

Inventory Management Applications for Healthcare Supply Chains

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Abstract— Recently, the healthcare industry has started using inventory management applications to achieve efficiency and effectiveness in its supply chains. There is a rapid growth in the demand of drugs and diagnostic systems within the healthcare industry. The biggest challenge for health care supply chains is to manage inventory efficiently and keep up the satisfactory service level at the same time. In order to meet the increased demand of healthcare products, healthcare supply chain professionals must find efficient and effective ways to improve and optimize inventory. Moreover, perishability and disposability of many medical products have been major problems in healthcare supply chain management. The current managerial practices and conflicts among different stakeholders in health care supply chains are directly associated with the issue of inventory management. This literature review will introduce various inventory management applications that are mainly focused on minimizing inventory costs and increasing overall efficiency in healthcare supply chains. Throughout this literature review, the uses of simulation, new technologies to track healthcare products, new managerial practices, optimization, and information sharing techniques have been discussed extensively. This review of literature contributes to the research field through providing one of the first comprehensive studies to address effectively managing inventory items in healthcare supply chains.

Keywords— *healthcare, supply chains, inventory, optimization, simulation*

1. Introduction

The United States healthcare system accounts for a vast portion of the economy. Studies have shown there are opportunities for improvement through “basic quality-control procedures, consumer satisfaction, and elimination of waste” [1]. In this literature review, we have selected seven themes that will be discussed in detail, which introduce various inventory management applications that were found useful in the healthcare system. The themes outlined within this literature review will explore the advantages and improvement strategies to eliminate waste through various inventory management applications. Eliminating waste, optimizing the usefulness of inventory, and fulfilling the consumer needs will drive the success of healthcare supply chains.

This literature review will discuss the importance of optimization, inventory ration, operations research, simulation, radio frequency identification (RFID), effective managerial practices, and information sharing techniques as it relates to improving the processes associated with inventory management in the healthcare sector. In the first theme, we will discuss how the health care supply chain is managed by reviewing the recent trends, issues, and solutions in relation to inventory management. Secondly, we will explore pharmaceutical supply chain inventory management strategies focused on the optimization of the pharmaceutical company and hospital [2]. In this study, the authors proposed an inventory model that integrates a continuous review system with a production and distribution system within the pharmaceutical company and healthcare facility. Thirdly, perishable inventory management in health care will be explored and discussed. Ref. [3] developed a model which incorporated a multi-supplier inventory system integrated with perishability and outsourcing under deterministic demand. Ref. [4] proposes an inventory rotation system which utilizes the perishable, long life medical supplies before they pass the expiration date. Next, we will discuss how conflicting goals among stakeholders influence managerial decision making as explored by Ref. [5]. The authors used operations research to study the managerial operational, tactical, and strategic level of decision making. In addition to the previous study, advancements and new trends in health care supply chains have also been examined [6]. These authors analyze innovative technology and practices used to improve inventory management within the health care industry. Some of the popular trends outlined in the literature would include but are not limited to: the use of RFID, vendor managed inventory (VMI), and centralization of supply chains. These trends have contributed to the significant reduction of inventory management costs and the elimination of waste in the health care industry. In addition, we have also explored the use of outsourcing in healthcare supply chain management. According to Ref. [7], outsourcing is used in the healthcare industry to save costs and time. The authors found that outsourcing to distribute non-critical medical supplies directly to the departments at the hospital has a positive correlation with the inventory costs and the service level. The use of outsourcing within the healthcare industry can generate lower inventory costs without disrupting the service level. For the healthcare industry to

minimize inventory costs and ensure superior service levels, it is necessary to incorporate inventory management applications in its supply chains operations.

2. Methodology

We have identified seven themes that cover many of the key issues involving inventory management applications in health care supply chains. We explored a vast amount of literature that provide different strategies and solutions to inventory management problems. Minimizing inventory costs and improving efficiency and effectiveness in inventory management practices are common goals presented in all of the studies. The themes have been discussed in detail in the following section.

