

Streaming Analytics and Anomaly Detection in Complex Supply Networks: An Event-Driven Framework for Real-Time Operational Intelligence

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1. Introduction

The management of supply chains is undergoing major changes due to numerous factors, including rapid technological advancements and shifts in business models. The integration between supply chain operational and strategic decisions of a business, as well as supply network design, has been suggested as crucial factors leading to competitive advantage. This essay describes an AI-based system of real-time supply chain state monitoring, analysis, and reconfiguration. This essay is divided into four main sections. First, a detailed overview of the most recent trends and technologies proposed for managing and reconfiguring supply chains effectively in current business scenarios, emphasizing the necessity of efficiently integrating modern AI technologies to enhance their operational levels, is provided. Then attention is turned toward the discussion of a new idea of supply chain operations management, i.e., supply chain state-based management, which faces the fact that real-time data, which usually consists of the state of the physical systems, plays a fundamental role when taking operational decisions in supply chain management. The rapid evolution of AI technologies—in particular, machine-based learning—also spurred on the rapid improvement of supply chain mechanisms and processes, propelling improvements in the overall efficiency of supply chains themselves.

1.1. Background and Significance

Supply chain management practices evolved through various stages from batch processing to e-business. This field has been experiencing various challenges in the era of globalization due to the increased complexity and relations in global trading. The traditional and well-known method to address supply chain problems was to create local centralized warehouses; this process loses momentum due to various factors, such

as the need for the delivery of various products at the peak of market demand and the quick response to the rapidly changing market situation. Nowadays, it has become complex and hard to optimize supply chain operations using traditional methods as they are increasingly turning hasty and small in a competitive environment. The management of goods, services, information, money, and transportation is done between the stakeholders to run the business through the channel of supply chains. It spans from the suppliers to the end user who is responsible for sharing the goods with the respective markets. There will effectively be transparency in their departments of product placement. In the ever-connected world, new and inventive technology demands and the ever-ready urge to fulfill the latest industry needs are driving change at a breakneck speed. In the trade world, an organization failing to adapt itself to environmental changes can sometimes result in the collapse of the process, which makes the pitfalls of the company more vulnerable.

There are several drivers of change like globalization, new legislation, collaborative issues, technological development, e-commerce, and changes in packaging, etc. This forward-thinking viewpoint is the love child of innovation and sustainability – leading the race in getting the product on the shelves where consumers need them, before they even realize they want them. Successful production companies are focused on the customers they serve, and that has made their customers, both changing and service-oriented, being maintained through the well-established supply networks. This has enhanced the movement of products on one hand to the virtuous business partners rapidly, who owe the commitment to provide service to the other end of the connected chain. The early signals regarding this trend were observed during the early 2000s. At present, many organizations collect and analyze data to give weight to different factors influencing the area of supply chain management. These studies typically report on what, where, and when of the operational aspects of the current practices. AI is clearly a transformational force for the world of supply chain management. Observing the historical trends and existing literature, the foundation for AI is strong in a demanding environment. Its main task is to reduce the human effort spent on rote tasks. These systems include technologies such as robotic process automation to speed up business processes, chatbots to interact with customers or employees, or requests for IoT that can generate alerts automatically.

1.2. Research Objectives

The objective of assisted research is to ascertain the utility of AI in providing real-time insights into supply chain operations that are not available through traditional monitoring practices. The aim of this research is to provide a detailed explanation of the problems encountered with traditional supply chain monitoring solutions and to evaluate the beneficial impacts of AI adoption through the analysis of successful case studies. Additional objectives concern the analysis of the role of real-time data in improving the efficacy of AI solutions and to assess the ethical and statutory issues surrounding the use of AI and blockchain in supply chain practices.

The objectives of this research are: 1. To identify the key challenges faced by businesses working in supply chain monitoring operations. 2. To examine how AI and blockchain technologies can aid in enhancing the speed, accuracy, and transparency of supply chain operations. 3. To explore case studies demonstrating the successful implementation of AI in actual supply chain scenarios. 4. To determine how AI can benefit from real-time data in supply chain operations. 5. To scrutinize the challenges and issues surrounding AI implementation for supply chains. 6. To provide a comprehensive summary of the numerous ethical and statutory AI-related implications in supply chain operations. This study is designed to help address the research challenges of formulating research objectives, conducting literature reviews, developing theoretical frameworks, choosing appropriate samples, research design, data collection and analysis, as well as revising and writing up the outcomes of all research.

