Migration Letters

Volume: 19, No: 6 (2022), pp. 1144-1158

ISSN: 1741-8984 (Print) ISSN: 1741-8992 (Online)

www.migrationletters.com

Deep Learning Applications In Materials Management For Pharmaceutical Supply Chains

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Abstract

The application of deep learning can help in augmenting the smart materials management in the pharmaceutical supply chain. Deep learning can potentially elevate the current operational efficiency of supply chains using machine learning-based analytic techniques. With the intelligent decision-making capabilities of deep learning applications, the overall performance of the supply chain with respect to inventory management, demand prediction, order management, and warehouse operations can be optimized. Currently, these decision-making [1]processes in the majority of pharmaceutical supply chains are performed by using intuition, consultants, machine learning algorithms, or analytics services based on datasets. Although these techniques are showing improved results in demand forecasting, inventory management, prescriptive analytics, classification, and warehouse optimization.

With the abundant existence of big data, faster computation, more sophisticated machine learning algorithms, and auto-piloted intelligent systems, there is great hope in incorporating deep learning in the pharmaceutical supply chain with respect to demand forecasting, inventory management, and warehouse operations. Embedded research in developing deep learning systems in materials management for analyzing vast datasets has not been reported yet in particular application research, neither in urgent drugs nor in the pharmaceutical supply chain domain due to the high non-linearities. Further practical implementation of deep learning systems toward the operational performance of the pharmaceutical supply chain has not been reported. Therefore, more research should be conducted to define the best methods of deep learning applications in pharmaceutical supply chains. Furthermore, deep learning can be utilized to enhance the procedures of purchasing, processing orders, and forecasting demand; and proper inventory rules. These applications will further reduce costs, improve the level of customer service, and create a feasible competitive advantage.

Keywords: *Deep Learning,Pharmaceutical Supply Chain,Inventory Optimization,Demand Forecasting,Supply Chain Automation,Predictive Analytics,Materials Management,Supply Chain Efficiency,Pharma Logistics,AI in Pharma,Drug Manufacturing,Supply Chain Visibility,Stock Level Optimization,Intelligent Routing,Cold Chain Management.*

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1. Introduction

Over the last decade, while ongoing consolidation has narrowed the pharmaceutical industry, cost pressures that limit revenue have increased. Supplying pharmaceutical drugs is increasingly more complicated, cumbersome, and risky as supply chains have mushroomed in size, scope, and ambition into global networks that distribute products all over the world. A major driver in this development has been the expiration of product patents, which has given marketers access to numerous active pharmaceutical ingredient plants and facilities to manufacture a wide range of products. As global competition mounts and pharmaceutical company growth flattens, brand owners are under pressure to work their supply chains more efficiently to both grow profitability and also to meet tougher regulatory requirements.
Concurrently, the growing wants and expectations of consumers have raised the bar that supply chain operators must strive to meet. A supply chain that historically could deliver a high percentage of orders on time is now marked for breakup as only a higher percentage of on-time delivery will now suffice for the Global Pharmaceutical Supply Chain Manager. Increasingly, technologies are sought after to both optimize and monitor performance across all components of a complex supply network to ensure that untimely and irregular supply does not automatically lead to the entry of new competition and a loss of market share. For individual companies seeking technical solutions, new technologies coupled with newly available data may offer a totally different view of how due materials really act when they traverse a global network of multiple hand-offs and transshipment, sourcing points, reliable stock, and inventory heights. Deep learning, in particular, can be beneficial for modeling data that is not structured in nature with multiple distribution curves. In regard to other machine learning methods, deep learning is presumed to be particularly advantageous in cases where data consists of visual, sound, and text, as it can capture compiled patterns of raw data through its layers.Over the past decade, the pharmaceutical industry has faced increasing pressure to optimize its supply chains amid growing global competition and heightened regulatory demands. As product patents expire, manufacturers have gained access to a wider pool of active pharmaceutical ingredient (API) plants, complicating the logistics and risk management of an already complex, global supply network. In this environment, the need for more efficient supply chains has become critical, as companies are expected to deliver a higher percentage of orders on time while managing rising costs and meeting consumer expectations for reliability and transparency. The integration of advanced technologies, particularly deep learning, offers significant promise in this regard. Deep learning models excel at analyzing unstructured data, such as visual, auditory, and textual inputs, making them ideal for capturing complex patterns in supply chain data. These technologies can improve forecasting, detect inefficiencies, and optimize performance across a global network, allowing companies to anticipate disruptions, reduce costs, and maintain market share in an increasingly competitive landscape.

