MACHINE LEARNING IN MANAGING HEALTHCARE SUPPLY CHAINS: HOW MACHINE LEARNING OPTIMIZES SUPPLY CHAINS, ENSURING THE TIMELY AVAILABILITY OF MEDICAL SUPPLIES

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***ABSTRACT*—Machine learning (ML), a subset of artificial intelligence, has revolutionized industries, dominating its presence in epidemiological dissemination. The notion of machine learning involves programming computers to optimize a performance criterion using example-generated data or past experience. Different algorithms underlie differing tasks based on their inputs and the type of desired output. Specifically, supervised algorithms involve learning a mapping from inputs to outputs, given examples of the desired mapping. Alternatively, unsupervised algorithms attempt to learn the structure or distribution of data, with the model required to make inferences from instances of incomplete input [1]. The plethora of methods may overshadow the mindset needed to make use of their capabilities. One must approach an analysis in a methodical and scientific manner. A clear definition of a problem should be established, followed by an approach in which performance is evaluated using data, then iterating the approach seeking improvement. Machine learning is a relatively new field in the context of healthcare supply chain management, with formidable relevance given its increasing complexity of operations and abundance of data [1]. The purpose of this paper is to provide a tutorial for healthcare practitioners on understanding the intricacies of machine learning and methods on how it can be used practically to optimize supply chain functions. This understanding is crucial, as the application of machine learning in an unsupervised fashion, without understanding on the part of the user, can lead to poor results and improper utilization of methods [1]. Through a basic understanding of these techniques, a user can make informed decisions on whether to seek collaboration with an analyst versed in machine learning, what type of analysis may be appropriate, and how to evaluate the analysis presented.**

***Keywords*— Healthcare, supply chain management, predictive analytics framework, challenges, machine learning, classification, regression, unsupervised learning, predictive analytics, data mining, supply chain management, data, Classification**

I. INTRODUCTION

Interconnected systems combined with data driven analytics allow real-time insights that make it much easier to be proactive and to perform better planning to maintain the inventory and activities. These technological advancements which not only increase the efficiency but also help to attain quality patient care and safety In a nutshell, integrating automation within the supply chain of the healthcare system for optimizing processes, providing visibility, and increasing collaboration necessitates a holistic view[2]. The healthcare organizations can intelligently come up with solutions of challenges, optimize operations and provide patients the best care possible by using automation power. Eventually, this will be translated into better healthcare and a healthcare system that can be adjusted to new challenges and demands.

Regression is the technique of breaking down complex data and using it for acquiring insights. Unsupervised learning algorithms infer from unlabeled data sets without being fed with specific labels on the inputs. Data mining is the process of analyzing data from different perspectives and summarizing it into useful information [3]. Predictive analytics is the application of data, statistical algorithms, and machine learning methods to determine the probability of occurring future events. SCM is the coordination and management of materials, information, and finances across the supply chain throughout its evolution from supplier to manufacturer to wholesaler to retailer to consumer. The main objective of SCM is to coordinate these activities with a view to implementing an efficient and cost-effective flow of information between companies with a view to improving the supply chain process.

RESEARCH PROBLEM

The main problem in this paper is to assess the use of machine learning in the management of supply chain in healthcare. A recent Cochrane review in the USA based the cost of an adverse event caused by a medication error at $5,857, and the estimated annual cost to the nation of medication errors in a hospital setting was $2 billion, mainly due to the need for extended patient hospital stays, the cost of replacing medication, and litigation resulting from patient injury. Stockouts and errors that occur due to lack of availability of product or wrong product being available are related to an overemphasis on cost containment, proliferation of products, and a disconnect between clinical work and logistical decision making, where only 1% of those involved in the clinical use of products produce 20% of the industry information that affects supply decisions - essentially due to ignorance as to the right and availability of product[4]. High-use products may have one that is clinically no different from an alternative product, but it may differ in the way it affects quality of life and patients may not be willing to receive the cheaper product or have to change to an alternative product. These logistical decisions are rarely audited for patient outcome and are often solely based on cost, and supply chain managers may resort to speculative tactics in fear of a stockout. Healthcare supply chains are increasingly complex, a result of industry progress and the development of new procedures and technologies to treat an aging population. This complexity has resulted in misalignments between clinical need, patient case mix, treatment protocols, and the inventory and distribution of supplies.

