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Exploring Avenues for Potential Improvement in Medical Supply Distribution

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Résumé

Un des maillons essentiels dans la chaîne d'approvisionnement en santé est l'hôpital. Les techniques de l'exploration des données peuvent fournir des modèles utiles d'information pour améliorer la qualité des différents processus et contribuer au système de santé en améliorant potentiellement l'efficacité de la chaîne d'approvisionnement interne de l'hôpital. La réduction des coûts du système de santé est un résultat attendu de la part du système de gestion de la chaîne d'approvisionnement. En effet, les hôpitaux gèrent des centaines de différentes fournitures médicales dans leurs unités de soins. La distribution des fournitures médicales aux unités de soins est un des facteurs les plus importants dans la chaîne d'approvisionnement interne de l'hôpital. Certaines des fournitures médicales sont fournies directement par les fournisseurs et, après en avoir effectué la réception, livrées aux unités de soins. Cependant d'autres fournitures médicales, qui sont utilisées pour le soutien des soins aux patients, doivent être traitées et entreposées dans des lieux centraux de stockage avant d'être distribuées aux unités de soins.

Actuellement, des progrès importants ont été apportés à la chaîne d'approvisionnement interne de l'hôpital et différents outils ont été introduits pour améliorer l'efficacité des pratiques dans le système. Un des systèmes les plus efficaces de réapprovisionnement en fournitures médicales à l'intérieur des hôpitaux est le système « two-bin enabled RFID ». Ce système contient un nombre considérable de données; en particulier, le point d'utilisation des données est saisi, puis enregistré dans le système. Toutefois, peu de recherche ont été réalisée afin d'utiliser ces données brutes et de trouver l'information utile à l'amélioration de l'efficacité des activités courantes effectuées par le système. Également il y a un manque de pratique dans l'utilisation des données historiques qui peuvent aider à l'efficacité du système actuel et introduire une amélioration éventuelle des processus.

Les techniques d'exploration des données peuvent aider à développer des outils soutenant la prise de décision de gestion à l'égard de la manutention des fournitures médicales au sein de la chaîne d'approvisionnement interne de l'hôpital. Dans cette recherche, nous présentons les techniques d'exploration des données afin de comprendre les ensembles de données hétérogènes et complexes d'un hôpital, de déterminer l'emplacement physique des fournitures médicales à l'intérieur du lieu principal de stockage de l'hôpital et dans les équipements de stockage de chaque unité de soins, ainsi que d'améliorer la stratégie de réapprovisionnement en tenant compte de la taille de l'espace disponible pour chacun des articles et la fréquence de réapprovisionnement pour l'ensemble de l'unité de soins. Nous présentons également un nouveau modèle de garder des stocks qui n'a pas encore été étudié dans la littérature. Les résultats de notre modèle heuristique proposé peuvent être utilisés par le personnel de gestion du matériel pour renforcer leur décision par rapport à un quelconque cours d'action relativement au stockage et au réapprovisionnement de fournitures médicales.

Mots clés : Gestion de la chaîne d'approvisionnement en santé, chaîne d'approvisionnement interne de l'hôpital, distribution de fournitures médicales, exploration des données

Abstract:

One of the key links in the healthcare supply chain is the hospital. Data mining techniques can provide useful patterns of information for improving the quality of different processes and contribute to the healthcare system, which can potentially improve the efficiency of a hospital's internal supply chain. Cost reductions in healthcare systems have an anticipated outcome in the supply chain management system. Typically hospitals manage hundreds of different medical supplies in their nursing units. Distribution of medical supplies to nursing units is one of the most essential factors of internal hospital supply chain. Some medical supplies are provided directly from the suppliers and after having been received are delivered to the nursing units. However, other medical supplies, which are used to support patient care, must be processed and stored in central stores, before being delivered to nursing units.

Currently, there is a lot of advancement in the internal supply chain of the hospital and different tools were introduced to improve the efficiency of these practices in the system. One of the most effective medical supply replenishment system within the hospitals is two-bin enabled RFID system. This system contains huge amounts of data; especially the point of use data is captured and saved to the system. However, there is a lack of research in order to use this raw data and find useful information in order to improve the efficiency of the current activities done within the system. Likewise there is lack of practice of use of the historical data that can assist in efficiency of the current system and introduce the probable improvement in the processes.

Data mining techniques can assist in developing new decision tools that support management decision-making regarding handling the medical supplies within the internal supply chain of the hospital. In this research we introduce data mining techniques to understand a hospital's complex and heterogeneous datasets, to determine the physical location of medical supplies within the main storeroom of the hospital and in the storage cabinets of each nursing unit, to improve replenishment strategy, which involves the size of the bin for each item and frequency of replenishment for the whole nursing unit. As such, we also introduce a new inventory model, which has not yet been studied in the literature.

The results of our proposed heuristic model can be used by material management personnel to fortify their decision about any possible course of action regarding the storage and replenishment of medical supplies.

Key Words: Healthcare supply chain management, hospital internal supply chain, medical supply distribution, data mining

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Chapter 1
Introduction and Research Motivation

1.1 Introduction

Recently, the U.S government imposed pressure on the healthcare system to find ways to reduce costs of which, in 2011, the system alone accounted for 17.9% of the U.S. gross domestic product (Wayne, 2012). Commonly, 45% of a hospital's operating budget is used for expenses towards hospital supplies and materials (Kowalski, 2009). It is estimated that by 2038, non-labor costs will surpass those of labor because of the dependency of healthcare on technology and supplies (Wayne, 2012). According to the growth trend, it is likely that hospitals and health organizations spend more on their supply chains than on labor (DeJohn, 2009). Therefore, supply chain management is considered one of the most significant areas of operation for CEOs and executive leadership of hospitals (Barlow, 2010).

Generally, hospitals use thousands of different types of supplies and equipment; these materials are of high value and require special handling. Due to the vast group of products with little hope of item consolidation, healthcare supply chain management may be regarded as more complicated than that of normal industrial supply chain management (Beier, 1995). Moreover, each item can be considered vital i.e. there should be a high degree of service reliability to make them available at the operation level of the hospital (Beier, 1995). Hence, the manner in which supplies and services are purchased, received, distributed, consumed, and dispensed will always be an important aspect of a hospital's management practices. Hospitals are seeking to find more efficient ways to manage vast inventories of medical supplies.

In addition, efficiently managing data is currently one of the most delicate issues in every organization and healthcare system. Not only is it imperative to transmit important information through different layers of supply chains, but also, it is crucial to manage and handle this huge amount of data. Some hospitals are equipping to new technologies such as RFID, which allows different parties in the supply chain to have access to the right information at the right time and the right place (Landry & Beaulieu, 2010).

On the other hand, in order to find meaningful information from the big set of data, different data mining techniques are used. Data mining is a computer-based methodology, and a new technology for discovering new, valuable, and nontrivial knowledge from massive data. The primary goal of data mining is description and prediction. Descriptive models describe patterns in datasets, which can be used in creating meaningful clusters of observations (Kantardzic, 2003). There are different common tasks of data mining such as clustering, data flow analysis, path-based classification and cluster analysis, frequent pattern and sequential pattern analysis. However, applying data mining techniques to RFID data effectively and mining the valuable information, should be addressed differently due to the simple, large quantity, accurate, and spatial type of RFID data (Kwon, Kang, Yoon, Sohn, & Chung, 2014).

For this purpose, our thesis considers different techniques that improve the current processes within the internal supply chain of the hospitals. Our study makes several contributions that are specifically important to the intersections between supply chain management and data mining.

1.2 Background

One of the main areas where cost reductions are an expectable outcome in the healthcare system is the supply chain management system (Butters & Eom, 1992). One of the key links in the healthcare supply chain are hospitals, which face their own particular challenges (Landry & Beaulieu, 2007). That is, hospital supply chains are distinctive from the industrial supply chains in several ways. First, hospital supplies are mission critical to the health of the public, because clinical operations require sufficient and precise supplies according to the different needs of patients (Beier, 1995). For today's hospitals, supply chain management extends its reach and influence to just about every clinical and operational area (Barlow, 2010b). Second, on average hospitals use thousands of different types of supplies and equipment; some of these materials are either in large quantity and of less value or of high value and need special handling to fight against spoilage or obsolescence. Third, unlike other industries, the lack of data standards and synchronization in hospital supply chain management practices, healthcare has yet to establish a specific worldwide product number classification system that helps to identify functionally equivalent products (Garvin, 2006; Sargent, 2010; VanVactor, 2008). Fourth, hospital supply selections are often driven by physician preferences, which is largely based on medical training, experience with specific brands, and context-specific demands. Lastly, the diverse types of healthcare supplies often change as a result of rapid technology and medical innovations so that the management of the healthcare supply chain is intense (Chen, Preston, & Xia, 2013).

It is usual for hospitals to manage hundreds of different medical supplies in their nursing units. Some medical supplies are delivered to the nursing units shortly after they have been received directly from the suppliers. However, other medical supplies, which are used to support patient care, must be processed and stored in central stores, before being delivered to nursing units. Keeping unnecessary levels of inventory can increase costs considerably; whereas lack of appropriate inventory levels may impede patient care and interrupt nurses' activities. Therefore, distribution of medical supplies to nursing units is one of the most important factors of internal hospital supply chain (Landry & Beaulieu, 2013). One of the most often used distribution method is where the hospital's central stores manage inventory and replenishment, which includes par level systems and automated cabinets, as well as the two-bin replenishment method. The two-bin replenishment method has been recognized as a best replenishment practice and when it is enabled with RFID technology, it will become a leading practice, introducing the possibility of proactively managing by initiating replenishment cycles on range of user-defined criteria (Landry & Beaulieu, 2013).

1.3 Distribution of medical supplies and best practices

As mentioned, distribution of medical supplies is one of the main aspects of hospital's internal supply chain. The hospital replenishment systems range from clinically driven requisition-based systems, exchange carts, and periodic automatic replenishment or par level system, RFID-enabled two-bin system, weight control bins, and user-driven unitary demand capture systems. For example, according to Landry and Beaulieu (2013) the inventory managements systems operate by a periodic review system, order point logic, or hybrid system, which is a combination of the former and latter mentioned. The periodic review system is utilized as a fixed interval reordering process in order that the review period duration within these inventory management systems maintains an order point logic (Landry & Beaulieu, 2013). This permits reordering quantities, and that safety stock can all be processed via computation, exploiting many random probability patterns that may be analyzed statistically within inventory models also known as stochastic inventory models (Landry & Beaulieu, 2013). This also helps to locate the accurate equilibrium amongst ordering costs and inventory carrying costs (Landry & Beaulieu, 2013). In short, extensive research proved that maintaining these inventory management parameters au courant help to catalyze better-quality performance and stability (Landry & Beaulieu, 2013). It is demonstrated that two-bin replenishment system is in general a better inventory management system for medical supplies than exchange carts, par level, and automated cabinets. Moreover, when it is combined with RFID technology, its ability will be enhanced (Landry & Beaulieu, 2013).

1.4 Statement of problem

As of today, a lot of advancement in the internal supply chain of the hospital has been made, and different tools were introduced to improve the efficiency of these practices in the system. However, there is still plenty of room to move further and improve the system. To reiterate, one of the most effective medical supply replenishment system within the hospitals is the two-bin enabled RFID system. In this system huge amounts of data, especially at the point of use is captured and saved to the system. Nevertheless, there is a lack of practice and research in order to use this raw data to find useful information as well as to improve the efficiency of the current activities done within the system. Particularly, there is lack of practice in utilizing and researching the historical data and to find the efficiency of the current system and introduce the probable improvement in the processes.

For replenishing medical supplies inside the hospital different replenishment techniques are applied from continuous replenishment system to periodic replenishment system. Recently Rosales, Magazine and Rao (2014) conducted a study in which they analyze the new hybrid replenishment system where both periodic and continuous systems are applied in the hospitals. Yet, there is still lack of research in the domain to find the optimal value of parameters applied in the new two-bin hybrid model.

1.5 Statement of purpose

Study in data science and predictive analytics lacks in research in the field of healthcare supply chain management. If research in data science and predictive analytics are both applied and practiced in the field, then they can change the way in which supply chains are managed. These tools will not only present innovative, and even, significant challenges to healthcare supply chain management, but logistics at hospitals as well. Indeed, it is equally important to have both data analysis skills and domain knowledge i.e. to be effective at making progress one must possess competency and expertise in data analysis and in healthcare supply chain management (Waller & Fawcett, 2013).

The purpose of this research is to evaluate the degree to which data mining algorithms emerging from the field of computer science can be applied to the hospital in order to find potential improvement points in its internal supply chain system. Using data mining techniques, this research aims to understand the hospital's complex and heterogeneous datasets. We hope to contribute and develop decision tools that support management decisions in regards to the best way of handling medical supplies within the hospital internal supply chain. We evaluate how well data mining techniques can be used with inventory and distribution system to have a positive impact in the way hospitals procure, store and replenish medical supplies. Moreover, along with studying different techniques to make a potential improvement in the efficiency of the hospital internal supply chain, a new inventory model, which has not yet been studied in the literature, is introduced.

In this study, the researcher visited Hôpital du Sacré-Coeur de Montréal and explored some avenues for potential improvement in medical supply distribution.

1.6 Research questions

We evaluate how well data mining techniques can be used with the combination of inventory and distribution concepts to have a positive impact in the way hospitals procure, store and replenish medical supplies. We intend to introduce and develop some decision tools to support management decision around determining:

1. Physical location of medical supplies within the main storeroom of the hospital and in the storage cabinets of each nursing unit.
2. Replenishment strategy, which involves the size of the bin for each item and frequency of replenishment for the whole nursing unit.

1.7 Significance of study

Hospitals are looking to find more efficient approaches to store and manage vast inventories of medical supplies because of the increase in the cost of medical supplies and services. The two-bin enabled RFID replenishment system is one of the well-known replenishment systems in North American hospitals leading to the real-time inventory visibility and proactively managing the medical supplies (Landry & Beaulieu, 2010). Applying data mining techniques along with analyzing the data on medical supply consumption received from RFID, can be used as a decision making tools; and in general, can be considered as a tool, which does not only help the hospital's material management personnel to analyze the current replenishment processes, but also to find the possible avenues to improve the current replenishment practices.

The significance of this study is considered in two different ways. After careful research, we found that applying data mining and data analysis tools to explore the possible improvement in the internal supply chain of the hospitals and its processes, does not exist in any publications regarding healthcare literature. As such, we introduce a new replenishment model in the inventory management concepts, which also was not found in the literature. However, it is a current feature in hospitals, which practices their replenishment system under the two-bin enabled RFID technology. On the other hand, we introduce the hybrid replenishment model, which is the combination of continuous and periodic inventory model, with fix lot-size quantity of replenishment and time interval between each replenishment. Moreover, we show that hospitals can use simple models and algorithms to explore significant improvement opportunities in their processes and the whole system.

1.8 Methodology overview

The methodology used to analyze the problem is through the descriptive data mining techniques (see Figure 1-1). Data mining analysis is done with the use of Excel, RapidMiner and R.