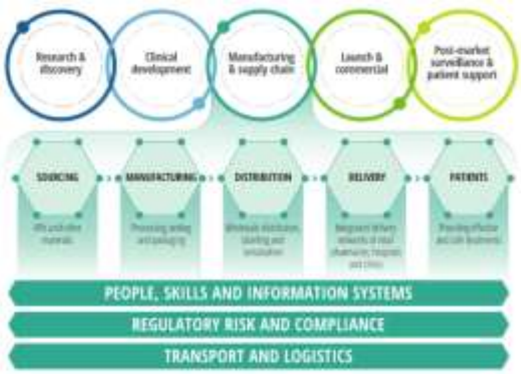

Fig 1: Pharmaceutical Supply Chain

1.1. Background and Significance

Today, with the increasing globalization of trade and decreasing product life cycle, the area of supply chain management has witnessed a great amount of evolution. The evolution of supply chain management from logistics to materials management and finally to the current supply chain strategy is evident. As supply chain management is becoming deep-rooted in the global market, the environment in which it functions is becoming intricate. Supply chain complexity can be attributed to ever-increasing globalization, changing customer expectations, market volatility, and stringent regulatory bodies. The growing complexity within supply chain operations is increasingly pushing traditional supply chain solutions to limitations. Recently, there has been a paradigm shift from cost-focused decision-making to a customer-centric approach; companies are building a demand-driven market and a customer-driven supply chain. The existing economic world, filled with uncertainty, is an abundance of qualitative and categorical information, where decision-making is based on guesswork. In such cases, the occurrence is very speculative. Without the use of advances in relevant technologies and techniques real-time data analytics and insights derived from structured and unstructured data, decision-making is totally impossible. Traditional predictive models have their limitations in capturing the complex underlying relationships within the data.

Deep learning methods offer significantly better prediction capabilities when the data that drives decision-making and supply chain functionality has a complex structure and relationships. Additionally, the pharmaceutical industry has traditionally been conservative and reluctant to adopt cutting-edge technologies; however, with the burgeoning demand for drugs and cost sensitivity, pharmaceutical firms are under stress to establish robust supply chains to achieve competitive advantages. A fast-evolving digital landscape, together with severe regulatory standards, has forced them to pursue digital transformation. The key advantages of improved reliability and reduced supply chain risk or efficiency can be realized from deep learning applications that can autonomously delineate obscure patterns and trends by capturing relationships between both internal and external sources of demand signals and supply chain data, enhancing decision-making across various managerial levels. An integrated supply chain with the flexibility to respond swiftly to the changing, uncertain market scenario has the potential to influence product availability and effect favorable outcomes for patients in terms of treatment. Against this backdrop, the objective of this chapter is to provide an evolutionary perspective on deep learning and its applications and displace dichotomies surrounding integrated pharmaceutical supply chain flows and management.

1.2. Research Objectives

The primary aim of this research paper is to provide an overview of the current use of deep learning in demand and inventory forecasting for materials management in the pharmaceutical supply chain. The research primarily identifies case studies and applications of deep learning in day-ahead demand forecasting and medium-term inventory management in the pharmaceutical industry and aims to supplement existing literature by further identifying other deep learning applications currently used operationally by pharmaceutical companies or in the process of being applied. This research also seeks to show the benefits of applying deep learning in solving the complexities and making improvements to materials management within the pharmaceutical supply chain, as well as to compare with current techniques for existing and potential adopters. This research is intended to be of interest to pharmaceutical companies that are currently working on the implementation of the digital supply chain and also companies currently investigating deep learning in inventory and demand forecasting. This research is particularly aimed at pharmaceutical practitioners involved in digital initiatives. For researchers, this paper can help identify the future research questions currently not addressed in existing literature for operational demand and inventory management in the pharmaceutical supply chain. This paper is consequently structured as outlined below, with section 2 now providing an overview of current trends in the pharmaceutical supply chain.