2.1 Trends, Issues, and Solutions to Inventory Management Applications from a Logistics Perspective

In 2001, the United States healthcare industry produced about 14.1% of the economic output. In today's economy, it is imperative that the healthcare industry continue to expand and improve efficiency and reduce cost. Some of the challenges that are faced by the healthcare industry in the USA would include mergers, acquisitions, cost containment, and outdated information management systems. The need to cut costs and compete has led to mergers and acquisitions in the healthcare industry [1]. Since the need of competition has increased, enterprises have created cost and efficiency initiatives. The use of simulation, information sharing techniques, and optimization helps illustrate and provide insight on ways to optimize inventory and purchasing. Ref. [1] discusses the five areas of the healthcare industry that can achieve exponential improvement and optimization. The five areas include demand management, order management, supplier management, logistics management, and inventory management. In the area of demand management, the potential savings would be included through incorporating demand-driven ordering, planning systems, and minimizing duplication. Managing consumption of clinical resources is key to controlling and managing demand and reducing the amount of supplies that navigate through the supply chain process. In the area of order management, the potential savings would be generated from consolidated purchasing and paperless order management initiatives. Establishing accurate order management processes, incorporating procurement through web or electronic data interchange, and implementing electronic product numbering and tracking processes are effective order management practices. As it relates to supplier management, savings could be obtained through supplier consolidation, optimal direct-from-manufacturer implementation, and compliance with group purchasing organization (GPO) agreements. Reducing the number of suppliers that provide inventory to the healthcare system and establishing a group purchasing contract that includes rebates and discounts are imperative to achieve effective supplier management processes. In the area of logistics management, savings can be realized via capacity utilization, integrated transport networks, and

consolidated service centers. Lastly, in the inventory management area, which is the focus of this paper, savings can be obtained through automated point-of-service distribution and the reduction in SKUs. Overall, reducing storage space, minimizing stock units and their stocking levels, and maximizing inventory turnover rates can achieve effective integrated management savings.

2.2 OR Modeling and Iterative Solutions for Hospital Inventory Management

As pharmaceuticals require special storage and control systems as well as incur higher research & development expenses, subsequently they make up a large portion of the total costs in the healthcare industry. There are many conflicting goals in decision making amongst the various stakeholders within the health care system in addition to managerial tradeoffs at the operational, tactical, and strategic levels of decision making. Application of an appropriate inventory management system can solve many of the problems faced within the current healthcare sector. Ref. [5] conducted a study on the inventory management system of a hospital's local storage unit for a specific care unit. The researchers developed a variety of OR models and iterative solutions to improve the hospital inventory management processes and practices of this facility. They proposed utilizing the reorder point and order up to level techniques that control automated ordering system for operational inventory decisions. The iterative process involved the optimal allocation policy based on both ordering costs and holding costs and then solely on ordering costs in a different model. This research study focuses on the tradeoffs among three key performance indicators, which are: expected number of daily refills, the storage space utilization, and the service level. Moreover, this study also focused on tradeoffs among the refill workload, the variety of drugs offered, and the emergency workload. The decision support tools developed by them are shown to have a positive effect on current managerial practices in the healthcare sector. Ref. [5] started their research from the analysis of current conditions fixed by the top-level decisions and discussed how these top-level decisions exert influence on optimal decisions on the lower levels. The idea is that the lower level decisions are sensitive to the changes in the upper level conditions. Their model was designed to provide iterative top-down and bottom-up decision support that improves the overall system performance measured by the key performance indicators mentioned previously. This research focused on improving the healthcare supply chain by revealing the tradeoffs and providing quantitative tools for negotiations among the stakeholders. Once the reorder point and order up to level that control the automated ordering system were determined at the operational inventory decision level, two other models were formulated. Both models have shown that inventory related pharmaceutical expenditures can be reduced up to 70%–80%. For the tactical and strategic decisions, it was shown that models can be applied as a visual decision support tool to analyze the tradeoffs between the refill workload, the emergency workload, and the variety of drugs offered.

2.3 New Trends in Health Care Inventory Management

Ref. [6] conducted a research study on new trends in health care supply chains that can improve efficiency and reduce overall supply chain costs. The authors focused on new trends that optimize costs associated with inventory, strategy, distribution and the overall supply chain. Although, the authors mentioned many new trends applicable to the health care supply chain, only the trends that are applicable to inventory management in the health care sector will be discussed. The three most effective inventory management techniques include Vendor Managed Inventory (VMI), the use of Radio Frequency Identification (RFID) technologies, and the centralization of Hospital Inventory [8].

