per order changes.

Based on these focus points the below research questions are framed:

Research Question - 1: How does the product substitution factor influence product variety?

Research Question - 2: How does the product variety affect the spending at Hospital's Central Storeroom?

Research Question - 3: How does the variable cost per order influence the results on product reduction and their corresponding spending?

1.1.2 Research Objective – 2

"Every decision has a consequence" (Pajunen 2015). As the quote suggests, the decision made at a particular level might have an impact on the subsequent levels. In the first objective, the research focus is on the Hospital's Central Storeroom echelon. The next objective is therefore set to focus on the impactions it causes in the subsequent echelon the nursing units. Based on this the below research question is developed.

Research Question - 4: How does the product variety decision at the Hospital's Central Storeroom affects its subsequent echelon Nursing Unit?

1.2 Structure of the Thesis

The remainder of the thesis is presented as follows. Chapter 2 presents the existing literature about the fields of product variety and inventory management. It is followed by the discussion on the research methods in Chapter 3. Chapter 4 presents the summary of the results for Research Objective – 1 and detailed results and discussion for the Research Objective – 2 is also presented in this chapter.

The detailed answers for the Research Objective – 1 are presented as a research paper in Chapter 5 with the title as *"Investigation of Product Variety on Inventories at Hospital's"*. In this paper, the developed empirical model is presented along with the detailed analysis and discussion of the results.

Finally, the consolidated conclusion of the entire thesis and the possible future research are presented in Chapter 6. This is followed by the reference list and appendix containing other details.

2. LITERATURE REVIEW

In this chapter, the theoretical foundation of the research is presented. First section is about the challenges present in hospital logistics, followed by a section on product variety and then inventory management. The last section presents few research gaps found in the literature.

2.1 Challenges in Hospital Logistics

The initial step is to understand the common challenges present with hospital logistics. Hospital consists of multiple stakeholders and each of them has divergent interests. For example, the focus of healthcare personnel is to provide the best possible care to patients ignoring other factors and for supply chain staff the focus is to provide necessary logistics support for healthcare personnel's (Melo 2012). Figure 2-1 below represents some of the other challenges present in hospital logistics.

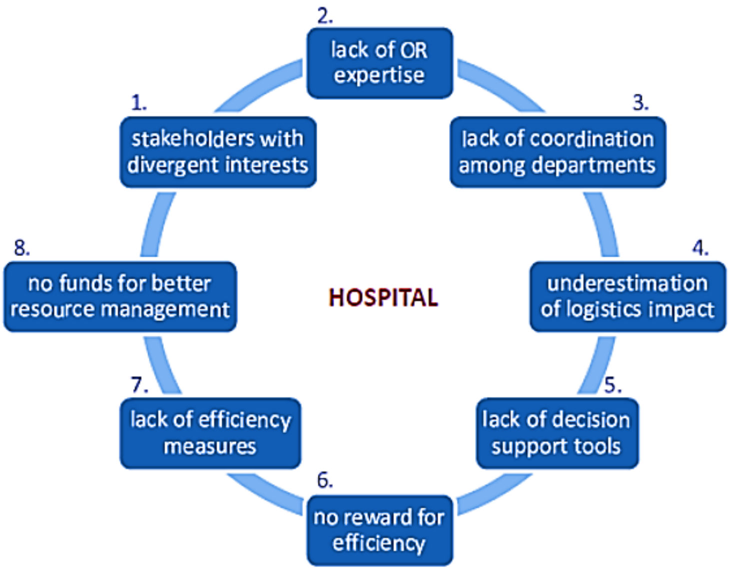


Figure 2-1: Common challenges in hospital logistics

Source: Melo (2012)

There also exists the underestimation of the logistics impact in hospitals (Melo 2012). These are seen in the example of various healthcare inventory optimization research. For example, Rachmania and Basri (2013) presented that 50% of cost reduction happens when following (s, Q) system for Oncology Medication for a Public Hospital in Indonesia. Apart from these challenges, the healthcare sector is slow in implementing the best practices created in supply chain management (McKone-Sweet, Hamilton, and Willis 2005).

2.2 Product Variety

A general approach in the study of product variety in the field of design is by using product hierarchy. It is also one of the simplest way for understanding the product (Malone 1987). Figure 2-2 below represents a typical product hierarchy structure. This is represented from the view of Fujita and Ishii (1997). It comprises of three levels namely the architecture level, configuration level and product level.

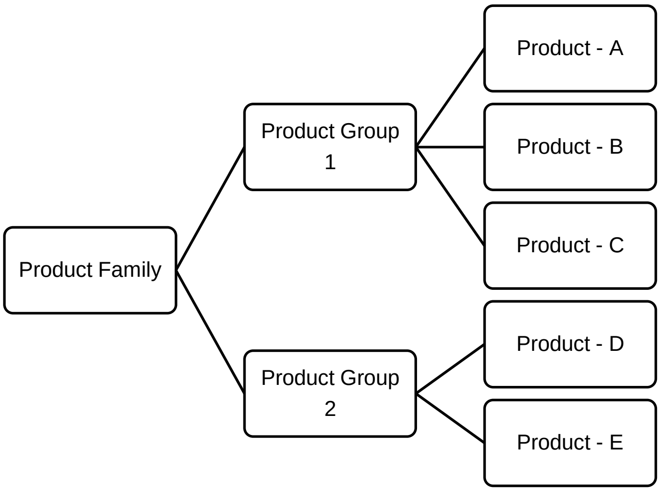


Figure 2-2: Product hierarchy
Source: Adapted from Fujita, Sakaguchi, and Akagi (1999)

The next step is to compare the hierarchy by mapping it based on different views. Erens and Verhulst (1997) defines three views namely customer view (required function), function view (technology realization) and manufacturing view (physical realization). Using this mapping method it is easier to analyse the entire product architecture.

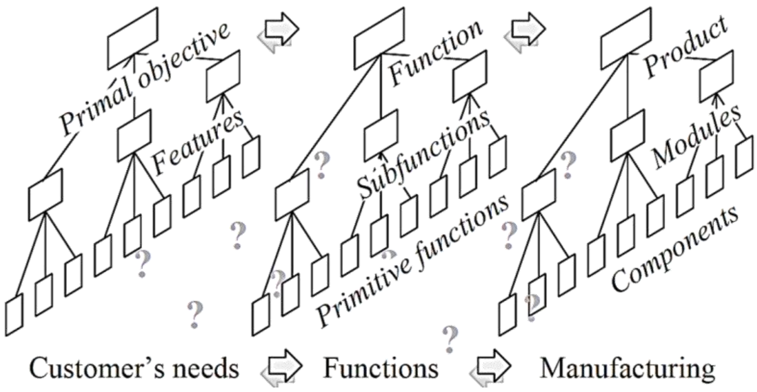


Figure 2-3: Mapping among customer, function and manufacturing
Source: Fujita, Sakaguchi, and Akagi (1999)

Due to these various needs, the number of variants of products increases. This variety seeking is because of different individuals behaviour (Tang and Ho 1998). Some of these are explored in some psychology research on consumer behaviour. An example is the research work done by Iyengar, Lepper, and Diener (2000) in which consumers product selection method based on different variants of jams and chocolates were studied.

Product variety have various impacts such as reduction in fill rates, sales quantity and its corresponding cost impact. Wan, Evers, and Dresner (2012) developed a model for finding the relationship between product variety with fill rate and sales. The result shows that, product variety and fill rate has negative impact with each other. Product variety generates an indirect effect on the sales. The important outcome of this research is that initially product variety increases the sales but later decreases it. Therefore, it is necessary to find the optimal product variety.

Syam and Bhatnagar (2015) developed a decision support model to determine the level of product variety based on marketing. A piecewise integer linear program along with simulation for making the decisions. The developed model is tractable and scalable which allows the cost functions that are specific to the firm. The result presented by them shows, cost and revenue plays an important role in the selection of optimal product variety level.

The research work of Nishino et al. (2014) presents in selecting product/service variety based on customer based preference. For this a case study on a large mall in Japan is chosen. The performance of customer's repeat rate of choosing a store in the mall is modelled. As the number of shops retained increases the repeat rate decreases.

One of the research work on product substitution is performed by Fujita, Sakaguchi, and Akagi (1999). This work is performed from the perspective of design. In this a cost optimization model is developed to find the best module combination for the product. An example of television receiver circuits is used for the evaluation of the model.

One of the work on product variety based on inventory management is done by Jayaraman, Srivastava, and Benton (1998). In this a mathematical model is developed to analyse different brands to increase the profit of a retailer. In this they included, partial replacement between brands for finding the optimal solution. Here, they considered the constraint of floor space and budget for the evaluation.

2.3 Inventory Management

"The branch of business management concerned with planning and controlling inventories" is the definition of inventory management in the dictionary from the American Production and Inventory Control Society (APICS) (Blackstone et al. 2013). Several kinds of research

have been made on inventory optimization in healthcare. The common reasons for the need of inventory management are overstocked, unjustified demand forecasting and the lack of IT support. One of the key issues in implementing the inventory management in hospitals is the fear on the unavailability of critical items causing life-threatening situations (Al-Qatawneh and Hafeez 2011). The main objective of inventory management is to reduce the investment in inventory with a balance of supply and demand of materials (Rachmania and Basri 2013).

Due to the probabilistic nature, safety stock has to be defined based on the service level (Rachmania and Basri 2013). In simple words, both the demand and lead time of products are probabilistic in nature (Silver, Pyke, and Peterson 1998). These variables are estimated separately and the equations (2-1) and (2-2) below calculates the expected demand and the standard deviation of demand during the lead time.

$$E(x) = E(L)\,E(D) \qquad (2\text{-}1)$$

$$\sigma_x = \sqrt{E(L)\,var(D) + [E(D)]^2\,var(L)} \qquad (2\text{-}2)$$

Where,

E(x) : Expected demand during the lead time

σ_x : Standard deviation of demand during the lead time

E(D) : Expected demand in unit period

var(D) : Variance of demand in unit period

E(L) : Expected length of the lead time

var(L) : Variance of length of lead time

The effect of stock–out situation is one important factor to be considered when dealing with the inventory in hospitals. There are different ways of defining the penalty cost when the stock – out occurs. One way of defining is the fractional charge of unit short. Since the products are taken from the shelves in the central storeroom and supplied to the internal sections, the specified service level (P2) has to be used (Silver, Pyke, and Peterson 1998).