2. Materials Management in Pharmaceutical Supply Chains

Materials management can be defined as the administration of the following elements of goods in the pharmaceutical supply chain. This includes all raw materials, intermediate goods, and of course finished products. Each company within a supply chain might have its objectives and management style, but there is still a shared intention among companies to guarantee an efficient flow of goods to meet the needs of consumers. Additionally, the pharmaceutical industry faces an enormous challenge of keeping what is known as "ripened goods" and having to turnover inventory. Material management at each phase is greatly affected by global environmental characteristics such as the adoption of risk management techniques and the latest quality systems of pharmaceutical companies. Regulations focus greatly on the facilities where their raw materials and intermediates are stored and how they should be handled. Controls and instructions from regulatory bodies are carried out in related documents concerning the subject matter of completed pharmaceutical products to be imported. Interested parties desire to add updated information on the forecasting and planning procedures in pharma and other industries that will require materials management. Materials management is an aspect of supply chain procedures that many businesses have looked into, as we can see the fact that there are also many innovation centers and medicines traced as part of their materials administration during research and development. Beyond the pharmaceutical industry, since current rate-driven international market economic downturns have resulted in significant financial impacts, almost 30 percent of GDP is represented by healthcare supplies: treatments, products, and services in demand. Particularly in the private sector, the amount of pharmaceutical products and healthcare supplies in the supply chain system remains significant. The demand, together with the ever-increasing rate of production methods, will aid healthcare outlets in building or increasing a resource supply chain program.Materials management in the pharmaceutical supply chain encompasses the administration of raw materials, intermediate goods, and finished products, ensuring an efficient flow of goods to meet consumer needs. While individual companies within the supply chain may have distinct objectives and management styles, there is a shared commitment to optimizing inventory turnover, especially for time-sensitive products like "ripened goods." The pharmaceutical industry faces unique challenges due to stringent regulations on the storage, handling, and transportation of raw materials and intermediates, as well as the need for compliance with quality systems and risk management techniques. In addition, materials management plays a crucial role in forecasting and planning, as pharmaceutical companies must adapt to evolving market dynamics, technological advancements, and international economic conditions. With healthcare supplies representing a significant portion of global GDP, especially in the private sector, the demand for pharmaceutical products continues to grow, pushing healthcare providers and supply chain stakeholders to enhance their resource management strategies and ensure the timely availability of essential treatments and products.

Equ 1: Demand Forecasting

$$J = \mathbb{E}\left[\sum_{t=0}^{T} \gamma^t R(S_t, a_t)\right]$$

2.1. Challenges and Opportunities

Pharmaceutical supply chains are confronted with a number of challenges that necessitate effective materials management strategies in order to deliver value to patients. These challenges are exacerbated by stringent regulatory requirements that affect all facets of operations. Manufacturers must also cope with high levels of market uncertainty caused by the long development times to bring novel drug products to market, uncertainties in outcomes associated with clinical trials, patent exclusivity rules, and many other factors. Furthermore, once pharmaceuticals reach the market, the demand for drug products is subject to rapid changes. Over time, demand for a drug may increase or decrease, for example, in response to changes in standards of care, newly approved therapeutic entities, or generic competition. Finally, there are many complexities in the logistics and distribution networks of the biopharmaceutical supply chain. As a consequence, once in production, drug product inventories would be carried out for a number of reasons, such as to be able to meet highly uncertain demand, for regulatory reasons, and to manage the overall global production network. One of the most critical decisions for materials management is determining the optimal inventory control strategies for each pharmaceutical supply chain node. In the ongoing discussion, we will focus on pharmaceutical inventory management at the downstream nodes. In fact, the increased agility that deep learning algorithms can provide would make it possible for pharmaceutical supply chains to become more agile when responding to highly variable customer demand. Deep learning could be used to more accurately identify the types and quantities of needed drug products in a rapidly shifting market and change demand management settings and supply chain structures to better respond to end-customer demand patterns. The increased accuracy of deep learning tools could lower the necessity for maintaining high levels of inventory. Low levels of inventory, in turn, preserve production capacity for other drug products. In this way, the ability to conduct deeper and more refined analytics on a large volume and variety of data using sophisticated and increasingly accurate computational models can provide tremendous value to pharmaceutical manufacturing. In other industries, these kinds of tools have already been used to transform operations in retail stores, in customer relationship management and marketing, in the analysis of cybersecurity threats, in web search algorithms, in recommendation engines for web-based products, etc. Opportunities for leveraging similar tools in the pharmaceutical industry are what have led to this investigation of the current state of deep learning in the management of drug product inventories.