2.3.1 Application of RFID in Health Care Inventory Management

Radio Frequency Identification (RFID) is a technology that can trace objects by connecting the objects to the internet. Companies can share the object information with any departments within the organization. While bar codes application requires line of sight identification, RFID tags are strong and do not require line-of-sight identification. This technology helps eliminate the need for human intervention. The technology uses tags that are programmable containing information regarding destination, weight, and a time stamp. The tags facilitate automation throughout the supply chain system. RFID enables warehouse space optimization and efficient goods tracking that reduce the cost and enhance customer service. RFID tags also enable real-time communication and offer accurate information. A large number of inventory items are usually stacked in hospital operating rooms. Unauthorized purchase of certain items and lack of visibility in the supply chain can increase the stock of "unofficial" inventory that could be reduced by managing the materiel ordering process. The inclusion of RFID technology in managing hospital supplies can decrease hospital inventory levels significantly as inventory is always a cost to any firm. Real-time tracking of goods throughout the supply chain is the main benefit of RFID technology. Real-time tracking of delivery time enables Just-in-Time (JIT) manufacturing and retailing. JIT helps hospital purchasing groups to make strategic decisions. Ref. [6] discussed in their research some of the obvious benefits of RFID in the health care sector. The benefits include improved tracking of high-value items/assets, improved production planning and smart recalls for effective scheduling, inventory visibility, accuracy, and efficiency at each stage, reduced shrinkage and shipping errors in the supply chain, and technology standards which drive down costs through economies of scale.

There are some technical barriers in the implementation of RFID. RFID systems are not always reliable, putting the entire system at risk. Accuracy of RFID also depends on different factors such as tag placement, tagged object,

angle of rotation, and read distance. The costs associated with RFID implementation are also very extensive. The costs include initial hardware and software, training, maintenance and continuous upgrade costs.

2.3.2 Vendor Managed Inventory

Many retail firms in today's society minimize their inventory cost significantly by using the VMI method. Under this method, the supplier is responsible for managing inventory and making decisions regarding replenishment [9]. This method builds on the process of stockless inventory systems to some extent. The VMI method is different from the stockless inventory system in the sense that VMI moves responsibility for stock control to the supplier as the ordering process is automated. The accurate information on current stock levels and consumption is necessary to implement the VMI method successfully. However, managing such information flow within hospitals is difficult [10], [11]. Ref. [12] mentioned that VMI has several advantages with little need of administrative procedures at the hospital. The advantages include fewer errors, improved information reliability and a 30 per cent reduction in inventory. However, Ref. [13] stated there is still a lack of trust in the supply chain process within the health care sector. Many hospitals continue to over-rule the VMI system, while keeping more inventories in the warehouse.

2.3.3 Centralization of Hospital Inventory

Because of recent economic crises and the recent high proportion of drug expenditures in healthcare costs, the centralization of warehouses owned and managed by multiple hospitals has been a trend in the pharmaceutical supply chain. Ref. [8], proposed a logistic network that integrates a central pharmacy which negotiates with suppliers, collects hospital orders, as well as stores and distributes materials. However, many hospitals operate under a non-cooperative inventory management system. The authors of this study compared the cost performance of the cooperative model they developed with a non-cooperative model via a simulation technique. The results of the simulation indicate there is often times a significant cost saving achieved if hospitals operate under the cooperative model, even if there are not any price-quantity discounts available.

