Multi-Agent Coordination and Optimisation in Distributed Retail Networks: An AI-Driven Framework for Supply Chain Synchronisation

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1. Introduction to Retail Supply Chain Network Coordination

Retail supply chain is a complex network that includes many circulation centers and hundreds of suppliers. When goods are delivered from the factory to retailing, including the warehouse and the terminal sales outlets, it forms a retail supply chain channel. The key to retailers' competition is dealing with suppliers and other issues in the channel service level. Regular channel coordination is not key yet, but with the aggravation of competition, problems in the retail supply chain network also appear. It provides efficient operation in the supply chain network, reducing waste, optimizing inventory, and minimizing transportation costs, etc. To coordinate all members of the supply chain networks, it is able to reduce the operating costs of the retail supply chain and minimize inventory in transit while improving customer satisfaction.

The coordination of the retail supply chain network is very important. With the aggravation of competition, the layers in the supply chain bring issues that increasingly resolve at the operational and strategic levels. On one side, retail supply chain enterprises use advanced control systems to increase production, inventory, warehouse, and sales management, incurring significant costs. This could improve the net profits of the retail supply chain and the company's competitive edge. On the other side, the retail supply chain network is a complicated system formed between many independent enterprises. Only one company can achieve business performance to enhance its ability to progress and penetrate up the chain. Considering the system of the retail supply chain network is very important; it will trigger a chain reaction once a link in the network is activated, which may impact other business enterprises. Therefore, supply chain coordination research is urgent, and with its level of computational intelligence, solving this problem is also a research focus in typical AI domains.

1.1. Challenges and Opportunities in Retail Supply Chain Management

Challenges: The retail supply chain faces various challenges, including the volatility of demand, a reduction in human resources available for processing orders, and excessive escalations due to exceptions. Indeed, natural or human-induced disasters can also cause supply chain disruptions. Moreover, today's supply chains are usually intentionally conservative; they have safety stock to be tiered in preparation for the unexpected. Of course, having all this robustness in the supply chain costs money, possibly resulting in inefficiency. To respond to volatility, supply chains in retail prefer to introduce a split, both in terms of goods and time. Opportunities: Risk can be mitigated by the use of technology to better integrate information and processing. If this data and data processing can span the entire supply chain, then the level of information integration could increase. Moreover, strategic, tactical, and operational decisions could be made to be better aligned with the entire supply chain in mind rather than with localities. It is known that this can lead to supply chains that perform more towards customer requirements and are better adapted to perform within the volatile retail climate. Data analytics could provide potential as the decision-making process can be enhanced by data-driven rather than gut feelings. Indeed, there could be a spectrum of strategies depending on how companies handle potential supply risks. This could be the approach of increasing the amount of inventory to balance the potential supply side risks that may be associated with becoming ever more data-rich but intelligence-poor. Alternatively, extensive risk mitigation measures could be considered that mirror, for example, the approach of reducing seven wastes in supply chains to something like the two-waste strategy of reducing waste of materials and waste of risks. Of course, the increasing supply risk approach bears a cost, as does the reduction in defectives. It is interesting to note that many of these strategies are naturally tightly bound to the various levels of integration into a more interdependent supply chain and could include horizontal flexibility, vertical flexibility, volume variation, product diversification, the make information flow strategy, the build inventive integration strategy, and the 'Demand Driven' supply chain strategy. Thus, developing a framework combining the various challenges and opportunities could be represented as a guide to the leanness of strategies under various differing supply chain maturity levels.

2. Fundamentals of Artificial Intelligence in Retail Supply Chain Management

Artificial intelligence (AI) includes multiple technologies that enable computers to perform tasks normally requiring human intelligence. A few popular AI technologies include machine learning, predictive analytics, natural language processing, robotics, and expert systems. These technologies have improved operations and retail processes, as well as service to consumers. Since all these technologies require data, they help make decisions based on potential impacts in trend changes. AI automates operational decisions by learning from historical data to identify patterns in demand changes.