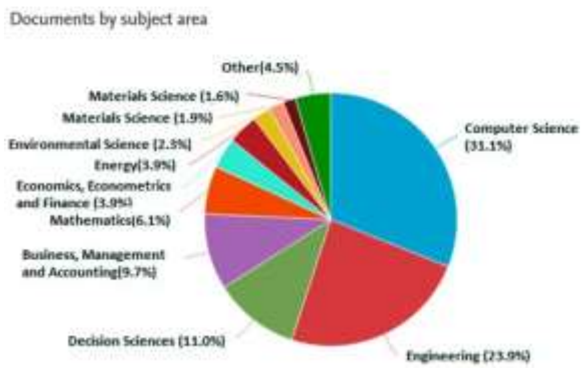

Fig : Machine Learning and Deep Learning Models for Demand Forecasting in Supply Chain Management

2.2. Current Practices

Pharmaceutical firms adopt different methodologies and practices to effectively manage materials in their supply chains. These practices are intended to create a balance between the availability and cost of the products. A systematic approach to inventory management, mainly the classification of products based on their value of usage, leads to very good deployment of inventory control efforts. The procurement of materials that meet both short-term production demand and long-term marketing objectives is carried out using different approaches like Economic Order Quantity, Just-in-Time, Just-in-Case, and VMI. Yet, the forecasting of the demand for the products is mainly carried out using time series or regression forecasting to get the possible sales values. The use of moving averages, exponential smoothing, or double exponential smoothing methods of time series forecasting gives a sum total of good practitioners. Although they agree that there could be long-term trends, historical data were used as the basis of their forecasting. The issue of the bullwhip effect, which is propagated due to multi-echelon ordering, also has to be addressed with good collaboration and lead time identification. In summary, many pharmaceutical companies do have a systematic way to manage their inventory and procurement, but it differs from one firm to another. However, many have agreed on certain issues as best practices in managing materials. The future of supply chain operations for this industry might focus on a continuous improvement effort in these identified areas based on the changes to the regulations and market requirements. Many current pharmaceutical supply chain operations are already in place and functioning reasonably well. However, there is always some room for innovation and adaptation, especially in the use of information technologies and materials management strategy. Current practice in materials management appears to be working well, yet maybe not as efficiently as it could be. The possibility of the top ten ranked inbound and outbound suppliers increasing their supply chain management index rating had doubled, or even possibly quadrupled if the customers associated with them were using IT proficiently or were 'Tech Friendly'.

3. Deep Learning in Materials Management

Section Summary: Deep learning technologies have experienced rapid development in various fields due to their potential to learn detailed and highly complex data representations, which translate into highly accurate predictive insights. Models based on deep learning differ from those built using traditional machine learning because of the deep models' intrinsic ability to automatically learn representations of the underlying data, reducing the need for complex feature engineering. Due to their construction, deep learning models do not require understanding the foremost principles of the underlying data in the same way as traditional statistical methods, and yet they simultaneously present high theoretical complexity. Generally, deep learning and deep data analytics can support increased predictive accuracy, which can be beneficial for improved pharmaceutical supply chain quality, safety, security, and efficiency. Deep learning models and algorithms are also primarily applied in research and in practice for operational process optimization, such as in demand forecasting, inventory management, distribution, and logistics optimization.