1.9 Limitation and difficulty of the study

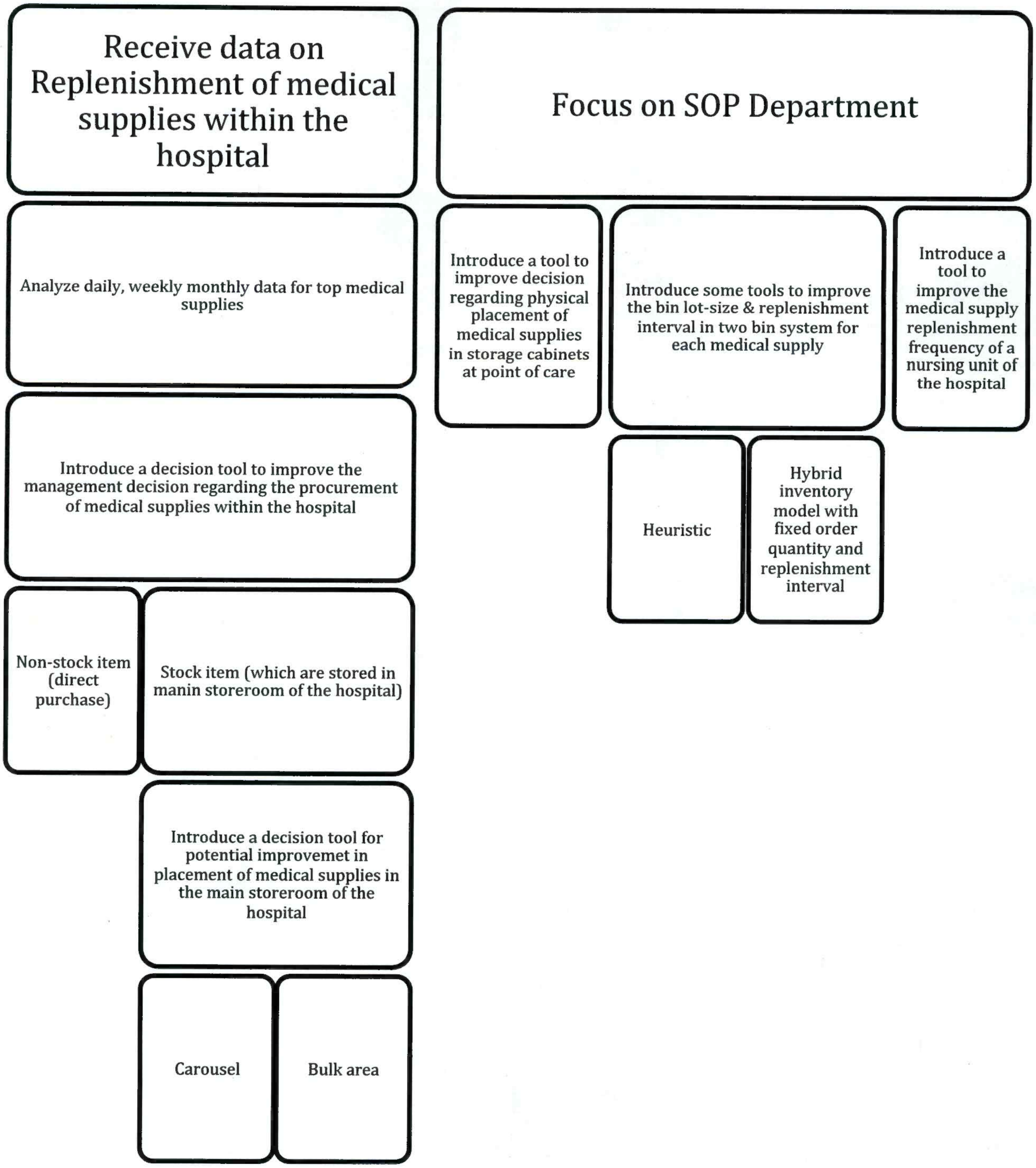
One of the limitations of the study is lack of access to the hospital's historical data; it was not kept in their database. Rather it is stored and managed by an external company (Logi-D). Furthermore, since Hôpital du Sacré-Coeur de Montréal there is only the possibility to have access to bin-level data (tracks bin-levels instead of unit-level items) on medical supply consumption. Nevertheless to develop the heuristics introduced in this study it proved useful to have access to the unit-level data.

Additionally, in order to improve the different recognized areas; different heuristic, exact, and simulated algorithms were applied and analyzed. For instance, different simulation models were run within the two-bin replenishment system by considering the stochastic continuous replenishment system with fixed quantity and stochastic lead-time. However, after reviewing the existing literature, analyzing the condition, and discussing the problem with some researchers in the field, a new inventory system, which is applicable within the two-bin enabled RFID systems in hospitals, was introduced. Consequently, lack of research at the intersection of data mining and supply chain management and hybrid replenishment systems are among the difficulties and limitations of this research.

1.10 Structure of dissertation

We aim to understand the huge medical supply dataset and current medical supply replenishment pattern by using 2013 and 2014 data on medical replenishment of Hôpital du Sacré-Coeur de Montréal and various analysis functions in Excel. Second, we propose a decision tool, which can be used to improve the medical supply procurement and placement within the main storeroom of the hospital. Third, with the focus on one of the main departments of the hospital, we evaluate the interrelationships among medical supplies and propose an algorithm that can be used to improve the physical placement of medical supplies in storage cabinets at point of care. Fourth, we suggest an algorithm to improve the lot-size within the two-bin system for each medical supply of a nursing unit. Finally, we develop an algorithm to improve the overall replenishment frequency of a nursing unit within the hospital (See Figure 1-1).

Figure 1-1: Research methodology



Chapter 2
Literature Review

The goal of this research is to introduce different data mining techniques to improve the decision-making in regards to the distribution of medical supplies within the internal supply chain of the hospital. We show that with efficient and widespread adoption of data mining in the inventory and replenishment system of the hospital, healthcare providers can explore new avenues to gain positive impact in the way hospitals procure, store, and replenish medical supplies.

This chapter provides background and context for the application of data mining techniques in distribution of medical supplies within the hospitals. Since the purpose of this research is to evaluate the degree to which data mining algorithms emerging from the field of computer science can be applied to internal supply chain of the hospitals, background information is provided in two sections. The first section presents background and context for supply chain management in healthcare. This includes healthcare supply chain, hospital supply chain, replenishment systems in hospitals including more details about two-bin enabled RFID system, and inventory management systems applied in hospitals. The second section presents background related to information technology and data mining applied within the healthcare industry. This includes information technology and data mining techniques such as association rules mining in healthcare supply chain.

2.1 Supply chain management in the context of healthcare

2.1.1 Healthcare supply chain

Today's healthcare executives face increasing pressure to reduce costs and improve patient care. To achieve this, many are reconsidering their organization's logistic processes to enhance the effectiveness of their structure and activities. Supply chain expenses are usually a healthcare organization's second biggest expense. Consequently, healthcare practitioners mostly focus, and take into serious consideration the price of materials in order to reduce the cost within the healthcare (Ballard, 2005). According to EHCR report, there could be possible savings over $11 billion in healthcare supply chain processes (CSC, 1996).

There are different activities such as procurement, storage, handling and movement of goods from point of origin to point of consumption within the healthcare supply chain management, which is also called healthcare logistics. There are different members in healthcare supply chain including manufacturers, distributors, transportation companies, hospital receiving and materials management departments, nursing units, point of cares, and finally the patient. The basic product flow in the healthcare supply chain is shown in Figure 2-1.

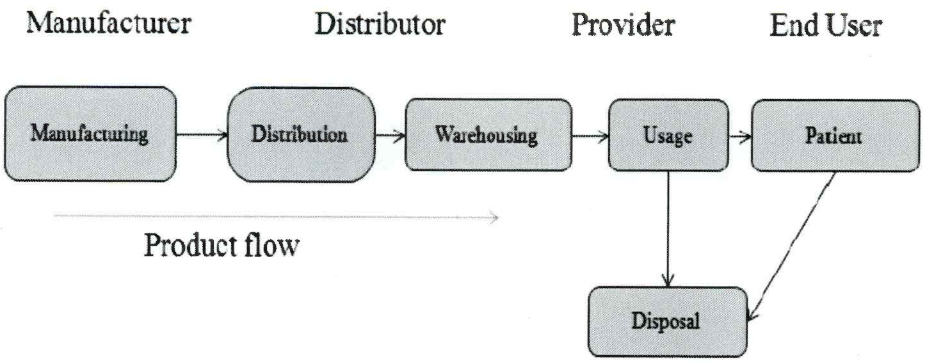


Figure 2-1: Healthcare Supply Chain Adapted from (CSC, 1996)

Each member in the healthcare supply chain has a specific task with the final goal of assuring product availability at point of care. These processes can be categorized as: external to healthcare provider, such as, manufacturing and distribution; and internal, such as, ordering, receiving, storage, picking and floor replenishment.

In 2008, researchers interviewed healthcare supply chain professionals to find important characteristics of supply chain; the results are as below (Nachtmann & Pohl, 2009):

- Most of the professionals are rich in talent
- Data for efficient collaboration among partners is not sufficient
- Improvement strategies are applied in healthcare supply chain
- A high level of collaboration exists among partners in healthcare supply chain
- Supply chain costs consists of more than one-third of annual operating expenses
- Fundamental processes are immature in healthcare supply chain

Thus, the report indicated that the organization's supply chain was at a low level of maturity. Some of the most common reasons for healthcare supply chain inefficiency are related to inventory management. Likewise, there are few organizations that improve their inventory efficiency. For instance, there are fewer than 10% of hospitals using inventory optimization techniques to improve their inventory practices such as forecasting and replenishment planning (Langabeer, 2005). From 1990 there was always a concern of using various techniques from other industries such as Just-in-Time (JIT) to enhance efficiency of inventory management in hospitals. However, the application of money-saving logistics practices such as Just-in-Time (JIT) has continually been slower in healthcare industry than other industries (Scanlin, 1997). Inflated inventory levels, problems such as product expiration or obsolescence, excessive capital tied up in inventory, high restocking costs, and other distribution problems could be managed efficiently with the use of JIT (Colletti, 1994). There is still a need to apply different techniques within hospitals to improve the inventory and prediction of medical supplies consumption.

2.1.2 Hospital supply chain

Among all the players in health care logistics such as manufacturers, distributors, hospital material management, hospital units, and patients (Chow and Heaver, 1994), hospitals play an important role i.e. they encompass the complicated logistics network. Typically, hospitals are composed of storerooms providing dozens of nursing units' stock locations with medical supplies. Before reaching the end user for consumption, medical supplies are first received at central stores of the hospital. They are then delivered to the main storeroom of each nursing units. There are also some secondary storage points located closer to the point of use in each unit of the hospital to support the needs of the clinical personnel (Landry & Beaulieu, 2013).

There exist two kinds of categories of medical supplies within the hospital supply chain. First, there is the direct purchases or non-stock items. These items are delivered directly to the nursing units shortly after they are received. The other category of hospital supplies is stock items; there is always the possibility of stock-out and over stock for these products in the hospitals that lead to inefficiency of the supply chain such as shortage of staff, duplicity of activities, etc. (Landry & Beaulieu, 2013).

According to Dembinska-Cyran (2005) healthcare logistics consists of four main activities where each activity has a directed function i.e. ensuring that simultaneously the stock items arrive at the right place, time and that each contains the accurate quantity and cost. For example the activities and their functions entail: (1) Inventory Management i.e. purchase, receipt and inventory control of stock and supplies; (2) Transport Management i.e. transport of patients to and into hospital, delivery of pharmaceutical and medical products; (2) Production i.e. laundry, cafeteria, sterilization; and (4) Distribution i.e. delivery and sorting of bulk items into order requests for individual departments (Dembinska-Cyran, 2005).

2.1.3 Review inventory policies in the hospital

Continuous and periodic review inventory policies are two common review policies in hospitals. There exist massive literature on these two inventory methods. Scarf (1960) presented the optimality policy for periodic review inventory systems; and Zheng (1992) put forward the optimality policy for continuous review inventory systems (Scarf, 1960; Zheng, 1992). Numerous exact and approximation algorithms to compute these parameters have been proposed by different people (Zheng & Federgruen, 1991; Feng & Xiao, 2000; Federgruen & Zheng, 1992). Most of the literature on inventory systems in hospitals is mostly related to periodic replenishment policies (Little & Coughlan, 2008; Lapierre & Ruiz, 2007; Friedman, 1994). Due to new technologies, the hybrid inventory policy (i.e. the combination of two continuous and periodic replenishment policies) is applied in hospitals. Within this policy, the periodic replenishment is applied with the alternative of performing an out-of-cycle replenishment in continuous time whenever inventory levels of hospital supplies has been reached to the specific amount at point-of-use (Rosales, 2011).

Each of the internal customers of the supply chain in hospitals has unique, and sometimes conflicting, expectations from the supply chain. Understanding and addressing each customer's expectation in a hospital supply chain helps to identify opportunities for cost and quality improvement.

2.1.4 Replenishment systems in hospital

Hospitals have a central inventory where medical consumables are held, broken down, and distributed to each of the nursing units of the hospital. Units generally have a main storeroom (primary location) and the secondary storage position closer to the point of use, which has different forms. As mentioned in chapter one, the distribution method (used to distribute supplies to nursing units) has ranged from clinically driven requisition-based systems, exchange carts, and periodic automatic replenishment or par level system to more recently introduced: the two-bin system, the RFID-enabled two-bin system, weight control bins, and user-driven unitary demand capture systems (Landry & Beaulieu, 2013). This research considers the two-bin system and RFID enabled two-bin system. In the next section detailed information about these two distribution systems is presented.

2.1.4.1 Two-bin/Kanban system

The specific quota for this method of medical supplies is kept in two divided compartments or bins. Whenever a compartment is empty, the related tag is removed and placed on the board where the material handler can scan its barcode, and then, send the replenishment order to the system. The system is based on a hybrid inventory management system. Two conditions must be met to trigger the replenishment of medical supplies: first, the bin must be empty; second, the replenishment process must be proceeding. Then the ordered medical supplies are placed in to the empty bins. Bins are reviewed periodically and empty bins are replenished.

2.1.4.2 RFID-enabled two-bin/Kanban system

The two-bin enabled RFID replenishment system is shown in Figure 2-2. It is composed of:

- Primary and secondary tags attached to the bins with a clip;
- A reader and its antennas inside a wall mounted board which import the data on tags installed on the board;
- A middleware system, which triggers the replenishment order.

The process explained by Bendavid, Harold, and Philippe (2010) is as follow (Figure 2-2):

Stock items are usually divided evenly between the primary and secondary bins. First the stock in the primary bin (a) is used. When the primary bin is empty, its tag is removed and placed on the board to alert of diminishing stock and trigger a replenishment procedure (b, c). Until the replenishment takes place, medical supplies are used from the secondary bin which acts as a safety stock (d). When the tag signal is received by the middleware, it links the tag ID with the bin and a specific medical supply quantity of replenishment to the location. There are three rules which trigger the replenishment: when a predetermined number of tags appear on the board, when a tag has been on the board longer than a preset period of time or, when a tag from secondary bin is placed on the board thus warning for a stock out situation. This information is passed to the system and is received by the material management personnel. When the replenishment quantity arrives, the remaining stock from secondary bin is placed in the primary bin to guarantee the stock rotation (e) while the latest stock is placed in the secondary bin (f). The system is then rearrange by putting the bin tags back to their original location on the bins (g) (Bendavid, Harold, & Philippe, 2010, p. 998).