For retail supply chains, AI assists the process by predicting when a customer is likely to purchase from an assortment, as well as predicting demand for each assortment. Compatible customer visitors and shipping carriers arrive at the store and inventory as they were predicted. AI plans demand and allocates assortments to each location, which in turn determines the mode of pick-up or delivery to the customer. In order to determine available inventory at any one location, as well as in the retailer's distribution network's supply chain, a demand forecast is used. In this case, AI can be used for predictive analytics in demand forecasting.

AI is slowly being integrated into supply chain frameworks, performing almost silently while making large impacts on logistics outputs. With AI, details are input into a system resulting in accurate predictions as a type of automated mechanism. The technology must be utilized in one form or another in some logistics areas without the use of AI or a form of forecasting; then the prediction and recommendation outputs would not follow, thus making the system seem either obsolete or unreasonable. Research into the growth and efficiency in common trade and markets have shown significant amounts of AI inclusion, thus turning over billions a year in revenue. The AI logistics factor is relatively newer and often goes unreported or unnoticed. It is crucial to understand how AI contributes to the efficiency and growth of global markets, as well as the modern retail market where customers are most dominant. The inclusion can result in unknown savings, and the entry and effect result in increased satisfaction in customer interaction, as well as quicker and cheaper delivery. AI is an expensive resource, but it is vital to understand customer satisfaction from their interaction with the company they are visiting. The supply chain is slowly and gradually shifting from what is best for supply to what service will be good for the customer.

2.1. Machine Learning and Deep Learning Techniques

Machine learning and deep learning are pivotal technologies that have attracted considerable research attention. Machine learning is a method of training a robust AI algorithm that is capable of making necessary decisions, analyzing data, and predicting the outcomes based on past data. Standard machine learning techniques can be categorized into supervised and unsupervised learning. Supervised learning techniques, including regression and classifiers, can predict continuous and discrete outputs, respectively. Unsupervised learning techniques include clustering and association that mutually identify hidden patterns and structures from the given data. Moreover, semi-supervised and transfer learning improve the classifier's performance and the reuse of the trained models in different scenarios. Deep learning is a modern subset of machine learning that generates decisions and uncovers past data patterns using artificial neural networks. The fundamental building unit of the neural network is the perceptron. Deep neural networks, including feed-forward, convolutional, recurrent, improved learning and regularization layers, and activation functions, have been developed to tackle complex system behaviors and enhance decision-making processes. Successful algorithms such as adaptive moment estimation, stochastic gradient descent, Adam optimization, and least mean square rule are utilized to update and optimize the weights of neural networks. Although these models are simple and easy to implement and understand, training becomes complex with increasing local and global minimum layers.

Several successful machine learning and deep learning models have been developed, including random forest, decision trees, Bayesian networks, K-nearest neighbors, XGBoost, AdaBoost, ResNet, Inception, LeNet, AlexNet, VGGNet, and many more. Over the past decade, these techniques have been widely implemented by researchers to solve real-world problems in vehicular ad hoc networks, the Internet of Things, virtual reality, health care, cloud computing, cybersecurity, robotics, transportation, finance, defense, and industry. When it comes to applying this AI technology to retailing, machine learning and deep learning models must be trained on training data to predict outputs, which may be in the form of numbers, categories, or values. Most models in retail supply chain management are related to time-series forecasts driven by historical and real-time data. The most common predictive models that are typically applied in retailing are demand forecasting, sales prediction, inventory management, pricing

optimization, and SKU classification. The most common supervised learning models in retail supply chain problems mostly include decision trees, boosting, and neural networks. However, using a prior training process for trained models with a pre-selected dataset is not always effective because of changing consumer behaviors, shopping trends, as well as seasonality, making the trained models invalid over time.

Continual supervised learning is significant in a dynamic retailing environment because it allows the AI model to dynamically evolve over time to improve forecast accuracy or to reevaluate the relationship between new inputs and outputs. This can be achieved by updating the trained models with newly available data while preserving the previous accuracy levels. Unfortunately, it is difficult to establish how and when a real-world situation occurs to implement adjusted or online models. Moreover, continual supervised learning has a potential drawback of training a new machine learning model every time the incoming data change, which results in a higher computational cost compared with online models.