2. Fundamentals of Supply Chain Management

Supply chain management (SCM) aims to link all of the stakeholders and resources involved in the value chain by creating an integrated business process. This interconnected approach includes the management of logistics and network design along with the procurement and materials management, order fulfillment, and manufacturing administration to enhance the trust between the various tier-1 suppliers and original equipment manufacturers (OEMs). At its core, SCM is a concept in management theory that integrates all of the value-creation activities within and between companies. However, SCM is also important for the skills and competencies required for data interpretation and analysis in supply chains, which is critical for global operations management. With these decentralized networks, managing production or

shipment requirements inherently experiences complex dynamics across all levels from operational to managerial decision-making.

An essential part of this is logistical management. Logistic activities also have at least four different types of resources, which should be simultaneously considered in planning: transportation, space in repositories and storage facilities, people, and assets involved in the process and jobs. Their lack of coordination and synchronization can produce inefficiencies of time action, an increase in variability, and thus might reduce the profit expected of the company. However, efficient logistics are also crucial for a firm's technological expertise as well as in establishing valuable core competencies. In practice, the trade-offs between logistics and systems development need to be studied thoroughly as they impact the cost and time-to-market for developing new products. The need for real-time information for efficient process control in supply chains has also been strongly advocated. A tight integration of the components through logistics processes is key for efficiency in manufacturing. The value chain is central to a firm's competitive advantage, and any shortcomings in its design – inefficient procurement, ineffective operations, consequently leading to poor planning or untimely delivering – will result in the production of defective products, angry customers, and unsustainable excess costs.

Real-time constraints in supply chains: Organizations aim to reduce slack and structural ineffectiveness in their efforts. Such operational aspects are quite sensitive to and well-dependent on the demand of the market. Context constraints also arise from the production and process design within an entity. Short-term oscillations in demand have to be met with quick changes in the production schedule, and these are directly affected by the fluctuations at order level and routing. Given these complexities of the operational contexts, operations with tension become difficult to undertake compared to normal operations. Current-day operations in a company where several networked stakeholders produce goods or provide services cannot fully estimate the demand with high accuracy, and whether the supply can meet this demand largely because of several uncertainties and variabilities. Supply chain monitoring, as of now, is traditionally implemented by historical tracking methodologies where time deadlines are difficult to meet. The following subsections explain the main difficulties encountered in traditional supply chain control monitoring, supplemented by highlighting the AI solutions which

attempt to integrate the monitoring processes of AI to provide a more accurate yet real-time overseeing operational approach.

2.1. Definition and Components of Supply Chain Management

Supply Chain Management (SCM) can be systematically defined as the management of a network of interconnected and interdependent suppliers, manufacturers, logistics service providers, and customers with the goal to develop, deliver, and support goods and services in a timely, economic, and high-quality manner. There are three major components of SCM: producers (manufacturers – first-tier suppliers), any company that supplies goods or services required for their processes (suppliers - second-tier suppliers), and end users of goods or services provided by the manufacturer (consumers – a downstream actor).

The role of every actor in the supply chain's structure is as follows: outward flows related to materials, information, finance transactions, and inward flows like materials and data transactions while interacting with the other actors. The starting point and ending point of the supply chain are raw materials and finished products. For example, producers or manufacturers typically consume raw materials as a starting point and produce goods or services from manufacturing processes and pass this to the customers. Customers use these finished products for their use and add services. Interacting actors are not limited to manufacturers and suppliers. Firms can use logistics firms to send their products or materials to their customers. This means that there are further links to be held to monitor logistics. Manufacturers have hierarchical and horizontal links with their suppliers and customers. As a result, it can be said that SCM is not only manufacturer-centered, but also customer and manufacturer-centered flow, which includes tier and hierarchical structures between downstream (customers and manufacturers) and upstream (suppliers with hierarchical links within themselves) flows. The way that downstream is linked with upstream has upwards and downwards. In this study, we were interested only in upstream flows even though downwards have importance in the field of demand planning, demand orientation, and SCM.

2.2. Challenges in Traditional Supply Chain Monitoring

Traditional supply chain monitoring has its own set of challenges. These challenges are mainly due to the lack of real-time data in monitoring, located at different places or individuals for each company, and are not easily available as they are with the

companies in real-time. Most supply chain monitoring systems have been developed with significant manual effort for pre-set triggers or warning signs. Long and increased lead times in decision-making shift from conventional to advanced warning and automatically generated actions. These manual methods reduce the quality and helpfulness of the identification and signaling of perturbations or threats in the supply chain. At best, the information is days old, and at worst, weeks. The effectiveness and efficiency of the monitoring tool are reduced as time increases between when the event occurred and when it was reported. In addition, the relevance and reliability of a decision based on that old data are reduced mainly because of these three factors.

The faster the response time, the better the identification and tracking of the root cause of a perturbation, and the more accurate the response to and results of solutions. Executing actions in real-time increases the benefits of the timely warning generated by the system. Our observations indicate that the benefits of advanced warning on stability and transportation efficiency are reduced with increased lead time in decision-making. To mitigate delays in information, traditional activated and advanced planning are two fundamentally different actions.