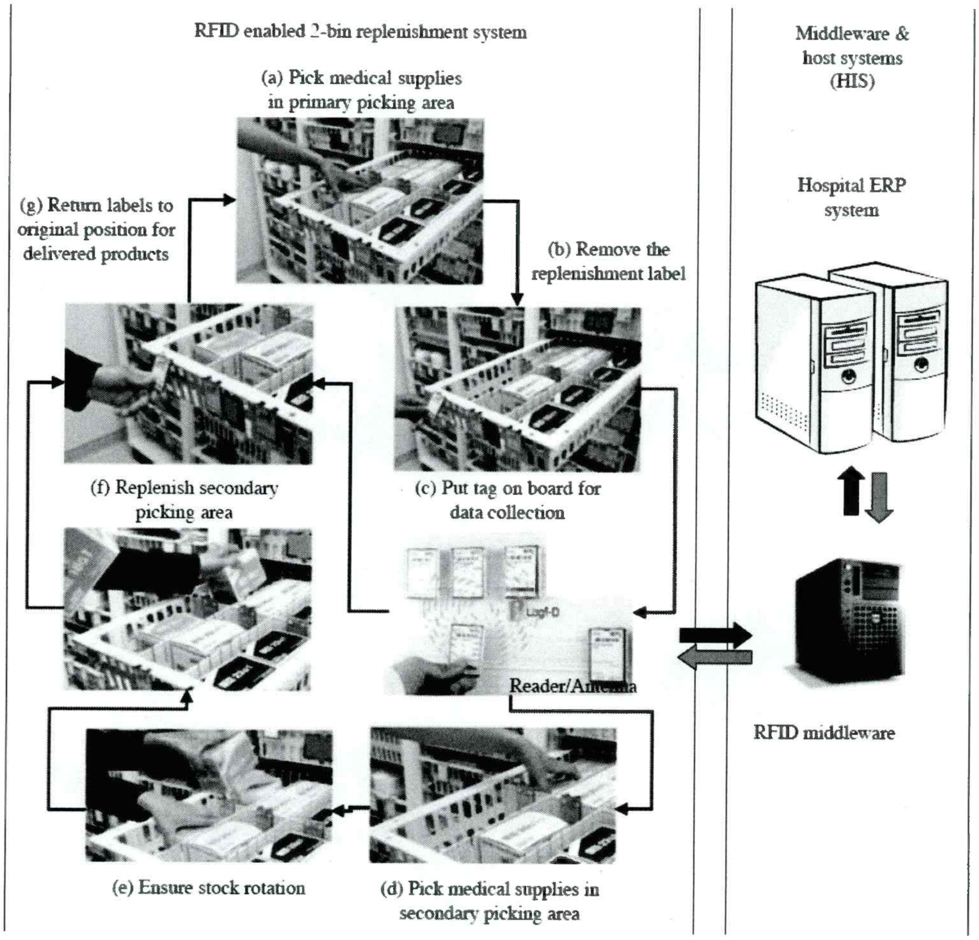


Figure 2-2: Two-bin enabled RFID system for medical supplies (Bendavid, Harold, & Philippe, 2010, p. 998)

2.2 Information technology concepts

2.2.1 Information technology in healthcare supply chain

Different tools exist in Information Technology (IT) that can play roles in resource planning, integrated purchasing catalogs, e-procurement transactions, and data collection; these tools can be applied in healthcare supply chain in order to make the processes more efficient (Neumann, 2003). For instance, Holmes and Miller (2003) show that there is an extensive effect on supply cost through the use of e-commerce (Holmes & Miller, 2003). Kim (2005) demonstrates that Collection of supply consumption data makes organizations to forecast demand more perfectly and leads them to the reduction of inventory cost (Kim, 2005). Therefore, if IT is utilized successfully, there will be a vital improvement to the healthcare supply chain.

The advancement of information technologies gave birth to the development of data mining techniques. One of the necessary needs of IT in healthcare is not only to have the ability to gather data, but also to integrate and use it to create information flow within and across organizations (Ballard, 2005). Despite all the benefits of applying IT in healthcare supply chain, there is always a concern of effective use of available data (McKone-Sweet, Hamilton, & Willis, 2005). Indeed, there are challenges to improve IT implementation in organizations, but studies support the needs and efforts for more development in IT.

2.2.2 Data mining

Knowledge Discovery in Database (KDD) or data mining, has been studied for several decades. It has been defined as "the nontrivial extraction of implicit, previously unknown, and potentially useful information from data" (Frawley, Piatetsky-Shapiro, & Matheus, 1991, p. 58). Data mining is the process of exploring useful information from the analysis of different perspectives of data. In other words, data mining is the process of discovering correlations or patterns among lots of fields in large relational databases. In contrast to statistics, data mining is focused on data exploration and description (Han, Kamber, & Pei, 2012). The exploration entails searching the data to find patterns without a basic formal model, and the description means the summary of the pattern that can provide reasonable answers to certain questions or produce some understanding into the problem. Han (2012) defined the description as a search of an empirical model rather than a mechanistic model, which stems from statistical analysis.

In short, data mining is a process to analyze the data set, summarize the results, assess the data in another way based on the earlier findings, and so on (see Figure 2-3). Domain experts, such as the database owner or domain process specialist, are required to provide input for interpretation and analysis of the result (Anand, Bell, & Hughes, 1995).

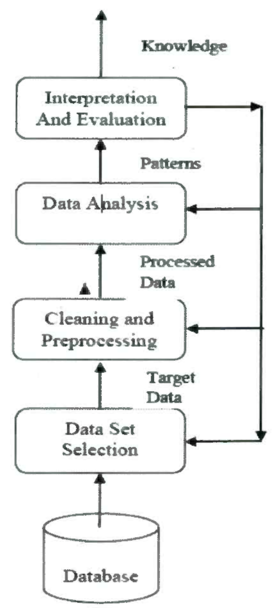


Figure 2-3: An overview of the data mining process (Bose & Mahapatra, 2001, p. 212)

2.2.2.1 Data mining in healthcare

There are four major categories where data mining is applied in healthcare domain:

1. Data mining in clinical medicine: There are huge amounts of data such as clinical, laboratory, equipment use, and drug management data in hospitals and clinical centers. Extracting information from this data set and transforming it into an understandable structure seems to be impossible because of the complexity in the data set (Ang, Wang, Zhao, Li, & Kai-yuan Li, 2010).

2. Data mining in public health: In order to plan, implement, and evaluate public health, data mining techniques can be used and applied in biomedical surveillance e.g. medical errors, death rates, and etc. in order to provide information of public health activities (Tsui, Chiu, Gierlich, Goldsman, Liu, & Maschek, 2008).

3. Data mining in healthcare text mining: Text mining techniques are used for finding hidden relationships between biomedical entities and for tracking the presence of specific illness in a specific population (Chen, 2005).

4. Data mining in healthcare policy and planning: Data mining is used in order to make decision about processes, predict different health situations, and evaluate the current health conditions.

Data mining has the ability to be face with large amounts of data and it offers more samples to find a meaningful pattern (Berry & Linoff, 2004). The ability of using data to find useful patterns of information for improving the quality of different processes is vital because the nature of the healthcare industry is data intensive. Indeed, data mining techniques in healthcare is fairly new but it can be utilized in medical databases to analyze, categorize data from different perspective and summarize it into useful information to increase the healthcare quality and decrease costs of the organization. Our study is within the field of data mining to provide policy and planning. That is, we apply different data mining techniques to find the optimal policies for procurement, physical placement, and replenishment of medical supplies within the hospital.

In next section we discuss Association Rules Mining technique, which is a data mining tool that finds the correlation among different items. Association rules mining is used in this research in order to find the optimal physical placement of medical supplies in the racks.

2.2.2.2 Association Rule Mining

Association rule mining is a famous method to find interesting relationships between variables in big databases. Agrawal et al. (1993) first introduced association rule mining, which has received great attention since his publication and the introduction of the Apriori algorithms (Agrawal & Srikant, 1994) . The original study of this method was mainly shaped by the analysis of market basket data. For example, from the transaction data of a supermarket, the rule {milk, egg} => {bread} is created, which denotes customers who buy milk and eggs and the likelihood of also purchasing bread at the supermarket. That is, the denotation expresses a conditional: if a customer buys milk and eggs then they will also buy bread. This information can help improve sales by assisting vendors to plan their shelf space. Moreover, managers are able to make better decisions in product promotion, self-design, and customer relationship by finding these relationships that explain the customers' buying behavior.

An association rule explains the relationship between the two item sets. Support and confidence are the two major statistics primarily used to identify if the association rule is acceptable and interesting (Agrawal & Srikant, 1994). They respectively reflect the usefulness and certainty of discovered rules. The support for an association rule X => Y is the percentage of transactions in the database that contain X and Y, and the confidence essentially explains the strength of co-occurrence between two items or sets of items. Usually, association rules are considered interesting if they satisfy both a minimum support and confidence threshold. These thresholds can be defined by experts and users (Han & Micheline Kamber, 2012).

Chapter 3
Methodology and Findings

3.1 Methodology overview

The methodology and findings in this research will be presented in the following order. First, a brief description of the hospital under study, Hôpital du Sacré-Coeur, is presented, demonstrating different points of making improvements within their inventory and distribution system. Second, the hospital's current inventory system is explained. Hospital replenishment and distribution systems are presented afterward. Third, the nature of the data received from Hôpital du Sacré-Coeur is discussed. Fourth, using the descriptive data mining approach, an algorithm is defined as a decision tool to improve the procurement policy of medical supplies. Fifth, in order to offer a tool to potentially improve the physical placement of medical supplies in storage cabinets, an algorithm is proposed. Sixth, considering the two-bin replenishment system within the nursing unit of the hospital, a heuristic method is introduced as a tool to potentially enhance the bins lot-size and replenishment interval for each medical supply. Finally, considering many practical scenarios, a heuristic is developed to support management decision regarding the suitable replenishment frequency for a nursing unit of the hospital. Excel, RapidMiner, and R are applied in order to find a solution for the proposed algorithms.
According to the nature of the data and its huge computation, it is not possible to show all the detailed data for all the medical supplies in this chapter. However, a brief summary of the result is presented after introducing each algorithm in order to explain the results.

3.2 Hôpital du Sacré-Coeur de Montréal

Hôpital du Sacré-Coeur in Montreal, Canada, with 554 beds was founded in 1898. Since 1973, it is affiliated with Université de Montréal to teach medicine and health sciences to students in a hospital setting. It is the largest training facility for orthopedic surgeons in the Province of Quebec (Hôpital du Sacré-Coeur de Montréal, 2009).

3.3 Hospital inventory

Hôpital du Sacré-Coeur has three types of central storerooms. One is in the basement of the hospital where special and expensive products, mostly used in the operations room department, are kept. The second is on the first floor where more general and low valued items are kept; and third is the carrousel. In this research all sections of the central storerooms, except the carousel are named as bulk inventory.

There are four floors in the hospital and on each floor there are different nursing units. Nursing units generally have a main storeroom where medical supplies are kept. This storeroom is not the final storage point in the hospital, but it is the primary storage area. There are also secondary storage areas such as mobile cart and point of use storage, which are closer to the point of use throughout the nursing units. These points allow medical staff to have access to medical supplies more easily. In total there are 191 storage units in Hôpital du Sacré-Coeur. These storage units are placed in various nursing units of the hospital.

The carousel

The carousel is usually installed in the main storeroom of the hospital for high-speed logistics picking, tracking, and distribution. Supply storage bins are fixed on an oval track that spins horizontally to deliver medical supplies to a picking operator (picker). Using the carousel allows the picker to choose medical supplies from one active carousel while the other carousel is positioning for the next pick. Special lights on the carousel direct the picker to the exact location of each pick (See Figure 3-1).

For the main inventory of Hôpital du Sacré-Coeur—regardless of the method of receiving the order—the process is the same. Once the order is released to the inventory software the order picker can start to fill the order immediately. Three horizontal carousels spin and position for the first pick. The picker picks the exact amount of a required specific medical supply by the guidance of the pick lights. After picking all required items, the order picker confirms the pick by pushing a green task complete button and places all items on the delivery cart. The carousel software organizes the pickings, keeping the horizontal carousels working one step ahead of the order picker, so there is very little wait time between picks. The system is operated with only one order picker. It is an efficient system, which helps to save the inventory space, lessen the number of order pickers, and shorten the picking time. Once the delivery cart has all necessary supplies from the horizontal carousel area, the cart is moved to the runner. Then the runner picks the rest of the supplies from the bulk area before delivery. When the order has all required supplies the runner takes the order up a few floors to replenish the two-bin systems. The inventory is reconciled and the process continues.

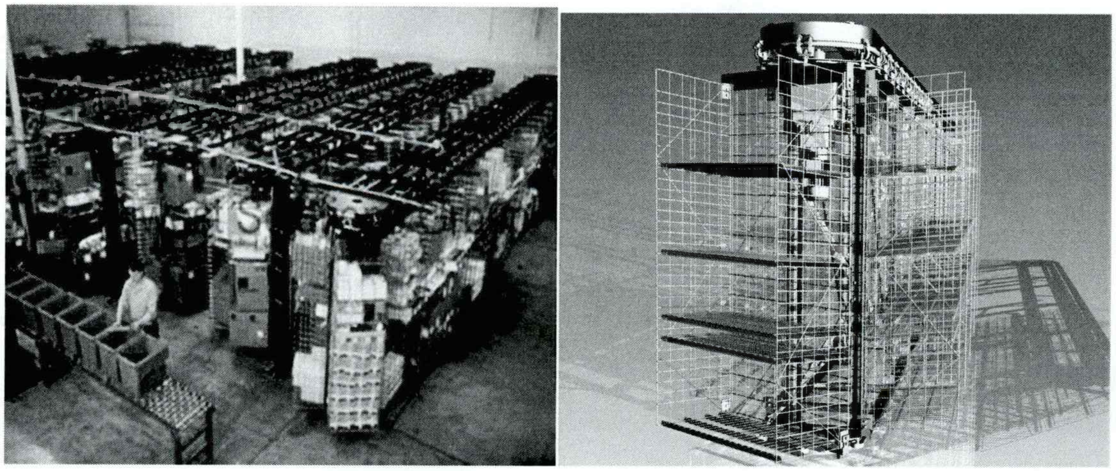


Figure 3-1: Carousel used in the main storeroom of the hospital (Southwest Solution Groups)

3.4 Hospital replenishment and distribution system

Most of the departments at Hôpital du Sacré-Coeur apply two-bin enabled RFID system to store medical supplies. However, there are still some departments, which use the two-bin system without RFID board; instead, the material handler reads tags on the board with the use of barcode reader. After receiving the quantity and code of items which need to be delivered to each unit of the hospital, the delivery is scheduled based on the prescheduled plan (periodic inventory system).