There are different inventory optimization policies such as a continuous review system which contains order–point, order–quantity (s, Q) and order–point, order–up–to–level (s, S) and periodic review system which is periodic–review, order–up–to–level (R, S) and a combination of (s, S) and (R, S) system making it to (R, s, S) system (Silver, Pyke, and Peterson 1998). Many of the researchers have used this technique for optimizing inventory in healthcare. Rachmania and Basri (2013) Calculates the possible savings of 72% by using (s, Q) continuous review system and 45% by (R, S) periodic review system. Similar research done earlier by Varghese et al. (2012) using (r, Q) system and Al-Qatawneh and Hafeez (2011) uses the computer simulated model, provides the savings for 14% in their total inventory costs.

2.3.1 Replenishment Systems

The different inventory review methods mentioned above are adapted for inventory replenishments for hospitals and few of them are discussed below.

- *Requisition*: In this process, the nursing staff checks the demand for all products individually on a periodic basis and fills a form manually or electronically and send it to the central storeroom. The central storeroom staff arranges the products for picking and inform the nursing staff. Then, the nursing staff brings the products back to the nursing units and fills the shelf (Landry and Beaulieu 2013, Costa, Carvalho, and Nobre 2015). In this process, the average inventory in the system is higher, the degree of involvement of nursing staff is high, and so is the communication between the staff in the central storeroom and the nursing units (Landry and Beaulieu 2010).
- *Exchange carts*: The products consumed is placed in a cart and consumed. When the cart is either empty or on predetermined schedule, the cart is sent back to the central storeroom for replenishment (Persona, Battini, and Rafele 2008, Landry and Beaulieu 2013). Using this process, we will be having a higher average inventory in the system, but the degree of involvement of the nursing staff becomes less also the amount of information passed reduces (Landry and Beaulieu 2010).
- *Par level*: The process follows a periodic inventory management system. In this process, the central storeroom staff checks the available quantity in the shelf of the nursing unit and make an order for the product to bring it back to stock level (Landry and Beaulieu 2010, 2013). In this system, the amount of average inventory is low, and the degree of involvement of the nursing staff is also reduced, but the degree of the communication between the central storeroom staff and nursing staff is high (Landry and Beaulieu 2010).
- *Two – Bin System*: The product used is divided into two and placed into different bins (or boxes). Initially, a bin is placed one behind the other. When the first bin becomes empty, the information is passed on to the staff in the central storeroom for replenishment. Based on the replenishment order, the product is arranged for either picking or delivered to the nursing unit. This quantity is placed in the current empty

bin and placed back of the currently used bin (Persona, Battini, and Rafele 2008, Landry and Beaulieu 2010, Ygal, Harold, and Richard 2010, Melo 2012, Landry and Beaulieu 2013, Costa, Carvalho, and Nobre 2015). This process reduces the average inventory, the degree of involvement of the nursing unit and the degree of contact between the central storeroom staff and the nursing staff (Landry and Beaulieu 2010).

The Figure 2-4 below represents these replenishment processes based on the attributes of average inventory and degree of involvement and contact of the staffs. Other replenishment systems are user – driven unitary demand capture systems, weight control bins and RFID – enabled two – bin/Kanban systems (Landry and Beaulieu 2013).

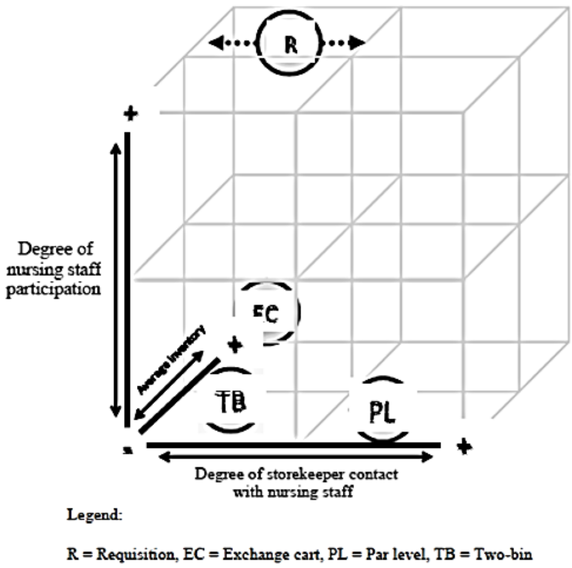


Figure 2-4: Different replenishment systems
Source: Landry and Beaulieu (2010)

2.4 Research Gaps

Based on the literature few research gaps were found and listed below.

- Focus on product variety on inventory at hospital is not explored.
- The combination of research between product variety and inventory management are limited.
- The product substitution with variable factor is not explored.
- When the study is made, it is limited to a single echelon and its subsequent effect on the below echelons are not explored.

3. RESEARCH METHODS

A combination of research techniques is used. The previous Chapter 2 presents the literature required for the study. This helps to gather the necessary qualitative information. This assisted in building a model for studying the impact of product variety on inventory at the hospital. In this model, all possible product substitution and its corresponding cost effect for a product group can be evaluated. The part of the model uses continuous review (s, Q) inventory system for cost calculation. The better way to understand the model is by making a case study research for achieving real time results (Yin 2014). The details of the case study are presented in the sub section below. Due to confidentiality, few details are withheld.

3.1 Case Description

A hospital from Norway is chosen for the study. In general, the two main categories of products used in a hospital are sterile products and non–sterile products (Persona, Battini, and Rafele 2008). This hospital uses 1,645 sterile products and 686 non–sterile products. The quantitative data collected in this case is presented below.

3.1.1 Data

All the products are classified in 10 different product families such as medical disposables, office supplies, laboratory supplies and so on. Both the external and internal orders created by the hospital for the last six years were collected. In this for each year a total of more than 6,000 external order placed by the Hospital's Central Storeroom to the supplier and more than 66,000 internal orders placed by the Nursing Units to the Hospital's Central Storeroom. From these order data, the product details are extracted. A total of more than 5,500 different products are used but based on the year 2015 data only 2,331 products were used making other data obsolete.

As mentioned in the literature above, the product architecture contains three levels such as product family, product group and products as mentioned in Figure 2-2 above (Fujita, Sakaguchi, and Akagi 1999). The currently available data does not contain the details of the product group. Using the concept of product mapping discussed in the above Chapter 2 the product groups are defined. In this, the classification is based on the function mapping of the products. During product substitution, the substitution factor has to be fixed. Based on the analysis of each product attributes within a product group, it is assigned manually. It generates a matrix formation when the values are assigned.

From the details of the external order, the statistical details such as average and variance of demand and lead time are evaluated. Based on the equations mentioned above, the expected demand during the lead time and standard deviation of demand during the lead time are calculated. This analysis is for Hospital's Central Storeroom level. Similarly, for each Nursing Units, the average demand is evaluated.

Currently, there is no information on the cost per order for placing an order. An assumption is made that, cost per order depends only on the time taken by the staff to create an order and place the received products back on the shelf. For the study on the influence of cost per order different scenarios on order time is listed below.

- Scenario 1: External order time 1.5 hours
- Scenario 2: External order time 1.0 hours
- Scenario 3: External order time 0.5 hours

At present, the hospital chosen for the study does not follow any standard replenishment system. Among the literature presented on replenishment systems, two – bin system offers better results for the hospitals. Therefore, a theoretical two – bin system is created for the analysis for achieving Research Objective – 2. For this, the time between replenishment is assumed to be seven days.

4. RESULTS

In this chapter, the summary of results for research objective – 1 and its details are discussed in the research paper. Also, detailed results of research objective – 2 is presented below.

4.1 Summary of Research Objective – 1

The results for a non – sterile product group containing three products which differ only the colour attribute and a sterile product group with two products which differ by size are presented for scenario – 1 in the research paper. The result shows that there is the potential impact of the product substitution factor. The product groups presented in the study shows the non – sterile group with substitution factor one, then the product with lowest unit price produces better results and for sterile groups with variable substitution factor resulted in usage of both the products is the best solution. Other scenarios also produce similar results which are presented in Appendix I.

The net product reduction and its effect on spending are presented for scenario – 1 in the research paper. The results show that approximately 11.2% of product reduction happens with its cost impact of 4.6% reduction between optimized inventory of all products used and minimized number of products. The other scenarios are presented in Appendix II.

The impact of variation of the input variable cost per order is explored in the research paper. The results show that, when the cost per order decreases, then the product variety study shows that the number of product usage increases.

4.2 Results of Research Objective – 2

The hospital contains multiple nursing units which offer different services to the patients and support to other internal units. The replenishment policy for the Nursing Units is designed to follow two – bin system. The cost factors involved with the two – bin system are the order cost, holding cost and the product cost.

The effect of product group decision made in the central storeroom has both positive and negative impacts on the nursing units of the hospital. Based on evaluation, 54% of the nursing units shows positive change when the time between replenishment is seven days. Still, the net impact on the overall cost value becomes negative for all scenarios. This excess cost lies between NOK 44,000 to NOK 45,500. It is summarized in the Table 4-1 below.

For better analysis, eight different nursing units are selected based on the number of product used. The nursing units selected are listed below.

1. Intensive care Section
2. Operation Section
3. Emergency Care Section
4. Surgery A Section
5. Surgery B Section
6. Medicine A Section
7. Medicine B Section
8. Neurological Section

	Approximate Cost Increase
Scenario – 1	NOK 45,318
Scenario – 2	NOK 45,139
Scenario – 3	NOK 44,035

Table 4-1: Approximate increase in cost spending based on product variety

Each of these nursing units is unique in nature and the products used between them differ in a broad perspective. These units use both the sterile and non–sterile products in different ratios. Figure 4-1 below represents this distribution. The number marked denotes the nursing unit number based on the list mentioned above. The units 1 and 2 uses the maximum number of products.