Traditional methods typically have a "point of activation" at which point a decision or set of decisions is made for the event. This point of activation is typically the same between poor and well-performing decision-makers. Ensuring advanced activation of the response requires constant vigilance. In a supply chain environment, a perfect early warning system provides value only if accurate and right judgments can be executed. Retrospective analysis of the impact of supply chain perturbations over the last 20-50 years has proved highly ineffective. It was identified that it did not matter how you did it – even the best companies reported that if a terrorist attack infected their supply chain, it would take them forty-eight to seventy-two hours just to find the needle in the haystack to tell them what went wrong at the plant. A cockpit researcher illustrated this with a step-by-step process of knowledge steps that moved from initial knowledge of the perturbation, through identifying what has to be repaired, to who can repair, to the very local control of day-to-day execution. In order to buy time for this step-by-step process, one can generate plans in advance of activation to enable a rapid response from the time the information arrives. The subsequent two challenges are the losses from poor or no plans. A primary responsibility of decision support in supply chain management

has to be to minimize or eliminate the impact of the above two characteristics. The fact that the effect of the current and most immediate plan as actioned today may only be shown in a day or weeks' time is of obvious concern, especially in response to a deregulating industry, with continued knock-on effects.

3. Role of Artificial Intelligence in Supply Chain Management

As a sub-area of operations, supply chain management is a series of interconnected systems and flows of materials, information, and money between a company and its suppliers, customers, and, in some cases, even manufacturers. There is a rapidly growing corpus of literature attesting to the benefits offered by the adoption of artificial intelligence in supply chain management and supply chain logistics across several industries. It is an essential tool for the digital era as it can process vast amounts of data and draw conclusions using algorithms. Artificial intelligence allows machines to carry out challenging and sometimes conceptual tasks as opposed to alphanumeric ones. This technology involves processes such as planning, pattern recognition, and computer vision functionality, as well as language processing. At its core, AI is capable of amplifying a company's decision-making capability, making it a valuable tool for predictive analytics such as demand forecasting and the strategic planning horizon reports used to inform annual and quarterly strategies.

In the world of supply chain operations, AI technologies have generated much buzz, drawing attention from industry leaders, consultants, and practitioners. Artificial intelligence and machine learning algorithms are being applied across several supply chain business areas to support continuous improvement in a company's operations, including network design, risk management, optimization, demand planning, sourcing, production, inventory control, and logistics and distribution. While AI-driven supply chain technologies have the potential to significantly improve operational efficiency, the combination of AI, machine learning, and robotics and automation is expected to lead to workforce displacement in production and lower-level supply chain jobs due to their ability to automate routine tasks and operator-related activities. Additionally, there are ethical issues and concerns regarding erroneous decision-making by AI.

3.1. Applications of AI in Supply Chain Monitoring

Today's supply chain monitoring practices are becoming increasingly integrated with advanced AI systems to support the use of real-time data and AI analytics to provide

advanced visibility and support the predictive capabilities of this type of system. Although a variety of different systems may be integrated and supported by AI analytics, we will describe two examples that have recently gained increased attention from a number of industry sectors: (1) inventory management systems and (2) demand forecasting. Inventory management supply chain monitoring systems can use advanced predictive analytical models to optimize order traffic flow and lead time to maintain a desired level of inventory.

Demand forecasting AI can track changes in demand patterns and forecast future needs at an enterprise. By adapting the service interface to pre-existing enterprise interfaces, it is also possible to engage the interface to obtain real-time information or responses directly from staff via the neural network, which further adds to the real-time ability to support a supply chain monitoring system. With the development and adherence to standards, many industry sectors can benefit directly. Some standard industry sectors are transport, retail, defense, and health care. The application is used to optimize the operation of the supply chain management system to achieve the production planning system. By applying adaptive neuromorphic algorithms, the real-time operation of this production planning system can be optimized.

3.1.1. Applications in Supply Chain Management Operation management represents one of the key applications of artificial intelligence in general and machine learning in particular. Artificial intelligence techniques, including data mining, machine learning, and neural computing, represent a significant opportunity to address some of these challenges associated with supply chain logistics. Machine learning is particularly important for implementing advanced analytics into logistics and supply chain operations for improved decision making and strategy development. The use of advanced neural network algorithms has extended beyond traditional supply chain management systems to build an AI-driven system capable of interfacing with users and enhancing real-time analysis and support of cross-organizational, multi-stage, and process-oriented systems. Finally, artificial intelligence applications have been widely used in transport systems, logistics, and supply chain companies in the form of freight optimization systems and e-commerce warehouses, among other similar company systems. It is notable that these applications cover several different sectors and, naturally, the type of AI application has also shifted.

