The impact of COVID-19 pandemic on supply chain performance: A case of an earth-moving equipment manufacturer

Submitted in fulfilment of the requirements of the degree of Master of Engineering in the Faculty of Engineering and the Built Environment at the Durban

University of Technology

Mfundo Mdletshe

December 2024

Supervisor: Prof M Dewa

Declaration

I hereby declare that this submission is my own and to the best of my knowledge, it neither contains material previously published nor written by another person, nor material that to a major extent has been accepted for the award of any other degree at Durban University of Technology or any other educational institution. I also declare that the intellectual content of this thesis is a product of my work. Any contribution made to the research by others, especially in the use of equipment for sample analysis, has been explicitly acknowledged in the dissertation.

Mfundo Mdletshe (Student Number – 21533812)

Signature Date: 03 December 2024

Supervisor: Prof M Dewa Signature:_____ ___

Dedication

I dedicate my thesis work to my family, for their endless patience and encouragement and to my partner whose understanding and love have been a constant source of strength. This work is dedicated to all of you who have made this journey possible.

Acknowledgments

I would like to thank my supervisor Prof Mendon Dewa for his guidance and support. This thesis would not have been completed without his unwavering support, guidance, and motivation.

Abstract

The COVID-19 pandemic impacted the supply chain performance of an earth-moving equipment manufacturer in KwaZulu-Natal, South Africa. The pandemic damaged the company's supply chain, causing material shortages and production problems which made it difficult to satisfy customer demand. This research aims to maximize the supply chain of an earth-moving equipment manufacturer in South Africa through the identification and addressing of supply chain blockages that were created by the COVID-19 pandemic. The study seeks to characterise the defining elements of supply chain, identify factors affecting performance, apply value stream mapping for efficiency, and develop a framework model for supply chain optimization. Ultimately, the study seeks to address gaps in comprehending the long-term effects of the pandemic on earth-moving equipment manufacturers' supply chains and propose strategies to build resilience against future disruption. Quantitative approach was used to analyse forecast data against actual deliveries to control productivity and delivery performance. Six Sigma, cause-and-effect diagrams, and time studies methods were used to identify inefficiencies. Supply change elements were characterised using Gemba walks and process flow mapping, which provided direct observations of operations and visualizing interconnected processes. Pareto analysis, cause-effect diagrams, value stream mapping, and time studies were used for identifying supply chain performance issues, improving supply chain efficiency, and recognizing waste and production blockages. Qualitative observations and quantitative measurements of production processes were used for data collection. The methodology provided a comprehensive insight into the supply chain problems and areas to apply targeted improvements to increase efficiency and customer satisfaction. Findings highlighted the importance of developing strategies including diversification among suppliers, workforce development, logistics optimization, adoption of digital technologies, and improvement in demand planning. The study also identified that adaptable production scheduling increased the company's capability to meet customer demands. The influencing factors on supply chain performance were found to be inventory management problems, supplier reliability, workforce issues, and technological adoption, requiring a collaborative approach for long-term supply chain resilience. The study concluded that a comprehensive approach to technological

adoption, workforce development, supplier collaboration, and flexible operations is fundamental for maximizing performance within the supply chain and building resilience against future disruptions.

Table of Contents

List of Tables

List of Figures

List of Acronyms

ADT	Articulated Dump Truck
BOM	Bill of Material
EOQ	Economic Order Quantity
FCR	Forecast Report
ICT	Information and Communication Technology
IoT	Internet of Things
LT	Lead Time
MO	Manufacture Order
MOS	Machine Ordering System
MPS	Master Production Schedule
MRP	Material Requirement Planning
MSS	Manual Scheduling System
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference
SRM	Supplier Relationship Management
TTR	Time to Recover
TTS	Time to Survive

CHAPTER 1 : BACKGROUND

1.1 Introduction

The navigation of supply chain disruptions and promotion of supply chain resilience from future pandemic-induced disruptions is critical for any organisation that is operating on a global scale (Bogiqi and Palmgren, 2024). The COVID-19 pandemic impacted the supply chain performance of many organisations globally causing material shortages and production problems which made it difficult for suppliers to satisfy customer demand (Sheffi, 2020). The earth-moving equipment manufacturing organisation is one of the important industrial pillar of South Africa's economy, contributing to agricultural, forestry, and construction machinery and creating 10 000 quality employment. The earth-moving equipment manufacturer distributes Articulated Dump Truck (ADT) only in Southern Africa and its clients value strength and reliability.

The COVID-19 pandemic has profoundly disrupted global supply chains, exposing vulnerabilities and challenges in industries worldwide (Williams, 2020). The unprecedented nature of the pandemic brought about supply chain shocks, such as demand fluctuations, production halts, and logistical bottlenecks. As governments implemented stringent lockdowns and travel restrictions, supply chain operations faced significant disruptions, from supplier delays to constrained transportation networks (Sheffi, 2020). These challenges not only hindered operational efficiency but also underscored the importance of resilience and adaptability in supply chain management. Covid-19 prevented the firm from meeting the customer's deadline and this study seeks to uncover production inefficiencies and propose methods to deliver ADT on time.

1.2 Research Problem

The effects of Covid-19 pandemic have caused huge disruptions on global supply chains. These disruptions were particularly acute in industries like earth-moving equipment manufacturing, which rely heavily on complex global supply chains for critical components and materials. In the earth-moving equipment manufacturing sector, supply chain performance is critical due to the industry's reliance on global suppliers for components and materials, as well as its role in supporting infrastructure and construction projects.

The pandemic exacerbated pre-existing challenges such as long supplier lead times and fluctuating raw material costs, while introducing new issues like workforce shortages and demand variability (Sheffi, 2020). These disruptions necessitated a reevaluation of supply chain strategies, including diversification, digitalization, and risk mitigation. Despite the significant impacts observed during the pandemic, there remains a lack of focused research on how supply chain performance was specifically affected in the earth-moving equipment industry. Previous studies have mostly focused on how Covid-19 affects the supply chain, but none have investigated how to lessen its effects on industrial businesses or make the problems it causes in the supply chain better.

Furthermore, much research has focused on general frameworks for supply chain resilience, yet, little attention has been given to tailored strategies for mitigating disruptions and enhancing operational efficiency within the earth-moving equipment manufacturing sector. If the earth-moving equipment manufacturer is not competitive, the demand for its products will decline, leading to reduced production, which might mean job losses and a smaller South African auto industry. Purwanto et al. (2023) highlighted that the car industry was in a very competitive market and that keeping costs down was critical in order to stay ahead of the competition. This study explores the impact of the Covid-19 pandemic on supply chain performance, focusing on a case study of an earth-moving equipment manufacturer. By examining the disruptions experienced and the strategies employed to navigate them, valuable insights will be provided into enhancing supply chain resilience and performance in the face of global crises in future.

1.3 Aim of the Study

The research aims to explore the impact of Covid-19 pandemic on supply chain performance of an earth-moving equipment manufacturer, and propose strategies to build resilience against future disruption. The focus of the study is to optimise supply chain by identifying bottlenecks and taking corrective and preventative measures to enhance earth-moving equipment manufacturer by integrating business environment transformation with business goals for sustainability and supply chain sustainability.

1.4 Objectives of the Study

The objectives of the study are as follows:

- To characterise the supply chain elements of an earth-moving equipment manufacturer;
- To identify the factors affecting supply chain performance of an earth-moving equipment manufacturer;
- To deploy value stream mapping to identify areas for improving supply chain efficiency;
- To develop a supply chain model to improve efficiency and satisfy customer demand.

1.5 Research questions

The following questions will be addressed by this study:

- What are the key processes in the supply chain of an earth-moving equipment manufacturer and how do internal and external stakeholders contribute to the supply chain operations?
- What variables, including internal and external factors impact supply chain performance?
- How can value stream mapping be used to identify bottlenecks and inefficiencies in the supply chain and what are the potential opportunities for enhancing efficiency based on the value stream map?
- What are the key performance metrics for evaluating supply chain efficiency and customer satisfaction and which strategies can be used to resilient supply chains and ensure adaptability and responsiveness to market demands?

1.6 Research Methodology

In this study, a quantitative research method is used, three methods were employed to characterise supply chains and these include Gemba walk, process flow analysis and identification of key performance indicators. KPIs for the earth-moving equipment manufacturer will be used to track progress towards long-term goals and comprehend supply chain performance. Supply chain performance was determined using pareto

analysis and cause-and-effect diagrams. Value stream mapping and time study analysis were utilized to identify areas for enhancing supply chain efficiency to meet consumer demand. For supply chain optimization, a business model was developed for the earth-moving equipment manufacturer to implement a comprehensive approach to technological adoption, workforce development, supplier collaboration, and flexible operations, which were fundamental for maximizing performance within the supply chain and building resilience against future disruptions.

1.7 Significance of the study

The research aims to promote ongoing improvement for Covid-19-affected automobile manufacturers. The research provides insights on the challenges that global disruptions, such as the COVID-19 pandemic, pose to supply chains in the earth-moving equipment industry. By focusing on insights into critical vulnerabilities, such as supplier delays, logistics bottlenecks, and workforce shortages, which are particularly relevant to industries reliant on complex and global supply chains, this study will provide valuable information for manufacturing companies failing to exceed consumer expectations because of the after effects of the Covid-19 epidemic.

The study aligns with global needs for sustainable and resilient supply chains, as it considers not only operational efficiency but also broader challenges like global logistics and supplier diversification. The research provides a valuable lesson learned from the pandemic, applicable across industries, particularly in adapting to future global crises, whether pandemics, natural disasters, or geopolitical conflicts. The study provides actionable insights for improving resilience and adaptability by identifying how the pandemic affected supply chain performance. These findings will be valuable not only for the case study organisation but also for similar manufacturers aiming to mitigate risks in future crises.

1.8 Scope and limitations of the study

The study examines supply chain dynamics within the operational regions of the earth-moving equipment manufacturer that distributes ADTs in Southern Africa. The study focuses on the supply chain of earth-moving equipment manufacturer which is characterized by complex global supply chains and relies on critical components. The

timeframe analysis is centred on the post - Covid-19 pandemic to find ways to fix supply chain problems and enhance efficiency.

However, the study also had some limitations since the findings are based on a single earth-moving equipment manufacturer, which may limit the generalisability of the research findings to other industries or organisations. Due to time and resource constraints, it was not feasible to conduct a comparative analysis across dissimilar manufacturers or supply chains. In addition, while the study focuses on the impact of the Covid-19 pandemic, it does not account for long-term trends or other supply chains disruptions. There was limited exploration of downstream customer-related disruptions since the research mainly focused on operational supply chain challenges of the earth-moving equipment manufacturer. The analysis of digitalization and technology-driven resilience measures is limited to the specific tools and strategies employed by the case study company.

1.9 Structure of the dissertation

The research will be presented as follows to help readers navigate the dissertation.

Chapter 1: Introduction

In this chapter, the study plan is shown. It includes the study's background, research problem, goal, research objectives, research scope and limitations, importance of the study, and dissertation structure.

Chapter 2: Literature Review

This chapter presents a theoretical foundation for continuous improvement tools and methods.

Chapter 3: Research Methods

This chapter explains the techniques used, including how the data was collected, how root cause analyses are done, six sigma, value stream mapping, and how the data was used to look at the factors that affect a manufacturer's ability to meet customer expectations.

Chapter 4: Results and Discussion

This chapter discusses research outcomes, methods, and ethics.

Chapter 5: Conclusion and Recommendations

The study's results lead to these conclusions and suggestions, which are laid out in this chapter. It also summarizes the earlier parts.

1.10 Conclusion

This chapter focused on the introduction of the research aim, objectives, research questions, significance of the study, scope, limits, and dissertation format. It was highlighted that the effects of Covid-19 pandemic caused huge disruptions on global supply chains which rely heavily on critical components and materials. The study will provide actionable insights for improving resilience and adaptability by identifying how the pandemic affected supply chain performance. The next chapter will focus on a comprehensive literature review on issues relating to the impact of Covid-19 pandemic on supply chain performance.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

This chapter focuses on the previous research that has been done on the theory and study of the basic supply chain principles that are used by organisations. The chapter commences with a literature on the concept of supply chain management followed by the Supply Chain Operation Reference. The literature review also focuses on key performance indicators for supply chains, factors affecting supply chain performance as well as models for supply chain optimization.

2.2 The Concept of Supply Chain Management

Supply chain management (SCM) is concerned with planning and managing the flow of information and goods within a company and coordinating between businesses outside the organisation (Cox 1997). Vorijhoef and Koskela (2000) highlighted that Toyota Motors' supply plans gave rise to the idea of SCM where controlling and synchronizing goods was seen to cut down on inventory as much as possible while also making it easier to control how suppliers interacted with the organisation’s production line. Supply chain management is closely linked to lean output and it embraces extra tools like managing transportation and Just-in-Time (JIT) shipping (McCaffer and Root, 2000). According to Croom, Romano, and Giannakis (2000), however, management of the supply chain has not been mainly and formally known, prompting for more research on clear definitions and theory models for SCM.