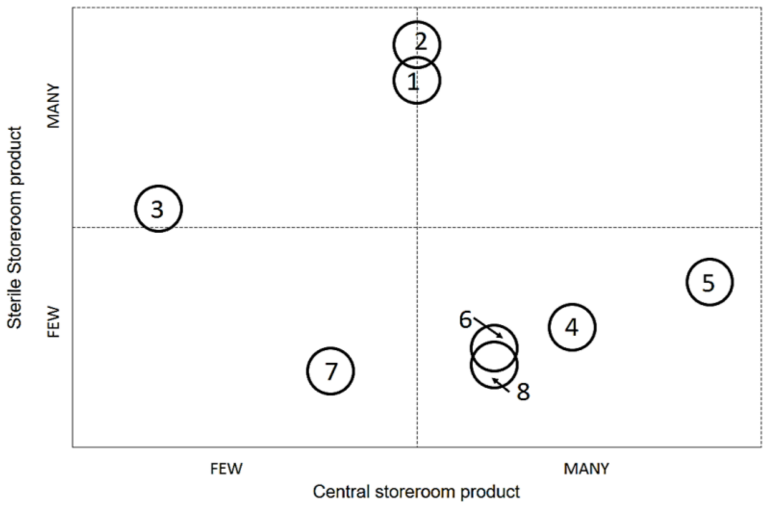


Figure 4-1: Product usage distribution between sterile and non - sterile products

Figure 4-2 below presents the results for the scenario – 1. The nursing units 1, 4 and 5 shows positive impact while the others have to spend in excess on the inventory if the product group decision is implemented. The cost factors that influence the results are the inventory holding cost and the product cost. Since there is no change in the number of orders placed by the units irrespective of the number of products used. Similar results are obtained in both scenario – 2 and scenario – 3 which is added in Appendix III.

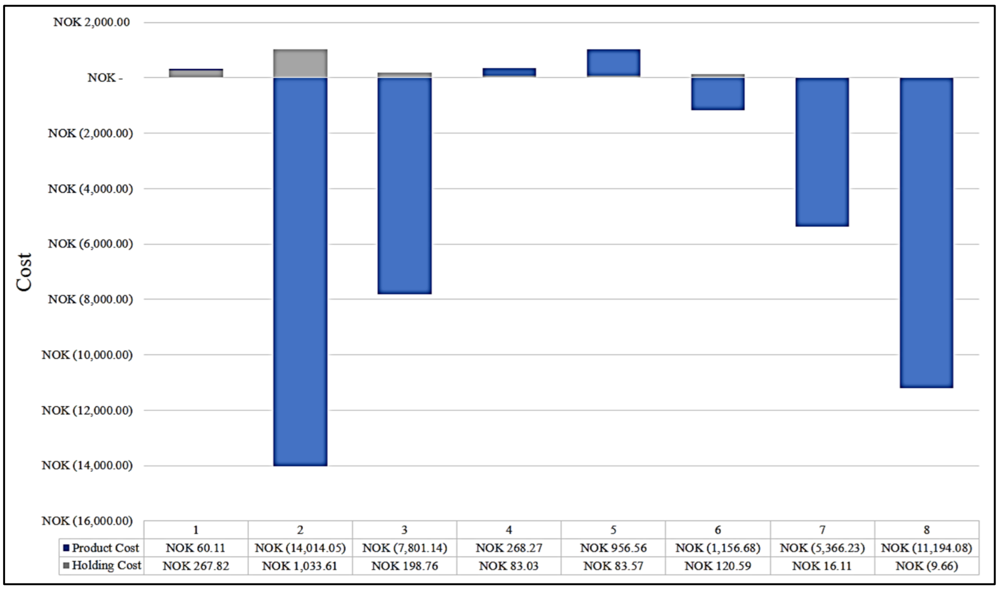


Figure 4-2: Effect of product variety on nursing units in Scenario – 1

During scenario – 1, the potential cost saving when the product variety decision on inventory made at the central storeroom from the present non – optimized situation is approximately NOK 3.62 Million. When the decision is implemented, then the potential cost increase in the nursing units is NOK 45,138. Therefore, the potential net saving reduces to NOK 3.57 Million. Assuming 50 such hospitals produce similar savings, then it results in a potential cost reduction of NOK 178.5 Million.

RESEARCH PAPER

Investigation of Product Variety on Inventories at Hospital’s

Abstract

The literature on product variety has shown to provide greater insights for the firms. However, little research has been conducted on product variety in the healthcare industry. This study aims to explore the influence of product variety on inventory at hospitals. A model is developed for exploring all possible product combination and substitutions. Here, the behaviour of product substitution for both sterile and non–sterile products in the hospital with substitution and cost factors are presented. The product variety reduction and its corresponding cost impact is discussed. The results show the hospital could have a potential product variety reduction of approximately 11% and cost savings from spending of approximately NOK 3.6 Million. An additional study of the impact on product variety decision on inventory when the cost per order varies is done. In conclusion, the results of product variety on inventory at hospital has promising results on both product and cost reduction. There is also potential for future results on various areas such as coordinated replenishments, automated replenishments and so on.

Keywords: *Product variety, inventory management, substitution effect, hospital*

5. INVESTIGATION OF PRODUCT VARIETY ON INVENTORIES AT HOSPITAL'S

5.1 Introduction

An important strategy for any organization is to decide the level of variants on the product usage which is commonly referred as product variety (Lancaster 1990). The study and implementation of product variety are done in different fields such as design (Fujita, Sakaguchi, and Akagi 1999), manufacturing (Hu et al. 2008), retail (Wan, Evers, and Dresner 2012, Nishino et al. 2014, Syam and Bhatnagar 2015) and so on. For example, retailers such as Walgreen Co. has reduced superglues type from 25 to 11 and Kroger Co. cut 30% of their cereal varieties. Firms such as Procter & Gamble, ConAgra Foods, Campbell Soup have also done product variety study (Brat, Byron, and Zimmerman 2009). These decisions were made based on increasing the profit margin (Syam and Bhatnagar 2015).

The study of product variety on inventory in healthcare is not focused upon despite their vast product usage. For example, Gujarat Cancer Research Institute, India purchases about 2,000 products from 12 product families namely, medicines and drugs, surgical, laboratories and so on (Ramani 2006). The lack of focus might be because, healthcare logistics is being slow for embracing the new theories and practices (Persona, Battini, and Rafele 2008). The hospital is one of the key players in the healthcare industry. When the term product variety is mentioned in a hospital, it also refers to the service provided by them. Since the approach of the paper is presented from the perspective of a supply chain manager, the term product variety represents the product variety on inventory.

The existing literature on product variety does not include the substitution of products with different attributes. Therefore, in this study, an investigation of product variety in healthcare is studied based on the product substitution factor and its corresponding influence of inventory cost. A model is developed for this investigation at the central storeroom level of the hospital. This model compares all the possible products substitution and combinations within a product group. An additional study on the impact of the cost per order is done.

The remainder of the paper is organized as follows. Section 5.2 provides the literature background for the study. It is followed by Section 5.3 which provides the research method followed in the study. Section 5.4 presents the details about the developed model for achieving the research objective. Next Section 5.5 presents the analysis and results generated from the model followed by Section 0 about the discussion on the results and recommendations drawn from it while conclusions and research limitations are discussed in the last Section 5.7.

5.2 Literature Review

The decision–making process in a hospital is made by different stakeholders and with divergent interests. Among them, the healthcare personnel's choices are weighed higher (Melo 2012). Each of the healthcare personnel has their choice of the products. This variety seeking behaviour is because of individual's diversity of choices (Tang and Ho 1998). Several types of researches are done based on the consumer choice of products. The work was done by Iyengar, Lepper, and Diener (2000) is a good example of it, but the study of product variety on inventory in healthcare is not present.

The work of Wan, Evers, and Dresner (2012) demonstrates the relationship of product variety between the fill rate and sales. An empirical model is used by them for the study. It is found that there is a linear relationship between product variety and fill rate. As the number of variety increases, there is a decrease in fill rate. When it comes to sales, as the variety increases the sales rises and eventually drops after a certain level. A method of optimizing the variety of shops to increase the customer satisfaction and profit level by using a large mall as a case study is presented in the research work done by (Nishino et al. 2014). Syam and Bhatnagar (2015) presents a mathematical and simulation model for making decisions. These decisions are to determine the level of variability in the products. The research is performed from the perspective of marketing personnel.

The product substitution is mostly prevalent in the research of product variety design in the field of design (Hu et al. 2011). The work of Fujita, Sakaguchi, and Akagi (1999) analyses the design of receiver circuit for television sets and its variety. In this selection of modules is made by comparing each of the modules by comparing the customer needs, functions and manufacturing needs (Erens and Verhulst 1997).

The method widely used in the retail field is studying product variety is by using inventory optimization approach (Jayaraman, Srivastava, and Benton 1998). In this study, the analysis is made for the selection of different brands based on mathematical modelling. The objective function for the model is to maximize the profit for the firm. Several types of researches propose the study based on the customer preference for product selection such as Green and

Krieger (1985) and the integer programming approach discussed by McBride and Zufryden (1988).

Separate inventory optimization studies have been undertaken in the field of healthcare. Rachmania and Basri (2013) Calculates the possible savings of 72% by using (s, Q) continuous review system and 45% by (R, S) periodic review system. Similar research was done earlier by Varghese et al. (2012) using (r, Q) system and Al-Qatawneh and Hafeez (2011) uses the computer simulated model, provides the savings for 14% in their total inventory costs.

5.3 Research Methods

The model developed in this paper is to assist the investigation of product variety in hospitals. The better way to understand the behaviour of the model is by making a case study research for achieving the real time results (Yin 2014). The details of the case study are presented below. Due to confidentiality, few details are withheld.

A hospital in Norway is selected for the study. Data were collected directly from the central database of the hospital for the last six years. These data contain more than 6,000 external orders each year. The products are distributed into 10 product families such as medical disposables, office supplies, laboratory supplies and so on. The type of products is divided into major two types such as sterile product and non – sterile product with 1,645 and 686 in number respectively.

The product architecture literature defines a product with 3 levels such as product family, product group and products (Fujita, Sakaguchi, and Akagi 1999). The data available does not contain the details of the product group. The literature on product mapping helps to define the product group for each product. The simple mapping is shown in Figure 5-1 below. This process creates 1481 groups in sterile products and 532 groups in non – sterile products. This product group numbers are the baseline for the analysis. A similar comparison on the product attributes is studied to assign the substitution factor between products within a group.

There is no information on the cost per order for placing an external. An assumption is made that, cost per order depends only on the time taken by the central storeroom staff to create an order and place the received products back on the shelf. For the study on the influence of cost per order different scenarios on order time are listed below.