3. Applications of AI in Retail Supply Chain Network Coordination

Several applications of artificial intelligence have recently been developed in the context of retail supply chain network coordination in order to lift the performance of the supply chain to a whole new level. These applications aim to process data and, as a result, allow for more effective, faster, cheaper, and better decision-making processes. Predictive analytics may be used to recognize trends in consumer behavior rather than just reacting to them. Real-time tracking devices can help retailers respond quickly to unusual events when rerouting orders. Companies can also interpret unstructured text from different sources to match demand and supply more effectively. With these tools and many others, retailers enhance various aspects of their supply chains, ranging from stock replenishment quantities at their stores' warehouses to increased volumes in reverse logistics. These processes not only raise overall supply chain performance but also play a significant role in sustainable retail operations.

A major stream of future research interest offered by AI would be to use such AI and machine learning applications to inform real, or at least close-to-real-time, demands by inventory and the replenishment problems that can be employed to manage them. The main outcome of such AI-driven decisions will result in the optimal stock levels of each SKU, which ought to be held to service the order pattern in a truly data-driven manner.

A vital question to be tackled is how AI technologies can solve inventory optimization problems more consistently and deliver increasingly better optimal stock levels, which should lead to larger assumed NSR while also lowering the costs. The most basic methodology used to model any retail supply chain is linear optimization. In particular, combinatorial optimization problems are NP-hard in their classical sense. This denotes that the models that AI processes by learning methods are of value when the size of the data is established. Initial point conditions in neural network optimization handle both local and global optima and accelerate the finding of the global maximum. If the optimization function is strong, the neural network can escape suboptimal local minima and retrain the network with a different set of weights.

3.1. Inventory Management and Demand Forecasting

Accurate predictions of customer demand are critical to managing an adequate inventory level consistent with timely replenishment in retail supply chains. Quantity-based or probabilistic algorithms and models are used to forecast customer demand, including moving averages, exponential smoothing, seasonality, trend, multiples, autoregressive integrated moving average, and artificial neural network approaches. Failure to maintain the optimum inventory level may result in both stockouts and overstocking, both of which have their own challenges and disadvantages. Excess stock can amplify both direct costs and opportunity costs. The maximum theoretical demand for a product is the potential revenue in a shortage condition, but unfulfilled demand can result in customer alienation, harming the retailer-client relationship. Unauthorized POS systems are the primary source of out-of-stock conditions rather than inadequate inventory balancing due to random fluctuations in demand.

By providing an accurate view of the customer demand distribution, AI-enabled solutions mitigate data inaccuracies and constraints in the retail industry. The AI-enabled replenishment system is advantageous because it enables rapid flow for replenishment, which allows for an increase in transport frequency by reducing busy moments. Additional advantages include efficient inventory in stock and a system for ordering bays and stocking up. Organizations can consider introducing a replenishment engine to improve efficiency. Nonetheless, the logistics end must ensure the completion of the backroom system in order to streamline the picking of items from the backroom and at the same time replenish any picked stocks. The real-time nature of the best-in-

class solution can drive joint business decisions in real-time. Flow can also comply with moving seasonal trends in customer buying preferences. Organizations can also be alert to the costs and inconveniences associated with data quality and system interoperability before committing to the solution. Commercial suppliers have standard information systems that facilitate the complex coordination of internal replenishment strategies. Probabilistic models can vary and can also mobilize the distribution inventory down a location transference channel.

Such systems address the inventory challenges of holding a large number of parts and products on the shelf by adjusting inventory preference at the SKU/Loc levels. As customer demand has a direct bearing on inventory, AI can significantly improve inventory control for different shoppers by using the inventory data collected. In order to highlight such range from this existing work, a few examples of AI application at the inventory level and its adoption scenario are given. AI's previous work in the population of megastores has shown that good inventory levels, combined with monthly themes in every department, increase sales and significantly decrease inventory holding. Given the connection between customer demand and inventory decision-making, dynamic inventory control is particularly relevant. Collected sales records can reveal shifting customer demand patterns over the months and the forecasted time to adjust stock levels. Sales data can be used to monitor and assist in finding any 'change points' in the inventory management process in a retail environment with data collection over time. For instance, anytime the number of non-purchases in subsequent days meets a threshold, the likelihood that 'change points' are relevant; however, the reader is urged to consider this experimental research carefully. At this level, the inventory decisions received can be disrupted due to buying binge—a changing customer preference—as the underlying model does not capture this marketing dynamic.