Lambert and Cooper (2000) posited that SCM is the integration and coordination of vital business processes, from the end user to the first supplier that provides the goods, services, and data that customers and other stakeholders would value. The equipment manufacturing sector has responded by diversifying suppliers, investing in digital technologies to enhance supply chain visibility, and adopting strategies to enhance resilience against future disruptions (Odulaja et al., 2023). The is due to the Covid-19 pandemic that had exposed vulnerabilities in global supply chains where organisations were dependent on single-source suppliers and were chararcterised by inadequate risk mitigation frameworks. With the rise of electric vehicles (EVs), the automotive industry in particular, has undergone significant changes in its supply chain dynamics (Patel et al.,

2022). The integration of sustainable practices, greater flexibility in supplier relationships, and the adaptation of traditional supply chains to include more environmentally friendly materials were necessitated by the shift from internal combustion engines to EVs has required.

Supply chain management has also been revolutionised by the adoption of technologies like Internet of Things (IoT), artificial intelligence and blockchain in the automotive industries, where these technologies are deployed to forecast demand, optimise production schedules, and enhance supply chain visibility in logistics operations (Khan et al., 2022). Such advancements are crucial for meeting customer expectations for faster delivery and personalized products.

2.3 Supply Chain Operation Reference

The supply chain operations reference (SCOR) model addresses, improves, and communicates supply chain management options to suppliers and consumers. This model explains the operational methods needed to satisfy clients and provides a foundation for improvement (Hasibuan et al., 2018). The SCOR model uses benchmarking, measurement, and process re-engineering for planning, sourcing, manufacturing, delivering, and returning in the supply chain (Haun et al., 2004). The SCOR model is a cross-functional framework that integrates business process re-engineering, benchmarking, and process measurement through:

- Explicit managerial processes;
- A foundation for conventional process linkages;
- Standardised process effectiveness metrics;
- Top-performing management methods;
- Standardised software functionality alignment.

SCOR's simple business architecture allows users to easily design and simulate supply networks, and after supply chain modelling, the reference model delivers best practices and KPIs for fast supply chain analysis and optimization (Hasibuan et al., 2018). High-level building blocks are detailed to understand company interdependencies and information and commodities flow. Supply chain management involves modelling the

essential components of the supply chain rather than every detail. As shown in Table 2.1, several key KPIs assess high-level activities including planning, source, produce, and deliver to manage the supply chain (Sengupta, Heiser, and Cook 2006).

Table 2.1: SCOR Process

SCOR Process	Description
Plan	Coordination of supply chain resources in the supply chain system to meet maximum demand, which involves establishing the requirements and actions that must be taken to accomplish the intended result.
Source	ordering, shipping, receiving, and transferring raw materials in order to carry out the task of producing goods and services
Make	Processes that add value to the organization, including scheduling and production, to produce a finished good with a high level of added value
Deliver	Process for managing orders and fulfilling them in shipping and distributing them to final customers
Return	Process for managing consumer returns of defective products from customers to the product's supplier or to carry out maintenance tasks
Enable	Process that supports the governance of supply chain planning and execution by facilitating the management of business rules, performance, and regulations to fulfill the demands of the corporation through interactions with other departments such as finances, facility, and legal

Source: (Sengupta, Heiser, and Cook 2006)

2.4 Key Performance Indicators for Supply Chains

Key Performance Indicators (KPIs) are critical factors that are used to check how well processes in the supply chain are running. They provide direction to many different supply chain management issues, which helps companies keep track of their success, find areas that need work, and make informed decisions. Some basic key success markers for the production supply chain are shown below:

2.4.1 On Time delivery

On-time delivery determines the percentage of on-time or early-order deliveries and reflects supply chain reliability (Acar et al. 2010). Global supply networks are susceptible to disturbances that lower efficiency, while supply chain failures usually damage the chain's ability to deliver products and services on time. Businesses in varied supply chains must learn to be resilient to interruptions and failure modes to deliver products on time

and remain competitive. Carvalho et al. (2022) conducted at study on the resilience of on-time delivery to capacity and material shortage, theorising the relationships between supply chain disturbances, failure modes, resilience practices, and on-time delivery as the primary indicator of supply chain performance, using case study data analysis and literature. The data demonstrate great on-time delivery resistance to the failure types, mainly because costly car production halts (Carvalho *et al.* 2022).

2.4.2 Supplier Lead Time

Supplier lead time plays a crucial role in supply chain agility and resilience, short and predictable lead times enhance supply chain agility, enabling firms to respond quickly to demand fluctuations and disruptions (Chang and Lin, 2019). On the other hand, long or uncertain lead times reduce responsiveness and can propagate disruptions through the supply chain, necessitating more robust planning and resilience strategies (Aslam et al. 2020). Mishra et al. (2024) concurred on this notion and highlighted that longer lead times negatively affect the supply chain's ability to succeed while shorter lead times are better for increasing customer value and making the supply chain more reliable. Uncertain or prolonged lead times can lead to higher inventory costs as businesses stockpile safety inventory to prevent stockouts. It also disrupts service levels, potentially impacting customer satisfaction and overall supply chain performance. Strategies such as optimised ordering policies and supplier collaboration are recommended to mitigate these effects.

Supplier lead time directly affects inventory management and service levels, and integrating the supply chain leads to improved supply chain performance. It is also imperative that organisations should improve their skills by sharing information and being able to adapt in order to achieve supply chain integration and agile practices such as reactivity and readiness (Alzoubi *et al.* 2022).

2.5 Kaizen in Supply Chains

Miranda *et al.* (2020) conducted a detailed examination of Kaizen costs and it was revealed that the Kaizen concept originated in Japan, where continuous improvement underpinned all company activities. Kaizen was formed by combining the Japanese letters "kai" and "zen," which mean improvement and transformation. According to the Kaizen Institute, five principles must be met to ensure kaizen project success, including:

- Know your customer
- Be honest
- Give people power
- Let it Flow
- Go to ZEN

Miranda et al. (2020) described Kaizen as a process by which employees constantly reevaluated their approaches to find a better way to perform jobs. It fostered intelligent and shared work team ideas and action to develop. Kaizen focusses on optimizing manufacturing processes, decreasing costs, boosting productivity, and enhancing service and customer satisfaction, according to studies (Glover et al., 2014).

2.6 Value Stream Mapping of Supply Chain Processes

As a lean management tool, value stream mapping (VSM) is designed to analyse and optimise processes by visually mapping the flow of information, materials and resources. In the context of supply chains, VSM provides a holistic view of interconnected processes, helping organisations identify bottlenecks and improve overall performance, and research highlighted the capability of VSM to identify waste, reduce lead times, and improve overall process efficiency (García et al. 2018).

In supply chain management, the main goals of value stream mapping are:

1. Identifying Waste: Wastes including overproduction, excess inventory, superfluous transportation, waiting times, faults, and underutilised resources may be identified using VSM.
2. Improving Lead Times: To minimise lead times and boost responsiveness, organisations should identify bottlenecks and optimise material and information flow.
3. Enhancing Quality: Value Stream Mapping helps businesses find possible flaws and quality problems, which leads to focused quality changes in both products and processes.
4. Reducing Costs: By removing waste and optimising processes, companies may save costs and boost efficiency.

5. Visualising present and future value streams helps organisations improve efficiency, customer happiness, and competitiveness. As VSM becomes part of the continuous improvement culture, organisations can use its transformational ability to survive in an ever-changing market and ensure that each supply chain phase provides value and helps them succeed.
6. VSM drives continuous development and helps companies compete in today's changing business climate.
7. VSM is a great tool for optimising processes and improving customer satisfaction. VSM as a key part of SCM helps organisations make data-driven choices, adapt to market changes, and compete globally.
8. Gemba Walks are essential for vertical integration in lean manufacturing. They keep "the Gemba," where value is produced, in touch with all levels of the organisation (Romero *et al.* 2020).

Despite its benefits, implementing VSM in supply chain processes is characterised by challenges such as complexity of supply chains due to the interconnected nature of global supply chains often complicates the mapping process (Anastasiadis et al. 2024). The adoption of lean practices like VSM may encounter resistance from employees and stakeholders unfamiliar with its methodology. Data availability also poses a challenge since many organisations struggle with obtaining accurate and real-time data collection and integration. Additionally, recent advancements have expanded VSM’s potential by integrating it with digital tools. These integrations enhance VSM’s capability to analyse complex, dynamic supply chain systems, making it more adaptable to modern industry needs (García et al. 2018).

2.7 Factors Affecting Supply Chain Performance

Several internal and external factors can affect how well a supply chain works. The factors include predicting demand, logistics and delivery, quality management, globalization, the state of the market, and wait time.

2.7.1 Demand Forecasting

Proper demand forecasting is necessary to match production, inventory, and distribution to consumer demand. Forecast errors may cause overstock or stockouts, reducing supply chain efficiency. Businesses must plan sales and inventories along the supply chain to save costs and increase efficiency. Thus, demand forecasting technologies help planners more. Software companies and its many implementers argue better demand forecasting leads to leaner inventory management (Gattinoni, 2022).

2.7.2 Logistic and Transportation

Timely delivery and cost-effective distribution need efficient transportation and logistics networks that avoid transportation delays, interruptions, and inefficiencies which negatively affect supply chains (Karia and Asaari, 2016). A hub-and-spoke network may reduce delivery costs and interruption by employing economies of scale and route flexibility. As highlighted by Esmizadeh and Mellat Parast (2021), a cross-docking network reduces inventory expenses, while a pick-up and delivery network speeds delivery, hence recommending hybrid logistics for organisations that require cost and durability. Logistics systems are usually designed to save costs and it is critical that an organisation must understand the trade-offs between logistics system goals including cost and service quality (Esmizadeh and Mellat Parast, 2021).

2.7.3 Quality Management

Masoudipour et al. (2017) posited that it is crucial for organisations to make sure that the quality of the goods at all points in the supply chain is excellent, in order to keep customers happy and protect the brand's image. When quality is low, it can cost more, take longer, and require more work (Esmizadeh and Mellat Parast, 2021). The managers of organisations need to come up with price strategies that work for both buyers and sellers. This means lowering the costs of buying from manufacturers, fixing them, and remaking them, while also raising the prices that customers, producers, and recyclers pay for them (Masoudipour, Amirian, and Sahraeian, 2017).

2.7.4 Globalization and Market Condition

Global economic factors, trade policies, and market dynamics affect supply chain tactics. Companies must adapt to global developments to be competitive (Gunasekaran at al., 2017). The global business market is dynamic and competitive. Globalisation, internet access, and technical advances have changed consumer behaviour and given enterprises foreign product marketing options and challenges. For their goods to compete internationally in this market, firms require powerful marketing strategy. However, owing to fierce competition and complex market dynamics, firms require an efficient marketing strategy (Sudirjo, 2023).

2.8 The Impact of Covid-19 Pandemic

Manufacturing enterprises strived to be competitive in a worldwide market due to material shortages caused by the Covid-19 pandemic as governments instituted lockdowns, delayed international travel, and curtailed exports and imports (Sidor and Rzymski 2020). The Covid-19 pandemic led to huge disruptions across supply chains globally, particularly in inventory management, production, and transportation, yielding lack of raw materials, reduced labor availability, and logistical challenges resulting in delays and increased costs (Sheffi, 2020). In order to mitigate such disruptions, resilience strategies such as building buffer stocks, diversifying suppliers, and leveraging digital technologies have been explored to balance efficiency with robustness to future shocks (Aslam et al. 2020).

Automotive and manufacturing sectors faced shortages of critical components due to factory shutdowns and trade restrictions and the pandemic highlighted these vulnerabilities in global supply chains, particularly for industries reliant on JIT inventory practices (Odulaja et al., 2023). There is also mounting recognition of the need of a paradigm shift toward more flexible and resilient supply chain models. The disruption of shipping raw materials from several nations changed consumer behaviours. Additionally, according to Sidor and Rzymski (2020), supply chain disruption caused various problems as highlighted:

- **Delays in delivery:** More than two-thirds of people who answered a poll in the tech business indicated that they were told to expect delays. The most common delay given was three weeks, but 15% of those who answered have been given

delays of six weeks or more. Manufacturers expected real delays of five weeks, which was two weeks longer than what they are being told.

- **Rising expenses** - Manufacturers wanted to maintain output levels as they anticipated a return to normal operations and increased demand. Manufacturers have had to find new suppliers to keep manufacturing going during supply chain disruptions. These suppliers were expensive therefore some producers must pass them on to buyers.
- **Doubt:** One of the few things that did not change in the industrial business in the more than two years since Covid-19 pandemic has passed is doubt. The most successful manufacturers have been able to change direction and stay flexible by responding to new business situations. This shows how important data, trends, and the ability to adapt are critical in supply chain management.
- **Decreased demand** - Travel businesses, including airlines and cruise lines, have seen large variations due to Covid-19 cases. Other industries have also faced demand cutbacks. These include lower demand for import-export facilities and commodities, energy, petrochemical activities, and more.

2.9 Supply Chain Efficiency

The study's third goal was to improve supply chain efficiency to meet consumer demand. Wong and Wong (2007) defined supply chain efficiency as a set of performance criteria for supply chain participants and their coordination and integration. Supply chain efficiency is achieved by increasing customer satisfaction while balancing cost, speed, and reliability. Efficiency depends on cost, quality, and time, where cost efficiency assesses supply chain efficiency in terms of order processing and inventory management expenses. Quality metrics assess product quality across the supply chain and this helps managers spot future issues, while time affects delivery accuracy and customer happiness. The integration of Information and Communication Technology (ICT) into supply chain management has significantly improved efficiency due to ability to streamline operations, enhance visibility, and reduce cycle times.