- Scenario – 1: External order time – 1.5 hours

- Scenario – 2: External order time – 1.0 hours
- Scenario – 3: External order time – 0.5 hours

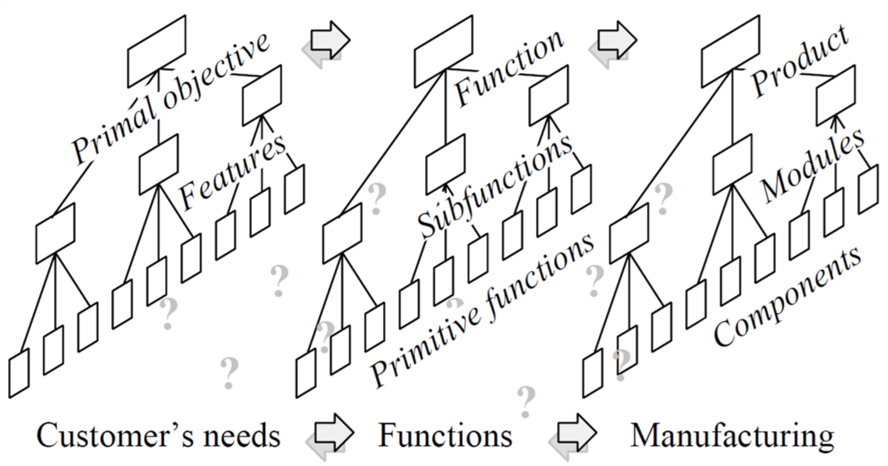


Figure 5-1: Mapping the needs from different viewpoints
Source: Erens and Verhulst (1997)

5.4 Model Development

The model developed for the study is discussed in the section.

5.4.1 Notations

The notations used in the model are listed below.

N : Number of products within the product group

M : Notation to represent the design point

TC : Minimum total cost for all design points in a product group

LC : Minimum logistics cost for all design points in a product group

TC^M : Summation of total cost of products in product group at the design point M

TC_i^M : Total cost of product i within the product group at the design point M

LC^M : Summation of logistics cost of products in product group at the design point M

LC_i^M : Logistics cost of product i within the product group at the design point M

C_{Oi}^M : Order cost of product i within the product group at the design point M

C_{Hi}^M : Holding cost of product i within the product group at the design point M

C_{SOi}^M : Stock – out cost of product i within the product group at the design point M

C_{Pi}^M : Product cost of product i within the product group at the design point M

A : Cost of placing an order

r : Carrying charge in % during the time horizon

v_i : Unit cost of product i within the product group

k_i : Safety factor of product i within the product group

B_{2i} : Penalty cost of product i within the product group in percentage of its unit cost during stock-out

$G_u(k_i)$: A special function of the unit normal (mean 0, standard deviation 1) variable. It is for finding expected shortage of replenishment cycle (ESPRC).

σ_{Li} : Standard deviation of demand during the lead time of product i within the product group

ID_i : Initial demand of product i within the product group

CD_i^M : Demand of product i within the product group at the design point M with the substitution factor

D_i^M : Demand of product i within the product group at the design point M with the conversion factor

Q_i : Ordering quantity of product i within the product group

U_i^M : $\begin{cases} 1, & \text{if product i within the sub-group is used in design point M} \\ 0, & \text{Otherwise} \end{cases}$

W_{ji}^M : $\begin{cases} 1, & \text{if product j is substituted by product i in design point M where } U_j^M = 0 \\ 0, & \text{Otherwise} \end{cases}$

S_{ij} : $\begin{cases} x, & \text{if x units of product i can replace 1 unit of product j within the sub - group} \\ 0, & \text{if product j cannot replace product i within the sub - group} \end{cases}$

Where x, is a real number

R_{ij} : $\begin{cases} 1, & \text{if } S_{ij} \neq 0 \\ 0, & \text{if } S_{ij} = 0 \end{cases}$

5.4.2 Model Description

Each product group contains a different number of products. For better understanding the model better, a product group containing three products is considered.

5.4.2.1 Objective Functions

The model contains two objective functions namely, logistics cost and total cost. The logistics cost contains the cost factors such as order cost, inventory holding cost, and stock – out costs. Whereas the cost function total cost contains the cost factors of logistics cost and the cost factor product cost. The equations (5-1) and (5-2) below represent the cost calculation for each product within a product at each design point.

$$LC_i^M = C_{Oi}^M + C_{Hi}^M + C_{SOi}^M \qquad (5\text{-}1)$$

$$TC_i^M = C_{Oi}^M + C_{Hi}^M + C_{SOi}^M + C_{Pi}^M \quad (5\text{-}2)$$

Next step is to calculate the summation of cost of all products within the product group. The equations (5-3) and (5-4) below represents the calculation for each design point.

$$LC^M = \sum_{i=1}^{N} LC_i^M \quad (5\text{-}3)$$

$$TC^M = \sum_{i=1}^{N} TC_i^M \quad (5\text{-}4)$$

The product variety decision is based on the design points with the lowest cost functions. The equations (5-5) and (5-6) represents the objective functions.

$$LC = \min(LC^M), \mathit{for\ all\ design\ points\ M} \quad (5\text{-}5)$$

$$TC = \min(TC^M), \mathit{for\ all\ design\ points\ M} \quad (5\text{-}6)$$

In order to reach the objective function, several steps have to followed and few constraints have to be fulfilled. These are discussed below.

5.4.2.2 Product Usage Rule

When there are N number of products within a product group, then it creates 2^N possible ways to use products within the product group. It is similar to the 2^k factorial design (Sanchez 2006). For all possibilities, at least one product has to be used. The equation below represents the same.

$$\sum_{i=1}^{N} U_i^M \geq 1 \quad (5\text{-}7)$$

For a product group with three products, 8 (= 2^3) possibilities occur. It is represented in the table below.

	U_1	U_2	U_3
0	0	0	0
1	0	0	1
2	0	1	0
3	0	1	1
4	1	0	0
5	1	0	1
6	1	1	0
7	1	1	1

Table 5-1: Possibilities for a product group containing 3 products

Due to the constraint represented by the equation above, the possibility 0 becomes invalid. Thus resulting in having only seven possibilities. Therefore, the number of possibilities for a product group becomes $2^N - 1$.

5.4.2.3 Estimated Product Substitution Rule

For each possibility, when a particular product is not used, its demand has to be substituted by another product. Irrespective of whether a product can substitute another product, different combinations of this substitution for each possibility are constructed. In each instance, only one product can substitute another product only once and there is no partial substitution. The number of substitution is equal to the number of products not used. These are represented by the equations (5-8) and (5-9) below.

$$\sum W_{ji}^{M} \ (over\ all\ i) = 1, for\ all\ j\ when\ U_j^M = 0 \tag{5-8}$$

$$\sum_{i=1}^{N} \sum_{j=1}^{N} W_{ji}^{M} = N - \sum_{i=1}^{N} U_i^M \tag{5-9}$$

There are various combinations of substitution for each possibility. The number of combinations that occur for each possibility is represented by the equation (5-10) below.

$$\left(\sum_{i=1}^{N} U_i^M \right)^{N - \sum_{i=1}^{N} U_i^M} \tag{5-10}$$

For example, in a product group of 3 products, with a usage of 2 products being used, the number of combinations is 2 ($=2^{(3-2)}$). The design point is represented as (possibility number, combination number). There are numerous possibilities and combinations based on the size of each product group. The table below represents the list of possibilities and design points based on the size of the product group.

Size of Product group	No. of Possibilities	No. of Design Points
1	1	1
2	3	3
3	7	10
5	31	196
8	255	41,393
10	1023	2,237,921
15	32767	1.39×10^{11}

Table 5-2: Number of design points

The Table 5-3 below represents the different design points for a product group containing three products along with the product usage and product substitution.

Design Points	U_1	U_2	U_3	W_1	W_2	W_3
1,1	1	0	0	0	0	0
				1	0	0
				1	0	0
2,1	0	1	0	0	1	0
				0	0	0
				0	1	0
3,1	1	1	0	0	0	0
				0	0	0
				1	0	0
3,2	1	1	0	0	0	0
				0	0	0
				0	1	0
4,1	0	0	1	0	0	1
				0	0	1
				0	0	0
5,1	1	0	1	0	0	0
				1	0	0
				0	0	0
5,2	1	0	1	0	0	0
				0	0	1
				0	0	0
6,1	0	1	1	0	1	0
				0	0	0
				0	0	0
6,2	0	1	1	0	0	1
				0	0	0
				0	0	0
7,1	1	1	1	0	0	0
				0	0	0
				0	0	0

Table 5-3: Design points for a product group with 3 products

5.4.2.4 Product Replacement Constraint

The modified demand based on the replacement factor is calculated from the equation (5-11) below.

$$CD_i^M = U_i^M \left[ID_i + \sum_{j=1}^{N} \left(1 - U_j^M\right) W_{ji}^M \, R_{ij}^M \, ID_j \right] \tag{5-11}$$

The part of the equation within summation calculates the demand added to a particular product. It is added to initial demand of the product. If the product is used, then this will be the changed demand of the product for this design point and when the product is not used the demand is nullified for this design point. The design point is validated by using the equation (5-12) below. In this, the modified demand of a product group is checked with the total initial demand of the product group. It is to make sure whether the replacement can meet the initial demand of products within the product group.

$$\sum_{i=1}^{N} CD_i^M = \sum_{i=1}^{N} ID_i \tag{5-12}$$

If the equation (5-12) is not satisfied, then the design point becomes invalid.

5.4.2.5 Modified Demand

For all valid design point, the new demand for product substitution is to be calculated. The equation (5-11) above is modified by changing the replacement factor by the substitution factor. The modified equation (5-13) is provided below.

$$D_i^M = U_i^M \left[ID_i + \sum_{j=1}^{N} \left(1 - U_j^M\right) W_{ji}^M \, S_{ij}^M \, ID_j \right] \tag{5-13}$$

5.4.2.6 Inventory Model

The next step is to make ordering line decision by calculating the different variables. In this model, continuous review system reorder–point and order–quantity (s, Q) and the calculation of cost factors is modelled based on modified demand.