4. Case Studies and Success Stories

In this subsection, we illustrate case studies and success stories of smart recovery after COVID-19 in a retail supply chain using AI techniques. In these case studies, we illustrate the background of the company, the challenges that the company is facing, and why AI could be a compelling solution to address these challenges. We elaborate detailed accounts of companies, including various retail firms. Moreover, for firms that have not employed AI techniques, we illustrate the practical challenges that they are

facing and propose a potential solution that could be implemented using AI techniques. This should provide actionable insights for other firms to solve similar problems by adopting within the context of coordination between AI and retail operations.

The main message is to capacitate readers with a nuanced perspective: AI can be a game-changer in retail business operations. To excel, companies must make the most of this knowledge. AI-driven supply chain management solutions have resulted in a significant reduction of total supply chain costs. These same technologies have also helped to reduce order lead time while inventory turns, while simultaneously developing an efficient, lower-cost replenishment strategy. In practical implementation terms, a reduction in out-of-shelf products and a sales increase were observed. Lesson: Collaborate with strategic partners. Sharing information and data helps to alleviate uncertainty. Finally, AI can specifically help supply chain demand managers to better identify trends and seasonal changes in demand.

4.1. Implementing AI Solutions in Real-world Retail Supply Chains

Artificial Intelligence and Retail Supply Chain

Real research has started to use AI-based solutions to solve real-world retail supply chain problems. This paper analyzes how retail firms develop and implement AI solutions within their supply chains. It suggests that robust infrastructure and tools are required to adopt AI and highlights how different retail organizations can decide on the most suitable approach. The paper also provides case studies highlighting how some of the leading global retailers are deploying AI within their supply chains. AI implementation has to progress in stages, from strategy formulation to execution. Nonetheless, various challenges typify this process. AI application is often met with resistance. Data-related issues often relate to managing and integrating internal data and defining quality and governance guidelines.

As AI operates in areas of management and retailing, several departments in the organizations are involved in the planning and implementation process. This collaborative process incorporates several areas, such as IT for maintaining current technologies, selecting vendors, developing business intelligence systems, data warehousing, networks, and middleware. In the planning phase, an executive leader drives the process; while not having expertise in using AI, the executive leader will be

responsible for guiding staff with an AI solution field in his or her choice of the business application. Case studies reviewed in this paper show how retail organizations in different industries approach AI in retail supply chains. As seen in the case studies, the implementation of AI technology requires careful planning and continued concern for post-implementation issues, including the process of monitoring the performance of the technology and ROI evaluation. Companies likely to benefit from smart deployment are those with large networks, especially those that involve multiple markets, fixed and very large demand, a lot of replenishment, and advanced planning, because errors at almost any stage of this process have an impact on the performance of the supply chain network.

5. Future Trends and Directions

5.1. Adoption of the next-generation AI enabler: We anticipate rapid developments in AI that will improve technologies for developing and operating the next generation of retail systems. A key area to watch is work involving mechanisms to automate the automation process itself, as we foresee a quantum improvement in commercial applications driven by this capability. 5.2. Improved security solution: We expect that blockchain as a commercial technology is still under development; any common or open standards for retail supply chains are prudent to keep an eye on in terms of security around supply chain information sharing, particularly in relation to the exploitation of data assets that may not be directly owned by an organization involved in management. 5.3. More creative data analytics: Given new patronage data analytics tools, we assume that the ability to proactively respond to competition and opportunities has commensurately arisen, as corporations can discern the preferences of patrons faster, and therefore have access to their selling human notions through patronage. As a consequence, a quantum leap in sell-side technologies sparked by a confluence of buyer-side data analytics capabilities is likely to alter the competitive landscape on both buyer-side and supply-side networks, as well as enriching customer experiences. The focus will shift from selling products to offering experiences. 5.4. Holistic approach to supply chain: The supply chains will, therefore, pass into a new age of transparency and efficiency with reduced costs of executing decisions and enhanced predictive capabilities. 5.5. Retail tailoring: Given these advances, retailers can potentially future-proof their systems and operations through healing and invigorative changes based on real-time data analysis of customer behavior. Ultimately, although supported by technology, the need for a