Smart manufacturing technologies, including IoT sensors and advanced robotics also enable real-time monitoring and decision-making, addressing bottlenecks and improving

overall efficiency (Zaidi et al., 2024). The emphasis of recent studies is striking a balance supply chain resilience and efficiency, principally in the face of global disruptions such as Covid-19. Resilience is characterised by building redundancy and flexibility while efficiency focuses on minimizing costs and optimizing processes, hence innovative approaches such as multi-sourcing strategies and scenario-based planning would aid to achieve both (Aslam et al. 2020).

2.10 Models and Strategies for Supply Chain Optimization

Different mathematical models and optimisation methods are used to make supply chain processes more effective and efficient. Companies can use these models to make better choices about transportation, production schedules, inventory management, and delivery. The following methods are common ways to improve the supply chains.

2.10.1 Inventory Models

Reorder point and Economic Order Quantity (EOQ) models optimise inventory levels, decrease holding costs, and guarantee timely order fulfilment (Odulaja et al., 2023). Many companies succeed by delivering products and services at the correct price, quantity, and location. ABC Analysis errors in forecasting and planning cause inventory control issues. Thus, precise inventory categorization is needed to use the EOQ model to efficiently control holding and ordering costs. The EOQ model may help any manufacturing organisation to estimate the right amounts of materials to purchase and when to order each item (Kehinde et al., 2020).

2.10.2 Demand Forecasting Models

Effective supply chain planning requires accurate demand estimates and several demand forecasting techniques such as Time Series Analysis, Exponential Smoothing, and Machine Learning models like Random Forests and Neural Networks can be used to anticipate future demand and supply side readiness required to satisfy demand. An organisation's supply chain is affected by inaccurate forecasting and data-driven statistical methods can be used to reduce errors and outliers and impute missing numbers (Adhikari *et al.* 2019).

2.10.3 Lean and Six Sigma Principles

Although Lean and Six Sigma are not standard mathematical models, they are useful tools for improving the supply chain through waste elimination to allow processes in the supply chain to become more efficient. Lean Six Sigma has been used more and more in the business sector over the last ten years and the idea behind lean is to get rid of all waste in the value stream process (Gultom and Wibisono, 2019). Six Sigma attempts to get rid of defects and both lean and six sigma have a positive effect on the performance. The benefits of Lean and Six Sigma in supply chains include enhanced customer satisfaction, improved efficiency, data-driven decisions as well as alignment with environmental sustainability goals. It is imperative to note that organisations can develop resilient, agile, and efficient supply chains that are prepared to handle volatile market conditions by integrating Lean and Six Sigma principles (Ahmed and Huma, 2021).

2.10.4 Resilient Supply Chain Framework

A robust supply chain structure can aid manufacturers to solve challenges and maintain operations since it promotes flexibility, backups, and proactive risk management (Ivanov and Dolgui, 2020). Supply chains may be stronger by being more flexible in sourcing, making, and moving items and businesses should promptly adjust to supply-and-demand shifts. Pettit et al. (2013) suggest robust supply networks to aid the manufacturer tackle pandemic-related supply chain issues, reducing wait times and accelerating delivery. Sheffi and Rice (2005) argue robust supply networks are flexible and have backups. Thus, a robust supply chain structure is essential to keep things operating smoothly even when issues arise (Ahmed and Huma, 2021).

2.10.5 Digital Transformation

The radical shift of going digital was found to be essential for improving the supply chain business plan. IoT, AI, and blockchain helped the organisations to improve their supply chains and make better decisions (Wamba et al., 2018; Queiroz, 2020). Digital tools can be used to keep an eye on resources and goods in real time, predict the demand through predictive analytics, and make sure that blockchain transactions were safe. These changes made the supply chain more reliable and efficient, which cut down on problems and enhance performance. Ivanov et al. (2019) posited that for the supply chain to be

strong and fluid, it needs to go digital and the results of the study demostrated that digitalisation is essential for business plans that aim to improve the efficiency of the supply chain.

2.10.6 Agile Supply Chain Strategies

The study found that producers were better able to respond to changes in supply and demand when they used flexible supply chain methods. Speed, flexibility, and adaptability are all pushed by agile supply chain management. Research on supply chain mobility shows that it improves performance (Christopher, 2016; Lee, 2004).

In our study, agile supply chain solutions cut down on lead times, sped up order cycles, and made it easier for people in the supply chain to talk to each other and work together. These strategies help the company respond quickly to changes in customer demand and supply, which enhances the performance of the supply chain. Swafford et al. (2006) say that to deal with threats and delays in the supply chain, businesses should change. The study posited that changing and uncertain situations call for flexible supply chain methods to improve results.

2.10.7 Sustainability in Supply Chain

A key aspect of sustainable supply chain approaches is keeping the company open, safeguarding the environment, and promoting good behaviour. After incorporating sustainability to its supply chain business strategy, an organisation can become more resilient and profitable (Anastasiadis et al. 2024). This is in support of the research on sustainable supply chain management (Seuring and Müller, 2008; Carter and Rogers, 2008), which shows how crucial long-term sustainability is. Sustainable supply chain strategies are crucial for long-term success and resilience.

2.11 Literature Gap

The problem of Covid-19 pandemic disrupted global supply chains, and earth-moving equipment manufacturers were also affected. While there is literature on pandemic's direct effects, it is also imperative to comprehend how it affected the long-term and complex performance of the supply chains for manufacturers of earth-moving equipment. A lot of research has been done on the first problems the pandemic brought, such as

problems with the supply chain, changes in demand, and problems with the workforce. However, less research has focused on investigating the long-term effects, and strategy changes that makers of earth-moving equipment made to make their supply chains more resilient and improve performance after the pandemic. Less attention has been paid into the long-term problems and contingent measures that are unique to making earth-moving equipment. There is little information about how companies in this field have changed their supply chain methods, tools, and partnerships with suppliers and wholesalers to make their businesses more resilient and effective over the long term.

2.12 Conclusion

The literature review in the second chapter focused on the impact of Covid-19 pandemic on supply chains and key aspects of supply chain management. The Covid-19 pandemic has significantly disrupted supply chains across various industries, including the earth-moving equipment manufacturing sector. The reviewed literature highlights how the pandemic exposed vulnerabilities in global supply chains, particularly in areas such as supplier reliability, transportation networks, and demand forecasting. Studies indicate that these challenges were exacerbated by widespread lockdowns, labor shortages, and fluctuating market demands, which collectively hindered supply chain performance. Additionally, the literature emphasizes the importance of adopting resilience-building strategies, such as supplier diversification, digital transformation, and inventory optimization, to mitigate the adverse effects of such disruptions. Key lessons from the pandemic also point to the critical role of collaboration, transparency, and real-time data analytics in maintaining supply chain continuity. While existing research provides valuable insights, gaps remain concerning the long-term implications of the pandemic on supply chain structures, especially in niche industries like earth-moving equipment manufacturing. This dissertation seeks to bridge these gaps by examining the specific impacts of Covid-19 on the supply chain performance of an earth-moving equipment manufacturer, contributing to the broader understanding of resilience and adaptability in supply chain management during crises.

.

CHAPTER 3 : RESEARCH METHODS

3.1 Introduction

The preceding chapter reviewed literature on the concepts of supply chain management and highlighted how the pandemic has exposed vulnerabilities in global supply chains. This chapter focuses on the research methods that were used to characterise supply chains, identify the factors affecting supply chain performance, deploy value stream mapping and to develop a supply chain model to improve efficiency and satisfy customer demand.

3.2 Research framework

A framework for data collecting and interpretation is essential in every research investigation.

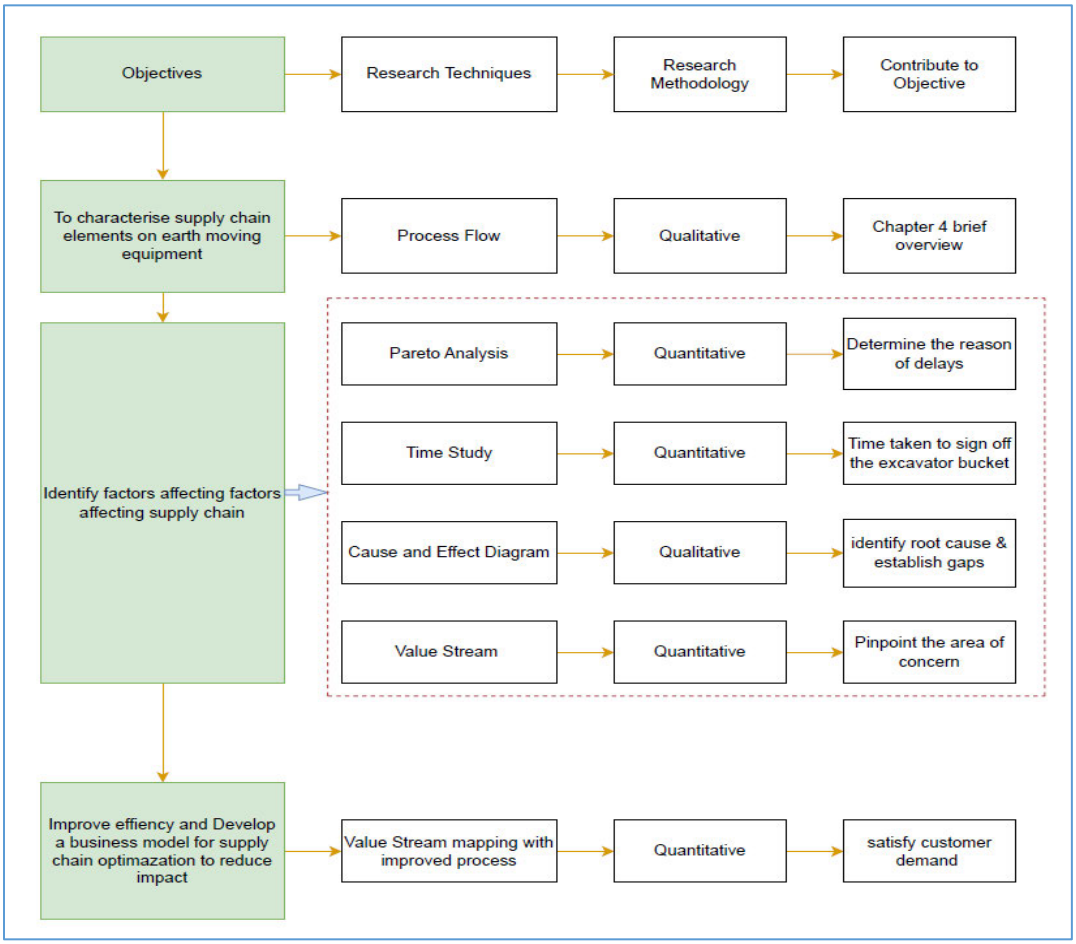

Figure 3.1: Research framework schematic

Figure 3.1 shows the research framework and how the objectives and methods relate. The conceptual framework also shows how quantitative and qualitative research methods were used to fulfil research objectives.

3.3 Methods for Charactering Supply Chain Elements

Three methods were employed to characterise supply chains and these include Gemba walk, process flow analysis and identification of key performance indicators.

3.3.1 Gemba walk

Mičieta (2021) posited that the Gemba walk, a Japanese idea of continuous improvement, is a simple qualitative assessment tool that uses "visual management" to find the root causes of the perceived gap between the desired and actual states. Gemba walks were first used to comprehend the manufacturing operations by physically going to the production floor, watching the work, and discussing with the front-line workers to gain understanding of the operations.

3.3.2 Process Flow Analysis

Aguilar (2024) defines a process flow as the combination of various internal business procedures within a framework, describing their interdependence and logical order to achieve a certain goal. Process flow modelling enables business process analysis and information sharing; thus, process flows must be clearly described. Shaker (2024) states that process flow modelling tools would aid to improve manufacturing procedures by helping business analysts and modellers discover the appropriate ways for their requirements and situations. Thus, manufacturers and enterprises may enhance revenue by optimizing process time, cost, and performance.

3.3.3 Identification of Key Performance Indicators

KPIs are numbers that businesses use to track their progress towards long-term goals and comprehend their performance. There is a clear link between organisational character and success, and while each organisation is different and has its own and goals to achieve, KPIs need to be tailored to each of these goals. Key performance indicators for this study were identified for the sales and operation department, procurement department, and the production department.

3.4 Methods for identifying factors affecting supply chain performance

The second objective of the study was to identify the factors affecting supply chain performance of an earth-moving equipment manufacturer. Arunkumar and Gnanaprakasam (2017) highlighted that the Fishbone diagram and Ishikawa diagram are other names for the cause and effects diagram. Because it looks like a fishbone, this figure is often called the "fishbone diagram." Widayanti (2020) posited that the purpose of a cause and affect map is to show the factors that lead to a problem and figure out which ones have the biggest impact on the main problem. Fishbone maps were used to find and list the different reasons why the supply chain was not performing adequately.