The inefficiencies in the supply chain have led to unscheduled stockouts and hoarding that, in turn, the cost of treatment and the risk to patient safety have augmented. The physicians and research colleagues at Dartmouth-Hitchcock Medical Center in the US, Upton and associates, examined the role of stockouts on patient care and financial outcomes [5]. They discovered that over a 12-month period, the stockout rates for those essential 289 high-use products varied from 3% to 6%, and the staff were unsurprisingly using 30% of their time looking for missing equipment.

III. LITERATURE REVIEW

A. SUPPLY CHAIN MANAGEMENT

Supply chain management in the healthcare sector has been marked as one of the key components for a long time. Hence, the healthcare industry is currently under immense pressure to cut costs while improving patient safety and health outcomes. In recent years, there has been a growing interest in the use of innovative management techniques to improve the overall efficiency and effectiveness of healthcare delivery[5]. Machine learning algorithms can help hospitals optimize inventory, reduce costs, and improve patient outcomes. These algorithms can be used to learn from current and past supply chain data to better predict the demand for medical supplies, determine the locations and quantities of inventory that should be kept on hand, and identify and implement process improvements. It is for these reasons that machine learning in healthcare supply chains warrants further investigation.

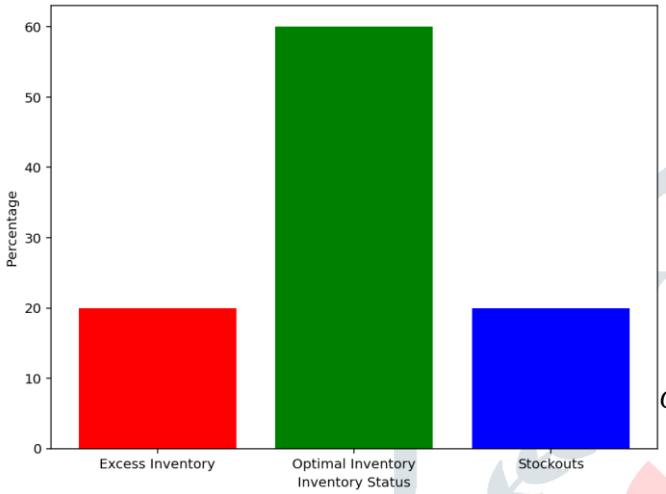

Fig. 2 Inventory Optimization

Economic principles will always be pertinent when discussing supply and demand issues. However, with supply chain being such a complex interrelated system involving multiple steps from when a product is first envisioned until it reaches the end user, there are countless areas where machine learning can be exploited to automate and optimize. Supply chain problems can often be modeled as operations research problems such as shortest path algorithms and network flow problems [6]. In fact, the concept of a supply chain being a network is contained within articles on simulation and optimization in the healthcare industry. This shows how the work being done in the broader area of supply chain and operations research can be directly applied to the healthcare supply chain. With machine learning algorithms being developed specifically to handle these types of operations research problems, this provides an avenue for machine learning to be applied to healthcare supply chains in a very direct manner.

B. SUPPLY CHAIN MANAGEMENT IN HEALTHCARE

Supply chain management (SCM) is seen as a means of optimizing an organization's functions to make it more efficient and cost-effective. The majority of healthcare providers may not yet understand what exactly SCM is. For example, it has been stated that "despite the interest in supply chain management by healthcare managers and the perceived potential benefits of its application, the healthcare sector has lagged behind other industries in that regard[7]. When compared to manufacturing and retail, healthcare SCM is far less developed, and the healthcare industry has only recently woken up to its importance. This is quite surprising given specific modern challenges that the healthcare sector now faces.

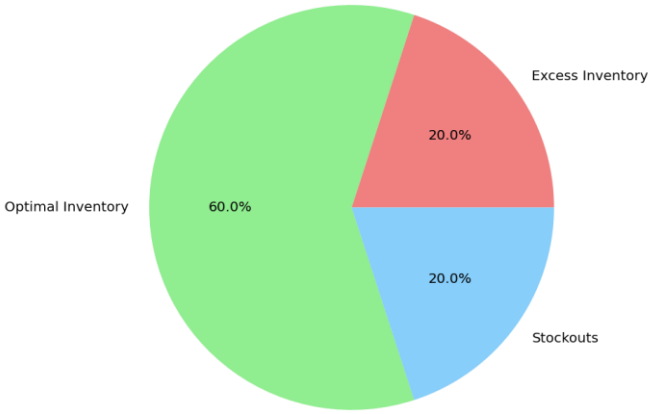

Fig. 2 Inventory Management in Healthcare Supply Chain

Today's healthcare environment includes pressure from various national governments to curb healthcare spending, globalization of healthcare providers, a growing aged population of customers, and a general movement from the "pay-for-service" model to the "pay-for-performance" model[8]. All of these factors combined put the present state and the future of healthcare worldwide under severe strain. In essence, there has never been a greater need to optimize operations in the healthcare sector than there is today. This is where SCM can play a major role. Now that the importance of SCM in healthcare is more understandable, it is important to understand what exactly SCM involves and the best way to apply it in healthcare.