favorable outcome driven, adaptable, and governing system is required to coordinate the full benefits of these advancements on the supply chain. 5.6. Monitoring regulatory and ethical concerns: In conjunction with the identification of the systems to be monitored, observer AI must accommodate advances in the legal sector that will recognize AI inventions and new blockchain tokens. 5.7. Incremental innovation and lowering barriers to entry: The swift evolution of competitors on the frontier of retailing is possible, but not guaranteed. Intending to use these changes requires an action of competitive intent, either to attract new retail innovation talent or to tokenize data coming from a company's behavioral operations. Within developing economies, therefore, we envisage a strategy to incrementally increase agility and attract innovation in retail supply chains by gradually allowing e-retail to bleed into unmanaged traditional supply chain environments.

5.1. Emerging Technologies and Innovations in Retail Supply Chain Management

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Retail supply chain management is experiencing an uplift due to the integration of cutting-edge technologies. Such new technologies enable us to achieve better operational efficiency in the retail supply chain. For instance, the integration of the Internet of Things in the traditional warehouse and logistics system improves inventory tracking, product personalization, and transparency of goods, thereby helping to engage better with modern-day customers. Blockchain in the last mile supply chain directly links the customer profile with the retailer and creates visibility and trust in the value chain. Similarly, advanced robotics for warehouse handling, sometimes called cobots, take care of bin-picking for eCommerce companies. 3D printing will help in offering personalized products more efficiently, so individual orders will be produced close to the end consumer.

Given the potential value of retail AI solutions to manage demand, it is very relevant to understand the company's views on using such solutions and their requirements. AI's data-driven approach to demand forecasting promises to deliver more accurate and efficient solutions for managing inventory required to meet fluctuating customer demand. No less crucial, however, will be decisions around which emerging technologies to invest in and how to integrate them into the existing retail supply chain ecosystem. Whether an AI solution alone can drive down costs and increase operational

efficiency is unclear, but certainly, the integration and coordination of complementary technologies such as AI, blockchain, robotics, and IoT across the retail supply chain is necessary. Holding back investments in these technologies are also issues of scalability, cost, and the skill set within companies to enable innovation. As can be seen with any new disruptive innovation, adoption or innovation must be strategic and well thought out. Such innovation affects the competitive landscape in the industry. Therefore, we argue that understanding the requirements of the multimodal retail supply chain ecosystem is crucial for creating AI-based solutions.

6. Conclusion

In this essay, we have discussed the importance of applying artificial intelligence to retail supply chain network coordination. The retail supply chain network is faced with new challenges and opportunities: first, the increasing uncertainty and competition require retailers to keep up with the changing development of suppliers, and second, retailers, as supply chain leaders, have the capability to enhance the adaptability in the supply chain system. Therefore, a retailer-integrated supply chain system is introduced to coordinate the actions of suppliers, distribution centers, and stores.

The essay also discusses some challenging issues for coordination and optimization. While substantial research attention is being devoted to developing demand forecasting methods by utilizing big data and AI technologies, the proposed approaches, based on theoretical proofs and optimization models, may not be used directly in practical operations. Therefore, we discussed some case studies based on industrial practices to demonstrate the benefits of deploying AI on supply chain network operations. Advances in AI technologies should alert all the supply chain enterprises that they need to equip themselves with the newest appliances to stay in the game. Getting the right product to the right place at the right time is the golden rule of successful retail, and with changes in consumer expectations already driving the need for a new breed of supply chain manager, the use of AI technology is set to shake things up even further.

From manually managing discrete points in the supply chain, the retail giants that fail to innovate their supply chain strategies will find themselves lagging behind the tech firms able to keep up with, and even predict, consumer demands. As supply chain management continues to improve, who you are working for will affect what you do. Increasingly, supply chain posts at tech companies are focusing on the ways to build

new technologies which use AI and data to analyze and rethink the supply chain. This critical and timely industry reconsideration will create more opportunities for innovative retailers and logistic firms who can then use AI and data to get ahead of the curve.