Considering the tools proposed in this research, we are looking for the possible ways to improve the performance of the system by well defining the procedures and forecasting the future replenishment based on historical data. Therefore, applying scientific techniques proposed in this research, we are looking for equipping material management personnel with the decision tool, which assist them to make a better decision regarding the replenishment cycle for each item. As such, scheduling the delivery more efficiently can result a higher service level of the two-bin enabled RFID system. In this study we are looking for the ways to address two important concerns in distributing medical supplies within the hospital internal supply chain: to reduce the frequency of replenishment review for each department of the hospital, and to reduce the quantity stored in each bin at the hospital by adjusting the lot-sizes.

3.5 Medical supplies in hospitals

Since we are interested in improving the distribution of medical supplies in the hospital, the investigation of the data on medical supply consumption is required. There are hundreds of different medical supplies, which are managed and distributed in several storerooms across different departments of the hospital. Since some nursing units are the only users of certain medical supplies, they are delivered directly to these nursing unit as soon as material management personnel receive them. These medical supplies are known as direct purchase or non-stock items. Some other medical supplies are kept in the main storeroom of the hospital before they are delivered to the nursing unit. These medical supplies are known as stock items. Therefore, hospitals receive a wide range of supplies that support the delivery of care either directly (medical supplies) or indirectly (Landry & Beaulieu, 2013).

Hôpital du Sacré-Coeur uses approximately 4000 medical supplies in its different departments. Medical supplies are procured from different sources such as sterilization department, hospital central storeroom, and external suppliers. The material management personnel are only responsible for direct purchase and central storeroom procured items since the sterilization unit manages the distribution of sterilization items. As a result of the different modification, such as the product improvement, product innovation, new packaging, new suppliers, etc., medical supplies used in the hospital are often changing. One of the difficult responsibilities of material management personnel is to keep tracking the changes in the medical supplies by changing their related primary and secondary tags.

3.6 Characteristics of data obtained

The hospital has many different departments (e.g. nursing units), each having several storerooms. The number of items per storeroom can vary greatly but usually ranges between 100 to 500 different items. The main replenishment system at Hôpital du Sacré-Coeur for medical supplies is the two-bin enabled RFID system, which allows to track empty bins instead of individual SKU's consumption. Thus, the data obtained includes bin consumption and replenishment data for all medical supplies used throughout the hospital in different departments.

An example of the data is provided in Table 3-1, which shows that in the Orthopedic department, Item 44440590, which is Handle knife No.3, with 1 units/bin replenished on January 1. Orthopedic department is replenished seven times a week. Note that the hospital data obtained does not include unit-level demand; the demand captured by the hospital is only at the bin level.

Table 3-1: Detailed Data on Medical Supply Replenishment

Date	Department	Product Code	Product Description	Unit of Product	Quantity of each Replenishment	Frq. Repl. /week
2013-01-01	Orthopedic	44440590	Handle knife No. 3	Piece	1	7

3.7 Data base used in this research

Most of the medical supply replenishment data within the Hôpital du Sacré-Coeur is obtained under the RFID system and material handler record rest of the data manually by the use of barcode reader. Logi-D group, service provider for Hôpital du Sacré-Coeur, gathers data and provides supply chain automation solutions for hospitals. Data for this study was provided by Logi-D since it is not possible to have access to historical point-of-use data from the systems within the hospital.

Information regarding medical consumption used for this research is available for one year and seven months from January 2013 until July 2014. However, we will not use data from the last month since the data was extracted during that month is incomplete. Therefore, the effective range of our usable data is from January 1, 2013 to June 31, 2014, which represents 18 months of data. The data received from Logi-D system represents the daily medical consumption for a product.

In this research in order to present the method to improve the location of medical supplies within the main storeroom of the hospital and on the Carousel, we consider all nursing units of the hospital. However, to reduce the complexity, we consider only data on recovery room of the hospital, which we call SOPrev[1] department in this research, to propose the method to improve the physical location of medical supplies within a nursing unit and to improve the bins lot-size and replenishment interval in two-bin system.

1 salle d'opération et salle de réveil

3.7.1 Weekly medical supply replenishment pattern

In this section we present the replenishment patterns of the three most often used medical supplies (we introduce them as top medical supplies) in SOPrev department of Hôpital du Sacré-Coeur. The consumption of these medical supplies has the most cumulative volume during the studied period and is highly relevant for evaluation and analysis of the distribution system. Since we do not have access to other information about medical supplies such as cost, more often used medical supplies are considered as the top ones. According to the data received, these medical supplies for Hôpital du Sacré-Coeur are:

1. Dextr. 5% sol.phys. ½ ML Conc. 1000
2. Mask 40% O2 tube with 84 " (B50U)
3. Oxygen tube U connect – IT (Telescope) C50U

These medical supplies are often replenished once a day and rarely twice a day, due to the emergency situation such as stock-out. In this section weekly replenishment for top medical supplies is presented (See Figure 3-2, Figure 3-3, Figure 3-4). From these figures we can understand that although there are some patterns in the medical supply replenishment, the replenishment has a chaotic behavior. Therefore, it would be difficult for the managers to perform accurate evaluation and analysis. These medical supplies are very noisy and do not follow any special pattern or trend. Due to the short time horizon of the research and chaotic behavior of data, it is not possible to predict the future data consumption pattern with the use of predictive data mining algorithms. However, aggregate weekly replenishment data is used to find association rules among medical supplies, which are usually used together and improve the location of them in the nursing unit of the hospital.

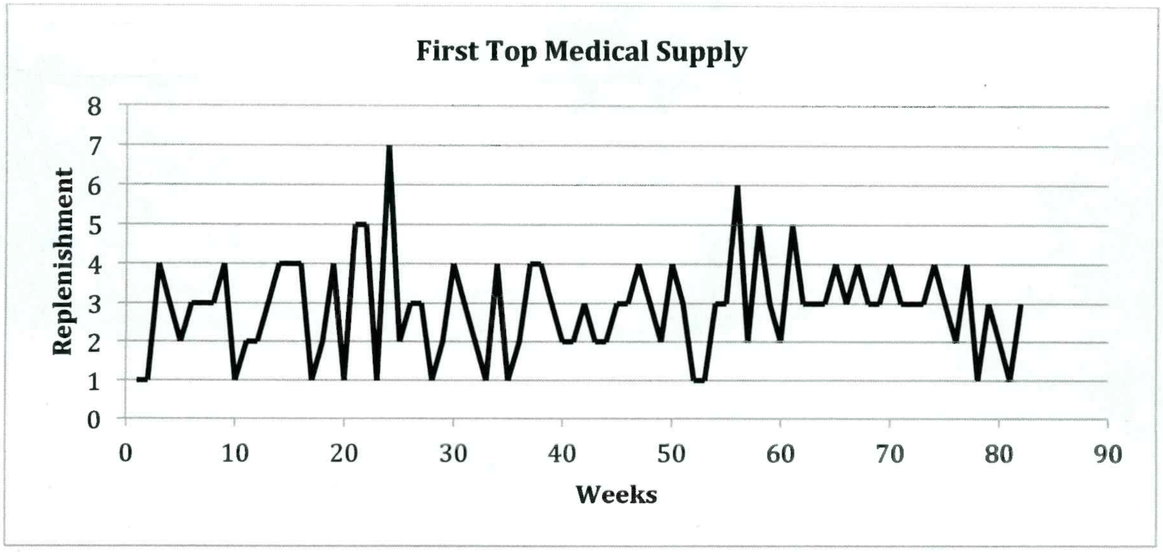


Figure 3-2: Weekly Replenishment for First Top Medical Supply

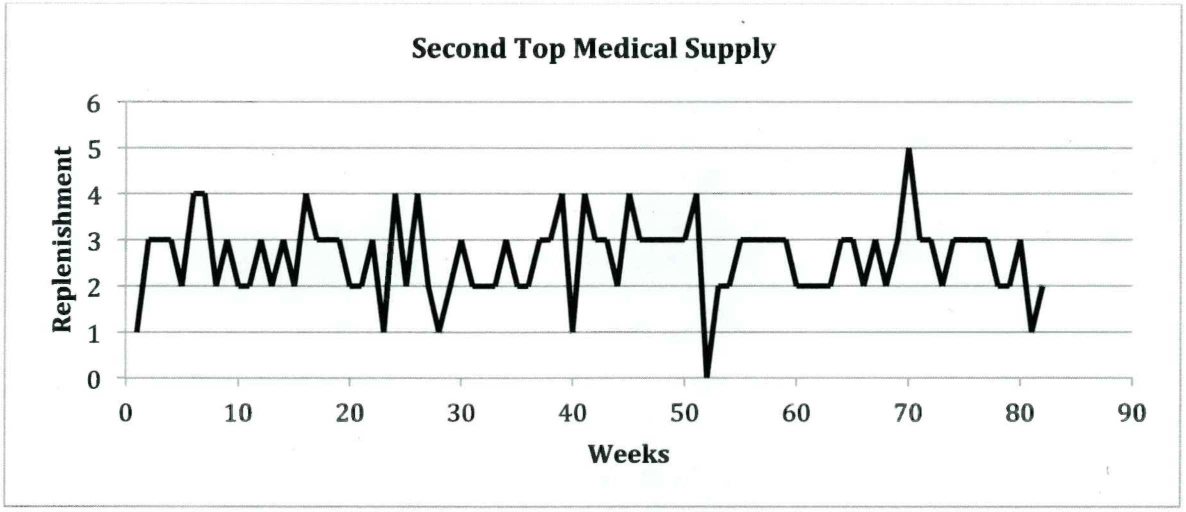


Figure 3-3: Weekly Replenishment for Second Top Medical Supply

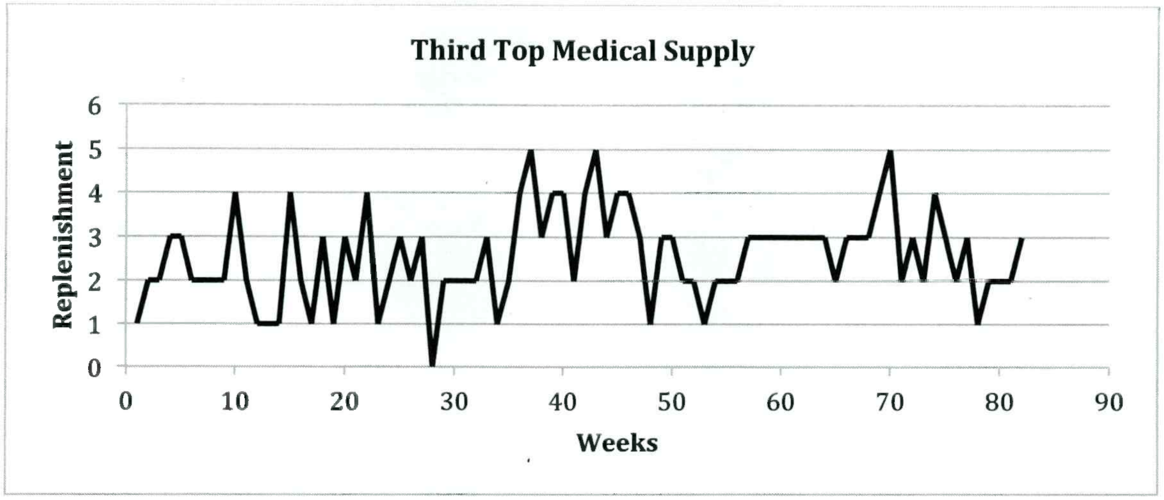


Figure 3-4: Weekly Replenishment for Third Top Medical Supply

3.7.2 Monthly medical supply replenishment pattern

In this section the medical supply consumption data is aggregated to the monthly pattern. From a monthly graphic description of the data (Figure 3-5, Figure 3-6, Figure 3-7) some conclusions can be made. First, the monthly replenishment still does not have any trend and it is very noisy. Second, there is a sharp fall in replenishment during some months of the year. However, due to the short time horizon of the research, monthly consumption data cannot be used to predict the future behavior of the system.