5.4.2.6.1 Order Quantity

Order quantity has the most effect on costs in the inventory model. In general, the demand and the lead time are probabilistic in nature, the ordering quantity including this condition is calculated. Here, the penalty is defined as the percentage of unit cost (B2). It is represented by the equation (5-14) below for each product in a design point.

$$Q_i^M = \sqrt{\frac{2\ A\ D_i^M}{v_i\ r}}\ \sqrt{1 + \frac{B_{2i}\ v_i\ \sigma_{Li}\ G_u(k_i)}{A}} \qquad (5\text{-}14)$$

5.4.2.6.2 Order Cost

The ratio between demand and order quantity provides the expected number of order placed during the period. The equation (5-15) below represents the calculation of order cost for a particular period for each product in a design point.

$$C_{Oi}^M = \frac{D_i^M}{Q_i^M}\ A \qquad (5\text{-}15)$$

5.4.2.6.3 Inventory Holding Cost

The holding cost of the product is based on the expected on hand inventory. The expected on hand inventory constitutes average inventory stored and the safety stock. The safety stock is calculated by the equation (5-16) below.

$$SS_i = k_i\ \sigma_{Li} \qquad (5\text{-}16)$$

The holding cost for a product is calculated by using the equation (5-17) below.

$$C_{Hi}^M = \left(\frac{Q_i^M}{2} + k_i \sigma_{Li}\right) v_i\ r \qquad (5\text{-}17)$$

5.4.2.6.4 Stock – out Cost

Since the behaviour of the inventory movement is probabilistic in nature, there are chances of having stock-outs. The cost due to the occurrence of stock-out is calculated by the equation (5-18) below.

$$C_{SOi}^M = \frac{D_i^M}{Q_i^M}\ B_{2i}\ v_i\ \sigma_{Li}\ G_u(k_i) \qquad (5\text{-}18)$$

5.4.2.6.5 Product Cost

The final cost factor in the inventory model is the product cost. It is the cost of the purchase value of a product during a particular period. It is shown in the equation (5-19) below.

$$C_{Pi}^{M} = D_{i}^{M} \, v_i \tag{5-19}$$

5.4.2.7 Comparison Model

The next step to assist the decision–making process is to create a comparison between different costs. For this study, three different costs comparisons are done and listed below.

- The minimum cost value is compared with the cost when all products within the product group.
- The cost difference in percentage between numbers of product used is modelled.
- The cost difference in percentage between each design points is modelled.

These comparisons were made for both logistics cost and the total cost for each product group. This entire model is programmed in Microsoft Excel using Visual Basic Application (VBA) programming language.

5.4.3 Model Limitations

The developed model and the program contain limitations which are presented in the list below.

- The number of products within a product group can be a maximum of nine. It is because, when we have ten products within a product group we have a combination of 2,237,921 where MS Excel has a limitation of 1,048,576 rows.
- Model does not consider the constraint of floor space
- The ordering pattern is not coordinated in nature.

5.4.4 Calculation Assumptions

Assumptions made for the unavailable data for the study are listed below.

- Carrying charge for the products is 20%.
- The products for which the supplier details are missing, the expected length of lead time is 3 days and the standard deviation is 0 day.

5.5 Results

The baseline for the product variety study is based on the product group created using product mapping. The Table 5-4 below represents the initial number of products used in the hospital, the number of products after grouping and the potential reduction of products. This will help to understand the behaviour of the substitution factor and cost factor.

	Sterile Product	Non – Sterile Product	Total
Baseline Case:			
Initial Data	1645	686	2331
After Product Grouping	1481	532	2013
# Reduction	164	154	318

Table 5-4: Baseline for product variety study

5.5.1 Product Substitution Effect

To understand the behaviour of the products better, a non – sterile product group with substitution factor 1 and a sterile product group with variable substitution factors is presented.

5.5.1.1 Non – Sterile Product group

The notation *NSPi* is used for presenting the result of a non–sterile product group where *i* represent the product number within the product group. The result presented contains a product group with three products, for scenario – 1. The chosen product group contains products which vary based only by colour. Therefore, the substitution factors are 1. The Table 5-5 below represents the initial details of the product group containing the non – sterile products.

	Demand	Unit Cost
NSP_1	260	NOK 0.17
NSP_2	461	NOK 0.13
NSP_3	162	NOK 0.13

Table 5-5: Initial detail of products in a non - sterile product group

The first step is to create the baseline by finding the cost when all the products in the product group is used. For a product group with three products, usage of all products occur in the design point (7, 1) as shown in the Table 5-3 above. The net demand for the product group is 883 units resulting in a logistics cost of NOK 205.66 and total cost of NOK 330.49. Summary of this result is provided in Table 5-6 below.

Design Point: (7, 1)	NSP_1, NSP_2 & NSP_3 are used			
	NSP_1	NSP_2	NSP_3	Total
Demand (Units)	260	461	162	883
Logistics Cost (NOK)	NOK 72.43	NOK 82.94	NOK 50.28	NOK 205.66
Total Cost (NOK)	NOK 117.13	NOK 141.52	NOK 71.84	NOK 330.49

Table 5-6: Cost when all products in a non - sterile product group is used – Scenario 1

When there is a reduction of one product from the product group, it occurs in six design points for a product group containing three products. The Table 5-7 below represents the summary of the results. For example, assume the firm has to choose between the design point (3, 1) and (5, 1). The logistics cost created in these design points are NOK 175.19 and NOK 170.82 respectively. If only these values were presented, then the firm's actual spending for this product group will approximately increase by NOK 10 because of the product cost. Therefore, the firm has to choose total cost as their main objective function and not the logistics cost.

Design Point: (3,1)	NSP_1 & NSP_2 used and NSP_3 is replaced by NSP_1		
	NSP_1 (NSP_3)	NSP_2	Total
Demand (Units)	422	461	883
Logistics Cost (NOK)	NOK 92.25	NOK 82.94	NOK 175.19
Total Cost (NOK)	NOK 164.80	NOK 141.52	NOK 306.32
Logistics Cost Saving (%)			14.81%
Total Cost Saving (%)			7.31%

Design Point: (3,2)	NSP_1 & NSP_2 used and NSP_3 is replaced by NSP_2		
	NSP_1	NSP_2 (NSP_3)	Total
Demand (Units)	260	623	883
Logistics Cost (NOK)	NOK 72.43	NOK 96.40	NOK 168.83
Total Cost (NOK)	NOK 117.13	NOK 175.56	NOK 292.69
Logistics Cost Saving (%)			17.91%
Total Cost Saving (%)			11.44%

Design Point: (5,1)	NSP_1 & NSP_3 used and NSP_2 is replaced by NSP_1		
	NSP_1 (NSP_2)	NSP_3	Total
Demand (Units)	721	162	883
Logistics Cost (NOK)	NOK 120.54	NOK 50.28	NOK 170.82
Total Cost (NOK)	NOK 244.49	NOK 71.84	NOK 316.33
Logistics Cost Saving (%)			16.94%
Total Cost Saving (%)			4.29%

Design Point: (5,2)	NSP_1 & NSP_3 used and NSP_2 is replaced by NSP_3		
	NSP_1	NSP_3 (NSP_2)	Total
Demand (Units)	260	623	883
Logistics Cost (NOK)	NOK 72.43	NOK 98.55	NOK 170.98
Total Cost (NOK)	NOK 117.13	NOK 181.46	NOK 298.59
Logistics Cost Saving (%)			16.86%
Total Cost Saving (%)			9.65%

Design Point: (6,1)	NSP_2 & NSP_3 used and NSP_1 is replaced by NSP_2		
	NSP_2 (NSP_1)	NSP_3	Total
Demand (Units)	721	162	883
Logistics Cost (NOK)	NOK 103.69	NOK 50.28	NOK 153.97
Total Cost (NOK)	NOK 195.31	NOK 71.84	NOK 267.15
Logistics Cost Saving (%)			25.13%
Total Cost Saving (%)			19.17%

Design Point: (6,2)	NSP_2 & NSP_3 used and NSP_1 is replaced by NSP_3		
	NSP_2	NSP_3 (NSP_1)	Total
Demand (Units)	461	422	883
Logistics Cost (NOK)	NOK 82.94	NOK 81.12	NOK 164.06
Total Cost (NOK)	NOK 141.52	NOK 137.28	NOK 278.80
Logistics Cost Saving (%)			20.23%
Total Cost Saving (%)			15.64%

Table 5-7: Cost of 1 product removed from a non – sterile product group – Scenario 1

When only one product from the product group is used the savings increases except when NSP1 is the only product used. It is because the unit value for the product NSP1 is higher than the other products within the product group. The design points (2, 1) and (4, 1) shows a potential saving of more than 25%. In these design points the product used is NSP2 and NSP3 respectively. The summary of the results is shown in the Table 5-8 below.

Design Point: (1,1)	NSP_1 is used and NSP_2 & NSP_3 is replaced by NSP_1	
	NSP_1 (NSP_2, NSP_3)	Total
Demand (Units)	883	883
Logistics Cost (NOK)	NOK 133.39	NOK 133.39
Total Cost (NOK)	NOK 285.19	NOK 285.19
Logistics Cost Saving (%)		35.14%
Total Cost Saving (%)		13.71%

Design Point: (2,1)	NSP_2 is used and NSP_1 & NSP_3 is replaced by NSP_2	
	NSP_2 (NSP_1, NSP_3)	Total
Demand (Units)	883	883
Logistics Cost (NOK)	NOK 114.73	NOK 114.73
Total Cost (NOK)	NOK 226.94	NOK 226.94
Logistics Cost Saving (%)		44.21%
Total Cost Saving (%)		31.33%

Design Point: (4,1)	NSP_3 is used and NSP_1 & NSP_2 is replaced by NSP_3	
	NSP_3 (NSP_1, NSP_2)	Total
Demand (Units)	883	883
Logistics Cost (NOK)	NOK 117.31	NOK 117.31
Total Cost (NOK)	NOK 234.82	NOK 234.82
Logistics Cost Saving (%)		42.96%
Total Cost Saving (%)		28.95%

Table 5-8: Cost when only one product is used in non-sterile product group–Scenario 1

In summary, for increasing the savings, it is better to choose the design point (2, 1) in which only the product NSP2 is used. The total cost savings occurring due to this is 31%.

5.5.1.2 Sterile Product group

The notation SPi is used for presenting the result for a sterile product group. The result presented contains a product group with two products with the order time of 1.5 hours. The Table 5-9 below shows the initial details about the products.

	Demand	Unit Cost
SP_1	50	NOK 54.95
SP_2	37	NOK 73.53

Table 5-9: Initial details of the products in a sterile product group

The differentiation between the products within the product group is based on their size. Due to this, the substitution factor plays a major role in the analysis. The Table 5-10 below shows the substitution factor for this product group.

	SP_1	SP_2
SP_1	1	2
SP_2	1	1

Table 5-10: Substitution factor

The cost when all the products in the product group is used similar as done before. For a product group with only two products, there are three design points occur and in the design point (3, 1) all the products in the product group are used. The results of which is presented in Table 5-11 below.