3.5 Methods for Improve supply chain efficiency to satisfy customer demand

Value stream mapping and process cycle time analysis were utilized to identify areas for enhancing supply chain efficiency to meet consumer demand. Sharma (2020) posited that value stream mapping is a visible way to find ways to get rid of waste. In the supply chain, the value stream shows all the steps, actions, and information flows that add value to a good or service as it goes through the system. From getting the base materials to the user at the end, the whole value stream was mapped out so that the flow of materials, information, and money could be understood. Businesses can use VSM to organize their learning about, analyzing, and improving their supply chain processes. Businesses can become more efficient, cut costs, and make customers happier by finding waste, streamlining processes, and always getting better. Process cycle time analysis was conducted for all chassis manufacturing operations to determine standard time from loading, clamping, fitting, and unloading.

3.6 Limitation of the study

The study was done in KwaZulu-Natal, South Africa. The research focused only on earth-moving equipment manufacturers. Financial constraints, time constraints, and the inability of a single researcher to review and obtain conclusive results will prevent the study from including other South African provinces.

3.7 Conclusion

The aim of this chapter was to outline how research framework, objectives and methods relate. It was also noted that the implementation of continuous improvement principles was critical to improve the supply chain processes and decisions. The chapter also pinpoints the methods used for characterizing supply chain methods which are used to collect data, identify factors affecting supply chain, analyses the methods of improving supply chain efficiency and limitation of the study. In the next chapter, the supply chain process for the earth-moving company is detailed.

CHAPTER 4: SUPPLY CHAIN PROCESSES FOR EARTH-MOVING EQUIPMENT MANUFACTURER

4.1 Introduction

The first objective of the study was to characterise the supply chain elements of an earth-moving equipment manufacturer. This chapter focuses on addressing this objective for the earth-moving equipment manufacturer which is characterised by four supply chain processes: sales and operation, procurement, production, and dispatch. This chapter describes the five operation lines and their processes for the earth-moving equipment manufacturer, which uses supply chain processes to cut plates, machine, fabricate, paint, assemble, and inspect.

4.2 Sales and Operation Department

Planning for sales and operations (S&OP) is a business process that involves operations, product creation, marketing, finance, and the supply chain. Figure 4.1 shows a schematic for Sales and Operation Planning. The main goal of the S&OP method is to make sure that supply and demand are equal over the medium to long run. Demand planning, sales forecasting, and production planning are all part of the Sales and Operations group.

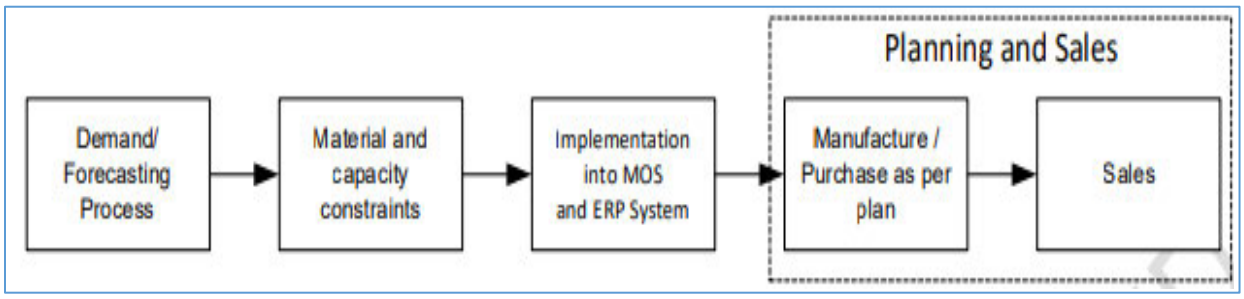

Figure 4.1: Sales and Operation Planning

The master planner in the sales and operation department is very important because they get unit requirements for new machines from different companies and third-party buyers and make it easier to process them. The need is put together in a Forecast Report (FCR) and put into action in a production plan known as Manual Scheduling System (MSS). Planners use the MSS plan to let the Manufacture Order (MO) go into the MRP system.

The demand manager puts the order on Machine Ordering System (MOS) and advised the customer when to expect it.

Table 4.1 shows the KPIs for Sales and Operation Department. The results demonstrate that there is room for improvement on all the KPIs which include demand forecast accuracy, inventory turnover, perfect order rate, on-time delivery, stockouts rate and order fulfilment cycle time.

Table 4.1: Key Performance Indicators for Sales and Operation Department

KPI	Description	Current status	Benchmark value
Demand Forecast Accuracy	Measures how accurately the department predicts demand compared to actual sales: [(Actual Demand - Forecast Demand) / Actual Demand] x 100	70%	85%
Inventory Turnover	Indicates how quickly inventory is sold and replaced over a period: Cost of Goods Sold / Average Inventory	2 times per year	4 times per year
Perfect Order Rate	Reflects the percentage of orders delivered on time, in full, and without errors: (Total Perfect Orders / Total Orders) x 100	45%	90%
On-Time Delivery (OTD)	Tracks the percentage of orders delivered on or before the promised date. (On-Time Orders / Total Orders) x 100	48%	90%
Stockouts Rate	Measures how often the inventory falls short of demand. (Total Stockouts / Total Demand) x 100	60%	10%
Order Fulfilment Cycle Time	Measures the time taken from receiving an order to delivering it to the customer.	30 days	5-15 days

4.3 Procurement Department

The procurement department buys supplies, equipment, and goods for the earth-moving equipment manufacturer. A buyer in the procurement department buys supplies, processes purchase orders, and helps end customers. The buyer also assists the procurement department in procuring goods at the best pricing.

Purchasing applications are used by procurement departments to place orders. The buying (PUR) software boosts procurement efficiency. This software also helps buyers engage with suppliers by checking that orders were placed, processed, and billed as agreed. Purchase orders, modifications, and quote requests may be printed and mailed or delivered electronically. Electronic data exchange can process invoices.

Buyer in procurement responds to MRP release notice and orders production materials from suppliers. Master Scheduling incorporated a factory construction plan to the material requirements plan (MRP), which requires purchase orders from local and foreign suppliers. Suppliers are sent the purchase order and asked to confirm. Purchase orders are placed using the mechanism shown below.

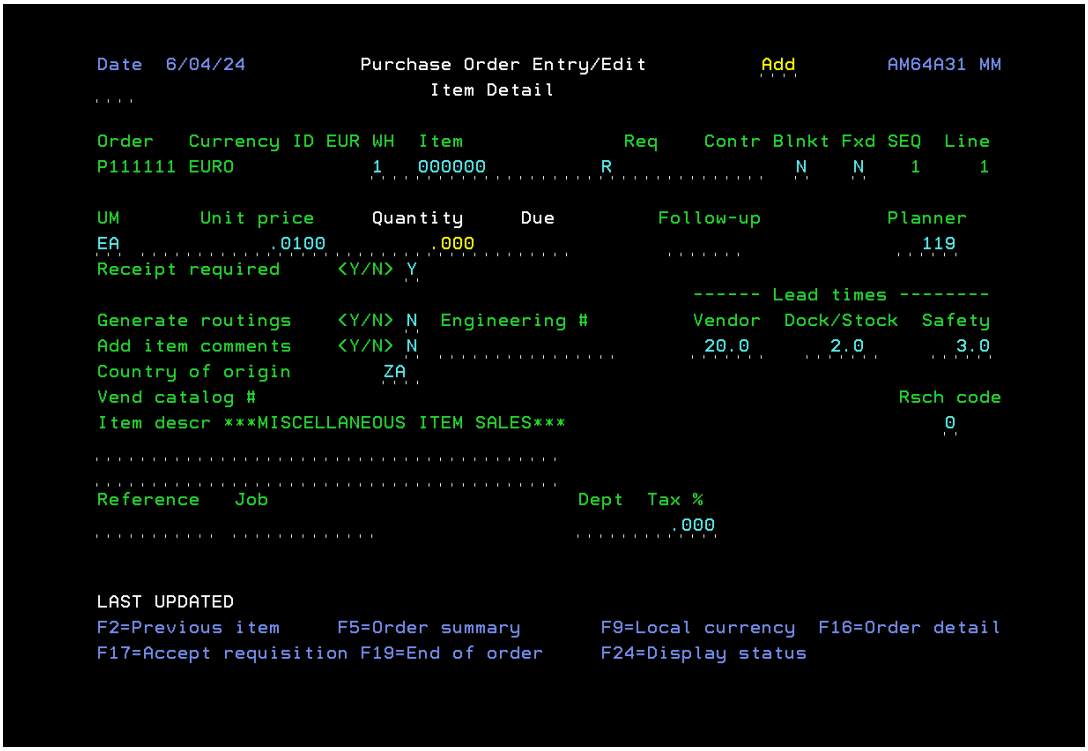

Figure 4.2: Purchasing system

The KPIs for this department include supplier lead time, purchase order accuracy rate, and supplier on-time delivery. Supplier lead time measures the average time suppliers take to deliver ordered materials, which is critical to maintaining an uninterrupted production process (Monczka et al., 2015). A shorter lead time indicates greater supply chain responsiveness. Purchase order accuracy rate assesses the percentage of purchase orders processed without errors, indicating the efficiency and precision of the

procurement process (Handfield & Nichols, 2020). High accuracy reduces the risk of delays caused by incorrect orders. Supplier on-time delivery measures the percentage of deliveries received on or before the agreed-upon date, ensuring production schedules are met and customer commitments are honoured (Cousins et al., 2019). Below is the table showing the KPIs.

Table 4.2: Key Performance Indicators for Procurement Department

KPI	Description	Current status	Benchmark value
Supplier Lead Time	The average time taken by suppliers to deliver goods after an order is placed.	60 days	7-21 days
Purchase Order Cycle Time	The time taken from when a purchase order is created to when it is fulfilled and received.	50 days	5- 10 days
Order Accuracy Rate	The percentage of orders that are fulfilled accurately without errors in terms of quantity, quality, and specifications.	60%	97%
Supplier Performance	The percentage of orders delivered on time by suppliers.	48%	95%
Supplier Defect Rate	The percentage of goods delivered by suppliers that do not meet the required quality standards.	2%	1-3%

The results from Table 4.2 reveal that the supplier lead time of 60 days for the earth-moving equipment manufacturer is below the benchmark value of 7 to 21 days. The purchase order cycle time, order accuracy rate, supplier performance as well as the supplier defect rate can also be improved.

4.4 Production Department

The production department is that part of the supply chain which oversees the fabrication, machining, welding, and assembly of earth-moving equipment components such as chassis, engines, and hydraulic systems. It uses people, machines, and outside influences to turn raw materials into finished products. It also ensures adherence to

production schedules to meet customer demands on time. Parts of the production process include machining, creating, painting, putting the parts together, and inspecting them. Figure 4.3 displays the subtask method in manufacturing from one area to the next.

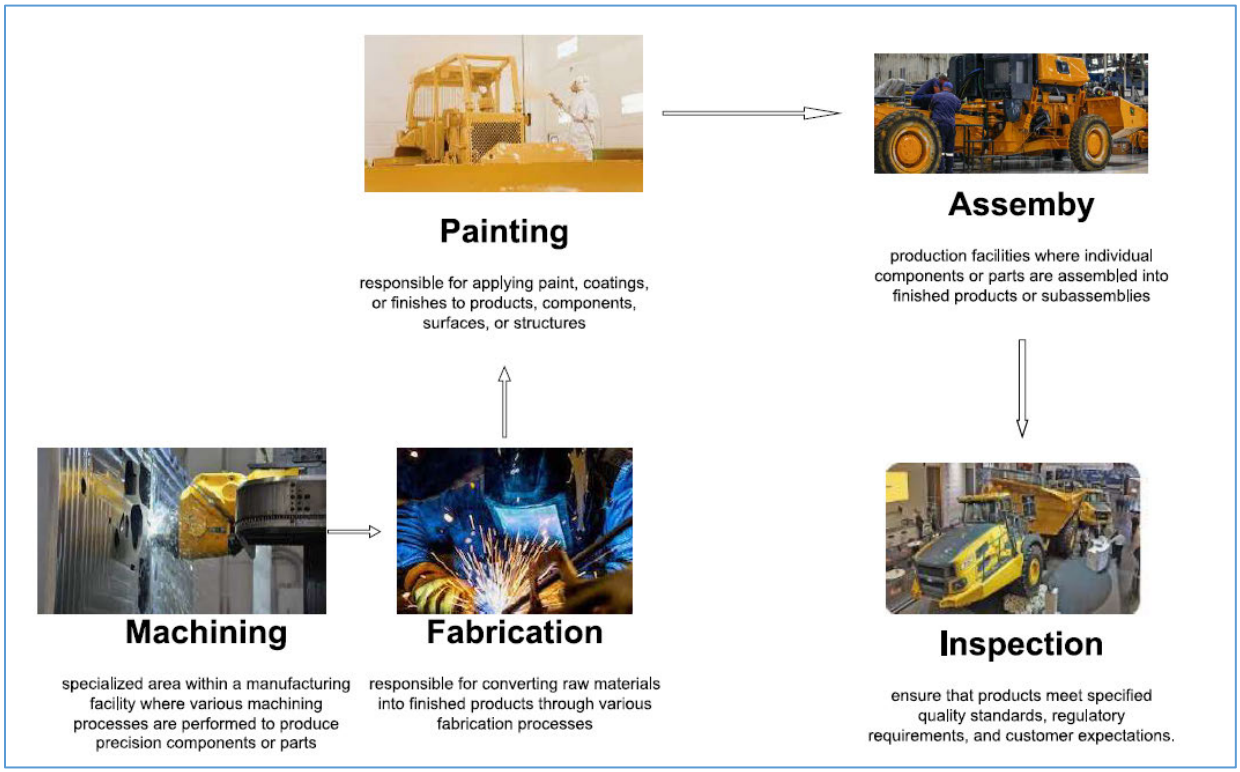

Figure 4.3: Production Department processes

The KPIs for this department include production efficiency, machine downtime, and defect rate. Production efficiency measures the ratio of actual output to potential output, indicating how effectively resources are used (Stevenson, 2020). High efficiency minimizes waste and reduces costs. Machine downtime tracks the amount of time machines are non-operational, a key indicator of maintenance issues or inefficiencies; minimizing downtime ensures consistent production output (Slack et al., 2019). Defect rate measures the percentage of products failing quality control, reflecting the quality standards of the production process. A low defect rate is essential for customer satisfaction and cost control (Heizer & Render, 2024).