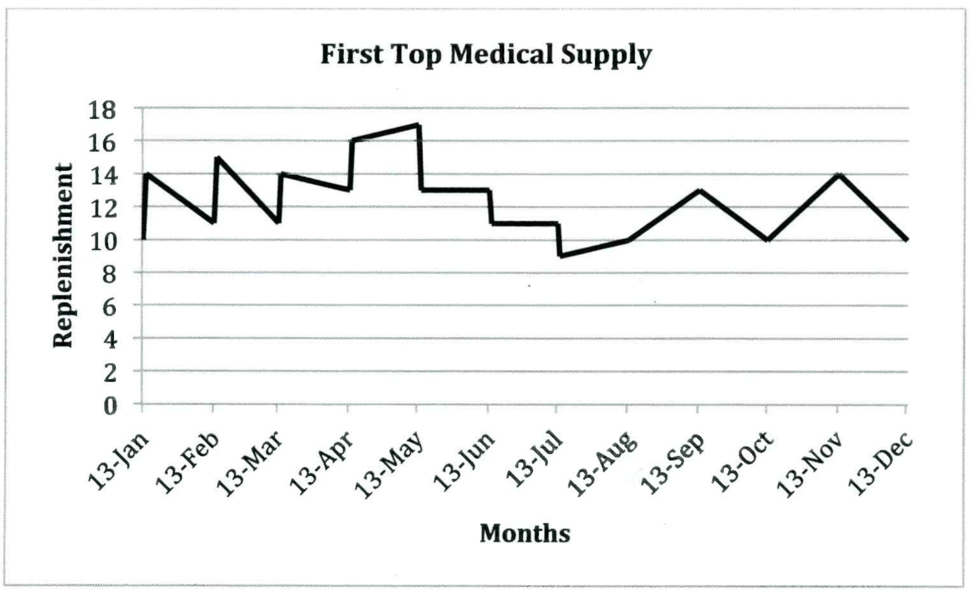


Figure 3-5: Monthly Replenishment Pattern for First Top Medical Supply

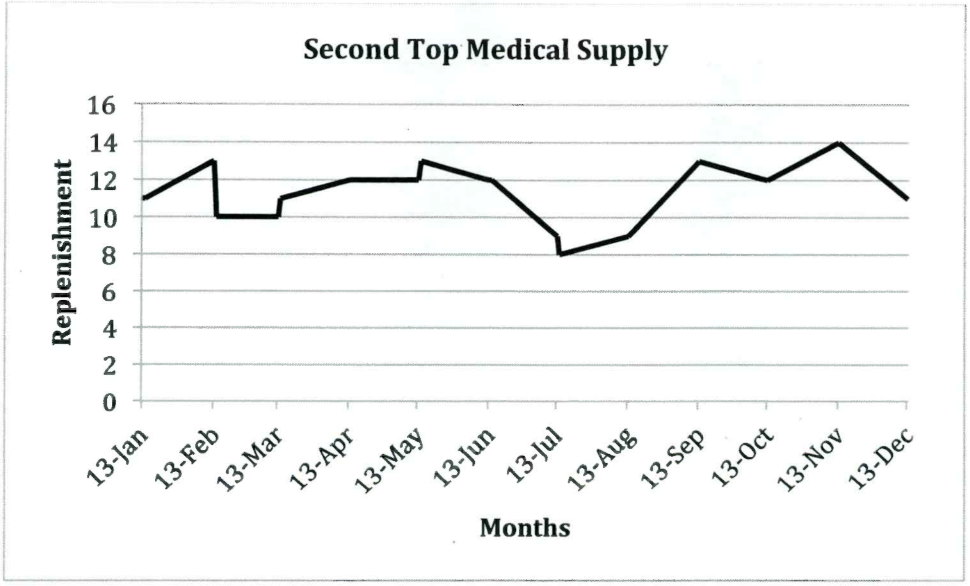


Figure 3-6: Monthly Replenishment Pattern for Second Top Medical Supply

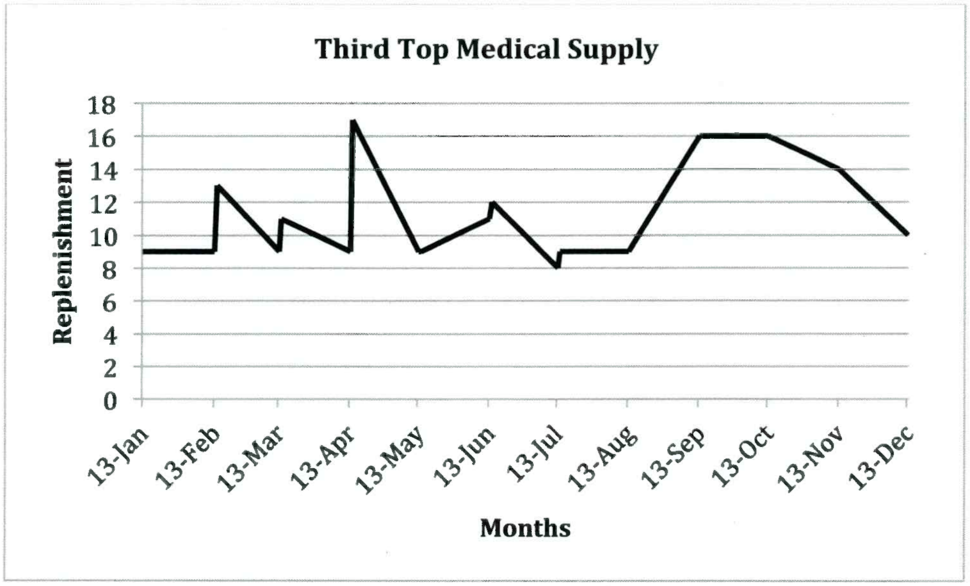


Figure 3-7: Monthly Replenishment Pattern for Third Top Medical Supply

We should note that, because of the short time horizon of received data, yearly, seasonally, and monthly data cannot be applied as the basis of the analyses of this research. Therefore, we apply daily and weekly replenishment data to explore the ways to improve the distribution of medical supplies within the internal supply chain of the hospital.

3.8 Improving the location of medical supplies

One of the objectives of this research is to improve the decision regarding the location of medical supplies used in the hospital. Therefore, this section is explained in two different subsections. First, we explain a decision tool to improve the location of medical supplies in the main storeroom of the hospital. Second, we present a decision tool to improve the location of medical supplies in the nursing units.

3.8.1 Improving the location of medical supplies in the main storeroom

There are two different types of medical supplies: stock items, which are kept in main storeroom and then delivered to the special nursing unit of the hospital; and non-stock items which are delivered to the nursing units shortly after they are received from the external suppliers. Since material management personnel in the hospital are responsible for the distribution of medical supplies procured either from the main storeroom of the hospital or external suppliers, in this section we decide about the procurement strategy of medical supplies and then about their location within the main storeroom.

Improving the medical supply procurement processes has a significant impact on reducing the cost of procuring medical supplies, the space needed to store medical supplies, and the operational time of the material management personnel. This decision can be changed every season according to the amount of consumption of each medical supply every season of the year.

As per the distribution histogram of medical supplies, some items are seldom utilized by the whole hospital. Therefore, it is not practical to store them in the main storeroom of the hospital. They can otherwise procure them straight from the external suppliers. However, there are some items consumed regularly by the whole hospital. Therefore, it is not cost effective to procure them from the external supplier because of the great amount of order expense. They should keep them in the main storeroom of the hospital. For instance, sodium chloride injection 0.9%, 1000 ML., glove S/L GR, and clamp tube are among the examples of stock items, while short tracheal tube number 10 is an example of non-stock items in Hôpital du Sacré-Coeur.

Our suggestion in this section is to consider the distribution of medical supplies used in all departments of the hospital (see Figure 3-8). Then subjectively define the appropriate thresholds in order to find the less often used medical supplies. These medical supplies will be considered as non-stock items and are procured by external suppliers. Next, another threshold is defined to decide about the placement of stock items within the main storeroom of the hospital.

At Hôpital du Sacré-Coeur medical supplies are either kept on the carousel or in the bulk area. The Carousel is usually installed in the main storeroom of the hospital for high-speed logistics picking, tracking, and distribution. Supply storage bins on the Carousel are fixed on an oval track that spins horizontally to deliver medical supplies to a picking operator (picker). Considering the distribution of medical supplies (Figure 3-8), among all stock items, which have already chosen, the more often used items are selected and kept on the Carousel.

As it is shown in Figure 3-8, without considering various formats of the same medical supply, such as different types of tubes, approximately 89% of the total consumption is provided from 22% of the medical supplies.

According to Figure 3-8, in general the quantity of the consumption of medical supplies in different seasons of year 2013 follows approximately the same trend. Furthermore, considering each medical supply individually, the quantity of the consumption of medical supplies in different seasons does not significantly change (see Figure 3-9). Therefore, according to the quantity of consumption, there is no need to change the procurement policy of medical supplies seasonally.

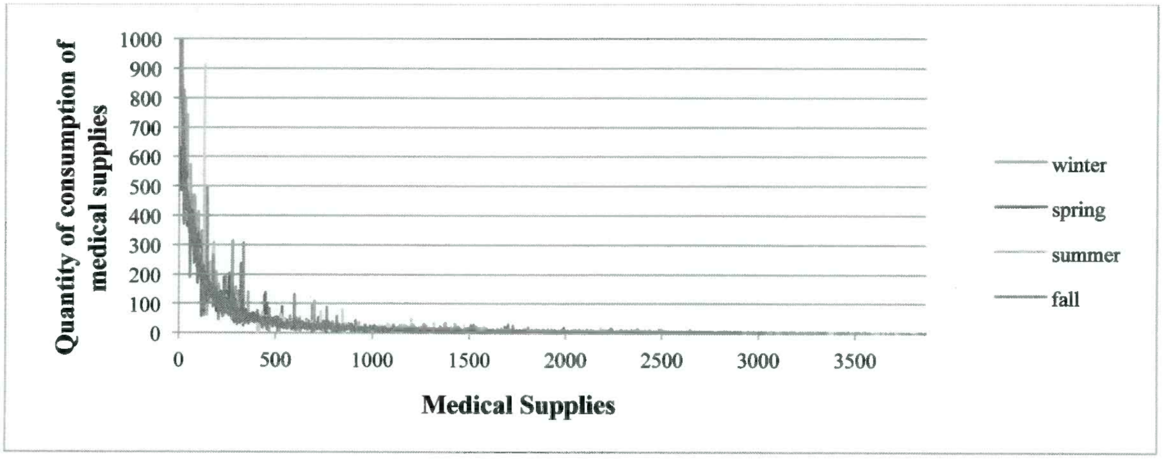


Figure 3-8: Quantity of the consumption of medical supplies in four seasons of 2013

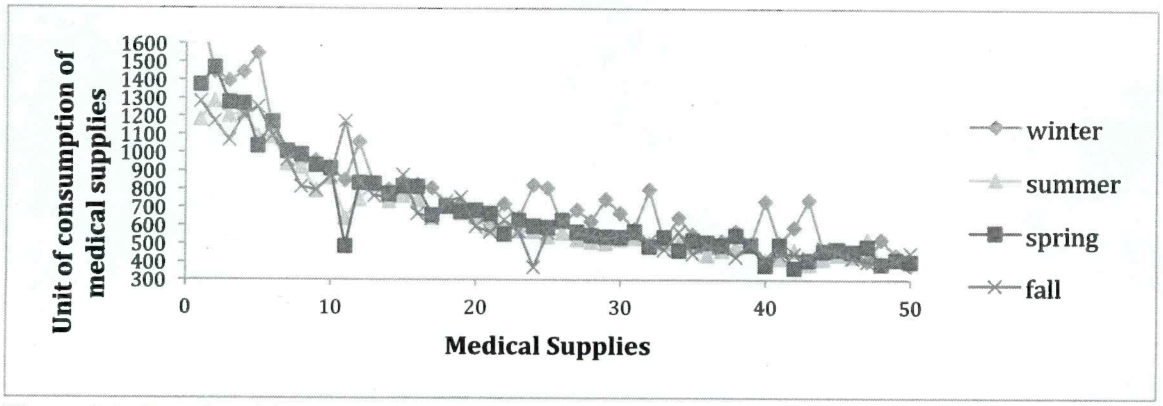


Figure 3-9: Quantity of the consumption of fifty more often used medical supplies

3.8.2 Improving the location of medical supplies in storage cabinets

As it was explained before, each nursing unit of the hospital has some storing points that are close to the point of use. Hôpital du Sacré-Coeur applies two-bin enabled RFID replenishment system. Medical supplies are placed in two-bins, which are usually considered as primary and secondary bins. Bins are usually located back-to-back in the storage cabinets with the secondary bin placed behind the primary bin. Sometimes depending on the size of the medical supplies, various medical supplies are placed in one bin. Physical placement of medical supplies in each bin and physical placement of bins in the storage cabinet are based on the experience (see Figure 3-10).

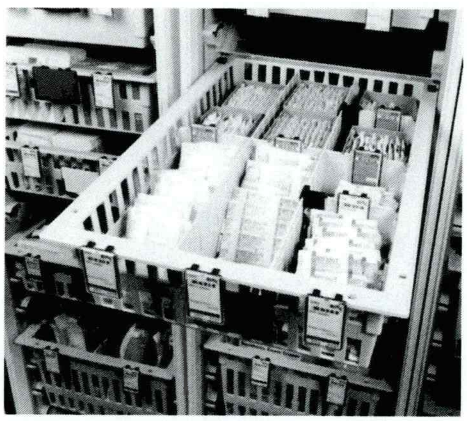


Figure 3-10: two-Bin system in hospital

In this section, we apply association rules to data from the consumption of medical supplies at the point of use to find the medical supplies, which are mostly used together, and place them close to each other in the storage cabinets. Using this method would help to arrange categories of supplies with a large range of items and clearly label each section of the storage cabinet, allocate items to a specific place, and label the position of the items on the shelf so that the store points will be tidy and well organized. An organized store points save time when ordering, locating, and using the items and decrease the probability of making mistakes at the time of usage. Therefore, placing medical supplies, which are mostly used together would improve the operation efficiency, staff satisfaction, and stock control.

In order to reduce the complexity we only consider recovery room (SOPrev) of the hospital. There are 81 medical supplies consumed in the recovery room (SOPrev). This department is daily reviewed for the replenishment. The association rules provide pairs or triples of medical supplies whose consumption is related. The algorithm used to find the association rules is "Apriori" (Han, Kamber, & Pei, 2012). These rules would ideally be used for improving the physical placement of medical supplies in bins and the placement of bins in the storage cabinets. As a result there would be an improvement in the operation efficiency, staff satisfaction, and stock control.

This section is composed of three subsections.

I. Pre-treatment of the data – Transformation of received data is required to perform association rules mining algorithms.

II. Description of the Apriori algorithm – This algorithm is used to produce association rules.

III. Association Rules Analysis – The parameters to analyze the created rules are discussed.

Section I: **Pre-treatment of the data**

1. Aggregate data on a weekly basis

   It is possible that the replenishment of different medical supplies, which are often consumed together, does not appear in the same transaction. Depending on the lot-size of each supply, they may appear on different transactions and give the false impression that their consumptions are not related. This artifact is reduced when a longer horizon is considered. On the other hand, if the considered horizon is too long, the patterns disappear (one can just compare averages). It is not possible to have any strong association rules on seasonal or monthly consumption. In the current case, a good compromise seems to consider weekly consumption.

2. Transform data on frequency to binary data

   In association rules analysis, the binary input data set is required to create rules. However, considering the weekly supply consumption data within the hospital units, there is a small chance of having binary data. Therefore, number of items consumed in each transaction (see Table 3-2) should be transformed to binary in order to find the association rules (see Table 3-2). Since the Apriori algorithm, which is used to create association rules, is constructed by reading the data set one transaction at a time and finding different related items, in this step we decompose each transaction into different hypothetical transactions in order to map the number of times that items are used together. For example in Table 1, to make hypothetical transaction from transaction 1 we consider the fact that items 1, 2 & 3 were consumed together for two times and item 1 was consumed alone only once. Thus for transaction one in Table 1 there are three hypothetical transactions in Table 2.

   As only some aggregated data is available, building a hypothetical consumption scheme yields a bias. For example, if two items were consumed once in two days, they may either be consumed on the same day, or not. In the first case, the association rules algorithm will detect a relation, while none will be found in the other one. It was decided to overestimate the relation (by supposing that both items were used together) as it is easier to discard a relation that was found than to find a relation that was not detected.

   The following algorithm is developed to transform the data on frequency to binary data (the R program for this algorithm is presented in Appendix 2):

Algorithm 1

Notations:

a_{ij}: Frequency of consumption of medical supply j in transaction i

C[m×k]: Binary hypothetical transaction matrix for m hypothetical transaction and j medical supplies

Main Steps

Step1. For i=1 to I

B[2][i] = $\max_{j=1,\ldots,J}\{a_{ij}\}$;

End for

Step2. B*[3][0] = 0

Step3. For i= 1 to I

B*[i] = B*[i-1] + B[i];

End for

Step4. For j=1 to J

For i=1 to I

If $a_{ij} = 0$ then

Break,

Else

For m= B*[i-1] +1 to B*[i-1] +a_{ij}

C[m×j]=1

End for

Endif

End for

End for

Table 3-2: Transaction database based on frequency of consumption of each medical supply

Transaction database				
Supply / Transaction	A	B	C	D
1	3	2	2	0
2	2	1	1	2

Table 3-3: Binary hypothetical transaction database

Hypothetical Transaction database				
Supply / Transaction	A	B	C	D
1	1	1	1	0
2	1	1	1	0
3	1	0	0	0
4	1	1	1	1
5	1	0	0	1

[2] B [I×1]

[3] B* [I×1]

3. Input data into the RapidMiner

   Save data in CSV or Excel format and then this input data is imported in RapidMiner software to create association rules.

Section II – Association rules mining and the Apriori algorithm

Association rule mining is applied to find interesting relationships between different medical supplies consumed at point of use. For example, from the transaction data of a nursing unit, the rule {C1} => {C2, C3} is created, which denotes that when the medical supply C1 is consumed, it is likely that the medical supplies C2 and C3 are also consumed. This information can lead to improved physical placement of medical supplies in storage cabinets.