Design Point: (3,1)	SP$_1$ & SP$_2$ is used		
	SP$_1$	SP$_2$	Total
Demand (Units)	50	37	87
Logistics Cost (NOK)	NOK 577.20	NOK 576.11	NOK 1,153.31
Total Cost (NOK)	NOK 3,324.46	NOK 3,296.70	NOK 6,621.15

Table 5-11: All products in the product group is used – Scenario 1

The number of product reduction in this product group possible is just one which occurs with two design points such as (1, 1) and (2, 1). During this reduction, the logistics cost saving results in more than 20%. Still, the total cost saving is negative. Therefore, when the firm considers logistics cost as the objective cost function, they will end up in spending more. The summary of these results is presented in Table 5-12 below.

Design Point: (1,1)	SP$_1$ is used and SP$_2$ is replaced by SP$_1$	
	SP$_1$ (SP$_2$)	Total
Demand (Units)	124	124
Logistics Cost (NOK)	NOK 903.11	NOK 903.11
Total Cost (NOK)	NOK 7,716.30	NOK 7,716.30
Logistics Cost Saving (%)		21.69%
Total Cost Saving (%)		(16.54%)

Design Point: (2,1)	SP$_2$ is used and SP$_1$ is replaced by SP$_2$	
	SP$_2$ (SP$_1$)	Total
Demand (Units)	87	87
Logistics Cost (NOK)	NOK 876.99	NOK 876.99
Total Cost (NOK)	NOK 7,274.05	NOK 7,274.05
Logistics Cost Saving (%)		23.96%
Total Cost Saving (%)		(9.86%)

Table 5-12: Only one product in the sterile product group is used – Scenario 1

In summary, both the products in the product group have to be used because the reduction by one product results in increased spending. This example is chosen to demonstrate not all the substitution in the product group will end up in the reduction of products.

5.5.2 Impact of Inventory Cost

In this section, the net product variety reduction and its corresponding inventory cost are presented in the Table 5-13 below for scenario – 1.

All the products are used

	Sterile	Non – Sterile	Total
Number of Products	1645	686	2331
Logistics Cost	NOK 663,507	NOK 245,603	NOK 909,110
Total Cost	NOK 7,651,830	NOK 5,572,990	NOK 13,224,920

Products after reduction

	Sterile	Non – Sterile	Total
Number of Products	1524	545	2069
Logistics Cost	NOK 636,228	NOK 215,468	NOK 851,696
Total Cost	NOK 7,123,596	NOK 5,483,927	NOK 12,607,524

Difference

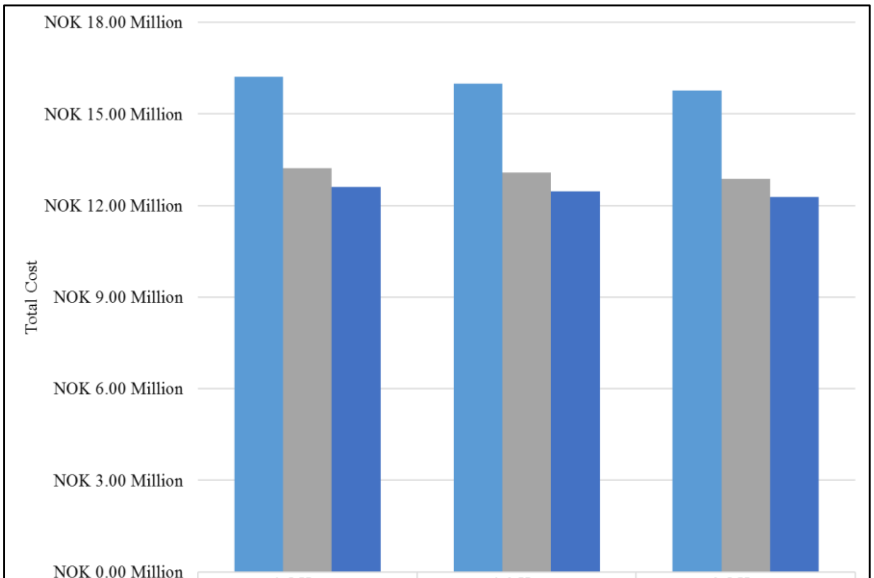
	Sterile	Non – Sterile	Total
# of products reduced	121	141	262
Logistics cost saving	4.11%	12.27%	6.32%
Total Cost saving	6.90%	1.60%	4.67%

Table 5-13: Summary of results when order time is 1.5 hours – Scenario 1

The product reduction is based on the objective cost function of total cost for each product group. In summary a total of 262 products are reduced which results in the logistics cost reduction of NOK 57,414 and NOK 617,396 approximately.

5.5.3 Impact of Cost per Order

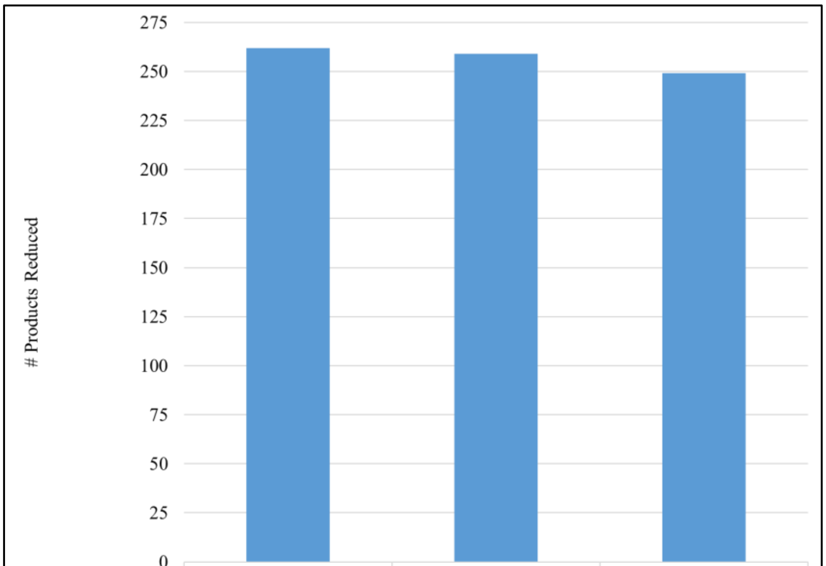
One of the objective of the paper is about the impact of cost per order on product variety decisions. The Figure 5-2 below represents the cost for different scenarios of cost per order. From the results, it is seen that irrespective of scenarios, when product variety decision is made, there is a potential saving when compared with present situation is approximately NOK 3.6 Million. Between the cost of all products used and the cost when the number of products are reduced, the potential saving remains to be approximately 4.6%.



	1.5 Hours	1.0 Hours	0.5 Hours
Present Model	NOK 16.23 Million	NOK 16.00 Million	NOK 15.77 Million
All Products	NOK 13.22 Million	NOK 13.07 Million	NOK 12.87 Million
Reduced Condition	NOK 12.61 Million	NOK 12.46 Million	NOK 12.28 Million

Figure 5-2: Cost based on different order cost

In summary, the potential saving irrespective of order time is approximately the same. The number of products used changes for different scenarios. The Figure 5-3 below represents the number of products reduced for different cost per order (order time). When the cost per order reduces, the number of product variety increases.



	1.5 Hours	1.0 Hours	0.5 Hours
Reduced Products	262	259	249

Figure 5-3: Number of products reduced based on product group decision

5.6 Discussions

The baseline for the study helped to understand the potential of the product variety reduction at hospitals. The results show that approximately 13% of the products currently used at hospitals could be replaced.

The substitution factor plays a major role in the resultant costs. In the provided result of a non – sterile group, with the product substitution factor for all possibilities is 1. This solution was to select only one product within the group of 3 products. The chosen product is with the lowest unit price among all the products within the group.

For the sterile group, the product substitution factor varies because of the size. There is no possibility of product reduction for this product group. The reason being, the difference in product unit price is less, and the corresponding substitution factor plays a role in the solution. If only product SP1 is used, then the product cost to pay for the replacement of one SP2 is NOK 109.90 whereas the price of product SP2 is NOK 73.53. Similarly, if the product SP2 is used, then the product cost for one replacement for one SP1 is NOK 73.53 whereas the price of product SP1 is NOK 54.95. Thus confirming the substitution factor plays a major role in the results.

As mentioned by various researchers, product variety has an adverse impact on the profit (Hu et al. 2008, Wan, Evers, and Dresner 2012). The results generated in the study also shows that product variety optimization helps in reduction of costs. A potential of approximately 4.6% (NOK 3.62 Million) could be saved if the product variety is implemented in the Hospital's Central Storeroom, which will reduce the number of products to approximately 11%.

The cost per order has an effect on the product variety decision. As the cost per order decreases the optimum number of products that can be used increases. It is the trend obtained from the results. Still more research has to be made to validate this impact. If this trend proceeds for all cost per order value, then it can be mentioned that it is better to have the lowest possible cost per order to have product variations. The minimum cost per order could be achieved by having automated replenishment system using RFID, barcodes, ERP systems and so on.

5.7 Conclusion

This paper investigates the product variety on inventory at hospitals based on the product substitution factor and the corresponding inventory cost. After the discussion on the literature, research method and the model developed for the study is presented. This model is universal in nature which can be used in other fields. The developed model contributes to the literature for the analysis of product variety on inventory based on the attributes of the products. The entire study also adds to the literature on the product variety on inventory at hospitals. The influence of substitution factor on the product variety decision is presented along with the corresponding inventory cost showing that there is combined influence of product substitution factor and the product unit cost. Also, the effect of cost per order on this product variety decision is presented showcasing that there is an influence on the number of product variety reduction but not having an influence of the cost.

The future research will focus on eliminating the limitations of the model presented in the above sections and including the healthcare personnel’s preference factor.

6. THESIS CONCLUSION

In this thesis, a model is developed to explore product variety on inventory at hospitals in the hospital's central storeroom level. The entire model is programmed in Microsoft Excel using Visual Basic Application (VBA) programming language. In this, all the possible combinations of product usage and substitution for products within a product group is explored.

A simple baseline based on product functionality reveals that there is 13.6% of possible product variety reduction for the hospital. Due to the influence of product substitution factor and the unit cost of the product, the product variety reduces to approximately 11%.

The cost difference between the optimized inventory between the present system and minimized product variety is approximately NOK 3.6 Million. When there is a change of the variable cost per order, it creates a minor effect on the number of products reduced but keeping the cost saving to be same.