C. CHALLENGES IN HEALTHCARE SUPPLY CHAINS

The healthcare industry has been used to apply management practices from other industries, while SCM is one of the management approaches being used in the healthcare industry. However, the management of healthcare supply chains faces different challenges compared to the other industries. [9]identified these challenges: unavailability of data and reluctance to share data, lack of awareness of the potential benefits of SCM, high turnover of clinical staff, and the majority of staff is trained in clinical, not management. Methods of measuring effectiveness and efficiency in the industry, and the multi-echelon nature of healthcare SCM. Unavailability of data and reluctance to share data has caused problems in information and inventory visibility. Different systems and patients with incomplete information will distort the demand for incidence of diseases and treatment rates. Lack of visibility increases the need for safety stocks and variety of products, resulting in increased cost and reduced efficiency. Healthcare professionals have their belief in clinical practice only and lack awareness of the potential benefits of SCM. Patients are not necessarily going to receive the same treatment by different providers [9]. This causes difficulties in the standardization and evaluation of the appropriateness of treatment. The turnover and majority of staff trained in clinical practice will cause resistance to change towards SCM practices. High turnover means frequent loss of knowledge and change of methods, while staff trained in clinical practice have knowledge in medical practice but does not mean they have knowledge to select the right medical products, equipment, or how to standardize the treatment process [10]. Methods of measuring effectiveness and efficiency are not well developed and the multi-echelon nature of healthcare SCM has created a conflict on the trade-offs between centralization and autonomy.

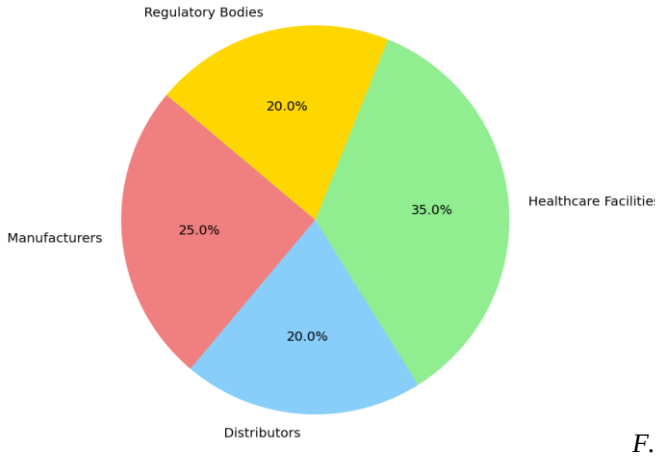

Fig. 3 Complexity of Healthcare Supply Chains

D. Traditional Approaches in Managing Healthcare Supply Chains

In the past, healthcare supply chain management has not been considered a primary source of competitive advantage for healthcare providers. In fact, it is often viewed as a necessity rather than a strategic function. Oftentimes, cost cutting measures in operational areas have been implemented and they sometimes involve just reducing the quantity of supplies as a means of saving money. An example of this was a US-based hospital that implemented a cost cutting measure to reduce on-hand inventory value by 25% across all 1600+ owned or affiliated perioperative suites[10]. The initiative resulted in varied forecast changes on product usage and too many stock outs for high use products. High use products often have a highly linear relationship between the historical usages of the product and the forecast of the product. An increase in forecast error for high use products increased inventory swings for these products. This initiative increased the hospital's inventory turns but too many stockouts frustrated nurses and sometimes prevented suture surgeries, which are the most profitable surgery for the hospital. The hospital initially estimated that the increase in inventory swings caused by the forecast changes and the increase in stock outs would cost $5 million in lost revenue [1]. This was a classic example of confusing cost with resource utilization and it's a similar problem that has been experienced in many other industries. The move did in fact cause a reduction in resources in the form of suture surgeries and increased suture product utilization, but it was not efficient and actually consumed more resources to accomplish the same result. Unfortunately, the initiative was short-lived, which is also a common problem as sustainability of initiatives has always been a challenge in the healthcare industry.