Association rules do not indicate causality, but instead suggest strong co-occurrence relationships that can be further investigated as associated factors. The strength of the rules is measured by support, confidence, and lift. Support indicates how often a rule is applicable to a specific data set and can be used to eliminate uninteresting rules, such as those that occur simply by chance (Tan, Steinbach, & Kumar, 2006; Hu, 2010). Confidence measures the reliability of the implication made by a rule, for instance, X ➔ Y, measured as how frequently items or attributes in Y appear in transactions or patients that contain X. Minimum support and confidence thresholds are selected for assessing the association rules extracted from the data. An itemset is frequent if its support is greater than or equal to that minimum support value (Tan, Steinbach, & Kumar, 2006).

$$\text{Support } (A \Rightarrow B) = \frac{\textit{Number of tuples containing both A and B}}{\textit{Total number of tuples}}$$

$$\text{Confidence } (A \Rightarrow B) = \frac{\textit{Number of tuples containing both A and B}}{\textit{Number of tuples containing A}}$$

In order to avoid an uncontrollable amount of rules created, it is important to clearly set criteria for assessing the quality of association patterns. This can be done:

a) Objectively, through measures that use statistics, such as support, confidence, and lift (or interested factor) to determine the interestingness of a pattern;

b) Subjectively, by using domain expertise to determine whether the information or knowledge revealed about the data is interesting.

One important issue with mining association rules in large data sets is the fact that it can be computationally expensive depending on the algorithm used. For example a brute-force approach for discovering patterns from data would consist of computing the support and confidence for every possible rule. As the number of rules that can be attained from a data set grows exponentially with the number of items in that set, this brute-force approach becomes excessively expensive. This approach also results in wasted transactions, as many of the rules would be discarded for falling below the minimum support and confidence levels selected (Tan, Steinbach, & Kumar, 2006). Thus, some methods are used in order to reduce the number of itemsets that need to be checked and to evaluate the support of selected itemsets efficiently. Three major scalable mining methods are Apriori, Frequent pattern growth, and Vertical data format approach. In this study we apply Apriori method as it is more popular algorithm to find all the frequent sets. The Apriori algorithm identifies the frequent individual items in the database and spreads them to the larger item sets as long as those item sets appear adequately often in the data base. These frequent item sets are used to produce association rules.

Apriori Algorithm - A Candidate Generation-and-Test Approach

Apriori pruning principle is if there is any itemset, which is infrequent, its superset should not be generated or tested (Han, Kamber, & Pei, 2012).

Apriori Method:

- Initially, scan data base once to get frequent 1-itemset
- Generate length (k+1) candidate itemsets from length k frequent itemsets
- Test the candidates against data base
- Terminate when no frequent or candidate set can be generated

Apriori Pseudo-code:

Variables:
C_k: Candidate itemset of size k
L_k: Frequent itemset of size k

Initialization
L_1 = {frequent items};

Main step
```
for (k = 1; L_k ≠∅; k++) do
    C_{k+1} = candidates generated from L_k;
    for each transaction t in database do
        increment the count of all candidates in C_{k+1} that are contained in t;
    end for
    L_{k+1} = candidates in C_{k+1} with min_support;
end for
return ∪_k L_k;
```

Section III - Association Rules Analysis

Once the frequent itemsets have been found, generating strong association rules from them is straightforward. An association rule A ⇒ B is strong if it satisfies both minimum support *min_sup* and minimum confidence *min_conf* threshold.

Methods:

1. For each frequent itemset I, generate all non-empty subsets of I.
2. For every non-empty subset s of I, output the rule s⇒(I-s) if conf(s ⇒(I-s)) ≥ *min_confidence.*

Usually limited numbers of rules are generated with high or moderate levels of confidence and support. In min_confidence and min_support equal to 0.5, the rules presented in Table 3 are interesting and strong. It means that when supply C1 is used supplies C2 and C3 are used as well; and when supply C2 is used, supplies C3 and C4 are used as well. In general by looking at Table 3, one can understand that there is a strong relationship among medical supplies C1, C2, and C3; also C2, C3, and C4; and among C3, C5, C6. Therefore, it is suggested to consider these relationships to place different medical supplies in the storage cabinet of a nursing unit. For example, it is better that medical supplies C1, C2, and C3 are placed close to each other in storage cabinet.

Table 3-4: Association rule results

Projected Databases and Sequential Patterns			
Premises	Conclusion	Support	Confidence
C1	C2, C3	0.7	0.8
C2	C3, C4	0.6	0.8
C3	C5, C6	0.6	0.8

3.9 Improving bins lot-size and replenishment interval in two-bin System

Under a two-bin system, bins are usually denoted as primary and secondary. It is common for both bins to hold the same amount of inventory. The amount of inventory to be stored is usually determined based on the number of desired inventory turns per year (Rosales, Magazine, & Rao, 2014). In order to avoid stock-outs many hospitals may be motivated by either increasing the frequency of reviewing empty bin status (replenishment frequency) or increasing the lot-size of medical supplies held in two-bin system. Increasing the frequent replenishment may increase the operational cost for the material management department. On the other hand, storing a lot of medical supplies in the two-bin system not only occupies a lot of space, but also increases the inventory costs. Therefore, this study suggests to control the replenishment frequency and inventory levels at point-of-use by finding a trade-off between the bins lot-size and replenishment interval for each medical supply used in a storeroom.

Improving the lot-size in each bin of two-bin system, this study proposes two different approaches. First, a heuristic method, which applies the descriptive data mining, is developed. Second, a new inventory model, which has not yet been studied in the literature, is introduced.

3.9.1 Heuristic Method

In this section, we derive a simple and efficient algorithm to find the lot-size held in a two-bin system and the replenishment interval for each medical supply used in a nursing unit of the hospital. First a brief description of the current system is presented. Then we explain the assumptions under which the algorithm was developed. Finally the proposed algorithm is discussed.

In two-bin enabled RFID system stock items are usually divided evenly between the primary and secondary bins. First the stock in the primary bin is used. When the primary bin is empty and its tag is placed on the board, the replenishment procedure is triggered. Until the replenishment takes place, medical supplies are used from the secondary bin, which composed of a safety stock plus the average demand during the lead time. The replenishment review is done based a predetermined cycle. For example one nursing unit is reviewed every Monday and Thursday to fill the empty bins.

We consider the following assumptions in order to manage the frequency of delivery and bin lot-size for each item used in the hospital due to high volume of transaction and high number of medical supplies.

1. We assume an unlimited capacity for the cart, which is used to carry medical supplies from the storeroom of the hospital to the nursing units.
2. We do not consider perishable medical supplies with the expiry date.
3. We do not consider packaging problem for different medical supplies.
4. We only consider stock items, which are delivered from the main storeroom of the hospital.
5. Shortages are not allowed.

Proposed Heuristic

Algorithm 2

Variables:

Q_i: Bin lot-size for medical supply i - The bin lot-size is equal to the amount of medical supply, which is delivered at the time of replenishment

SQ_i: Secondary bin lot-size for medical supply i

P_i: Replenishment period (P_i = 1,…,P), where ($P_i = \frac{N}{R_i}$)

Inv_{ip}: Average inventory of medical supply i for the replenishment period P_i

Parameters:

Q_0^i: Current bin lot-size for medical supply i

R_i: Replenishment review interval for each medical supply i; $R_i = \{1, \dots, 7\}$

N: The total 18 months of research period

BR_i: Bin-level replenishment amount received from RFID for medical supply i

UC_{ij}: unit-level consumption of medical supply i during the day j

$t_{i,k}$: Day of the k^{th} replenishment for medical supply i

Main steps:

Step 1: Produce unit-level consumption data from bin-level replenishment data.

Under the two-bin replenishment system, the hospital data obtained does not include unit-level demand; the demand captured by RFID system is at the bin level. It means that under a two-bin inventory system only empty bins are tracked and replenished instead of unit-level medical supply consumption. Moreover, the replenishment of some of the medical supplies only happens some days a week, but not everyday. In order to find the proper amount of medical supplies held in each bin to avoid stock-out or surplus, it is required to have daily unit-level consumption data. Bin-level replenishment data does not show the day-to-day amount of medical supplies required at point of use. Therefore, each unit of medical supplies used at point-of use is required to define the improved lot-size kept in two-bins. In order to generate daily unit-level consumption data, the bin-level replenishment data is divided by the time interval between two consecutive replenishments (Equation 1). It is important to analyze the daily consumption to find out the best possible policy to fit the daily consumption.

$$UC_{ij} = \frac{BR_i}{(t_{i,k} - t_{i,k-1}) + 1} \quad (1)$$

For example, if we replenish an item with the 400 bin lot-size and the number of days until the next replenishment is 3, to obtain the daily unit-level consumption, 400 is divided by 3 (See Table 3-5).

Table 3-5: Retrieve unit-level consumption data from bin-level replenishment data

Day	Number of Replenishment	Quantity of Replenishment	Hypothetical Daily Consumption
1	1	400	133
2	0	0	133
3	0	0	133
4	1	400	200
5	0	0	200

Step 2: Evaluate different strategies by changing the combination of primary bin lot-size (Q_i) and replenishment review interval (R_i)

Considering the current bin lot-size, different values for primary bin lot-size (Q_i) and replenishment review interval (R_i) are tested. Since we are looking for weekly replenishment frequency, the values for R_i ranges from 1 to 7, which represents the number of days between two replenishments. Then for the fixed number of R_i, different values of Q_i are tested. The values for Q_i are varied around the bin lot-size (Q_0^i) currently practiced at the hospital. Since it is assigned based on experience of the material management personnel, it is a good initial value to start the computations. Therefore, K (a reasonable positive value) units above and below this number (Q_0^i-k, Q_0^i+k) are tested.

$$Q_i \in (Q_0^i - K,\ Q_0^i + K), \textit{ Where K is a reasonable constant such that K>0} \quad (2)$$

Step 3: Find amount of shortages and surplus in each replenishment review interval

In this step, it is important to note that the primary bin is replenished only if there is no medical supply left in the bin. Therefore, if there is any leftover (D_{p-1}), the bin is not replenished. When the primary bin is empty the amount of replenishment (Q) is subtracted from accumulated unit-level consumption of medical supply for that period and shortage or surplus from the previous replenishment period will be added in order to find the amount of shortage or surplus in each replenishment period (D_p) (Equation 3).

$$D_p = \begin{cases} Q_i + D_{p-1} - \sum_{j}^{R} UC_{ij} & D_{p-1} \leq 0 \\ D_{p-1} - \sum_{j}^{R} UC_{ij} & D_{p-1} > 0 \end{cases} \tag{3}$$

If the remainder of the above equation is positive then there is a surplus and if it is negative there is a shortage (or stock-out) in the considered replenishment review interval (p) (Equation 4).

$$\begin{cases} ST_{ip} = -D_p, & D_p < 0 \\ SP_{ip} = D_p, & D_p \geq 0 \end{cases} \tag{4}$$

Step 5: Improve the second bin lot-size

Subsequently, the second bin lot-size is improved based on the maximum amount of shortages happened during the research period (Equation 6). Therefore, in each review interval the shortages are met by the second bin lot-size.

$$SQ_i = \text{Max } SP_{ip} \text{ , } p=(1, \ldots, P) \tag{5}$$

Step 4: Find the average amount of inventory for different combination of Q and R

In this step the determined defined amount of second bin is added to average amount of shortages and surplus in order to find the average amount of inventory for different combination of Q and R

$$Inv_{ip} = SQi + \frac{\sum D_p}{Pi} \tag{6}$$

Step 5: Define the best possible value for the combination of Q_i and R_i

In this step considering the amount of replenishment, replenishment review interval, second bin lot-size, and average inventory, the best Q and R is defined. The best Q is the one, which has the lowest amount of shortage and surplus. The best combination of Q and R is the one with the least amount of average inventory and second bin lot-size. Moreover, due to the costs related to the frequency of replenishment, material management personnel can find the best policy by considering some trade-off between all the important variables.

Note that in this section of our study, we propose a method to improve the bins lot-size in two-bin system and replenishment review interval for each medical supply. Since there are various medical supplies used in a nursing unit of the hospital, this algorithm should be applied for all medical supplies within that nursing unit. In order to find an improved replenishment review interval for the whole department, we should consider the replenishment intervals of all the medical supplies used in that nursing unit of the hospital. Then, we may be able to find the most common replenishment review interval appropriate for the entire medical supplies and assign it as the replenishment interval of the nursing unit. Moreover, after finding the improved replenishment review interval and primary and secondary bin lot-size, the material management personnel can take costs into consideration in order to make the final decision. However, in this study we do not have access to the data on cost and we cannot go further.

An example of Hôpital du Sacré-Coeur

In order to find the best possible combination of Q and R, the second bin lot-size and average inventory (stock) level are compared in each combination. The smaller the lot-size in the second bin, the smaller would be the average inventory and therefore the solution will be better. In Table 3-6 and Table 3-7, the primary and secondary bin lot-size, and average inventory for each strategy of one of the medical supplies (oxygen tube U/connect-IT (telescope) C50U) in SOPrev department of the hospital are presented. According to the results, there are only some combinations of Q and R, which lead to the reasonable second bin lot-size. For the rest of the strategies it is impossible to satisfy the demand with the proposed parameters. In such a case, the simulation suggests a very large second bin lot-size, but this size does not have any real meaning, as it depends on the horizon considered in the model.

Table 3-6: Second bin lot-size for each combination of Q and R

R \ Q	R=1	R=2	R=3	R=4	R=5	R=6	R=7
Q=10	50	785	1675	2135	2415	2593	2725
Q=15	45	122	795	1455	1860	2130	2330
Q=20	30	53.75	125	782.5	1325	1670	1935
Q=30	30	33.75	45	90	266	795	1145
Q=40	40	40	53.75	53.75	80	145	426
Q=50	50	50	50	50	80	84	132

Table 3-7: Average inventory for each combination of Q and R

R \ Q	R=1	R=2	R=3	R=4	R=5	R=6	R=7
Q=10	42	402	850	1077	1220	1300	1360
Q=15	37	85	403	730	943	1068	1165
Q=20	20	42	77	400	666	840	970
Q=30	15	20	30	70	152	401	580
Q=40	20	19	34	33	56	83	222
Q=50	23	23	23	22	55	53	65

According to the result of the proposed heuristic (see Table 3-6 and Table 3-7), for instance, one of the reasonable strategies is Q= 30 and R = 3, which leads to the second bin capacity and average inventory of 30 and 45. Therefore, it is possible to keep the same amount for both primary and secondary bins and have a reasonable amount of inventory.

In order to make a better decision, it is suggested to use the result of the algorithm to evaluate each policy and eventually make a better decision regarding the bin lot-size and replenishment review interval for each item used at the hospital. The following charts are presented to the material management personnel to compare each option (Figure 3-11, Figure 3-11). These charts depict the relation between second bin lot-size and average inventory in two-bins for each reasonable combination of Q and R.

This is a multi objective optimization in which the bin lot-size is minimized and the replenishment interval maximized. Therefore, there is no single solution that simultaneously optimizes each conflicting objective; except with, a representative set of Pareto optimal solutions among which a single solution is chosen to satisfy the material management personnel's preferences. That is, they can better decide according to the space availability, and replenishment and storage cost. They can also consider the results obtained from the algorithm along with the cost analysis for each possible option. Finally, they can equally make better decisions regarding the distribution of medical supplies within each unit of the hospital. For instance, they may prefer to reduce the replenishment interval, but increase the capacity of the primary and secondary bins.