The Table 6-1 below represents the summary of the results. In this table, the number of reduction and the percentage of reduction of product variety is presented. The cost reduction during this situation between the optimized inventory of all products used and the minimized product variety and between the present situation and minimized product variety is shown. The potential of product variety can be visualized from this table.

	Number of Reduction				Cost Reduction (%)	
	Sterile Product	Non – Sterile Product	Total	% Number of Reduction	All prod. Vs Min. product variety	Present situation Vs Min. product variety
Baseline	164	154	318	13.6%	–	–
Scenario – 1	121	141	262	11.2%	4.67%	22.30%
Scenario – 2	118	141	259	11.1%	4.64%	22.10%
Scenario – 3	110	139	249	10.7%	4.62%	22.18%

Table 6-1: Summary of results on product variety

When the product variety is implemented in hospitals at the Hospitals Central Storeroom level, it creates a positive effect on 54% of the Nursing Units. Still resulting in a cost increase of approximately NOK 45,000. The overall cost difference is approximately NOK 3.56 Million.

In conclusion, the implementation of product variety on inventory at hospitals offers better results and a potential for future research discussed in the below section.

6.1 Future Research

There is a significant amount of research that could be undertaken to increase the literature on product variety on inventory at hospitals. The possible research areas are discussed below.

The model developed for the research is universal in nature which could be used in other fields such as retail, marketing and so on. This research determined the potential number of product variety reduction and its corresponding cost reduction. However, it did not address the issue such as time taken by healthcare personnel's to adapt this change or flexibility of the hospital and other factors.

This research contained few limitations such as not having coordinated replenishments and floor space limitations. The future research can focus on having these included into the model for having better real-time results.

The research did not include a factor for healthcare personnel's product preference. It is one of the important factors that will involve in the implementation of the results of product variety. It will make sure that their most preferred product will not be eliminated.

The current advancement in technology such as RFID, barcodes and so on haven't been put into full use in the healthcare industry. The implication of the involvement of these technologies in the product variety on inventory at hospitals will be a good area to focus upon.

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8. APPENDIX

Appendix I: Impact of product substitution factor on product variety

Non – Sterile Product

Scenario – 2: External order time – 1.0 Hours

	Demand	Unit Cost
NSP_1	260	NOK 0.17
NSP_2	461	NOK 0.13
NSP_3	162	NOK 0.13

Table 8-1: Initial detail of products in a non - sterile product group

Design Point: (7, 1)	NSP_1, NSP_2 & NSP_3 are used			
	NSP_1	NSP_2	NSP_3	Total
Demand (Units)	260	461	162	883
Logistics Cost (NOK)	NOK 59.16	NOK 67.75	NOK 41.06	NOK 167.98
Total Cost (NOK)	NOK 103.86	NOK 126.33	NOK 62.62	NOK 292.81

Table 8-2: Cost when all products in a non - sterile product group is used – Scenario 2

Design Point: (3,1)	NSP_1 & NSP_2 used and NSP_3 is replaced by NSP_1		
	NSP_1 (NSP_3)	NSP_2	Total
Demand (Units)	422	461	883
Logistics Cost (NOK)	NOK 75.34	NOK 67.75	NOK 143.09
Total Cost (NOK)	NOK 147.89	NOK 126.33	NOK 274.22
Logistics Cost Saving (%)			14.82%
Total Cost Saving (%)			6.35%

Design Point: (3,2)	NSP_1 & NSP_2 used and NSP_3 is replaced by NSP_2		
	NSP_1	NSP_2 (NSP_3)	Total
Demand (Units)	260	623	883
Logistics Cost (NOK)	NOK 59.16	NOK 78.74	NOK 137.90
Total Cost (NOK)	NOK 103.86	NOK 157.90	NOK 261.76
Logistics Cost Saving (%)			17.91%
Total Cost Saving (%)			10.60%

Design Point: (5,1)	NSP_1 & NSP_3 used and NSP_2 is replaced by NSP_1		
	NSP_1 (NSP_2)	NSP_3	Total
Demand (Units)	721	162	883
Logistics Cost (NOK)	NOK 98.44	NOK 41.06	NOK 139.50
Total Cost (NOK)	NOK 222.39	NOK 62.62	NOK 285.01
Logistics Cost Saving (%)			16.95%
Total Cost Saving (%)			2.66%

Design Point: (5,2)	NSP_1 & NSP_3 used and NSP_2 is replaced by NSP_3		
	NSP_1	NSP_3 (NSP_2)	Total
Demand (Units)	260	623	883
Logistics Cost (NOK)	NOK 59.16	NOK 80.47	NOK 139.63
Total Cost (NOK)	NOK 103.86	NOK 163.38	NOK 267.24
Logistics Cost Saving (%)			16.88%
Total Cost Saving (%)			8.73%

Design Point: (6,1)	NSP_2 & NSP_3 used and NSP_1 is replaced by NSP_2		
	NSP_2 (NSP_1)	NSP_3	Total
Demand (Units)	721	162	883
Logistics Cost (NOK)	NOK 84.69	NOK 41.06	NOK 125.75
Total Cost (NOK)	NOK 176.31	NOK 62.62	NOK 238.93
Logistics Cost Saving (%)			25.14%
Total Cost Saving (%)			18.40%

Design Point: (6,2)	NSP_2 & NSP_3 used and NSP_1 is replaced by NSP_3		
	NSP_2	NSP_3 (NSP_1)	Total
Demand (Units)	461	422	883
Logistics Cost (NOK)	NOK 67.75	NOK 66.24	NOK 133.99
Total Cost (NOK)	NOK 126.33	NOK 122.40	NOK 248.73
Logistics Cost Saving (%)			20.23%
Total Cost Saving (%)			15.05%

Table 8-3: Cost of 1 product removed from a non – sterile product group – Scenario 2

Design Point: (1,1)	NSP_1 is used and NSP_2 & NSP_3 is replaced by NSP_1	
	NSP_1 (NSP_2, NSP_3)	Total
Demand (Units)	883	883
Logistics Cost (NOK)	NOK 108.93	NOK 108.93
Total Cost (NOK)	NOK 260.73	NOK 260.73
Logistics Cost Saving (%)		35.15%
Total Cost Saving (%)		10.96%

Design Point: (2,1)	NSP_2 is used and NSP_1 & NSP_3 is replaced by NSP_2	
	NSP_2 (NSP_1, NSP_3)	Total
Demand (Units)	883	883
Logistics Cost (NOK)	NOK 93.71	NOK 93.71
Total Cost (NOK)	NOK 205.91	NOK 205.91
Logistics Cost Saving (%)		44.21%
Total Cost Saving (%)		29.68%

Design Point: (4,1)	NSP_3 is used and NSP_1 & NSP_2 is replaced by NSP_3	
	NSP_3 (NSP_1, NSP_2)	Total
Demand (Units)	883	883
Logistics Cost (NOK)	NOK 95.79	NOK 95.79
Total Cost (NOK)	NOK 213.30	NOK 213.30
Logistics Cost Saving (%)		42.98%
Total Cost Saving (%)		27.15%

Table 8-4: Cost when only one product is used in non-sterile product group–Scenario 2

Scenario – 3: External order time – 0.5 Hours

	Demand	Unit Cost
NSP_1	260	NOK 0.17
NSP_2	461	NOK 0.13
NSP_3	162	NOK 0.13

Table 8-5: Initial detail of products in a non - sterile product group

Design Point: (7, 1)	NSP_1, NSP_2 & NSP_3 are used			
	NSP_1	NSP_2	NSP_3	Total
Demand (Units)	260	461	162	883
Logistics Cost (NOK)	NOK 41.87	NOK 47.95	NOK 29.05	NOK 118.87
Total Cost (NOK)	NOK 86.57	NOK 106.53	NOK 50.61	NOK 243.71

Table 8-6: Cost when all products in a non - sterile product group is used – Scenario 3

Design Point: (3,1)	NSP_1 & NSP_2 used and NSP_3 is replaced by NSP_1		
	NSP_1 (NSP_3)	NSP_2	Total
Demand (Units)	422	461	883
Logistics Cost (NOK)	NOK 53.31	NOK 47.95	NOK 101.26
Total Cost (NOK)	NOK 125.86	NOK 106.53	NOK 232.39
Logistics Cost Saving (%)			14.81%
Total Cost Saving (%)			4.64%

Design Point: (3,2)	NSP_1 & NSP_2 used and NSP_3 is replaced by NSP_2		
	NSP_1	NSP_2 (NSP_3)	Total
Demand (Units)	260	623	883
Logistics Cost (NOK)	NOK 41.87	NOK 55.72	NOK 97.59
Total Cost (NOK)	NOK 86.57	NOK 134.89	NOK 221.46
Logistics Cost Saving (%)			17.90%
Total Cost Saving (%)			9.13%

Design Point: (5,1)	NSP_1 & NSP_3 used and NSP_2 is replaced by NSP_1		
	NSP_1 (NSP_2)	NSP_3	Total
Demand (Units)	721	162	883
Logistics Cost (NOK)	NOK 69.65	NOK 29.05	NOK 98.70
Total Cost (NOK)	NOK 193.59	NOK 50.61	NOK 244.20
Logistics Cost Saving (%)			16.97%
Total Cost Saving (%)			(0.20%)

Design Point: (5,2)	NSP_1 & NSP_3 used and NSP_2 is replaced by NSP_3		
	NSP_1	NSP_3 (NSP_2)	Total
Demand (Units)	260	623	883
Logistics Cost (NOK)	NOK 41.87	NOK 56.92	NOK 98.79
Total Cost (NOK)	NOK 86.57	NOK 139.83	NOK 226.40
Logistics Cost Saving (%)			16.89%
Total Cost Saving (%)			7.10%

Design Point: (6,1)	NSP_2 & NSP_3 used and NSP_1 is replaced by NSP_2		
	NSP_2 (NSP_1)	NSP_3	Total
Demand (Units)	721	162	883
Logistics Cost (NOK)	NOK 59.93	NOK 29.05	NOK 88.98
Total Cost (NOK)	NOK 151.55	NOK 50.61	NOK 202.16
Logistics Cost Saving (%)			25.15%
Total Cost Saving (%)			17.05%

Design Point: (6,2)	NSP_2 & NSP_3 used and NSP_1 is replaced by NSP_3		
	NSP_2	NSP_3 (NSP_1)	Total
Demand (Units)	461	422	883
Logistics Cost (NOK)	NOK 47.95	NOK 46.86	NOK 94.81
Total Cost (NOK)	NOK 106.53	NOK 103.02	NOK 209.55
Logistics Cost Saving (%)			20.24%
Total Cost Saving (%)			14.02%