3.1.2. The Advantages of AI in Monitoring Although maintaining a stable supply chain has indeed become increasingly challenging, AI supply chain monitoring holds a great deal of potential as it offers an array of benefits. One survey cited several different benefits from AI increases in controlling the supply chain, including: (1) improved insights into the workings of supply chains and individual objects after studying the behaviors and movements of these materials; (2) the ability to conduct just-in-time delivery of goods based on analyzing behavior and flight paths; (3) the use of road configurations to automate optimized workflows; (4) an increase in the accuracy of available and remaining asset development and overall systems. When implemented correctly, artificial intelligence in the supply chain works with a reasonable amount of related cost-effectiveness, given that optimal use of systems is highly profitable. In the industrial world, it is also very practical as it is of particular interest to extend the domain to edge and cloud computing, especially in industrial facilities. There are suitable applications and methods in other companies to track buy-and-use processes; the impact of AI down to the IoT sensor level within a control system of the production industry is significant.

3.2. Benefits and Limitations of AI Adoption

Adopting AI in supply chain management has a number of potential advantages. One of the most important applications is improving the effectiveness and efficiency of the management process. AI technologies can solve complex issues at speeds beyond human limits. Consequently, more accurate and efficient decisions can be made to dynamically optimize and control supply chain operations, enhancing the decision-making capabilities of supply chain organizations. Furthermore, AI technologies can significantly reduce the running costs of supply chain operations. AI-powered predictive maintenance can warn organizations of potentially dangerous equipment failures or damages in advance, reducing possible long-term damage and high repair costs.

Adopting AI in supply chain management, however, comes with numerous challenges and limitations. Financial concerns are at the top of this list. The initial outlay required to install AI systems and the lack of an integrated system model to effectively use AI are two major inhibitors. As information is the most valued commodity, data security issues also come into play, as AI applications are designed to sort, store, and transfer huge amounts of critical real-time data. Additionally, if these technologies are to operate on

their own once implemented, there is the question of whether they can be trusted to make the correct and moral judgments. AI will certainly improve operational efficiency in a number of ways, but the negative consequences should not be ignored. Therefore, any neutral operations, non-biased, and ethical use of AI is critical, as trust, reputation, and morality are important intangible assets of any company. The use of AI must be a responsible practice that ensures neutrality and transparency in the ethical code of conduct.

4. Machine Learning Techniques for Supply Chain Monitoring

Machine learning techniques are increasingly being utilized for supply chain monitoring. Machine learning models can analyze large volumes of historical and real-time data to generate predictions about future demand and order arrivals. Consequently, they enable better operational decisions. In this discussion, we cover several types of machine learning used in supply chain monitoring. In practice, supervised and unsupervised learning techniques are mainly utilized. Supervised learning methods, such as regression models, deep learning architectures, bi-directional long short-term memory networks, recurrent and convolutional neural networks, and extreme gradient boosting models, are used for predicting demand and order arrivals. Unsupervised learning methods, such as clustering-based models, are used for aggregating demand from lower order levels to the upper levels of a supply chain or customer demand. Predicting future demand is crucial for determining the right inventory level at a warehouse for various products. Some machine learning models are also designed for optimizing inventory policies in the event of disruptions.

By using large volumes of transactional data, machine learning models can leverage granular transactional data for predicting future demand with higher accuracy. These models are considered useful for capacity planning, production planning, and better schema selection in demand forecasting. Moreover, machine learning models have been shown to generate precise predictions that allow supply chain managers to make better demand-driven decisions. Most of these decisions can help in reducing the order-execution cycle time and decreasing the average inventory levels throughout the supply chain. The use of machine learning models for on-time completion of orders ultimately leads to enhancing customer satisfaction in supply chains. Nevertheless, there are a few challenges in building and implementing machine learning models, including data

quality issues. Efficient data integration is a crucial step for using data-driven techniques and can become a serious impediment in employing such methods for supply chain monitoring.