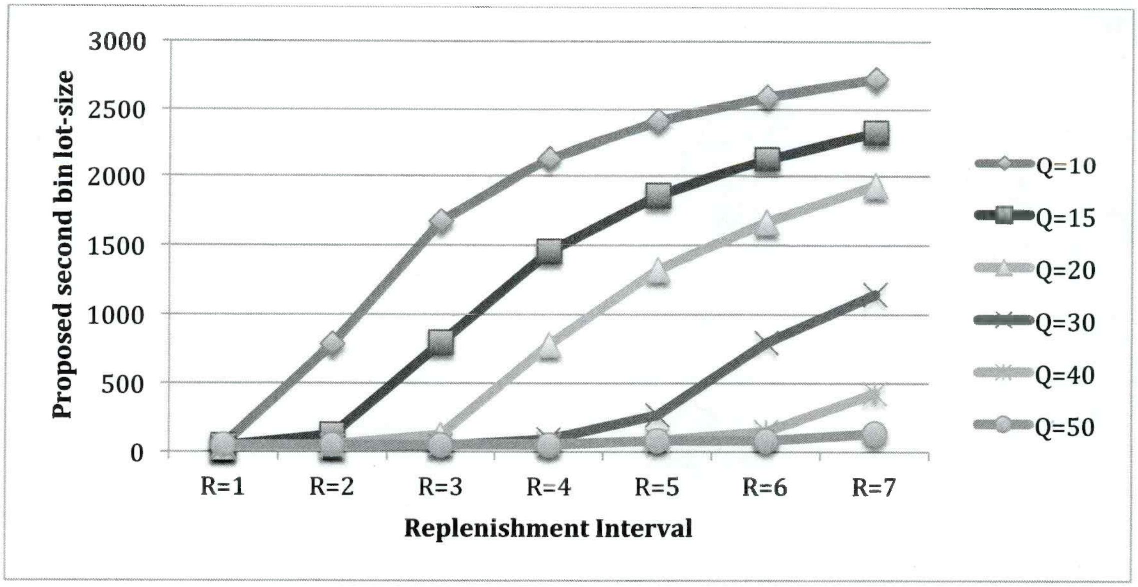


Figure 3-11: Second bin lot-size based on the proposed heuristic for each combination of primary bin lot-size and replenishment review interval

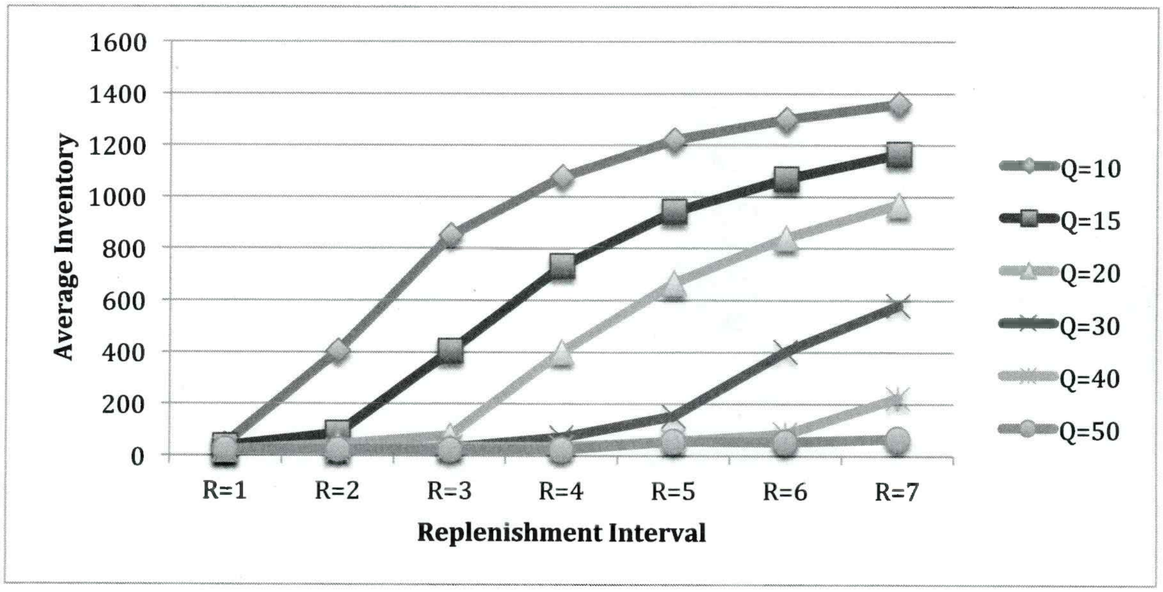


Figure 3-12: Average inventory for each combination of primary bin lot-size and replenishment interval

Note that in this section of our study, we propose some solutions to improve bins lot-size in two-bin system and the replenishment interval for each medical supply. This algorithm should be applied for all medical supplies within the studied nursing unit in order to find the enhanced replenishment interval for the whole department. However, in next section we propose another algorithm, based on pre-determined thresholds subjectively defined by material management personnel, to find the improved replenishment frequency of the whole nursing unit.

3.9.2 Introducing a new Hybrid Inventory Model with fixed quantity and replenishment interval

Two-bin systems are reviewed periodically based on a predetermined cycle. In each replenishment review only empty bins are filled. For example one nursing unit might be reviewed to fill the empty bins every Monday and Thursday. The two-bin inventory system is under periodic and continuous review system. Rosales, Magazine and Rao (2014) show that the inventory systems in the hospital follows the hybrid system and they present mathematical models in order to find the inventory management parameters. Hybrid replenishment inventory policy is replenished periodically at the beginning of every shift to provide incoming nurses with adequate levels of supplies, but inventory may also be replenished between shifts when the inventory of a particular item falls to a predetermined critical level.

During this research, we evaluated different inventory methods, such as continuous inventory models with stochastic demand and lead-time with fixed quantity of replenishment. However, after reviewing the literature, we understood that the inventory model, which is applied for two-bin system in the hospital of our study is different from the ones currently exist in the literature and it follows the hybrid system with both fixed quantity and replenishment interval. Rosales, Magazine and Rao (2014) studied the two-bin system model in hospitals. However, our proposed inventory model differs from them by considering the unit-level demand, fixed quantity of replenishment and replenishment interval. In the current two-bin system, the safety stock and re-order point and the optimal order quantity, they all have the same size. They are often defined based on experience. So that applying the proposed inventory model we can find the way to improve the primary and secondary bin lot-sizes.

In this thesis, we propose to solve this problem by the mean of a heuristic method based on data mining to compute the optimal sizes of each bin for each medical supplies in the hospital.

3.10 Improving replenishment frequency of a nursing unit

In order to avoid medical supply stock-out, many hospitals may stipulate to review empty bin status with high frequency but frequent replenishment may increase the material management operation time and cost. On the other hand, the occurrences of any stock-out between review intervals usually lead to wasted time and distraction for medical staff and eventually the detriment of patient care. In this section we propose a heuristic algorithm in order to improve replenishment frequency of a nursing unit in the hospital.

We consider the following assumptions in order to improve the replenishment frequency of the hospital:

1. We assume an unlimited capacity for the cart, which is used to carry medical supplies from the storeroom of the hospital to nursing units.
2. We do not consider perishable medical supplies with the expiry date.
3. We do not consider packaging problem for different medical supplies.
4. We only consider stock items, which are delivered from the main storeroom of the hospital.
5. Shortages are not allowed.

In order to evaluate the performance of the proposed algorithm, the current practice in the hospital is compared with results of the algorithm. The objective is to decrease number of visits for replenishment of a nursing unit of the hospital without decreasing the service reliability.

Steps to improve the replenishment frequency of a nursing unit of the hospital are as follow:

Step1. Group medical supplies

Since the number of medical supplies used in a hospital is relatively high, grouping items and studying the group instead of each member reduces the computation time. Medical supplies are grouped with the use of Association Rule Mining (ARM). ARM analyzes the medical supplies transaction database to find an antecedent (if) and a consequent (then) relationship among medical supplies. An antecedent is an item found in the data. A consequent is an item that is found in combination with the antecedent. Therefore studying the antecedents would be enough to improve the replenishment frequency of a nursing unit. The process of applying ARM has been explained in section 7 of this chapter.

Step2. Algorithm

This algorithm (Algorithm 3) is based on thresholds defined by material management personnel based on their experience and on different types of nursing units (specialized and general). The objective of the algorithm is to find the best replenishment frequency for one department of the hospital by tracking the weekly replenishment frequency of all the medical supplies used in that department during the whole eighteen months of the research period.

Algorithm 3

Variables

I = Medical supplies

X= Nursing unit replenishment frequency per week

B_i= Bin capacity for the medical supply i

K = Weekly replenishment frequency; K ∈ {1,2,3,4,5,6,7}

Parameters:

A_{ki} = number of weeks that medical supply i has been replenished k times a week in 18 months

M_1 = threshold for number of i that are allowed to meet k+1

M_2 = threshold for acceptable sum of $A_{k+1,i}$ which can surpass K

Main Steps

```
Step 1. T=0,
        H=0,
Step 2. For K=1 to 7
          t=0
          For i =1 to I
              If sum_k Aki >0, for k = K+1…7 then
                t=t+1,
              Else
                X=k,
              End if
          End for

        If t<m1, then
              For i=1 to I
                 If sum_k Ak+1,i >m2, then
                    h=h+1,
                 End if
              End for

          If h=0, then
            X=k,
          Else
               Then for X=k, find the best value of Qi (by using the algorithm 2)
               X=k,
          End if
      End if
      End For
```

According to the algorithm, for a given value k, we count the number of medical supplies that surpass the threshold. Considering both defined thresholds, an improved replenishment frequency for the whole nursing unit of the hospital is found. However, there will remain medical supplies that do not meet the thresholds. For these items the second bin lot-size will be increased based on the results from the algorithm 2 in section 3.9.1.

Since we did not get a lot of strong rules among medical supplies of SOPrev department, we do not group them for this department of the hospital; however, if there are a lot of medical supplies used in the hospital, grouping medical supplies can reduce the computation. In the next step with the use of the algorithm 3, Table 3-8 is generated. The purpose of this algorithm is to consider the historical data and find the more often replenishment frequency, which is appropriate for most of the medical supplies. In Table 3-8, number of weeks that a medical supply has been replenished k times a week during the whole research period (18 months) is presented. For example "Supply 1" has been replenished once a week for 37 weeks, twice a week for 9 weeks, and three times a week for one week. Comparing the data in Table 10, we can conclude that most of the medical supplies in SOPrev department are replenished only once a week. However, significant numbers of medical supplies are replenished more than once a week during the studied period of the research. In the next step, we define two thresholds, one is to define acceptable number of weeks that a product i has been replenished k+1 times a week during 18 months of the research period, the other is on the number of medical supplies which are allowed not to meet the first threshold. Finally, the results of the heuristic are compared and the final decision regarding the nursing unit replenishment frequency is made.

In summary, in order to find the best replenishment frequency for the department, we need to consider a trade-off that meets the manager's expectations. Considering the second threshold, we find the medical supplies, which do not meet the assigned weekly replenishment frequency and they need to be replenished more often. For these items, after consulting with the logistic manager, we can increase their capacity in two-bin system with considering the results obtained from previous section. For example, if we set the threshold to 4, then there will be only one medical supply that is required to be replenished more than four times a week. For this medical supply, regarding its type, we can increase the capacity of its second bin, which has been found from previous section. If we set the threshold to 3, then there are more medical supplies that should be replenished more than three times per week. Therefore, it is important to consider the type of medical supply and find the proper amount of second bin lot-size with the use of algorithm defined in previous section. Finally all the results are presented to the logistic manager in order to choose the best policy according to other important factors such as cost (See Table 3-9).

Table 3-8: Medical Supply Weekly Replenishment Frequency

Weekly Replenishment	**Supply A**	**Supply B**	**Supply C**	**Supply D**
1	37	6	3	13
2	9	1	1	17
3	1	0	0	29
4	0	0	0	17
5	0	0	0	4
6	0	0	0	1
7	0	0	0	1

Table 3-9: Find the ideal replenishment frequency for the whole nursing unit according to replenishment frequency of each medical supply

Frequency Threshold	**Supply C**	**Supply D**	**Supply I**	**Supply J**	**Supply K**	**Supply L**	**Supply M**	**Supply N**
4	0	0	0	0	MR	0	0	0
3	MR	MR	MR	MR	MR	0	MR	0

*MR depicts the replenishment frequency for the item is more than considered threshold

3.11 Conclusion

In this chapter, different areas were recognized to improve the efficiency of the current medical supply distribution processes along with describing the hospital's inventory, replenishment, and distribution system.

At Hôpital du Sacré-Coeur the procurement, placement, and replenishment of medical supplies are done based on experience. Therefore, there is a space to improve the current practices regarding the distribution of medical supplies within the hospital by applying scientific methods. We proposed the use of some algorithms as tools as to improve and advance the current procurement and placement policy. Also, two issues we want to address when considering the storage of medical supplies in nursing units. First is the placement of medical supplies in the provided shelves; this will improve the inventory management cost and operation. Second is the amount of medical supply kept in two bins along with the replenishment interval. Currently, the size of primary and secondary bins for each medical supply is the same, which increase the amount of waste and obsolete items in two-bins. We further proposed a heuristic to improve the two-bins lot-size and replenishment interval for each medical supply used in a nursing unit of the hospital. Furthermore, since the previous proposed algorithm is used to improve the bins lot-size and replenishment interval for each medical supply, another heuristic was suggested to improve the frequency replenishment of the whole nursing unit of the hospital. These algorithms can be used as a tool for hospital managers to evaluate the consequences of each options, allowing to make a better judgments and assessments in the procurement and placement policy when taking into consideration the replenishment of medical supplies.

Therefore, according to the research questions, we introduced some decision tools through which material management personnel will be able to improve the location of medical supplies in the main storeroom of the hospital and in the storage cabinets. In short, some tools were presented to make a better decision regarding the replenishment of medical supplies by improving the size of the bin and replenishment frequency.

Chapter 4
Conclusion and future research

According to the growth trend, it is likely that hospitals and health organizations spend more on their supply chains than on labor (DeJohn, 2009). Therefore, supply chain management is considered as one of the most important areas for the CEOs and executive leadership of hospitals (Barlow, 2010). Due to the fact that hospitals use thousands of different types of supplies and equipment, finding an efficient method to procure, place, and distribute these supplies is always regarded important. On the other hand, efficiently managing data is one of the hottest issues in every organizations and healthcare systems. Not only it is important to transmit important information through different layers of supply chain, but also it is crucial to manage this huge amount of data to discover meaningful information that enhances the whole system. To sum up, in this study we combined supply chain management and data mining concepts to improve the current practices within the internal supply chain of the hospital.

We used data from Hôpital du Sacré-Coeur in order to discuss the proposed methods and meet the objectives of our thesis. There is no specified pattern in the medical supply consumption at Hôpital du Sacré-Coeur, but there is some chaotic behavior, which makes the future forecast more difficult. These medical supplies do not seem to have any trend. The patterns in these data sets are diverse, noisy, and distorted. Therefore, in order to find important information from this database, we developed some algorithms to explore potential improvements within internal supply chain of the hospital.