Since it does not rely on traditional statistical methods, workers do not need a strong statistical or mathematical background to utilize it. This is particularly important in professions such as procurement, warehousing, and distribution, which tend to employ primarily business workers without a profound background in statistical analysis. Many of the tasks in materials management in the pharmaceutical industry can be complemented or improved when using deep learning and AI-driven solutions. However, some challenges in the application of deep learning and AI in the public sector are the relatively high costs of implementation, particularly infrastructure and training, and reliability and compliance, including data security and privacy. Other challenges or potential barriers include the political environment, where others may not understand and accept the use of data-driven solutions, as well as ethical concerns regarding the use of data.

Equ 2: Supply Chain Risk Management (Deep Learning-based Prediction of Risks)

$$L = -\frac{1}{N}\sum_{i=1}^{N}\left(y_i \log(\hat{y}_i) + (1 - y_i)\log(1 - \hat{y}_i)\right)$$

3.1. Overview of Deep Learning

Deep learning is a subfield of machine learning, a branch of artificial intelligence based on the teaching of systems through data, which allows them to understand, generalize, and make predictions. At the core of deep learning techniques are the artificial neural networks, expanded to so-called 'deep networks.' Neural networks consist of layers of small elements called 'neurons' that compute various functions. All these layers are parameterized, and each layer transforms the input to obtain the desired output through training on the provided examples. Deep learning is able to work directly with raw data to identify patterns learned through large amounts of data; therefore, they do not require any domain expertise or feature engineering.

Deep learning models adapt to the data instead of the converse, and this characteristic implies great scalability, making it possible to use big data to extract better results. In this way, this model will adapt better to reality and make more accurate predictions. The improvement compared to traditional methods depends on the amount of data used to train the deep learning model; in fact, using a small dataset, the improvement will be less relevant. There are plenty of applications of deep learning techniques, without any limitation in any field. Some of the most striking successful products of deep learning include the self-driving car, AlphaGo, Google Translate, and virtual assistants. In business sectors, particularly in the oil and gas industry, deep learning has shown good performance in predicting oil reserves. The technical requirements for using deep learning include access to powerful parallel processing hardware, huge amounts of annotated training data, and stable APIs and libraries. In materials management, deep learning is applied to improve the prediction of demand, particularly when there is missing data or a lot of noise, as the predictions made by traditional algorithms often fail. The specific deep learning technologies that have been employed are Artificial Neural Networks, Recurrent Neural Networks, Long Short Term Memory networks, Convolutional Neural Networks, and Deep Belief Networks. Many different types of deep learning models have been developed to improve their performance, including linear regression, logistic regression, time series analysis and forecasting, classification models, and neural network ensembles, among others. Additionally, deep learning models process nonlinearly multivariate input and do not need hand-engineered features; thus, they are pipeline-free and more flexible. Deep learning models consist of more than three layers of artificial neural networks. This allows deep learning models to better capture the complex structures inherent in a great variety of clinical datasets, such as images, time series, and text.

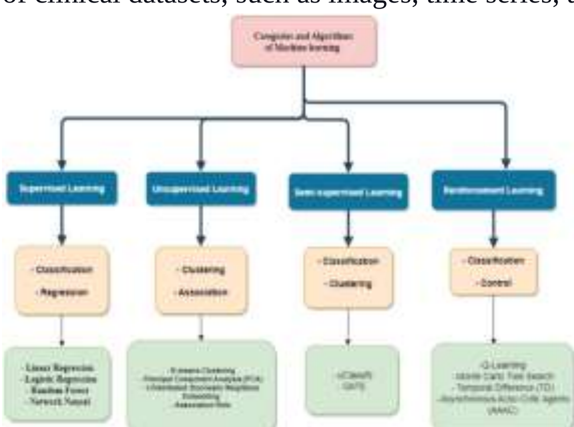

Fig 2 : Understanding of Machine Learning with Deep Learning

3.2. Advantages and Limitations

Machine learning and deep learning techniques offer a wide range of new opportunities for materials management. The main advantage is that learning algorithms can be used to make predictions of future wants. Additionally, machine learning and deep learning can be used for the automation of planning and decision-making processes, which include analyses in real-time and taking various supply chain components into account, such as suppliers and transportation options. Most importantly, these technologies are essentially based on data, and so decisions in the supply chain are in part based on data-driven insights. Finally, years of wear and tear on pharmaceutical packages and random incidents during international transportation no longer need to be simulated for assessment but can be directly assessed.