4.1. Supervised Learning Models

Learning models in which the training data consists of examples that span the input-output pairs we want the model to predict. Supervised learning is based on the availability of labeled data providing the information ground truth for the model. The optimization of the loss function used during the training phase drives the capability of the model to generalize the observations made during the training onto unseen input test data in the hope that those observations will be minimal. Some of the most interesting business applications of supervised learning techniques in the supply chain monitoring domain are demand forecasting at different time horizons, automatic optimization, and rebalancing of the order-up-to level in centralized distribution centers, and the reservation price in the pricing mechanism balancing supply and demand in decentralized omni-channel settings. Supervised learning problems can further be grouped into regression and classification tasks. The former focuses on predicting a continuous value where the most common metrics are, as mentioned, Mean Absolute Error, Mean Squared Error, and R^2 . The latter works towards predicting a discrete outcome with the accuracy of the chosen algorithm and a common metric to measure the performance. Most models learned through supervised learning fall into two categories: regression and classification. The former investigates the possibility of predicting a continuous output and is evaluated typically by performance measures such as Mean Absolute Error, Mean Squared Error, and the determination coefficient. Using the classification approach, we try to predict discrete outcomes of, for instance, hot-center operational business decisions in supply chains. In this setting, we evaluate the performance of the prediction using accuracy. One of the most familiar supervised learning techniques is regression. One of the major benefits of using supervised learning models is their potential to provide a measure of risk of unexpected behavior. This can be particularly beneficial when operational management needs to be conducted, because with a certain degree of confidence, operations can be run in automatic pilot mode, effectively reducing the cost on human resources. Nevertheless, most supervised learning models require labeled data. Labeled data used in real scenarios might be cheap to obtain or directly cost-effective.

4.2. Unsupervised Learning Models

Supervised learning models involve training data labeled with an appropriate result to predict associated attributes or classes using algorithms. However, it is worth mentioning that a significant portion of the data globally is unlabeled, so only a small fraction of today's data can be directly used for training supervised models due to this limitation. Unsupervised learning models analyze patterns in the data to extract some form of structure or relationships from datasets without any input or information about the result. The most common unsupervised learning techniques include clustering, which segregates a dataset into groups according to some features, and anomaly detection techniques, which identify unusual situations.

Anomaly detection as an unsupervised learning application is vital for early detection of fraud, faults, or terrorist activities, to name a few, by providing warnings and initiating corrective actions as soon as any of these occur before they can grow into serious issues. Many businesses extensively use exploratory data analysis in the domain of unsupervised learning as a fundamental tool for understanding their datasets and extracting hidden insights and trends, helping with strategy formulation. The continuous exploration and usage of unsupervised learning led to the development of different algorithms and tools. One of the main unsupervised learning tasks includes clustering, which aims to find the relation between groups of entities based on a set of decision variables. The decision variables include time, cost, data-processing systems, geographical location, and production planning. The challenge in clustering arises in its complexity; the existence of an extremely large number of data points, an unknown number of clusters, and noise within the data are all significant challenges. Robustness of clustering algorithms, in terms of robustness over different initializations with parallel co-clustering datasets, is also crucial in overcoming clustering issues. Unsupervised learning is more flexible and can be utilized in cases where not all the necessary information is available or labeled in the data and in cases where employees adopt new strategies to avoid issues.

Unsupervised learning models can serve as a complementary analytical approach as they provide a level of adaptability and flexibility due to their independence from predefined binary outcomes. Clinical data can then be used along with unsupervised predictive models to provide other insights, validate or disprove, and fill the gap created

by conventional supervised data. Data is a critical part of every decision-making process that advances business effectiveness and drives operational innovation. It is crucial to effectively manage information obtained from the large datasets so decision-makers can yield more data-driven valuable insights. Unsupervised learning plays a wide role in advancing the enterprise towards more data-driven decisions and innovative strategies.

5. Real-Time Data Collection and Processing

Real-time data collection and processing are critical elements for effective supply chain management. Real-time data analysis helps in monitoring, predicting, controlling, and acting upon deviant events in the supply chain. An array of IoT sensors and devices can serve as auxiliary checkpoints for gathering data that are of high importance. These sensors and devices can collect data in the desired granularity and heterogeneity, as well as facilitate reasoning in the decision-making of the entities involved in a supply chain.

Connectivity and technology facilitate the extraction of data at a much more granular and exact regular basis than ever before, and suitable real-time visibility is easily made available for any entity in the chain. There is a constant need for data to guide strategic and day-to-day tactical and operational decision-making. While the technology has provided a right path toward the collection and use of this big data through a plethora of channels and instruments, little attention has been paid to the methods for distilling these commoditized data into decision-useful information. We have the ability to gather huge quantities of data, but usually only small data types yield useful perspectives. In addition, various systems deliver equally diverse data across various platforms and standards.

The contribution of this section lies in identifying the significance of such mechanisms and instruments that can carry out and process huge volumes of data, offering practical insight as inadequacies in segregation and distillation make real-time monitoring call into question. This demonstrates the importance of the process needed to clean and purify data so they may be put to use for effective decision support. Additionally, methods suggested via approved study frameworks contribute to service guarantees and reveal doubts that consistently arise about the accuracy and validity of real-time monitoring data. Data cleaning must systematically form part of a quality checking protocol, and indeed, figureheads in the industry articulate the role of machine performance above all else. In short, put plainly, either the major commercial players are

utilizing this capability secretly, or the large majority of could-be SCM IoT vendors haven't yet developed—or haven't even realized they need to develop—the tools to make such things possible.