2.4 Outsourcing Inventory Management Decisions: A Comparison between in House Three-Echelon and Outsourced Two-Echelon Distribution Networks

Outsourcing inventory integrates some of the concepts involved in the centralization of hospital inventory, which has been discussed previously. Ref. [7] conducted a research study that addressed the issue of managing inventory costs for healthcare settings through the use of an outsourced distribution network. This research focuses on comparing inventory costs and service levels of an in-house three-echelon distribution network and an

outsourced two-echelon distribution network in the healthcare sector. The researchers compared inventory policies in both networks and focused on non-critical inventory items. Non-critical items, in a healthcare setting, are defined as the supplies which constitute a larger number of items, cost very little compared to critical items, have a very long shelf-life, and require relatively cheaper storage facilities. The researchers constructed two optimization models, model A for the in-house distribution network and model B for the outsourced distribution network. While developing these optimization models, the authors tried to minimize the total holding costs based on expected inventory levels at in-house three echelon distribution networks including central warehousing, as well as hospital warehouses and departments within each hospital. In model B, the authors included two decision variables containing par levels for each department of the service center. The objective function was to minimize the holding costs calculated based on expected inventory levels at the departments and service centers only. The two models were compared and the results indicated outsourcing non-critical medical supplies distributed directly to hospital departments through using two-echelon distribution networks generates lower total inventory costs than the in-house three echelon distribution network. They also compared the service levels in both networks and found the same level of service being achieved in both systems. The decision to outsource allows hospital facilities to generate substantial costs savings. Another study by Ref. [14] suggests that outsourcing not only reduces costs but also reduces the full-time equivalent labor hours.

2.4.1 Factors Driving Outsourcing Inventory Decisions

Ref. [15] identified three factors that contribute to the outsourcing of inventory in healthcare supply chains. First, the healthcare industry incurs large investments in inventory every year. The investment amount is estimated to be between 10% and 18% of net revenues. For example, IASIS Healthcare experienced a net revenue of \$232,619,000 for the quarter ending March 31, 2001 and net expenditures amounting to \$23,354,000 for inventory items, which is approximately 10.04% of their net revenues. Another finding suggests that University Health Services had net revenues of \$561,790,000 while its inventory investment amounted to \$89,709,000, which is equivalent to approximately 15.97% of their net revenues. Therefore, savings in inventory management will directly contribute to increased profitability.

Second, maintaining quality of service both from an internal and external perspective is the main concern to most health care providers. A move towards outsourcing inventory can help improve internal performance as indicated by service levels. Thirdly, in recent times, a large number of third party suppliers have evolved and shown evidence of success in the health care industry. Many health care consulting firms and health care specific service providers have earned trust by providing stockless inventory management services [14].

2.4.2 Centralization of Hospital Inventory vs. Outsourcing Distribution Network

Outsourcing distribution networks are very similar to centralized inventory management systems as described in the previous section. In both cases, the pull system is used and the lowest echelon is responsible for the distribution of materials. Outsourcing involves a third party in the system and eliminates multiple internal entities involved in the network. In outsourcing, hospital supplies are directly distributed to a specific department from an outsourcing firm. On the other hand, the centralization of hospital inventory can also be implemented internally without involving a third party. A well-coordinated information system is important for such a centralized system to operate effectively.

2.5 Pharmaceutical Supply Chains and Inventory Management Strategies

Pharmaceutical supply chains have become the focal point to improve the rising cost of health care. Pharmaceutical supply chains can be defined as the integration of all activities associated with the flow and transformation of drugs from raw materials to finished products consumed by the end user, as well as associated information flows, through improved supply chain relationships to achieve a sustainable competitive advantage [2]. The pharmaceutical supply chain can be separated into three categories: Producers, Purchases, and Pharmaceutical providers. Producers would be considered device manufactures i.e. surgical product companies, pharmaceutical companies, and manufacturers of capital equipment and information systems. Purchasers would include pharmaceutical wholesalers, grouped purchasing organizations, medical surgical distributors, product representatives, and independent contracted distributors. Providers would include integrated delivery networks, alternative site facilities, and hospital systems.

The responsibility of the pharmaceutical supply chain is very extensive and its main objective is to make sure the correct drug reaches the patient or consumer at the most efficient time in order to provide relief against diseases and suffering of pain. The goal of the pharmaceutical supply chain is to achieve a 100% customer service level due to the direct impact within the health care industry. To achieve this goal, many pharmaceutical supply chains carry a large amount of inventory to ensure product availability. In conjunction with this solution, there are many risks involved. For example, product perishability is a major issue faced by the pharmaceutical supply chain. Expired and outdated items may be overlooked in a high-volume atmosphere, and ultimately dispersed to patients and consumers. As a result, these expired and outdated items would ultimately have disastrous effects on both the patient and consumer care.