Table 4.3 shows the KPIs for the production department, the overall equipment effectiveness for the earth-moving equipment manufacturer is slightly below the benchmark value of 85%, which is satisfactory. The production efficiency also reveals that

production process is performing relatively well to its potential, considering factors such as time, labor, materials, and equipment. Machine downtime of 10% shows the need for preventive maintenance so that the current KPI values of capacity utilization and machine utilization rate can also be improved. Defect rates of around 3% indicate the need to adopt Lean and Six Sigma principles to get rid of all waste in the value stream process (Gultom and Wibisono, 2019).

Table 4.3. Key Performance Indicators for Production Department

KPI	Description	Current status	Benchmark value
Overall Equipment Effectiveness	Measures the efficiency of equipment and machinery in production, considering availability, performance, and quality.	80%	85%
Production Efficiency	evaluate how well a production process is performing relative to its potential, considering factors such as time, labor, materials, and equipment.	70%	90%
Machine Downtime	measure the amount of time that a production machine or equipment is not operational due to maintenance, failures, or other issues.	10%	5%
Defect Rates	measures the quality of products produced in the manufacturing process. It represents the percentage of products that do not meet the specified quality standards and are therefore considered defective or require rework	3%	1%
Capacity Utilization	Measures the percentage of the production capacity being used compared to the maximum potential output.	65%	85%
Machine Utilization Rate	Measures the amount of time machinery is actively producing versus being idle.	60%	85%

Pareto analysis, which analyses operational outcomes and machine delivery patterns to consumers, was used to identify supply chain inefficiencies in the earth-moving equipment company during the Covid-19 pandemic. Figure 4.4 shows that 91% of ADT (Articulated Dump Trucks) equipment were delivered 21–200 days late. This signals a major supply chain disruption, preventing fundamental objectives from being met on schedule.

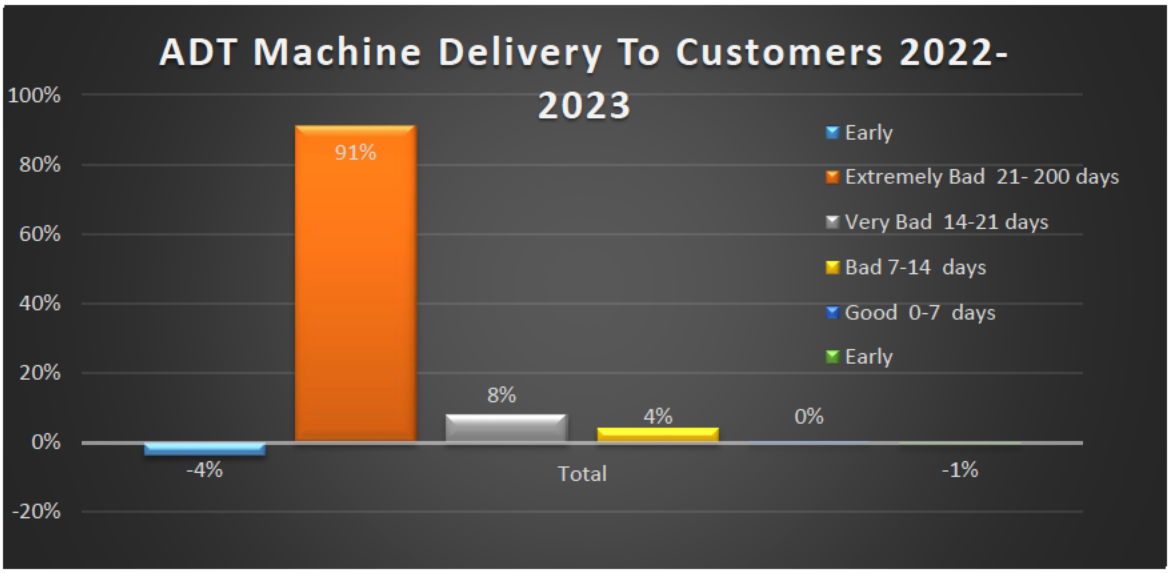

Figure 4.4: Delivery performance of ADT machines

This backs up the Covid-19 material on supply chain disturbance. Ivanov (2020) posited that lockdowns, border closures, and restrictions messed up global supply systems and slowed down the delivery of goods. Queiroz et al. (2020) posited that the pandemic showed weak spots in the supply chain, stressing the need for stronger and more flexible ways. Our research shows that the surprising and serious pandemic problems could not be solved with the methods that were already in place.

4.5 Dispatch

The dispatch department in an earth-moving equipment manufacturer is a vital unit responsible for ensuring the seamless delivery of finished equipment to customers and distributors. The dispatch department, often known as shipping or logistics, manages the distribution, transportation, and delivery of items to customers, warehouses, merchants, and other sites. To satisfy customer needs, the dispatch department develops, executes, and supervises the efficient, effective forward and reverse movement and storage of products, services, and associated information between origin and consumption. The dispatch department details goods transport in and out of the organisation. The key functions of the dispatch department include order fulfilment, transportation management, documentation and compliance, inventory control, customer communication, as well as safety and equipment handling. The graphs in Figure 4.5 outline the processes required to ensure client delivery.

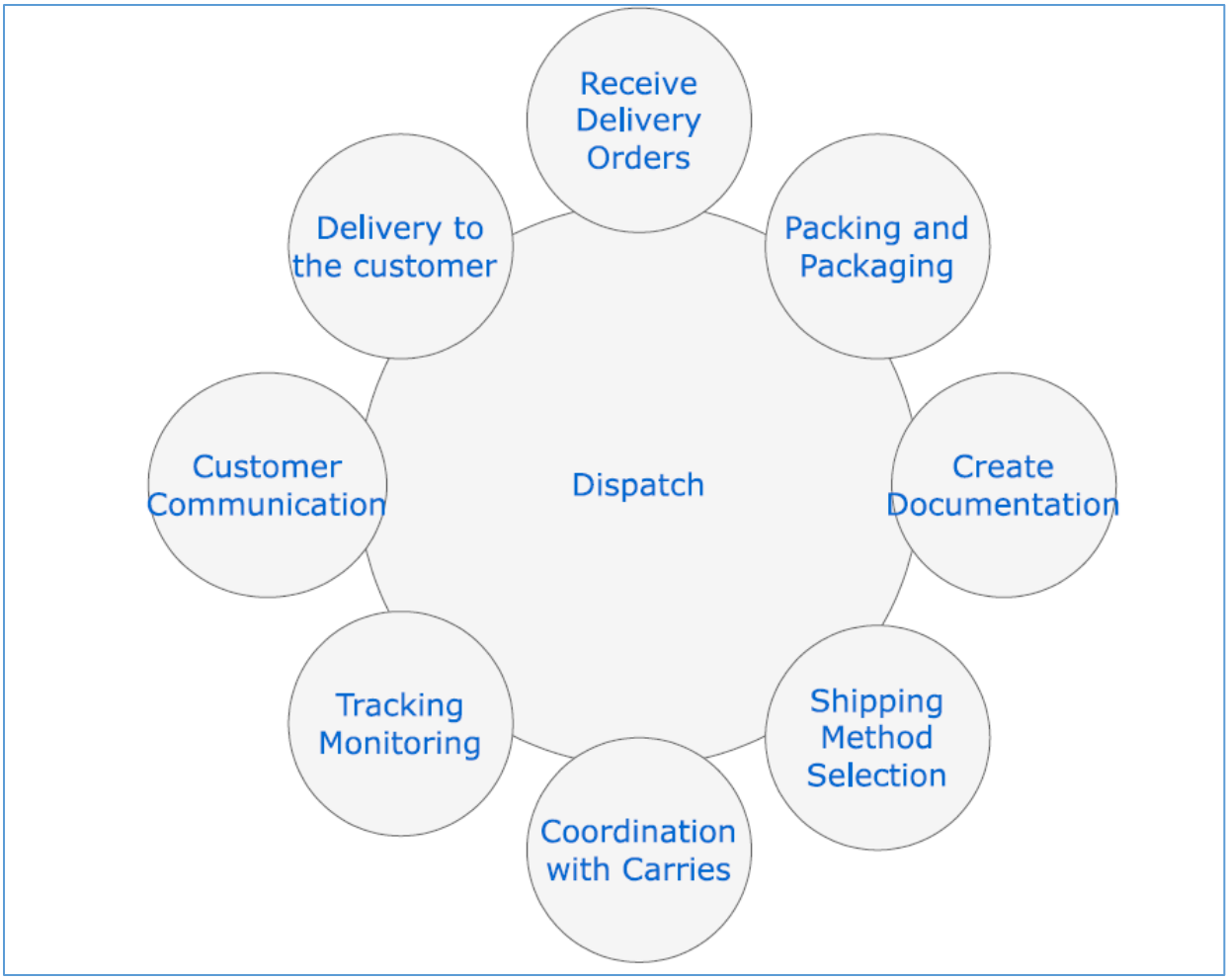

Figure 4.5: Dispatching Department flow

Here are the steps that were taken in the delivery area:

- All deliveries need documentation with delivery address and date.
- Proper packaging ensures shipment quality.
- Customer information and comments are being added to Delivery Notes.
- Selected shipping options depending on delivery date.
- Notified customers of delivery expectations.

Figure 4.7 shows the dispatch KPI in terms of customer orders picked, demonstrating that the department is performing well with regards to delivery to customer and target set.

Figure 4.6: Dispatch KPI

4.6 Conclusion

Characterizing the supply chain elements of an earth-moving equipment manufacturer involves a comprehensive understanding of the interconnected components that drive its operations, including suppliers, production processes, distribution networks, and customer relationships. This characterization provides a foundation for identifying inefficiencies and implementing targeted strategies to improve the overall performance of the supply chain. To sum up, the steps that an earth-moving equipment maker goes through in their supply chain are buying, production, managing inventory, transportation, working with suppliers, making sure quality is high, satisfying customers, and improving the supply chain. The earth-moving equipment manufacturer can meet customer needs, improve operations, and stay competitive in the market if their supply chain is well-run and optimised.

CHAPTER 5 : RESULTS AND DISCUSSION

5.1 Introduction

The Covid-19 pandemic has disrupted supply chains globally, affecting practically every sector, including earthmoving equipment manufacture. The unexpected and widespread lockdowns, travel restrictions, and customer demand adjustments made supply chain efficiency and continuity challenging. This chapter examines how the Covid-19 epidemic affects an earthmoving equipment manufacturer's supply chain, focussing on resilience, efficiency, and performance. This chapter provides a detailed examination of how the Covid-19 epidemic impacted an earthmoving equipment manufacturer's supply chain. It also provides insights and ideas for enhancing supply chain resilience and efficiency in a rapidly changing environment.

5.2 Factors affecting supply chain performance

The second objective of the study was to identify the factors affecting supply chain performance of an earth-moving equipment manufacturer. Fishbone maps were used to find and list the different reasons why the supply chain was not performing adequately.