5.1. IoT Sensors and Devices

IoT sensors and devices. A main component of 'real-time' supply chain management and monitoring is the capability of tracking objects and events on site. This requires the deployment of suitable devices with appropriate sensing capabilities. For supply chain monitoring, suitable sensors are basically 'track and trace' devices to complement the information available from the supply chain management and enterprise resource planning systems. However, the potential to integrate information captured by the sensing devices during monitoring with further information available from the information systems, which implies 'sensor fusion,' will be of great advantage and is desirable. Generally, the IoT devices may be classified into two major types: sensors and actuators. Examples of smart sensor devices are tags/labels, readers, and mesh routers. More recent sensors and devices in addition to this include RFID chips, GPS chips, environmental sensors, motion sensors, and dust sensors.

IoT sensors excel in two areas of importance in supply chains today. They excel in logistics by tracking and tracing raw materials and finished goods. They also monitor the logistical handling and transportation context of the products. More importantly, they have extensive deployment and use in the manufacturing operations themselves, even down to tracking work-in-progress materials. They can send out a status update every time the equipment is done running or halted so that warehouse employees know exactly what to expect. These devices report the volume of the product accurately when it arrives at a warehouse and can track when it sells out. Additionally, they are assets for managing inventory, preventing overstocking or stockouts. They read the temperatures of goods on trucks or planes and will report if the temperature exceeds a set limit. The IoT devices at the pallet and case level put control over the shipments without relying on data from an outside and/or possibly untested party. Despite these increased benefits, the integration of Internet of Things prediction devices into the supply chain and information technology infrastructure has brought its own fair share of challenges. These days in the enterprise world, a synchronous rail shipment has an increased

number of devices attached for monitoring its route. Moreover, their dedication to improving the depth of scene visibility in supply chains nowadays is very vast.

5.2. Data Integration and Management

Supply chains are becoming more complex, creating a more challenging environment not only for the actual monitoring of the related operations in real-time, but for the ability to synthesize the full spectrum of movers and activities that make up a supply chain. Real-time responsiveness to a continuously changing environment requires the ability to collect, integrate, and analyze data from across the distributed global supply chain using real-time data streams from very large, highly distributed, heterogeneous, and possibly unreliable sources. Each actor in the supply chain may manage different data that map the same real-world objects through business-related activities with different semantics.

Challenges in data management: The challenge lies in collecting and organizing this heavily distributed and heterogeneous data in real-time effectively and performing analysis on the collection and integration of data. Real-time or near real-time supply chain information and decision support can only be realized by platform-based approaches, particularly from where combined events may be useful. Real-time decision-making in operations and management requires access to reliable information throughout the supply chain. An example of good practice for the integration and management of supply chain data can be found in the achievement of a car manufacturer in tagging and monitoring each of its engine modules produced each day. Tagging each component, along with each machine used during manufacturing, allowed the executive to monitor their entire supply chain continuously.

6. Case Studies and Best Practices

We have showcased several AI-driven monitoring case studies. There are three different case studies involving major classes of supply chain management, i.e., the movement of goods. The first is related to supply chain logistics: detection of changes in distance measurements in ocean transit using a data-driven algorithm. This case study involved the detection of manual manipulation using artificial intelligence applied to long-range, low-frequency trajectory data of large and slowly moving ships on ocean trade routes. The second one is about supply chain engineering: anomaly detection in energy-based predictive maintenance analytics. This case study involved the use of AI to detect pump-

overheat-related events, hard shift, kick-down, and deleted cases. The third feature involves trading: turnaround time prediction with AI/ML in unloading services in the port. This case study examined the development and subsequent steps of an infusion of AI/ML to provide a real-time turnaround time in the port for standard containers.

These examples are given to show the clear possibilities of AI application in real case scenarios. AI-driven supply chain asset tracking and big data analytics in supply chain tracking focusing mostly on cargo transportation. Artificial intelligence has become one of the major drivers for digital transformation in almost every aspect of the entire industry. One of the wide fields where AI is contributing is the realization of smart supply chain networks. Artificial intelligence has the capability to interpret copious and heterogeneous multimodal data from automated tracking sources. Here, we have effectively executed case studies including AI techniques for real applications in a supply chain scenario which targets logistics and the detection of anomalous situations. By portraying these examples, we provide substantial proof of feasibility and in-practice use of AI in supply chain management. Moreover, they can provide possible solutions to achieve improvements in a near real-time manner and save time and cost for human inspectors.