Pharmaceutical supply chain decision making is very critical, as health care managers, have the responsibility of selecting order quantities, purchasing dates, and the

inventory levels needed to care and serve patients. When a hospital carries inventory, it may face limitations involving the availability of floor space, total investment in inventory, the total number of orders to be placed per year, the number of deliveries that can be accepted, and the delivery size that can be handled [2]. In addition to these limitations, many hospitals have limited pharmacy storage space to hold the quantity of the products needed for patients being served.

Management of pharmaceutical inventory has become an issue for health care industries. Pharmaceutical companies have the responsibility of carrying a vast amount of inventory to ensure they are able to achieve close to a 100% customer service level. Obtaining such a service level is a huge challenge, but can be mitigated with a supply chain focus and processes that are streamlined towards customer demand and need.

2.6 Perishable Inventory Management in the Healthcare Industry

Diminishing the amount of perishable inventory held has become an objective for those working in the healthcare industry. After the expiration date, the product or item is unsafe to use. Additionally, perishable items can deteriorate over time in terms of quality and product satisfaction. The inventory management of medical products raises particular challenges, as medical inventory is highly sensitive to storage conditions (temperature, humidity, etc.). In order to illustrate how to effectively manage perishable medical inventory, healthcare agencies have created specific simulation models [3]. Since the early development of perishable medical inventory models, a variety of models have been established to address specific issues regarding medical inventory management. Researchers from Bar-Ilan University, located in Israel, have developed a model that includes and considers perishability and deterioration of medical products under demand. The supply chain model includes multiple suppliers, a centralized distribution center, and the end user. Their model also includes a dimension of outsourcing. According to the research, outsourcing suppliers usually charge more per product when compared to regular suppliers, but outsourcing can lower overall costs, as the supplier endures the holding costs. In addition to outsourcing, perishability adds another dimension to the simulation model. In general, inventory managers do not want to have excessive quantities of perishable products in inventory. As a result, inventory managers typically order fewer perishable products than they would when compared to non-perishable products. Inventory managers quickly send perishable items with short expiration dates to hospitals to maximize usage for patients and customers.

A health services facility located in Israel motivated the Bar-Ilan University to conduct research on perishable inventory. The goal of the managers at the health services facility was to improve the general healthcare service. This includes two main aspects: 1.) providing hospitals and other medical organizations with their required products in a timely manner; and 2.) decreasing the total

cost of all operations in the supply chain by using a centralized distribution center [3]. Using a centralized distribution center requires planning and execution processes. It is necessary to keep track of the age and expiration dates of the products in stock. The demand planning department orders the needed quantity of medical items based on the known demands from the designated hospital. After the orders are agreed upon, the supplier sends the order quantity to the distribution center. At the distribution center, the quantity and quality of the perishable items are checked. After these items are checked, the items are then placed in "put-away storage". When the demand arises, the workers of the distribution center pick the needed products from the storage area. During this step, human error can often times occur. For example, a worker may pick an item that is needed for a specific order, but may not pay attention to the expiration date of the item. If this is the case, the worker may pick an item that is far from expiration and leave items that are close to expiration inside the storage area. To avoid this issue, each distribution center should incorporate audits to check for the expiration dates of the products being shipped to the consumer.

2.7 Inventory Rotation of Medical Supplies for Emergency Responses

Many countries keep certain amounts of medical supplies as reserve to prepare for emergencies. Typically, specific types of frequently used medical supplies such as anti-flu drugs, gowns, gloves, vaccines syringes, etc. are held in stock so these supplies do not run out suddenly. The minimum stock level for frequently used supplies are generally very high because hospitals hold back-up supplies which should be sufficient for an entire affected population during an emergency. Such emergencies are rarely experienced, resulting in the expiration of a vast number of medical supplies. The medical stocks expire before they are used as there is no efficient rotation system. Ref. [16] states New Zealand has discarded 1.5 million doses of anti-flu drugs as they have reached expiration. The doses were valued at \$30 million in production cost and \$110 million in retail price. Another study by Ref. [17] suggests that \$200 million worth of reserve products have been discarded as the products passed their expiration dates. This phenomenon is not limited to certain countries, but instead is faced by multiple health care systems across the globe. This problem is experienced by hospitals in almost all countries. Ref. [4] observed a hospital with a similar supply and demand structure for certain medical items and proposed to rotate the items in reserve before the expiration date was reached. Therefore, old reserve items would be used first and replenished as soon as they were utilized in the hospital. If hospitals adopt a rotation system, as proposed by Ref. [4] they can save money and efforts associated with the disposal of expired stocks and the replenishment of these items. However, there are some extra holding costs involved with inventory rotation of medical supplies. The authors in their study weighed the benefits against the costs and investigated the key issues involved with this rotation system.