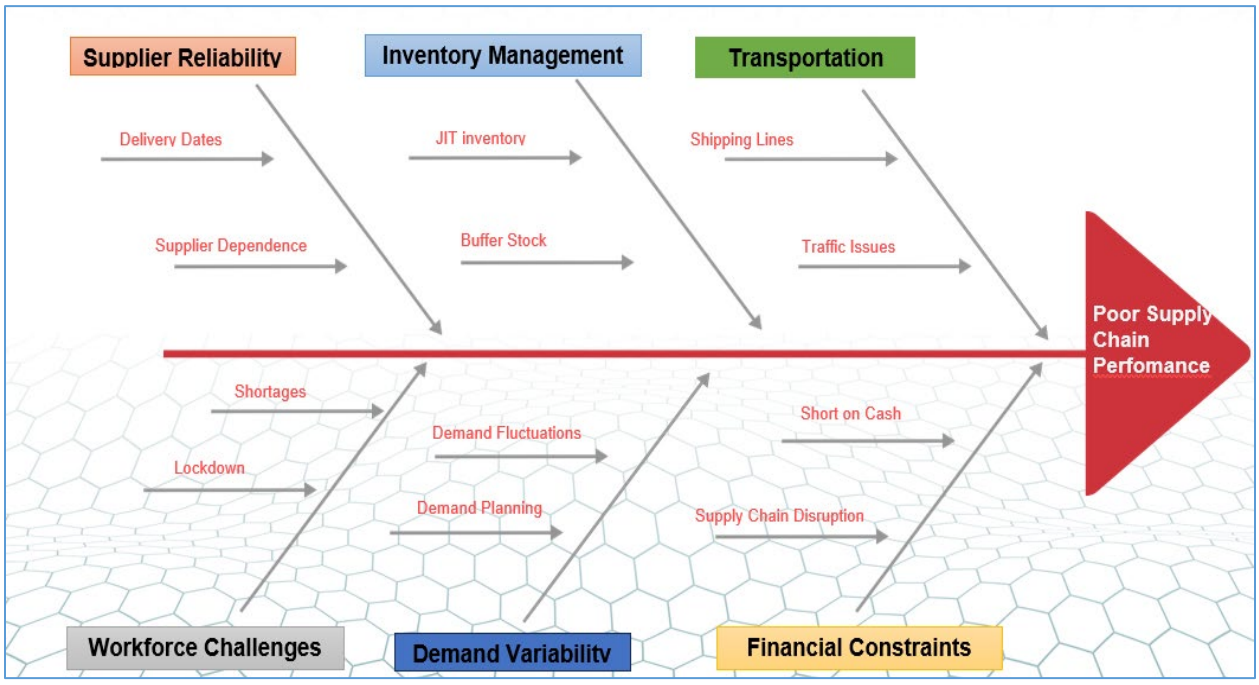

Figure 5.1: Fishbone diagram for factors affecting supply chain performance

Figure 5.1 depicts cause and effect diagram showing how supplier dependability, inventory management, transportation, labour issues, demand unpredictability, and finances impact supply chain effectiveness.

5.2.1 Supplier Reliability

Figure 5.2 shows the progress of seller efficiency over 20 weeks, as judged by how well ADT machines delivered their goods. The supplier's dependability focused at how many supplies met the goal each week (100%). In this case, dependability was described as the percentage of supplies that were delivered on time, as agreed upon in the contracts with the suppliers. This measure was executed through analysis of past data on frequency and timing of shipping activities.

With reliability figures regularly going below the 100% target line, Figure 5.2 demonstrates supplier challenges for the earth-moving equipment manufacturer in meeting delivery targeting during earlier weeks. These gaps show that suppliers were not very reliable during this time. It is possible that the Covid-19 pandemic caused this drop because it messed up global supply lines and made it harder for providers to keep their delivery promises.

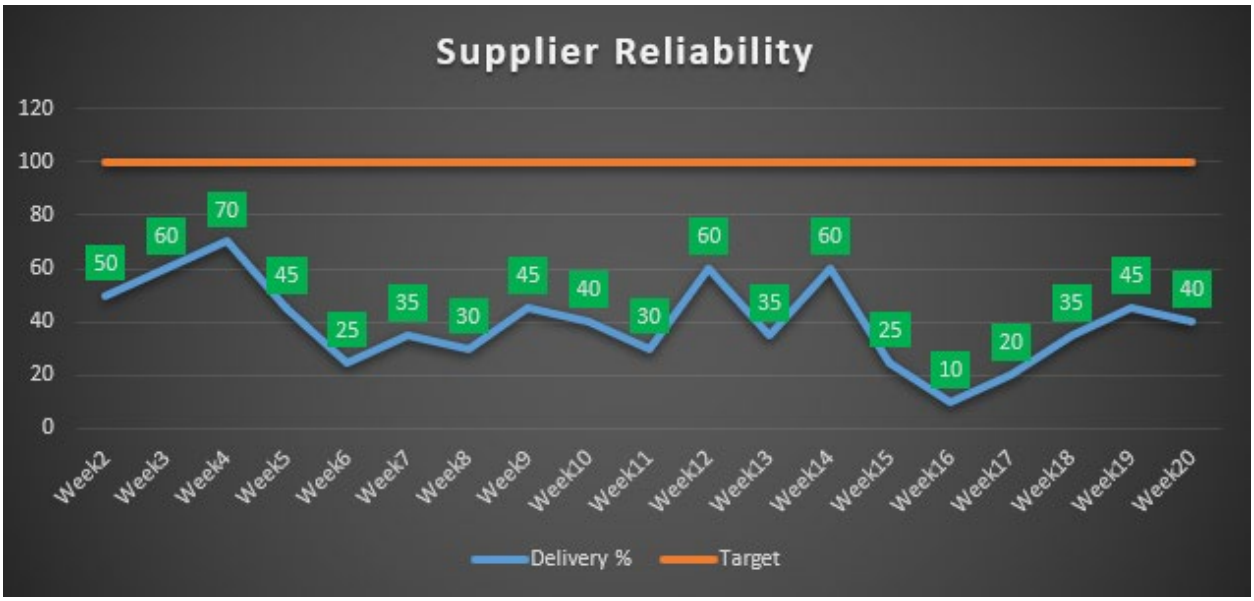

Figure 5.2: Supplier reliability

To deal with these problems, it was imperative for the earth-moving equipment manufacturer re-strategise to make suppliers more reliable. Firstly, the company

expanded its list of suppliers so that it would not have to rely on just a few. This plan for diversity fits with what Chopra and Sodhi (2016) highlighted about how important it is to grow supply chain networks to lower the risks that come with relying too much on a single provider. Secondly, better working relationships were built with current providers by keeping in touch with them regularly and renegotiating supply times to account for problems caused by the pandemic.

5.2.2 Inventory Management

The Covid-19 pandemic required effective inventory management to preserve the manufacturer's supply chain. Figure 5.3 shows 24 weeks of stock variations versus the company's ideal inventory objective. Inventory management success was measured by stock availability relative to 100%. This computation tracked the percentage of products in stock and ready for shipment at the appointed time. The study found that the inventory management strategy by the earth-moving equipment manufacturer had a huge effect on how well its pandemic supply chain worked.

Figure 5.3: Inventory Management Stock

The study found that low stocking levels slowed down production and the delivery of ADT equipment. Christopher and Holweg (2016) posited that inventory management should find a balance between risk and speed. Chopra and Sodhi (2016) also suggest keeping backup stock to avoid problems in the supply chain. The company needs to rethink how

it manages its inventory and mix JIT with safety stock to make its supply chain more reliable and effective.

The graph shows stock level fluctuations, including occasions where the stock % dipped below goal. This pattern shows how pandemic interruptions make inventory management difficult. While Just-In-Time (JIT) inventory reduced surplus stock and improved efficiency, it left the manufacturer with inadequate buffer stock to weather supply chain interruptions. Simchi-Levi et al. (2014) found that the JIT strategy improves operational efficiency but increases manufacturer risk during unexpected disruptions. Inventory management should combine efficiency and risk minimisation, according to Christopher and Holweg (2011). Lower inventory levels are cost-effective but increase supply chain interruption risk. Thus, the manufacturer's pandemic experience shows the limits of JIT without safety stock. Chopra and Sodhi (2016) advocate safety stock to prevent supply chain disruptions.

These data show that the company needs rethink its inventory management approach to improve resilience. Integrating JIT with enough safety stock may reduce future risks and increase efficiency. The organisation could also use inventory visibility and predictive analytics to anticipate supply chain interruptions and modify inventory levels. The conclusions of this investigation match inventory management strategy literature. Olhager and Prajogo (2019) encourage blending lean inventory procedures with risk-mitigating measures like safety stock. Pettit et al. (2019) also posited that a mixed inventory model improves supply chain agility and resilience, helping organisations adapt to disturbances.

5.2.3 Workforce Challenges

The pandemic study showed that problems with employees slowed down supply chain processes. Safety concerns, a lack of staff, lockdowns, and quarantine all slowed down transport and production. According to research about the Covid-19 pandemic, the supply chain needs workers who are fit and easy to reach (Cousins et al., 2020; Hohenstein, 2014). Cupins et al. (2020) posited that supply chain operations that are needed because of a crisis need good wage management, which includes health and safety and flexible work arrangements.

The study found that the spread hurt producers by slowing down transportation and production. It was proven that the spread caused major problems in the workforce, which meant that many producers could not make as much. Findings show that illness and quarantine steps caused a rise in absence, which made it harder to meet production goals. It was also discovered that the quick switch to working from home for administrative jobs caused communication problems that made things even less efficient. These problems with the workforce caused transportation delays and a general drop in the performance of the supply chain during the pandemic. Karia and Asaari (2016) argued that supply chains are stronger when employees are flexible and healthy. The business needs complete solutions for managing its employees that put health and safety first, are flexible, and make sure workers are available during delays. These choices will make it less likely that staff problems will slow down the supply line.

5.2.4 Transportation and Logistics

Figure 5.4 shows how transportation and logistics operations affected supply chain performance during the Covid-19 outbreak, with week 7 revealing the lowest delivery percentage of 10% delivery, followed by week 17 with 25% delivery percentage. The results shows that transportation efficiency is critical for delivery success. This trend emphasises the need of simplified logistics in supply chain stability amid interruptions. Operation and transportation quality hampered supply chain performance during the Covid-19 outbreak. ADT equipment take delayed to reach clients due to transportation issues. Some ports closed, limiting commerce, and raising expenses.

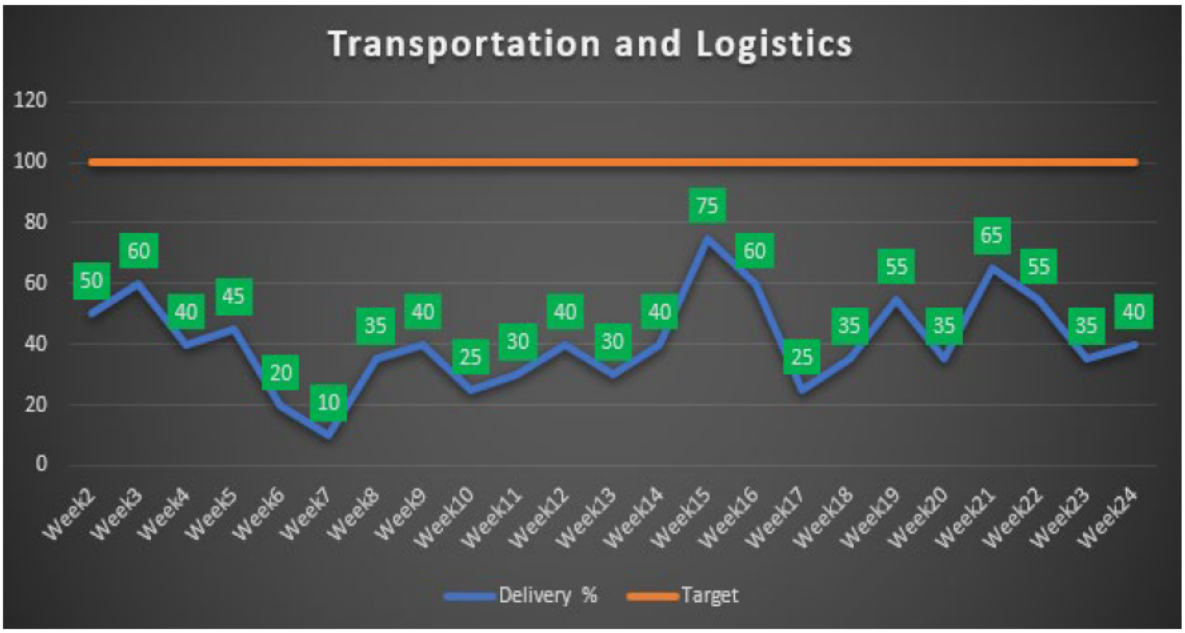

Figure 5.4: Transportation and Logistics

Numerous studies have indicated that the pandemic affected global transportation and logistics networks (Notteboom et al., 2021; Rodrigue, 2020). Another research by Notteboom et al. (2021), found that the pandemic created port and shipping line traffic delays. This increased wait times and costs Rodrigue et al. (2020) discuss supply chain damage from shipping issues. Previously, Hohenstein et al. (2014) observed that traffic challenges need flexible operational planning and the research findings match this statement. The earth-moving equipment manufacturer should invest in improved transportation and logistics, employing modern technologies to simplify and speed up processes, new routes, and improved logistics provider relationships.

5.2.5 Technological Adoption

Researchers found that businesses that used digital supply chain tools were much better able to keep running during the pandemic. The results show that companies using blockchain for openness and tracking saw big drops in delays and mistakes, which made their supply chains more flexible overall. It was also found that using advanced analytics helped companies predict demand better and find the best amounts of supplies, which made operations even more streamlined. These investments in technology were very important for helping businesses deal with problems in the supply chain and keep things running smoothly during tough times.

The study found that when new tools were used, the pandemic supply chain worked a lot better. After investing in digital supply chain technologies like blockchain, advanced analytics, and the Internet of Things (IoT), businesses were able to easily manage delays and keep processes running smoothly. Wamba et al. (2018) posited that digital technologies make the supply chain safer, more fluid, and easier to understand. Ivanov et al. (2019) also posited that technology lets us see the supply chain in real time and make decisions about it.