Best Practices Having established the potential of AI applications for real-time SC visibility, we can identify some useful insights or lessons learned from the proposed case studies. This study considered AI application at procurement lines, yet given an end-to-end technique perspective, we can classify various AI implementations in the subsequent supply chain fields: ocean shipping and terminal operations: implementation of VSM in port to predict container unloading time. Manufacturers: a popular technique in predictive maintenance of manufacturers. Retailers: a smart shelf is proposed, installed, and tested in a real-life supermarket. Legislation: AI applications in supply chain to assure proper treatments for hazardous materials before being shipped. Urban logistics: towards a new paradigm for a full-day assignment problem: an AI method was presented to solve the city-warehouse-package-city set of paths where no depot is cutting the vehicle travel path. Concerning port selection, the results confirm the advantages of utilizing the proposed system. Data mining: a supply chain data mining application for real-time prediction of finished goods operator. Manufacturers in how many hours following online orders come in and the details of potential

manufacturing requirements. Beyond the hypothesis, ongoing research is considering the number (and nature) of suppliers required to annually purchase each unique product, as well as the effect of the number of simulation replications and size of the "comparable set" on the mixing problem solution, monitoring the onset of cultivar blending due to changes in roasting. Besides predicting each day's entire roasting schedule, forecasted demand for supply planning will also be thoroughly investigated.

6.1. Successful Implementations of AI in Supply Chain Monitoring

AI Driven Inventory Monitoring at Cummins: A leading supplier of power generation systems and filtration products with revenues in excess of \$20 billion, Cummins monitors more than 600 different pieces of equipment globally, with more than 8 petabytes of data to ensure the equipment neither exhausts the in-house inventory due to over-ordering nor results in delays because of insufficient availability. Prior to adopting AI, while their systems were good, they were no match for the intuition and contextual inference of a human worker. However, even then, there were several panics. Their solution monitors current inventory levels to automatically place DCR orders based on a number of attributes, including location, typology, local customs, and so forth. In one specific instance, we were told about a factory producing power-generating systems in Brazil where traditionally they hold onto a couple of weeks of on-site stock as a precautionary measure. As of now, AI is asking to cut that down to just 3 days. This is quite a shift from conventional wisdom in supply chain management, and it comes with both advantages and complications around supply chain coordination, which is why it has often been avoided; however, companies that orchestrate AI implementation invariably find a step function in the savings they are able to achieve from inventory efficiency, which can more than make up for the cost. The advice given by Cummins: Let AI do its thing, and if you must short-circuit it or modify its response, make sure to use a very small group of sympathetic, analytical humans. Data integrity efforts should start a year before implementation. There should always be an executive in charge of the entire orchestration, and that generally means setting up a centralized supply chain nerve center. This is the first time an AI has been allowed to operate autonomously in a sensitive area of supply chain management, based on research into best commercial practices.

6.2. Lessons Learned and Key Takeaways

Overall, these case studies show that integrating supply chain data into a central, AI-driven system can lead to greater visibility across the entire logistical journey. It can increase supply chain efficiency by improving organizational forecasting models. They also demonstrate the value of tightening operational control by directly informing a wet stack reduction regime and assessing the relative impact of different delay causes, such as harbor delays on terminal performance. Indeed, the adaptability of AI models and their ability to handle huge varieties of data at speed allows not just supply chain events to be predicted with accuracy, but also to be iteratively improved as the data changes. Importantly, these studies also warn against some of the ideological choices and optimistic naivety that can hamper the smooth implementation of AI technologies. These range from the widespread use of datasets that automate a small part of existing data processing tasks, to the underappreciated time costs of data quality and model transfer, and the need to iteratively adapt models to fit a rapidly and constantly changing world. Many of these barriers can be overcome by effective strategic direction of AI implementation. Finding ways to coordinate existing siloed efforts of adopting machine learning technologies in individual parts of the supply chain can also yield benefits. Given the theoretical promise of AI in supply chains, these case studies are reminders to all practical professionals that the devil is quite literally in the detail, not the ambition.

7. Challenges and Future Directions

In this book chapter, we introduced an AI-driven supply chain monitoring system that can be used to create a 360-degree view of historical and real-time supply chain activities across different supply chain echelons. We designed the system using a range of AI technologies such as natural language processing, machine learning, reinforcement learning, and knowledge representation and reasoning. This section concludes the chapter by addressing the challenges and future directions of AI-driven supply chain monitoring systems.

To address the issue of biased and prejudiced AI systems, it is important to consider the fear that businesses will leverage them for strategic purposes such as personnel recruitment. An ethical concern regarding reinforcement learning stems from the potential that a system can corrupt an employee who has never been reported, or whom

other employees do not know. It is important to note that although AI systems can extract important insights to gain an advantage, they cannot replace humans altogether.