First, we applied descriptive data mining approach to find the better procurement policy for medical supplies. By analyzing historical data and by applying the proposed method, more frequent items is suggested to be procured from main storeroom of the hospital and less frequent ones directly from the external suppliers.

Second, a heuristic used to place stock items, which are procured from the main storeroom of the hospital, in two different areas within the main storeroom. These items are either kept in the bulk area, where all medical supplies are placed in different shelves with special codes, or on the carousel. By the use of the proposed heuristic we suggest to keep more frequently used items on the Carousel. Because the automatic nature of the carousel leads to the saving in the operational time and the number of runners who pick items from the inventory and operate the replenishment.

Hôpital du Sacré-Coeur applies a two-bin RFID enabled replenishment system. Medical supplies are placed in two bins (denoted as primary and secondary) usually of the same size and located back-to-back, the primary bin being in the front. Sometimes depending on the size of the medical supplies, various medical supplies are placed in one bin. Physical placement of medical supplies in each bin and physical placement of bins in the storage cabinet are based on the experience and they do not follow any scientific rule. Therefore, we suggested to use association rules mining, derived from data mining, to find the interrelation ship between medical supplies and place the ones which are mostly used together close to each other.

In this study we suggest two methods in order to find the improved size of each bin for each medical supply used in each nursing unit. First, the heuristic method applies the descriptive data mining to improve the bin lot-size for each medical supply within a nursing unit. Second, a new inventory model, hybrid replenishment system with fixed order quantity and replenishment interval, was introduced to find the optimal bins lot-size. In the proposed heuristic different possibilities for the primary bin lot-size and number of replenishment were tested. Finally the material management personnel can make the better decision regarding the storage amount of each medical supply and their replenishment frequency can use the results of the system. It is strongly suggested to take cost analysis into account along with the results of the suggested heuristic to reach to the better decision. Comparing the results of the current practice with the results of the heuristic, we conclude that the current practice can be improved.

Finally, in order to avoid medical supply stock-out, many hospitals may stimulate to review empty bin status with high frequency. However, frequent replenishment may increase the material management operation time and cost. On the other hand, the occurrences of any stock-out between review intervals usually lead to wasted time and distraction for medical staff and eventually the detriment of patient care. Therefore we proposed a heuristic algorithm in order to find the better replenishment frequency of a nursing unit in the hospital.

The results of our heuristic model can be used by material management personnel to fortify their decision about any possible course of action regarding the storage and replenishment of medical supplies. We understood that the current practices have high potential for improvement.

4.1 Limitations of research

1. As is the case with any research, it is important to consider the presented results within the context of limitations. Also, the process of posing and answering particular research questions typically generates more questions that need to be explored through further research. Most importantly with respect to the current research, the main limitations are:
2. We considered only one department of the Hôpital du Sacré-Coeur, where small amounts of medical supplies are consumed. Other departments of the hospital, where more medical supplies are consumed, may produce different results.
3. To improve the location of medical supplies within the main storeroom and on the carousel, we did not take into account the storing area in each nursing unit of the hospital because we did not have access to this data. Moreover, we did not have access to the size of the medical supplies kept in the inventory, which could be applied to provide better results.
4. We could only have access to aggregated data to improve the location of medical supplies in storage cabinets. Therefore, we decided to overestimate the relations among medical supplies rather than to overlook any relation.
5. Since Hôpital du Sacré-Coeur de Montréal applies two-bin enabled RFID system, there is only the possibility to have access to bin-level data on medical supply consumption. Nevertheless to develop the heuristics introduced in this study it proved useful to have access to the unit-level data.
6. Since we did not have access to the data on average inventory for each medical supply, we could not compare the results of the proposed heuristic with the current situation of the hospital.
7. Lack of research at the intersection of data mining and supply chain management and hybrid replenishment systems are among the difficulties and limitations of this research.

4.2 Future research

There are some suggestions to improve either the models proposed or the internal supply chain of the hospital.

1. It is better to apply the proposed methods in hospitals where there is access to consumption data at point of use and analyze the results.
2. It is always profitable to be able to schedule for a group of material instead of each of them especially when we are dealing with large amount of materials. One way to group the materials is to study the interrelationship between them and find out which are used together with what frequency. Then we can propose to have some item packs. However, we have this for operation room, but maybe it is interesting to have it for other departments as well.
3. Developing the research area to cover both internal and external supply chain in hospitals.
4. For placement of medical supplies we only introduce association rules mining, but we can use this algorithm along with other data mining algorithms in order to consider different families of medical supplies and then considering all of these families we can find an improved placement of medical supplies.
5. By finding the interrelationship among medical supplies, we can offer the better handling practices, vendor choice, and buying decision. Therefore, we can improve order-processing methods.
6. For replenishment interval, other factors such as cost of inventory is involved as well. Cost of delivery, priority of the medical supplies and their importance, relation between different department of the hospital, and relation between medical supplies and that is where and in which department they are used is important as well.

Appendices

Appendix A

Association Rules Mining Results

#	Antecedents	Subsequent	Support	Confidence
1	V70	V13, V56	0.7	0.8
2	V56	V13, V73	0.6	0.8
3	V56	V42, V73	0.6	0.8
4	V13	V69, V73	0.67	0.8
5	V13, V42	V70, V69, V56, V73	0.6	0.8
6	V13, V69	V76	0.6	0.8
7	V13, V42, V56	V70, V76	0.56	0.8
8	V13, V42, V56	V70, V69, V34	0.56	0.8
9	V70, V42	V13, V56, V73	0.62	0.8
10	V42, V56	V76	0.58	0.8
11	V42, V56	V69, V34	0.58	0.8
12	V69, V73	V70, V34	0.56	0.8
13	V13, V42, V69	V56, V76	0.56	0.8
14	V70, V13	V56, V73	0.63	0.8
15	V70, V13	V42, V69, V73	0.64	0.8
16	V70	V42, V69	0.7	0.8
17	V56	V69, V73	0.6	0.8
18	V70, V56	V42, V69, V73	0.6	0.8
19	V13, V56	V42, V34	0.59	0.8
20	V70, V42, V56	V76	0.57	0.8
22	V70, V13, V56	V69, V34	0.57	0.8
23	V34	V56, V73	0.56	0.8
24	V34	V70, V13, V42, V69, V56	0.56	0.8
25	V13, V69	V34	0.61	0.8
26	V70, V73	V76	0.58	0.8
27	V70, V42, V69	V56, V34	0.57	0.8
28	V13, V42, V56	V69, V76	0.56	0.8
29	V70, V13, V69	V76	0.59	0.8

Appendix B

R program to transform frequency data to binary data

```
M<-t(matrix(c(4,11,1,5,2,1,0,0,4,1,1,3),3,4))

ncol<-dim(M)[2]
nrow<-dim(M)[1]
Max_row<-c()
for (i in 1:(nrow)){
 Max_row[i]<-max(M[i,])
}
sum_max<-sum(Max_row)
cum_sum_max<-cumsum(Max_row)
index<-c(0,cum_sum_max)
Mtx<-matrix(0,(sum_max),ncol)
for (i in 1:(ncol)){
 for (j in 1:(nrow)){

 Mtx[c((index[j]+1):(index[j+1])),i]<-c(rep(1,M[j,i]),rep(0,(Max_row[j]-M[j,i])))
 }
}
```

Bibliography

1. Agrawal, R., & Srikant, R. (1994). Fast algorithms for mining association rules. In: Proceedings of the International Conference on Very Large Databases (VLDB'94). 487-499.
2. Anand, S., Bell, D., & Hughes, J. (1995). The role of domain knowledge in datamining. *Proceedings of the fourth international conference on Information and knowledge management* , 37-43.
3. Ang, Q., Wang, W.-d., Zhao, B.-y., Li, J., & Kai-yuan Li. (2010). Application of data mining based on clinical medicine database. *Second International Conference on Signal Processing Systems (ICSPS). 3*, pp. 719-723. Signal Processing Systems (ICSPS).
4. Ballard, R. (2005). Strategic Supply Cost Management: Physician Preference Without Deference. *Healthcare Financial Management , 59* (4), 78-84.
5. Barlow. (2010b). Manifesting destiny in supply chain's wild west. *Healthcare Purchasing News, , 34*, 10-14.
6. Barlow, R. (2010). Navigating the c-scape in supply chain management. *Healthcare Purchasing News , 34*, 8-12.
7. Beier, F. J. (1995). The management of the supply chain for hospital pharmacies: A focus on inventory management practices (Vol. 16). Journal of Business Logistics.
8. Bendavid, Y., Harold, B., & Philippe, R. (2010). Redesigning the replenishment process of medical supplies in hospitals with RFID. *Management Journal (Emerald Group Publishing Limited) , 16* (6), 991-1013.
9. Berry, G. S., & Linoff, M. J. (2004). Data Mining Techniques: For Marketing, Sales, and Customer Relationship Management.
10. Bose, I., & Mahapatra, R. K. (2001). Business data mining-a machine learning perspective. *Information and management* , 211-255.
11. Butters, S., & Eom, S. (1992). Decision support systems in the healthcare industry. *Journal of Systems Management , 43* (6), 28-31.

12. Chen. (2005). Medical informatics: knowledge management and data mining in biomedicine. *Springer* .

13. Chen, D. Q., Preston, D. S., & Xia, W. (2013). Enhancing hospital supply chain performance: A relational view and empirical test. *Journal of Operations Management , 31* (6), 391-408.

14. Colletti, J. J. (1994). Health care reform and the hospital supply chain. *Hospital Material Management Quarterly , 15* (3), 28-38.

15. CSC. (1996). Improving the Efficiency of the Healthcare Supply Chain.

16. DeJohn, P. (2009). Moving up to the c-suite. *Materials Management in Health Care , 18*, 18-22.

17. Dembinska-Cyran, I. (2005). Internal and External Supply Chain of the Hospital. *LogForum 1, 1 , 5.*

18. Federgruen, A., & Zheng, Y. (1992). An efficient algorithm for computation of optimal (r, Q) policy in continuous reveiw stochastic inventory systems. *Operations Research , 40*, 808-813.

19. Feng, Y., & Xiao, B. (2000). A new algorithm for computing optimal (s,S) policies in a stochastic single item/location inventory system. *IIE Transactions , 32*, 1081-1090.

20. Frawley, W., Piatetsky-Shapiro, G., & Matheus, C. (1991). Knowledge discovery in databases. *Al Magazine , 3*, 57-70.

21. Friedman, J. (1994). Justification of a point-of-use inventory management system. *Hospital Material Management Quarterly , 15* (3), 57-62.

22. Garvin, K. (2006). The time is right for the healthcare supply chain to reap the benefits of data synchronization. *30* (5), 48-49.

23. Han, J., & Micheline Kamber, a. J. (2012). *Data Mining: Concepts and Techniques* (3 ed.).

24. Han, J., Kamber, M., & Pei, J. (2012). *Data Mining: Concepts and Techniques* (Third ed.).

25. Holmes, S. C., & Miller, R. H. (2003). The strategic role of e-commerce in the supply chain of the healthcare industry. *International Journal of Services Technology and Management , 4* (11), 507-517.

26. Kantardzic, M. (2003). Data Mining: Concepts, Models, Methods, and Algorithms. EEE Press, Wiley-Interscience.

27. Kaur, Manjit, & Hall, Sarah (2001). Medical Supplies and Equipment for Primary Healthcare A Practical Resource for Procurement and Management. *ECHO International Health Services Limited.*

28. Kim, D. (2005). An Integrated Supply Chain Management System: A Case Study in Healthcare Sector. 218-227.

29. Kowalski, J. (2009). a Strategic Approach to Supply Chain Management. *Healthcare Financial Management , 63*, 90-98.

30. Kwon, K., Kang, D., Yoon, Y., Sohn, J.-S., & Chung, I.-J. (2014). A real time process management system using RFID data mining. *Computers in Industry , 65* (4), 721-732.

31. Landry, S., & Beaulieu, M. (2010). *Achieving Lean Healthcare by Combining the Two-bin Kanban Replenishment System with RFID Technology* (Vol. 1). International Journal of Health Management and Information (IJHMI).

32. Landry, S., & Beaulieu, M. (2013). *The Challenges of Hospital Supply Chain Management, from Central Stores to Nursing Units.* International Series in Operations Research & Management Science.

33. Landry, S., & Beaulieu, M. (2007). *The Hospital: not just another link in the healthcare supply chain.* (Thomson, Ed.) Newyork: In: Starr MK(ed) Foundations of production and operations management.

34. Langabeer, J. (2005). The evolving role of supply chain management technology in healthcare. *Journal of Healthcare Information Management , 19* (2), 27-33.

35. Lapierre, S., & Ruiz, A. (2007). Scheduling logistic activities to improve hospital supply systems. *Computers and Operations Research , 34*, 624-641.

36. Little, J., & Coughlan, B. (2008). Optimal inventory policy within hospital space constraints. *Health Care Management Science , 11*, 177-183.

37. McKone-Sweet, Hamilton, K. E., & Willis, S. B. (2005). The ailing healthcare supply chain: A prescription for change.

38. Nachtmann, H., & Pohl, E. (2009). The State of Healthcare Logistics: Cost and Quality Improvement Opportunities.

39. Neumann, L. (2003). Streamlining the supply chain. *Healthcare Financial Management , 57* (7), 56-62.

40. Rosales, C. (2011). Technology Enabled New Inventory Control Policies in Hospitals.

41. Rosales, Claudia R and Magazine, Michael and Rao, Uday (2014). The 2Bin system for controlling medical supplies at point-of-use. *European Journal of Operational Research.*

42. Sargent, J. (2010). GS1 standards will transform US healthcare supply chain-and improve patient care. *Healthcare Purchasing News, , 34*, 40.

43. Scanlin, T. (1997). A case for "just in time": could it be right. *Journal of Healthcare Resource Management , 15* (8), 10-14.

44. Scarf, H. (1960). The optimality of (s,S) policies in the dynamic inventory problem. In K. Arrow, S. Karlin, & H.Scarf, *Mathematical methods in the social sciences* (p. Chapter 13). Stanford: Stanford University Press.

45. Tsui, K. L., Chiu, W., Gierlich, P., Goldsman, D., Liu, X., & Maschek, a. T. (2008). A Review of Healthcare, Public Health, and Syndromic Surveillance. *Quality Engineering , 20* (4), 435-450.

46. VanVactor, J. (2008). RFID tags and healthcare supply chain management. *Healthcare Purchasing News , 32*, 54-55.

47. Waller, M. A., & Fawcett, S. E. (2013). Data science, predictive analytics, and big data: A revolution that will transform supply chain design and management. *Journal of Business Logistics , 34* (2), 77-84.

48. Wayne, A. (2012). Health-Care Spending to Reach 20% of U.S. Economy by 2021. . *BusinessWeek, Bloomberg .*

49. Zheng. (1992). On properties of stochastic inventory systems. *Management Science , 38*, 87-101.

50. Zheng, Y., & Federgruen, A. (1991). Finding optimal (s,S) policies is about as simple as evaluating a single policy. *Operations Research , 39*, 654-665.