Individual cases differ from one another, and as a result, reductions of shortages might be different. However, depending on the costs entailed for the reduction of shortages, automating the reduction of shortages can be profitable. Moreover, products that otherwise would be split or removed from the market, unrelated to one another, in view of belonging to different sectors, may be associated with shortages and may need to make joint reimbursement investments. Consequently, the advantage of analyzing treatments for shortages becomes potential cost reductions. However, machine learning and deep learning technologies have several limitations and critical challenges that need to be clearly addressed: obtaining many clean, well-labeled training data; substantial computational resources are required; deep learning adoption within companies requires new tools, languages, and skills; monitoring data 24/7; potential bias in machine learning; and ethical, regulatory, and database protection compliance. The potential of deep learning for demand forecasting in pharmaceutical supply chains is untapped. Various studies discuss machine learning to increase demand forecasting accuracy in pharmaceutical supply chains, but the potential of deep learning remains, in general, untapped. Deep learning forecasting methods have been overlooked in HPV, even though promising capabilities of these techniques have been established in retail, consumer packaged goods, and auto parts companies. Anecdotal evidence suggests that some pharmaceutical wholesalers are using deep learning to make demand forecasts that outperform machine learning algorithms. This research suggests that deep learning technologies have not yet been used extensively in research or possibilities such as demand forecasting.

4. Applications of Deep Learning in Pharmaceutical Supply Chains

Deep learning can have a significant impact on the future of pharmaceutical supply chains. This section discusses some possible intersections between theory and practice. Some relevant application areas include the following.

Inventory Management: Deep learning techniques can calculate the remaining shelf life of a product using sensor data and computer vision. The resulting inventory leads to cost savings and a reduction in the generation of waste. Demand Forecasting: Deep learning models can more accurately forecast future demand, contributing to the reduction of holding stock and out-of-stock. Demand Planning: Demand planning can benefit from the integration of different internal and external data sources for production planning and sales and operations planning. Material Requirement Planning (MRP): Deep learning can optimize material resource planning processes. Dedicated models can produce long-term forecasts to make sourcing decisions. To realize the impact of the implementation of deep learning, various pharmaceutical companies have already started to integrate deep learning applications into their supply chain processes. Through a pilot study, a solution that employs IoT tracking sensors and deep learning to accurately forecast arrival times and identify temperature excursions of pharmaceutical shipments has been developed. An international pharmaceutical manufacturer incorporates deep learning into its last-mile delivery network to monitor and optimize medical product delivery times. By doing so, the company can reduce its operating costs, improve customer service levels, and ultimately enhance patient satisfaction.

A recent case study has investigated the implemented applications of deep learning techniques in the supply chain of the pharma industry. Through a two-day interactive and online workshop, three different applications have been prototyped and developed employing different deep learning algorithms and data sets. These applications included the following.

Vaccine cold chain management and trade compliance based on synchronization of temperature habitation territories and exposure to the internet. The solution is based on a convolutional neural network algorithm. Route optimization and dynamic planning based on deep learning self-regulation – prediction of origin and destination lanes and net flows based on trends and market fluctuations, which are plotted and predicted by a recurrent neural network. Lot Sizing policies based on quality technicians' notes and KPI prediction were modeled and run on a long short-term memory network – a self-supervised regression model predicting the variability of the product based on input feature variables.