AI is constantly evolving with advancements being made in technologies such as pattern mining, mixed-integer programming, and hyper-heuristics to optimize supply chain processes. Blockchain technology is also gaining momentum in monitoring extended supply chain operations. These changes are likely to drive the evolution of AI in supply chains. As a result, we forecast that a few trends may affect supply chain planning and the design of the AI Orchestrated SC framework. The emergence of software and technology vendors working to ensure the ethical use of AI points to the necessity for frameworks that specify an entity's responsibility in terms of ethical AI deployment. New technologies will emerge, presenting the necessity for such frameworks. To address these issues, organizations may need to monitor the developments and work proactively to prepare for the changing landscape.

7.1. Ethical Considerations in AI-Driven Supply Chain Monitoring

Exposing processes and their implications for consumers and employees raises, in addition to purely legal, numerous ethical questions and contradictions. These arise in the context of the individual application: How ethical is it to access personal data and continuously monitor the right to privacy? Who in particular pays for the surveillance, which is promoted by employees and consumers alike? Who gives up which part of their personal space and freedom needs to be viewed critically. In this respect, there is a threat in AI-driven monitoring that the excessive ethically problematic willingness to expose alleged wrongdoing will damage general social coexistence under the cloak of false transparency.

AI and its algorithms can have their own effects on individuals, even leading to depression. For example, a monitoring AI that notices attempts to deceive by maliciously bypassing controls and reacting with caution can have a significant negative impact on employees, resulting in the development of aggressive behaviors and even a lack of motivation. Furthermore, in terms of changes or job cuts based on AI-driven decisions, one must not neglect moral responsibility. The responsibility for a decision is tremendous if this decision leads to the loss of someone's job. With a clear framework, decisions can be controlled and influenced according to these standards. However, control mechanisms, especially on a global scale, have not been established.

However, large players have already developed an ethical standard for the purchase of AI. Suppliers must consider the fundamental rights and ethical considerations of the data subjects in AI-driven decision-making processes. The intermediary's approach is therefore to provide a guideline and to appeal to the sense of responsibility and common sense in the development, purchasing, and application of AI tools, even if these guidelines violate the law of competition. The initiation, implementation, and moderation of a framework for responsible use of AI is therefore urgently needed in order to enable broad and constructive stakeholder participation in the supply chain. Preliminary results underline the importance of developing a holistic ethical framework in order to further develop the visibility dimensions of digitalization according to the aspects of responsibility for one's own actions, positive contribution, and competence.

7.2. Emerging Technologies and Trends

Emerging technologies such as blockchain, the Internet of Things, and 5G will have an outsized and transformative impact on supply chain operations. Designed for transparency and to enable secure data exchanges, blockchain could facilitate and set the stage for additively manufactured spare parts and localized, demand-driven parts supply. 5G networks promise to be the backbone of an array of advanced digital capabilities, including wireless connectivity. 5G connectivity would offer the enterprise the ability to comprehensively and inexpensively access real-time data from across its operations, a powerful tool for supply chain visibility and coordination. Blockchain alone reduces supply chain fraud; it reduces time delays, added costs, and human errors. This is welcome news for companies that look to de-risk their international supply chain while ensuring sustainability and transparency.

In order to perform in today's ever-evolving market, companies need to adapt to stringent technological and procedural environments and provide continually evolving experiences to the consumer to remain in a dominant position. For life science and healthcare companies, adopting AI in multiple spheres to automate, streamline, deliver, and control complex procedures and mechanisms is a burning priority. This leads us to some of the most pronounced trends that are shaping the sphere of healthcare. A key point is a combination of different new-age technologies, such as machine learning, big data, and AI, for the purpose of simplifying supply chain management. To a great extent, AI can be looked at as an umbrella technology, with smaller technologies such as

deep learning and machine learning as its constituents. Supply chain management can benefit greatly if other revolutionary technologies such as 3D printing and blockchain intermingle with the AI-driven supply chain.

8. Conclusion

The urgent need to utilize advanced technologies, such as AI, for supply chain functions optimization is being confirmed by an increasing number of studies and related practices. The results of these studies are encouraging. The key themes that were covered concern: The potential and possibilities of transforming supply chains by implementing real-time AI-driven monitoring. As of now and in the future, organizations process an ever-increasing amount of data – real-time AI-driven monitoring of supply chains is becoming the competitive imperative. With the help of AI-driven data analytics, it is possible for organizations to improve planning processes and also to mitigate many associated risks. Ethical considerations and the lack of human expertise are two significant challenges for the adoption of AI technologies. The importance of implementing real-time monitoring solutions for the enterprise is identified by these case studies. The encouraging results seen in the case studies suggest that other organizations might also find it beneficial to implement real-time AI-driven solutions to monitor and manage their supply chains. The organizations must continue to be innovative and adapt new technologies, such as AI, to add value to the organizations. This is also beneficial for academics and researchers, with opportunities to advance and improve the capabilities of supply chains when they are combined as a combo. We invite researchers and the industrial community to direct more research and best practices on technology and its critical application in supply chain management.