Table 8-7: Cost of 1 product removed from a non – sterile product group – Scenario 3

Design Point: (1,1)	NSP_1 is used and NSP_2 & NSP_3 is replaced by NSP_1	
	NSP_1 (NSP_2, NSP_3)	Total
Demand (Units)	883	883
Logistics Cost (NOK)	NOK 77.06	NOK 77.06
Total Cost (NOK)	NOK 228.86	NOK 228.86
Logistics Cost Saving (%)		35.17%
Total Cost Saving (%)		6.09%

Design Point: (2,1)	NSP_2 is used and NSP_1 & NSP_3 is replaced by NSP_2	
	NSP_2 (NSP_1, NSP_3)	Total
Demand (Units)	883	883
Logistics Cost (NOK)	NOK 66.31	NOK 66.31
Total Cost (NOK)	NOK 178.51	NOK 178.51
Logistics Cost Saving (%)		44.22%
Total Cost Saving (%)		26.75%

Design Point: (4,1)	NSP_3 is used and NSP_1 & NSP_2 is replaced by NSP_3	
	NSP_3 (NSP_1, NSP_2)	Total
Demand (Units)	883	883
Logistics Cost (NOK)	NOK 67.75	NOK 67.75
Total Cost (NOK)	NOK 185.26	NOK 185.26
Logistics Cost Saving (%)		43.00%
Total Cost Saving (%)		23.98%

Table 8-8: Cost when only one product is used in non-sterile product group–Scenario 3

Sterile Product

Scenario – 2: External order time – 1.0 Hours

	Demand	Unit Cost
SP_1	50	NOK 54.95
SP_2	37	NOK 73.53

Table 8-9: Initial details of the products in a sterile product group

	SP_1	SP_2
SP_1	1	2
SP_2	1	1

Table 8-10: Substitution factor

Design Point: (3,1)	SP_1 & SP_2 is used		
	SP_1	SP_2	Total
Demand (Units)	50	37	87
Logistics Cost (NOK)	NOK 473.25	NOK 472.61	NOK 945.86
Total Cost (NOK)	NOK 3,220.50	NOK 3,193.20	NOK 6,413.70

Table 8-11: All products in the product group is used – Scenario 2

Design Point: (1,1)	SP_1 is used and SP_2 is replaced by SP_1	
	SP_1 (SP_2)	Total
Demand (Units)	124	124
Logistics Cost (NOK)	NOK 739.27	NOK 739.27
Total Cost (NOK)	NOK 7552.46	NOK 7552.46
Logistics Cost Saving (%)		21.84%
Total Cost Saving (%)		(17.75%)

Design Point: (2,1)	SP_2 is used and SP_1 is replaced by SP_2	
	SP_2 (SP_1)	Total
Demand (Units)	87	87
Logistics Cost (NOK)	NOK 718.37	NOK 718.37
Total Cost (NOK)	NOK 7,115.43	NOK 7,115.43
Logistics Cost Saving (%)		24.05%
Total Cost Saving (%)		(10.94%)

Table 8-12: Only one product in the sterile product group is used – Scenario 2

Scenario – 3: External order time – 0.5 Hours

	Demand	Unit Cost
SP_1	50	NOK 54.95
SP_2	37	NOK 73.53

Table 8-13: Initial details of the products in a sterile product group

	SP_1	SP_2
SP_1	1	2
SP_2	1	1

Table 8-14: Substitution factor

Design Point: (3,1)	SP_1 & SP_2 is used		
	SP_1	SP_2	Total
Demand (Units)	50	37	87
Logistics Cost (NOK)	NOK 337.83	NOK 337.82	NOK 675.65
Total Cost (NOK)	NOK 3,085.09	NOK 3,058.40	NOK 6,143.49

Table 8-15: All products in the product group is used – Scenario 3

Design Point: (1,1)	SP_1 is used and SP_2 is replaced by SP_1	
	SP_1 (SP_2)	Total
Demand (Units)	124	124
Logistics Cost (NOK)	NOK 525.87	NOK 525.87
Total Cost (NOK)	NOK 7,339.05	NOK 7,339.05
Logistics Cost Saving (%)		22.17%
Total Cost Saving (%)		(19.46%)

Design Point: (2,1)	SP_2 is used and SP_1 is replaced by SP_2	
	SP_2 (SP_1)	Total
Demand (Units)	87	87
Logistics Cost (NOK)	NOK 511.35	NOK 511.35
Total Cost (NOK)	NOK 6,908.40	NOK 6,908.40
Logistics Cost Saving (%)		24.32%
Total Cost Saving (%)		(12.45%)

Table 8-16: Only one product in the sterile product group is used – Scenario 3

<u>Appendix II</u>: Impact on product reduction and cost

Scenario – 2: External order time – 1.0 Hours

All the products are used

	Sterile	Non – Sterile	Total
Number of Products	1645	686	2331
Logistics Cost	NOK 545,479	NOK 209,066	NOK 754,555
Total Cost	NOK 7,616,191	NOK 5,454,064	NOK 13,070,255

Products after reduction

	Sterile	Non – Sterile	Total
Number of Products	1527	542	2072
Logistics Cost	NOK 523,954	NOK 184,386	NOK 708,340
Total Cost	NOK 7,093,190	NOK 5,370,706	NOK 12,463,896

Difference

	Sterile	Non – Sterile	Total
# of products reduced	118	141	259
Logistics cost saving	3.95%	11.80%	6.12%
Total Cost saving	6.87%	1.53%	4.64%

Table 8-17: Summary of results when order time is 1.0 hours – Scenario 2

Scenario – 3: External order time – 0.5 Hours

All the products are used

	Sterile	Non – Sterile	Total
Number of Products	1645	686	2331
Logistics Cost	NOK 391,958	NOK 162,295	NOK 554,253
Total Cost	NOK 7,570,522	NOK 5.299.440	NOK 12,869,964

Products after reduction

	Sterile	Non – Sterile	Total
Number of Products	1535	534	2069
Logistics Cost	NOK 376,826	NOK 144,492	NOK 521,318
Total Cost	NOK 7,062,635	NOK 5,213,123	NOK 12,275,758

Difference

	Sterile	Non – Sterile	Total
# of products reduced	110	139	249
Logistics cost saving	3.86%	10.97%	5.94%
Total Cost saving	6.71%	1.63%	4.62%

Table 8-18: Summary of results when order time is 0.5 hours – Scenario 3

Appendix III: Impact of product variety on the subsequent echelon

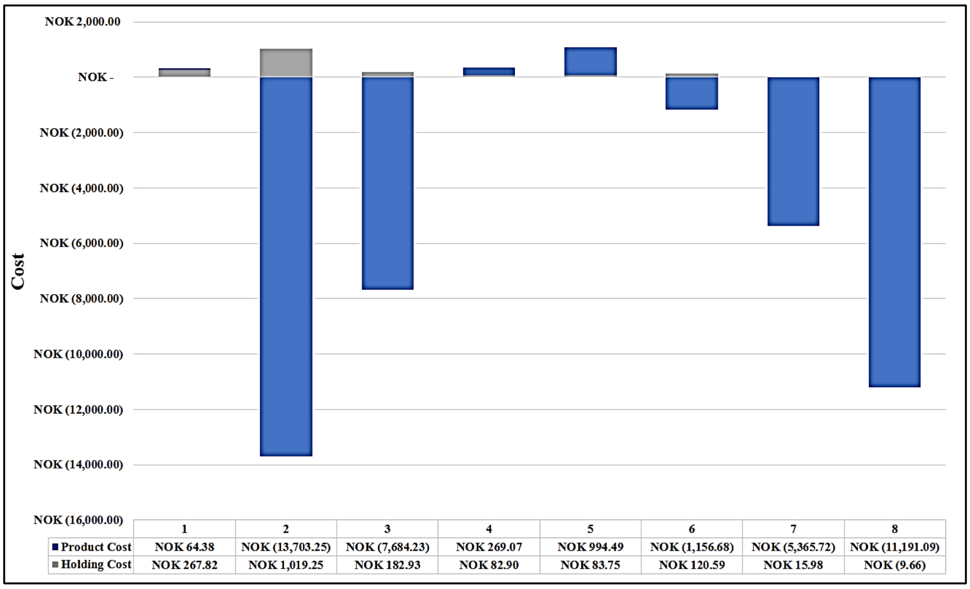

Figure 8-1: Effect of product variety on nursing units in Scenario – 2

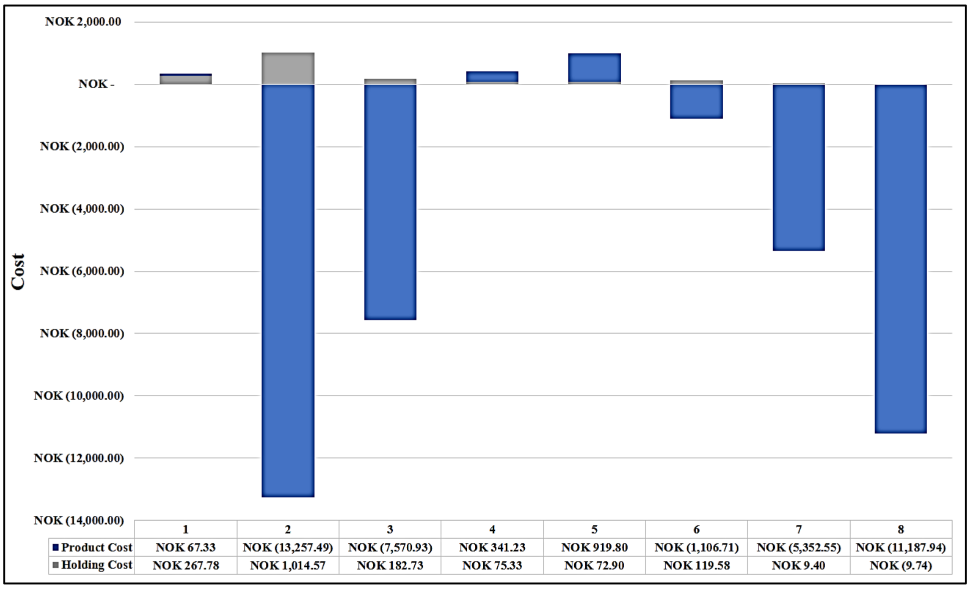

Figure 8-2: Effect of product variety on nursing units in Scenario – 3