Medical reserves are often located far from the main health center so they can be saved and utilized in the event of a natural disaster. The volumes of inventory stock are so vast that on site warehouses are not capable of holding all products at the same time. As many hospitals are located in urban areas and corresponding warehouses are located far from the hospitals, it is not very effective to expand the warehouse capacity to keep more reserves for emergency responses. Most importantly, high reserves of medical supplies will increase inventory holding costs and decrease operational efficiency as lean inventory systems are possible to implement in hospital facilities. Ref. [4] propose that the rotation system could significantly improve the inventory management process for many hospitals. The researchers investigated rotation systems for perishable items that have minimum volume requirements and that stay on the shelf for a long period of time. The authors also studied stock rotation policies in association with the hospital's ordering policies. Later, the optimal policy structure was analyzed and implications of the analytical results were discussed. The optimal policy was characterized by two thresholds, one threshold is for ordering and the other is for rotation. This policy will be optimal only when two thresholds are linear. The base model showed that the policy with both rotation-up-to level and order-up-to level was optimal and the time horizon was also divided into two phases including a non-rotation phase and a rotation phase. Tradeoffs around the rotation and ordering decisions which involve different costs functions generated an interesting result. It was found that the optimal policy structure was more effective when scenarios have capacity constraints and multiple planning horizons that are extended. The proposed system underlines the importance of considering the perishability of long-life medical supplies such as gloves, syringes, anti-flu drugs, etc.

3. Conclusion and Future Work

Recently, many researchers in the field of operations research and supply chain management have shown much interest in inventory management for health care supply chains. However, historically the health industry has rarely been a subject of research for many inventory specialists even in the last decade. The majority of researches in this field are largely focused on minimizing inventory costs by using various supply chain tools and techniques to increase efficiency and effectiveness in the overall management of inventory. In our research, we have investigated many studies involving inventory management applications in health care supply chains. Although, we have reviewed a large number of articles on this topic, we have found some common themes among them, which include controlling inventory management costs from different angles and applying new technologies and management techniques. Our objective was to discuss inventory management applications under seven specific themes. In the first theme, we discussed recent trends, issues, and solutions to inventory management from a logistics perspective. Second, we discussed pharmaceutical supply chain inventory management

strategies broadly, while focusing on optimization approaches for pharmaceutical companies and hospitals. Thirdly, perishable inventory management in the healthcare sector was discussed using studies that have previously addressed this topic. The authors of these studies were able to demonstrate the practicality of their research findings by applying their models to a real-life health care supply chain. Fourthly, we investigated how conflicting goals among stakeholders influence managerial decision making. There are often times conflicts among three main stakeholders: physicians, pharmacists, and group purchasing organizations on the issue of medications to be held in the hospital. In the discussion of theme five, we reference the research addressing new trends in the health care supply chain. Ref. [6] mentioned some of the revolutionary technologies and practices used to improve inventory management in the health care industry. Some of the trends such as the use of RFID and VMI contributed to the significant reduction of inventory management costs in many health care settings.

The next theme discussed involved outsourcing, which is another cost savings tool used in the health care supply chain. Researchers compared the inventory costs and service levels between in-house three echelon distribution networks and outsourced two echelon distribution networks. Their findings determined outsourcing non-critical medical supplies generate lower inventory costs while maintaining similar service levels amongst both network options. The last theme focused on inventory rotation systems, which utilize the perishable medical supplies before they pass their expiration date to reduce the amount of waste incurred in healthcare facilities.