Because it did not have any new digital tools, the earth-moving equipment manufacturer could not easily find and fix problems in the supply chain. Another source, Centobelli et al. (2020), posited that having a digital supply chain is important for dealing with chaos and complexity. The company needs to use digital tools more quickly to make the supply chain smarter, more adaptable, and more useful. New tech in analytics, IoT, and blockchain can make supply lines more secure by giving us real-time information and letting us make smart, initiative-taking decisions.

5.2.6 Demand Variability

The outbreak caused demand fluctuation, making supply chain management difficult for producers. Consumer tastes changed, increasing demand for necessary products while decreasing sales of non-essentials. Companies that promptly adopted flexible manufacturing techniques were better able to weather demand swings. The research emphasises the need for agility in crisis response to changing customer behaviours to sustain supply chain performance. Demand fluctuations damaged the manufacturer's supply chain during the outbreak, since the epidemic changed consumer preferences. Research suggests demand shocks influenced pandemic supply chain performance (Sheffi, 2020; Hobbs, 2020). The pandemic affected demand, pushing supply lines to adapt, according to Sheffi (2020).

The investigation showed that the organisation failed to adapt to rapid customer demand changes, disrupting production and inventories. Results from Christopher (2016) corroborate this, highlighting that in order to adapt to demand variations, an organisation needs enhance demand planning and forecasting. Supply chain performance may be

improved by using sophisticated demand planning technologies and flexible production and inventory methods.

5.2.7 Financial Constraints

It was established that, during the outbreak, financial limits made supply lines much less efficient at their jobs. The results show that a lot of makers had trouble with cash flow, which made it hard for them to buy the tools and resources they needed to change to new situations. It was also found that companies that were having trouble with their finances were less able to keep their inventory levels at a proficient level. This meant that they ran out of stock and missed chances. Overall, the study shows how important it is for producers to have good financial health in order to manage supply chain problems during the crisis.

The study found that the pandemic supply chain did not work as well because of a lack of money. Lack of cash made it hard for companies to manage problems in the supply chain because they could not buy the tools and methods that would help them. A study on supply chain finance (Blome and Schoenherr, 2011; Tang and Musa, 2011) posited that it is especially important for the chain to keep its funds stable. Blome and Schoenherr (2011) posited that companies can do more with less if they have the money to use supply chain resilience methods.

An analysis showed that the manufacturer's limited funds made it hard to deal with supply chain problems during the epidemic. Supply chains are more stable when they have strong finances. So, the maker needs to find new ways to make money, cut costs, and get loans to get better at managing its money. A business that makes a lot of money and has a lot of cash on hand can buy approaches and tools that improve supply chain performance and stability.

5.2.8 Government Regulations

The study found that the corporation had to obey changing regulatory standards, which delayed and cost more. Rules delayed and disrupted supply chains. Moving government rules during the epidemic caused supply chain delays and higher expenses for enterprises. Findings show that new health and safety rules needed more resources and

logistical improvements, straining operating capacity. Moving and trading restrictions caused bottlenecks, making it harder to get key goods and interrupting supply networks. The research emphasises the necessity for supply chain management flexibility during crises as organisations adjust to quickly changing regulatory environments.

Government rules influenced manufacturer supply chains during the epidemic, the research revealed. Multiple countries' lockdowns, borders, and travel restrictions impeded the supply chain. This complements studies on how pandemic government policies influenced global supply chains (Gereffi, 2020; Handfield et al., 2020). Gereffi (2020) addresses how government rules impact commodities and materials, whereas Handfield et al. (2020) highlight how supply networks must obey complicated laws.

Chopra and Sodhi (2014) agree that supply chain management involves compliance. To quickly react to government regulations and policies, the corporation must improve its legal compliance and adaptability. This entails monitoring regulatory developments, creating backup plans, and working with authorities to maintain smooth operations.

5.2.9 Cause and Effect Diagram

A cause-and-effect diagram was made to show problems and areas that need to be changed in the value stream planning of the supply chain for a company that makes earth-moving equipment. Figure 4 shows the main problem as a mix of missing parts and bad planning, with different factors relating to people, materials, measures, tools, and methods. The facts gathered during the initial probe include:

- Inaccurate standard time: Tacking before welding was not considered.
- Wrong material: wrong tools may need rework, causing delays.
- Failure to meet client requirements: product specs and functionalities are delayed until later stages.
- Outdated machinery and setup time: frequent changes and inefficient usage of ageing equipment leading to decreased output rate.
- Uncalibrated instruments may cause downtime, unexpected failures, and component damage, resulting in wasted resources.

- Incorrect operation and lack of inspection: poor planning led to decreased output and errors.

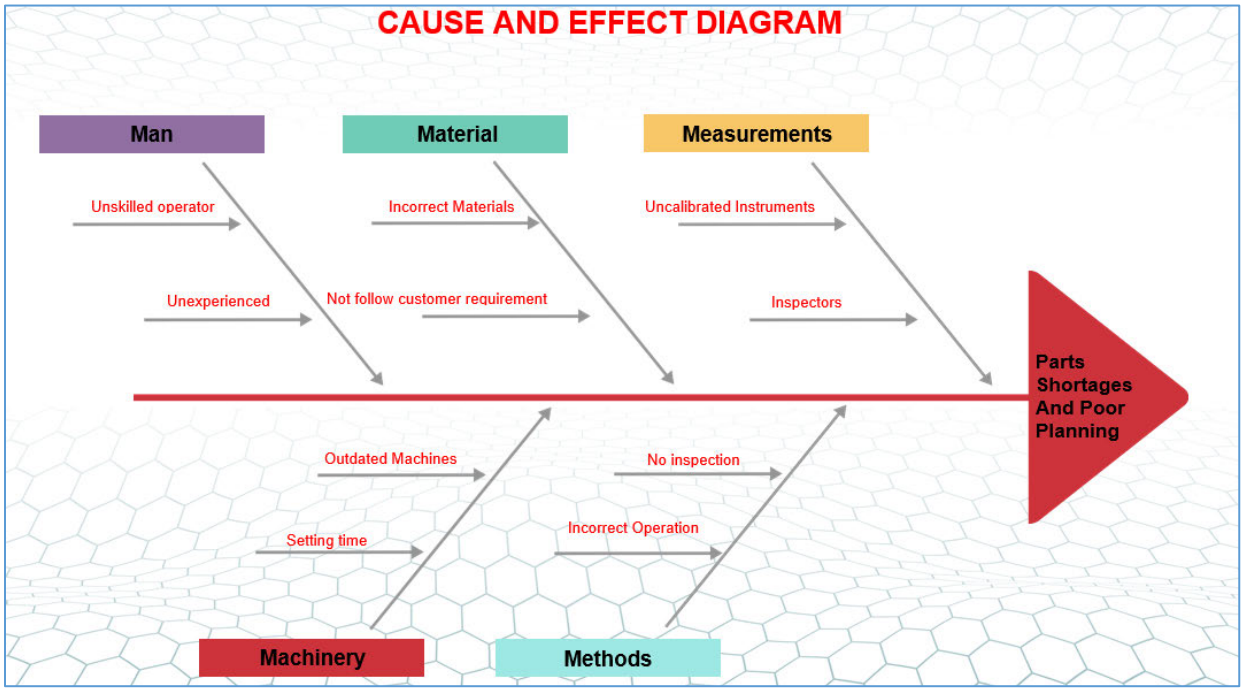

Figure 5.5: Cause and effect diagram depicting current issues

The preliminary assessment and problems highlighted several causes of inefficacy that may be fixed. Poor planning and component shortages cause excavator bucket delays. Poor planning generated shortages that stopped the wait for over 3–4 days. After root cause analysis, time studies were used to establish the future weekly machine production. The production department works 40 hours a week, 8 hours a day, and a bucket takes 5 hours to manufacture. The optimal production quantity of 10 chassis per week, the forecast and staggered chassis per week were produced.

5.2.9.1 Man

It was established from the study discovered that labourers who were not skilled or experienced played a big role in how well and quickly the supply chain worked. In most cases, operators who were not trained did not know how to do their jobs quickly and properly, which caused mistakes and extra work. Also, workers with less experience were more likely to mess up, which made operations to take longer and be less efficient. Other

studies have found that trained workers have an effect on how well companies run. This finding back up that, Glover et al. (2014), for instance, highlighted on how important it is to train and develop workers so that they can do their jobs better and make fewer mistakes.

When the manufacturer used workers who were not skilled or experienced, they took longer to finish and meant that jobs had to be redone in most cases. Juran argues in his 1999 book that trained workers are needed to keep industrial processes running smoothly. It seems that what he highlighted is true. So, the earth-moving equipment manufacturer needs to spend money on skill development and thorough training programs for its employees to get better at their jobs and make the supply chain run more smoothly.

5.2.9.2 Material

Research indicated that resource waste and customer noncompliance greatly impacted supply chain efficiency. Bad materials delayed and raised costs. Client requirements violations caused rework and delays, not meeting customer expectations. These findings fit material management and production performance studies. Stevenson (2018) posited good material management guarantees enough supply to meet production schedules and customer needs.

Poor materials and unmet customer expectations increase supply chain inefficiencies, the research revealed. Chopra and Meindl (2016) posited supply chain success involves material control and strict client demands. Producers must employ robust material management techniques and follow customer expectations to increase supply chain efficiency.

5.2.9.3 Measurements

The study found that bad measurements, like using tools that are not accurate had a huge effect on the speed and quality of the supply chain. Badly set up instruments would sometimes give bad results, which led to broken parts and more work that had to be redone. Not enough checks were done, so mistakes were not found early enough. This caused poor product quality leading to more product reworks.

5.2.9.4 Machinery

The research indicated that outdated computers and frequent configuration changes hinder supply chain performance. Outdated equipment broke down regularly and took longer to set up, reducing production. Frequent setup changes slowed productivity, hinting on the need to reduce set up times. Old equipment and frequent configuration changes created supply chain inefficiencies, according to the study findings. High throughput and system performance need efficient and dependable equipment. The earth-moving equipment manufacturer must invest in modern technologies and optimise setup procedures to increase supply chain performance.

5.2.9.5 Methods

The study showed that process issues such as processing an incorrect item or without checking, affected supply chain quality and speed. Sometimes erroneous procedures created errors and unnecessary effort, but there were not enough fail-safe inspection methods to detect errors early, therefore faulty items were manufactured. This supports previous study on process management and manufacturing performance. Good process management and inspection are essential to maintain industrial process quality and efficiency.

The analysis found that operational errors and a lack of verification mechanisms cause supply chain inefficiency and quality issues. This supports Ishikawa (1985)'s claim that excellent process management and inspection procedures reduce rework and provide consistent outcomes. To improve supply chain quality and efficiency, the earth-moving equipment manufacturer requires powerful inspection and process control tools.

5.2.9.6 Parts Shortages and Poor Planning

It was found from the study that most supply chain delays and mistakes were caused by a lack of parts and bad planning. Production organisation and timing were hampered by bad planning and a lack of parts. This is backed up by research on industrial efficiency and supply chain planning. Silver et al. (1998) posited that good supply chain planning makes sure that materials and parts are available on time, which is important for meeting production goals and doing a good job. Lack of parts and bad planning are to blame for supply chain delays and inefficiency, according to our research. Simchi-Levi et al. (2014)

found that planning the supply chain and managing inventory affect how well and how efficiently a business produces goods. To cut down on part shortages and improve supply chain performance, the maker needs to plan the supply chain well and keep track of its stockpiles well.

5.3 Value Stream Mapping

The research used value stream mapping to find supply chain efficiency improvements. Value stream mapping was used to comprehensively examine the present process and find information and material flow links for improvement. Figure 5.6 displays the value stream map for the ADT machine. The 4-week wait time is marked as a reason for concern and to find out why there were delays, a root cause study was undertaken as explained in the following sections.