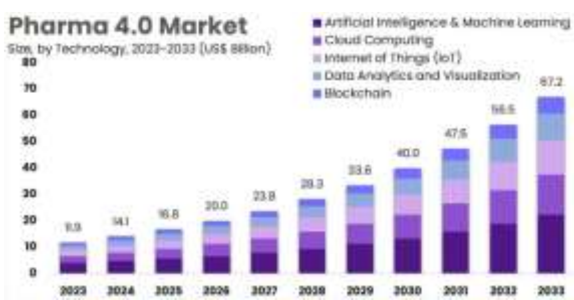

Fig :Pharma 4.0 Market By Technology (Cloud Computing, Internet of Things, Artificial Intelligence & Machine Learning

4.1. Inventory Management

ANNs and deep learning models can help in finding solutions to the involved complex interactions by analyzing huge amounts of data as well as being able to represent the interactions. This can lead to better inventory control methods that can reduce the risk of stockouts. Reports after the use of ANNs showed up to 40% higher prediction accuracy than traditional statistical methods. This is especially interesting for high-value pharmaceuticals and active products with short expiry dates, where low stock levels can lead to significant financial benefits. Deep learning can further enhance the traditional forecast-based inventory replenishment technique to perform real-time monitoring of inventory status and can adapt actual replenishment strategies, including the frequency and amount of deliveries, based on lead times. This will lead to massive time and cost savings and hence reduce drug prices or at least preserve the profit. One of the most important steps in inventory management is demand forecasting as it quantifies potential sales.

Deep learning in inventory management aims to address unique challenges related to the pharmaceutical environment and come up with different solutions. For example, inventory models such as (S, s), Economic Order Quantity, and Stochastic Bore are used to attain a balance between holding costs and stockout costs. Hence, destruction costs can be calculated under multiple scenarios to specify inventory levels and prepare for pandemics. Different pharmaceutical companies used deep learning for progressing their inventory management. Many modern-day pharmaceutical giants stated multiple case studies that present the successful use of ANN in moving from mere inventory management theory to daily state-of-the-practice.

4.2. Demand Forecasting

Deep learning technologies are now being used to address various issues in different sectors. The current implementation of behavior analytics and deep learning technologies will address forecast accuracy in the pharmaceutical industry's supply chain. A critical phase in pharmaceutical supply chain management is demand forecasting. Accurate demand forecasts are crucial for pharmaceutical manufacturers since they have significant competition in the marketplace. In addition, suppliers cannot retain their inventory stocks for an extended period. They must have an accurate marketing prediction to monitor the production schedule and keep enough supply, which will help reduce the supply chain's overall expense. Methods such as linear regression and autoregressive integrated moving averages are most typically utilized to forecast demand. However, these conventional techniques could not reflect precise information products that hold too many variables. Customers' buying habits are complex in pharmaceutical supply chains since product life cycles are long. Deep learning techniques not only produce more accurate demand forecasts than traditional technologies but also cut the mean absolute percentage error down by at least 46%. Deep learning can detect intricate patterns, trends, and relationships in the data. Many firms have implemented deep learning and experienced the most precise outcomes. As a result, deep learning can improve the functional capabilities of the pharmaceutical supply chain. Traditional methods of demand forecasting are outdated for the supply chain's responsiveness. This complete forecast can help pharmaceutical companies change their supply chains from producing items for inventory to creating goods as required. It is one of the crucial components required to preserve cash while reducing waste. When demand forecasting accuracy grows, production performances also increase. Providing the right volume at the right time to the right location is critical because it enhances customer satisfaction.

Equ 3: Inventory Management (Optimization Problem)

$$L = \frac{1}{N}\sum_{t=1}^{N}(Y_{t+1} - \hat{Y}_{t+1})^2$$

5. Case Studies and Implementation Challenges

After the theoretical presentation of deep learning applications in materials management for pharmaceutical supply chains, with a separate focus on data integration and transparency, we now provide a set of case studies reflecting on different functionalities and perspectives. Our aim is to provide insights and concrete examples of how and in what ways deep learning is being used. In addition, we discuss the major challenges experienced by the organizations that contributed and presented their cases during the workshop. Furthermore, we provide an in-depth discussion that serves as a practical introduction for companies that want to refine their operations. The next section deals with the implementation of best practices and guidelines based on these case studies as well as on discussions that took place during the workshop.