E. Role of Machine Learning in Optimizing Supply Chains

Machine learning has been an important research area in the field of supply chain management (SCM) for the past two decades. It has been widely used in SCM to automatically extract information, classify objects, and understand the hidden patterns for optimization and decision support. [12] classified the uses of machine learning in SCM into five different aspects. They are data clustering, prediction, data classification, association rule discovery, and data transformation. These are all useful tools for SCM to better understand the data and make informative decisions. In healthcare, SCM has gained much attention over the recent years, although the focus is on dealing with the industry's specific issues of patient safety and cutting costs, rather than actually improving the way SCM is managed. With a growing pressure on healthcare organizations to provide a higher standard of care with fewer resources, these issues are becoming more significant. Traditional SCM in healthcare is not well equipped to deal with its issues and often translates strategies and solutions from the retail or manufacturing sectors, which may not be effective. Though challenging, these issues provide an ideal environment for machine learning to be applied in the aim of utilizing data and resources effectively to move towards better patient care. Machine learning is highly suited to these tasks, and studies have shown that these are effective avenues for improving SCM in other industries. In saying this, there has been very little done to investigate the use of machine learning in healthcare SCM, and there is vast potential for improvement in an industry where even small changes in resource allocation can greatly affect patient outcomes[11].

F. Previous Studies on Machine Learning in Healthcare Supply Chains

Several attempts have been made to apply machine learning techniques to problems in the healthcare domain. Basak and colleagues built a decision support system to identify cervical cancer patients who were at risk of dropping out from a course of radiotherapy treatment. The system was based around a feedforward neural network trained on historical data from 448 patients[12,13]. It identified a small group of patients who had a very high probability of default. Being able to identify such patients prospectively will allow health care providers to target the patients with interventions designed to maintain their adherence to the treatment regime. A similar prediction problem is addressed by Louis and colleagues who built a model to predict which diabetes patients were at high risk of missing primary care appointments. The patients at highest risk were found to have a 46% rate of appointment missing. Implementing an intervention using this model would have potentially large benefits for relatively low cost. In both the studies described above, the authors' hope is that the insights provided by the machine-learned models can be turned into improvements in patient outcomes. [14] present an interesting case study in using machine learning as a tool for discovering new medical knowledge. They used data mining techniques to uncover an association between the receipt of a particular pediatric vaccine in the 1960s and incidence of a chronic disease in the adult population. This result has potentially huge implications for public health policy, especially if the association can later be shown to be causal. Lasko and colleagues describe a machine learning venture with similar aims. They used an existing registry of adult cardiac surgery patients to build a model for predicting which patients were at risk of postoperative atrial fibrillation (POAF)[15,16]. They then used the black box nature of a support vector machine model as a basis for doing some exploratory analysis into the complex and non-linear correlations between variables which lead to the occurrence of POAF. This work is a good example of extracting additional diagnostic information from a machine learning model beyond its predictions themselves.

IV. SIGNIFICANCE AND BENEFITS

The significance of the research lies in its potential to drastically reshape and revolutionize the ways in which healthcare supply chains are managed in the United States. This facet's utmost relevant and remarkable contribution is the proposed work on learning and harnessing the power of advanced predictive algorithms to forecast and anticipate demand for crucial medical and surgical supplies. Startling evidence has emerged, suggesting that a staggering one third of the United States healthcare budget is currently being allocated towards supplies, and alarmingly, up to 40% of this expenditure may be attributed to wasteful spending practices [16,17]. By effectively and intelligently applying cutting-edge machine learning algorithms to extensive historical and transactional data, the envisioned outcome is nothing short of awe-inspiring:

the creation and implementation of powerful decision support tools that will enable healthcare administrators to meticulously monitor and discern emerging trends in the utilization of supplies. This, in turn, will empower them to make more informed and precise forecasting decisions. The possible consequences of such progress are no doubt of great importance. The direct result from the decrease in both overstock and stockout incidents within hospitals and the stock suppliers will be the decrease in the associated costs for both parties[18]. This is as important as timely, considering the current economic challenges such as budgetary problems, fiscal issues, and capital restriction. Shifting to automation in the supply chain will reduce taxes, save on labor costs and bring in a host of other added benefits too. The most apparent benefit that emanates from this is that the levels of effectiveness of supply management are high which in turn translate into better healthcare for the patients. This injection of financial capital can enable healthcare institutions to spend on high-tech equipment, modern research, and experienced workers. Hence, the level of overall healthcare provision will improve which will also translate to better patient outcomes[18]. Moreover, cost cuttings that emerge from the impeccable supply chain management can also result in the reduction of financial dependencies as well as government institutions. Healthcare providers can alleviate the drain on public funds by creating a sustainable framework and minimizing waste so that the government entities can use the resources for something else more vital. This health insurance facility finances treatment and leads to the virtuous circle: the enhanced healthcare services develop the community and increase general well-being [19]. We can conclude that the prospects of this research scale are extraordinary and utterly change-inducing. The healthcare supply chains can get transformed thanks to the leveraging machine learning and advanced data analytics, where the cycle can be changed into a seamless, efficient as well as cost-effective system. The promising fusion of technology and healthcare holds immense promise and intricately ties cost savings and improved patient care into a seamless tapestry of progress and transformation.

V. FUTURE

As the evolution in the management of supply chains to higher levels of efficiency and cost control plays out, it is evident given the state of current technology and the potential cost savings that management at all levels in healthcare supply chains will benefit from modern operations research methodologies. When healthcare supply chains begin to employ advanced methodology in inventory management and incorporate strategies targeting product flow and supply/demand mismatch error, there will be a growing need for professionals that specialize in healthcare [19]. Major inroads for healthcare supply chain management are on the horizon, and the more quantitative approaches to managing supplies will be an open field of success for operations researchers in both academic and industry settings.

Taken from a Carnegie Mellon study, 72% of purchases of medical supplies are made by clinicians. This number speaks loud and clear. If the future of supply chain management in the healthcare sector plays out in such a way where costs are controlled, materials selection is more heavily regulated, and product standardization is mandated, then data-driven, clinician-involved decision making will be the approach to managing supply chains. This means that the time is near where clinicians will be highly involved in the decision making and management of healthcare supply chains.[19] They face a future where this data-driven approach to evidence-based practice will carry over to managing materials and supplies. An approach involving higher accountability and more informed decision making on the selection and utilization of medical materials will lead to higher efficiency in patient care and better management of resources in the healthcare sector.

- Future of US Health Supply Chain The future of supply chain management in the healthcare sector in the United States will entail more collaboration and information sharing among healthcare providers, suppliers, and distributors. Currently, a significant portion of the healthcare supply chain is managed through distributors [19]. With potential cost savings in supply chain management for the US healthcare sector estimated to be in the billions, it will not be long before government regulation mandates cost containment. When this occurs, manufacturers and distributors will be forced to share pricing and usage information in an effort to control costs. Cost-based regulation is the anchor to taking supply chain management out of the early stages in the healthcare sector.

CONCLUSION

Throughout this project work, machine learning has been seen as a very powerful tool which generates rules and relations from data to solve problems. Now, what we have tested is just the tip of the iceberg of what machine learning is capable of. With concepts like data mining and optimization, machine learning has a very strong potential to provide new methods to solve complex supply chain management (SCM) problems in better ways than current existing methods and, more importantly, in a much more automated manner. But there are various challenges in integrating these methods in the healthcare sector, which will require a lot of research. It forms an interesting research domain and is left for future work steps. Taken together, it can be concluded that machine learning provides tools that could substantially improve the management of healthcare supply chains. The goal of this study was to identify the potential of machine learning to solve such complex problems step by step that current existing methods are unable to solve. Even though the use of operations research (OR) methods and simple statistical techniques are still quite prevalent, we showed with examples that by using available data, it is possible to find relations and underlying patterns that will not be visible otherwise. Setting the focus of our example, we dealt with the simplest supply chain starting with building an analytical model to determine population health, linking it with product demand, and finally taking an optimal decision to purchase the right quantity of products given the consumer price. Throughout the progression, we explored various techniques and learned that they have their respective advantages and drawbacks in different areas.This chapter summarizes the research work and discusses the major contributions. It is human nature to be inclined towards improving current conditions and finding better alternatives to existing systems. In healthcare, the situation goes to the next level because it directly concerns human life. With constantly increasing healthcare needs, it becomes quite difficult for managers to identify the population needs and plan to purchase or develop the right quantity of products and services at the right price and the right place. In other words, developing, producing, and handling products in the right quantities and qualities, and getting these products to the right place at the right time, and in the right condition represents the ideal supply chain for that product. And so, managers constantly seek ways to improve their supply chain in an efficient and cost-effective manner.

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