Although, many researchers have identified solutions to certain problems faced in healthcare supply chains, there is still much research left to be performed in this field. In future, it is important to investigate the effect of demand uncertainties on workloads. Factors such as the number of workers needed to satisfy an excess workload generated by inventory management issues demand more attention. Outsourcing vs. in-house distribution network models can also be further investigated. It is possible to investigate the trade-off between the predetermined service level throughout the entire system as well as the predetermined service level at the department level. There is also an opportunity to investigate the trade-offs between the desired target inventory levels for warehouses based on incremental echelon cost and the desired target inventory levels which are based only on installation cost.

References

- [1] Chandra, C., & Kachhal, S. K., "Managing health care supply chain: trends, issues, and solutions from a logistics perspective", Proceedings of the Sixteenth Annual Society of Health Systems Management Engineering Forum, pp. 20-21, 2004.
- [2] Uthayakumar, R., & Priyan, S., "Pharmaceutical supply chain and inventory management strategies: optimization for a pharmaceutical company and a

- hospital*”, *Operations Research for HealthCare*, 2(3), pp.52-64, 2013.
- [3] Perlman, Y., & Levner, I., “*Perishable inventory management in healthcare*”, *Journal of Service Science and Management*, 2014.
- [4] Zhou, Q. S., & Olsen, T. L., “*Inventory rotation of medical supplies for emergency response*”, *European Journal of Operational Research*, 257(3), pp.810-821, 2017.
- [5] Kelle, P., Woosley, J., & Schneider, H., “*Pharmaceutical supply chain specifics and inventory solutions for a hospital case*”, *Operations Research for Health Care*, 1(2), pp. 54-63, 2012.
- [6] Mathew, J., John, J., & Kumar, S., “*New trends in healthcare supply chain*”, *International Annual Conference, Production and Operations Management Society*, 2013.
- [7] Nicholson, L., Vakharia, A. J., & Erenguc, S. S., “*Outsourcing inventory management decisions in healthcare: Models and application*”, *European Journal of Operational Research*, 154(1), pp. 271-290, 2004.
- [8] Iannone, R., Lambiase, A., Miranda, S., Riemma, S., & Sarno, D., “*Cost savings in hospital materials management: Look-back versus look-ahead inventory policies*”, *International Journal of Services and Operations Management*, 22(1), pp. 60-85, 2015.
- [9] Darwish, M. A., & Odah, O. M., “*Vendor managed inventory model for single-vendor multi-retailer supply chains*”, *European Journal of Operational Research*, 204(3), pp. 473-484, 2010.
- [10] Haavik, S., “*Building a demand-driven, vendor-managed supply chain*”, *Healthcare Financial Management*, 54(2), pp. 56-56, 2000.
- [11] McKone-Sweet, K. E., Hamilton, P., & Willis, S. B., “*The ailing healthcare supply chain: a prescription for change*”, *Journal of Supply Chain Management*, 41(1), pp. 4-17, 2005.
- [12] Kim, D., “*An integrated supply chain management system: a case study in healthcare sector.*” *International Conference on Electronic Commerce and Web Technologies*, pp. 218-227, 2005.
- [13] Stadler, H., & Kilger, C., “*Supply chain management and advanced planning*”, *Concepts, Models, Software and Case Studies*, 4, 2008.
- [14] Rivard-Royer, H., Landry, S., & Beaulieu, M., “*Hybrid stockless: A case study: Lessons for healthcare supply chain integration*”, *International Journal of Operations & Production Management*, 22(4), pp. 412-424, 2002.
- [15] Veral, E., & Rosen, H., “*Can a focus on costs increase costs?*”, *Hospital Material Management Quarterly*, 22(3), pp. 28, 2001.
- [16] Duff, M., “*Mass dump of Tamiflu a bitter pill to swallow*”, <http://www.stuff.co.nz/national/health/9768461/Mass-dump-of-Tamiflu-a-bitter-pill-to-swallow>
- [17] Woodhead, M., “*National medical stockpile dumps \$200 million of stock.*” <http://www.australiandoctor.com.au/news/latest-news/national-medicalstockpile-dumps-200m-of-stock>, 2014.