The limited number of industrial case studies in state-of-the-art research underscores the need for and value of a practical orientation. To this end, we received statements and short presentations from three different leading companies. All three companies presented specific cases in which they have worked with deep learning-based scenarios. The examples demonstrated well how data integration, or automatic ordering and monitoring, with deep learning models, can lead to real improvements and support decision-making activities. However, any positive development is countered by challenges and, ultimately, by the necessary steps toward achieving harmony or improving processes. Generally, the results show the different functionalities and potential of deep learning models. However, this may be the most important aspect: the presentation of the three companies also makes it clear that new technologies do not work in a vacuum, and a broad understanding of the environment and organizational context and their implications is crucial. Discussing deep learning implementation and challenges is the purpose of this section. These topics are addressed within the case studies presented at the workshop and are aimed at providing critical insights and practical guidance. We cover the topics with a separate approach for each case study: drivers of success, challenges, main implementation hurdles, and technical challenges. Overall, this section serves as a bridge between the theories and hypothetical discussions provided in previous sections, and the practical aspects of implementing and managing a deep learning solution within the supply chain framework, providing valuable inputs into additional research and development efforts.

Fig 3: Pharmaceuticals Supply Chain Challenges and Solutions

6. Conclusion

In conclusion, we argue that deep learning applications in materials management have the potential to drive the required technological renewal within the pharmaceutical industry. Given the ever-increasing pressures facing the industry, stakeholders have a clear impetus to invest in innovative answers. The main message of our contribution is that better materials management innovation can drive performance that helps quench the critical thirst for efficiency and responsiveness from the end customer to the biopharmaceutical manufacturer. Yet, fundamental issues related to data accessibility, transparency, privacy, and knowledge exist that limit the reach and possibly even the effectiveness of cognitive technologies. We therefore stress that a degree of caution to temper immediate exuberance is appropriate. Implementation of these technologies takes significant preparation at the organizational level, and technological solution providers, as well as potential integrators, should take congruity of organizational strategies and enablers into consideration before garnering investments.

The primary value of deep learning rests in its capability to manage unstructured and vast datasets – images, voice, text, and scaling to big data – which make it operational not only within supply chain materials management but across the supply chain. These technologies are advancing fast, and a wide range of research lines should be pursued to illuminate their applicability to supply chain materials management and therefore the dynamic network end effects, including better-reaching pharmaceutical customers for making materials and products available at the right time and place.

6.1. Future Trends

Key technological trends, including increasing process automation in companies with the potential for new job profiles, will shape materials management in the years ahead, with significant investment from logistics service providers and pharmaceutical companies going into the development of AI technologies. Artificial intelligence technologies will play a central role in this, and blockchain technologies and other machine learning areas are also expected to develop rapidly. The architecture that ADPEs are working on features a decision-making process supported by technological advances in the medical chain. This is the result of pharmacogenetic testing based on the prediction of potential responses to different diagnoses or drugs. With regard to the supply chain, AI can support various processes in the pharmaceutical industry today. It can not only help to better forecast demand but also enable predictive maintenance in the supply chain. This preventive method ensures maximum machine efficiency, avoids machine downtime, and repairs early problems that would lead to material shortages.

As demand cannot be predicted with 100% accuracy and fluctuations in supply volumes occur, decision-makers in particular areas of the supply chain have to closely examine different factors influencing the entire supply network. The use of predictive analytics has the potential to improve materials management. This area is characterized by serious specifications. In materials management, the key factors recommended by industry experts include reduced stock-out situations within the pharmaceutical company and LP that would result from a breakdown of the current concept of open collaboration between several companies with respect to production plans and mechanisms. Essentially, the increase in simulation capability made possible by real-time information process capabilities will lead to a rise in backup stocks to cover these types of disturbances. Pharmaceutical companies will need large quantities of these materials because of the higher safety factor range. They will need to integrate both AI for analysis of the parameters involved and to draw relevant conclusions. Biological data will play a bigger role by describing the situation as closely as possible. Regulatory authorities need to clarify the necessity and conditions of different safety inventory policies. This future scenario will not be possible without funding for research and development of infrastructure, networks, software, etc. involved in training as well as the testing of human resources in sophisticated career paths at a university or higher education level. As a result, effective collaboration between actors within the region will enable reliable feedback and foster innovation between theory and industry, between science and technology, and between researchers and information technologies.

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