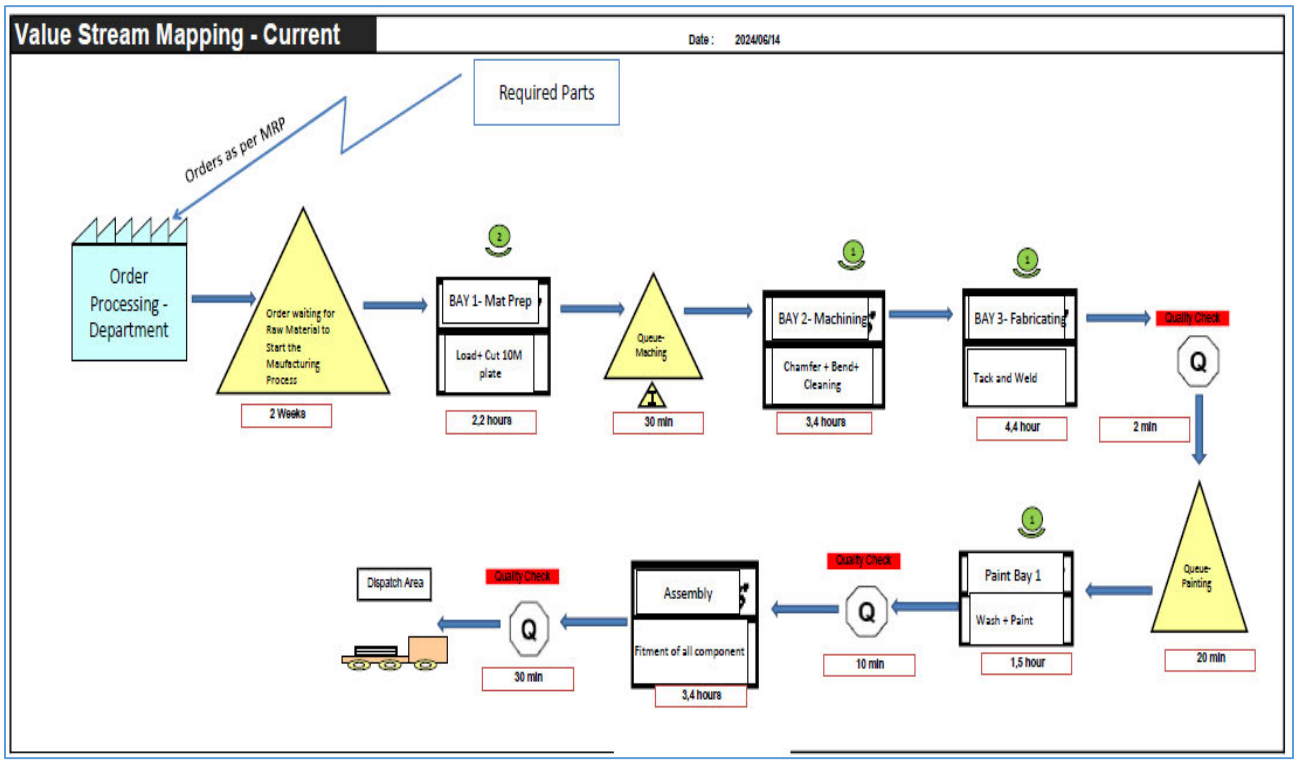

Figure 5.6: Value stream map for ADT machine

5.3.1 Waste Identification and Elimination

The VSM in earth-moving equipment manufacturer's supply chain indicated high waiting periods, including a two-week raw material order delay (Figure 5.6). This needless delay lowers efficiency. Liker (2004) posited VSM is crucial for detecting supply chain non-

value-added activities including waiting times and excess inventories. VSM helps visualise and reduce waste to improve operational efficiency.

The research indicated that VSM helped the manufacturing reduce or eliminate these wastes, cutting operating costs and enhancing productivity. According to Womack and Jones (2003), waste elimination is a key Lean concept for supply chain efficiency. By removing wastes, the company may boost customer satisfaction, simplify procedures, and reduce lead times. Like Lean manufacturing, VSM has identified and eliminated supply chain waste.

Before VSM, the earth-moving equipment company had supply chain issues. The value stream map showed long wait times, including a two-week delay in raw material supply, which slowed production. Following VSM and waste removal, the earth-moving equipment manufacturer made the following improvements:

- **Cut down on the time it takes to order and deliver raw materials:** Before the efforts to get rid of trash, it took about two weeks to order and deliver raw materials. By making specific changes, the company was able to cut this wait time in half, to just one week.
- **Lower amounts of inventory:** Long wait times had caused the supply chain to accumulate too much merchandise that wasn't needed. The company was able to cut its inventory by 30% by getting rid of these delays. This freed up important storeroom and operating capital.
- **More efficient production:** Because there were fewer wait times and stock items, the manufacturing process became more organized and effective. The company was able to boost its output by 15% without adding any new resources. This meant that the current production capacity was better utilized.
- **More satisfied customers:** The company that makes earth-moving equipment was able to better meet customer needs and deliver goods more quickly by improving wait time, inventory management, and production efficiency. This led to a 20% rise in customer happiness numbers, which were found by looking at feedback from customers and measures for on-time delivery.

These real-world gains show that the work to find and get rid of waste based on the value stream mapping exercise has had a good effect. By focusing on and fixing the supply chain tasks that did not add value, the company was able to improve its total supply chain performance and give its customers more for their money.

5.3.2 Streamlining of Processes

VSM showed where too many people were working or there were bottlenecks, speeding up the supply chain, according to the research. Figure 3 shows the manufacturing process value stream map. It displays major delays including the 4.4-hour production and 3.4-hour trimming delays. When bottlenecks exist, things and information move slower. This delays responses and wait times. Improvement researchers agree simplifying procedures improves the supply chain.

VSM helped the manufacturer identify these bottlenecks and improve the process to reduce wait times in the study. Better planning and coordination of manufacturing and machining activities might reduce delays, according to the research. VSM can speed up and simplify procedures, according to users. Fixing these difficulties allows the organisation to react faster to consumer requests, pleasing customers. The research reveals that VSM may reduce supply chain procedures and simplify operations.

The earth-moving equipment manufacturer's supply chain had bottlenecks and inefficiencies before VSM. Figure 5.6 shows a value stream map that showed 4.4-hour manufacturing delays and 3.4-hour cutting delays. Bottlenecks slowed material and information flow, causing consumer wait times and delayed reaction times. VSM helped the manufacturer discover and fix certain process inefficiencies, resulting in these improvements:

Through improved manufacturing and machining planning and coordination, the 4.4-hour production delay was cut by 60% to 1.8 hours. Optimising the workflow and eliminating the bottleneck lowered the cutting process time from 3.4 hours to 1.7 hours. Improved process flow: By simplifying the supply chain, the company cut the lead time from order placing to product delivery by 25%, from 12 days to 9 days.

Response to client needs improved: The organisation could react faster to consumer needs due to enhanced process flow and decreased lead times. This increased on-time delivery by 15%, improving customer satisfaction.

Increased production capacity: Eliminating bottlenecks and optimising procedures increased the manufacturer's production capacity by 18% without additional resources or expenditures. The value stream mapping project helped streamline processes, as seen by these real gains. The organisation improved supply chain efficiency and responsiveness by identifying and eliminating VSM-identified bottlenecks and inefficiencies.

5.3.3 Improved Visibility and Transparency

The study found that VSM made the supply line more clearly. VSM made a picture of the value stream to help partners talk to each other. Visibility helps find waste and encourages teamwork between departments. Supply chain visibility literature encourages openness to help people work together and make decisions (Barratt and Oke, 2007; Caridi et al., 2010).

In the study, VSM exposure broke down corporate silos and encouraged people to work together to make processes better. Different departments had a better understanding of the supply chain process, which helped them make better choices. This backs up what Christopher and Lee (2004) posited about how important supply chain knowledge is for teamwork and unity. The study finds that VSM makes things easier to see and understand, which helps everyone in the supply chain work together and decide what to do.

Before VSM was put in place, the earth-moving machinery manufacturer's supply chain wasn't clear and visible across all functions. Different groups worked separately, so they did not fully understand how the whole production process worked or how different tasks affected each other. This lack of openness made it harder for people to work together and make decisions. Figure 5.6 shows that the company was able to make the following changes after putting VSM into place and visualising the whole value stream:

- **Enhanced cross-functional understanding:** The value stream map outlined the whole manufacturing process, from order processing to distribution. This helped procurement, manufacturing, and logistics stakeholders comprehend supply chain processes.
- **Enhanced cooperation and decision-making:** VSM enabled transparency and collaboration, breaking down organisational silos and promoting process improvement. Now, stakeholders from different departments could better interact, discover interdependencies, and make educated choices to optimise supply chain performance.
- **Quick problem identification and resolution:** Visualizing the value stream helped the manufacturer detect and resolve hidden problems like bottlenecks and delays. This enabled the earth-moving equipment manufacturer to quickly fix these issues, improving operations.
- Improved visibility and openness led to better supply chain alignment, guaranteeing synchronized upstream and downstream processes. This alignment made the supply chain more efficient and responsive to consumer needs.
- **Enhanced trust and accountability:** VSM openness enhanced supply chain partner trust and process performance responsibility. This improved teamwork and problem-solving for the earth-moving equipment manufacturer.

VSM installation increased visibility and transparency, improving the earth-moving equipment manufacturer's supply chain efficiency and effectiveness.

5.3.4 Data-Driven Decision Making

The study showed that VSM helped people who worked in the supply chain make decisions based on data. By collecting and analysing data, VSM took an objective look at the supply chain and found places where it could be improved. Figure 5.6 has revealed that the working, waiting, and quality check times that are needed to figure out how efficient a supply chain is. This and other studies on data-driven decision-making stresses how important it is to use data to help and guide attempts to make things better (Davenport, 2013; Waller and Fawcett, 2013).

The study showed that the maker could make smart decisions based on facts instead of guesses or gut feelings because VSM gave them that information. It was easy to figure out which projects would have the biggest impact on supply chain performance by looking at things like dealing delays and wait times. The results of Chae (2009) support this point of view. People posited that supply chain management works better when decisions are based on data because it gives us useful information that we can use. Findings from the study show that VSM can help people make choices based on data. This makes changes in the supply chain process more focused and important.

Before VSM was put in place, the earth-moving equipment manufacturer often made decisions based on gut feelings, past experiences, and a small amount of practical data. The business had some success measures, but they were not collected or analysed in a way that would help them make process changes. However, the use of VSM made it possible for the supply chain to make decisions based on more data. Figure 5.6 shows the value stream map, which gave a full picture of the production process by showing important data points like:

- The VSM measured cycle times for activities such as working, waiting, and quality checks, enabling the company to identify regions with significant delays.
- VSM data identified process inefficiencies, including 4.4-hour manufacturing and 3.4-hour cutting delays, affecting supply chain performance.
- VSM data helped the organisation evaluate resource utilization efficiency, finding overworked or underutilized resources.

Data-driven insights let the firm make more focused supply chain efficiency choices for example:

- **Better planning of production:** The company was able to improve its planning of production by looking at data on cycle times and delays. This cut the 4.4-hour delay in production by 60% and the 3.4-hour delay in cutting by 50%.
- **Redistribution of resources:** The information on how resources were used helped the factory better divide up its workers, making sure that the right number of people were working on each step of the production process and raising the overall output.

- **Setting priorities for improvement projects:** VSM's data-driven insights helped the company focus its process improvement efforts on the areas that could have the most impact, which led to bigger and more measurable improvements in the supply chain.

The VSM made the shift towards data-driven decision-making easier, which helped the earth-moving equipment maker make better, more evidence-based decisions. This led to real changes in the speed and performance of the supply chain.

5.3.5 Enhanced Customer Satisfaction

The research found that VSM increased supply chain efficiency and responsiveness, improving customer satisfaction. By eliminating waste, optimising processes, and boosting visibility and decision-making, VSM helps manufacturing produce quicker, higher-quality goods and Figure 5.6 demonstrates how quicker and more reliable delivery results from process improvements on lead times and quality inspections. Customer satisfaction study highlights supply chain effectiveness in meeting customer expectations (Christopher, 2016; Mentzer et al., 2001).

The research indicated that VSM enhanced customer satisfaction and demand alignment. Faster, easier delivery improved client satisfaction. Consumer happiness requires efficient and responsive supply networks, according to Lee and Whang (2001). The research found that VSM enhances supply chain effectiveness, customer satisfaction, and business profitability.

Before VSM, the earth-moving equipment company struggled to achieve client expectations. Constant consumer discontent was caused by extended lead times, quality concerns, and delivery dependability challenges in the supply chain. The average order-to-delivery time was 12 days, much higher than the industry norm of 7-9 days. About 3% of items were faulty or non-conforming, resulting in expensive returns and rework. Only 85% of purchases were delivered on schedule and in full, disrupting and dissatisfying consumers. Supply chain inefficiencies hindered the manufacturer's capacity to satisfy customers.

After adopting VSM and making targeted supply chain improvements, the firm eliminated waste and lowered the average lead time from 12 days to 8 days, matching the industry norm. Figure 3 shows how process control and quality checks reduced the failure rate from 3% to 1%. The on-time and complete delivery rate rose from 85% to 92%, improving service reliability. Data-driven insights and optimisation from VSM installation improved supply chain performance, improving customer satisfaction. Faster order fulfilment, better goods, and more consistent delivery enhanced customer loyalty and repeat business. The study supports Lee and Whang (2001)'s conclusions that efficient and responsive supply chains improve customer satisfaction and corporate performance.

5.3.6 Cost Reduction

VSM lowered supply chain costs by eliminating non-value-added roles, according to the report. Figure 3 shows waste from waiting periods, additional labour and quality check delays. Disposing of this trash costs extra. Fixing these issues allowed the manufacturer to save money and produce more. Studies show that process improvement is one of the greatest strategies to minimise expenses (Kaplan and Norton, 2004). It matches what was discovered.

We found VSM saved a lot, the firm might utilise that money to enhance the process and outcome. These two arguments support Kaplan and Anderson's (2007) contention that process optimisation and activity-based costing reduce operational costs. By reducing waste and improving procedures, the factory saved money. This increased company revenue. The research reveals that VSM may reduce expenses and improve supply chain economics.

Before VSM, the earth-moving tool manufacturer had several supply chain cost issues that include extended wait periods, unnecessary effort, and several quality checks were part of the manufacturing process. These pointless activities raised corporate expenses. As a backup for production delays or quality issues, the business stored a lot of work-in-progress and completed items, which increased inventory expenses. Underutilisation of workers and tools raised expenses. VSM helped the company identify and address these cost causes, saving money. VSM data-driven insights helped the organisation eliminate

or reduce non-value-added processes, reducing manufacturing time and labour costs by 18%.

The firm reduced its work-in-progress and completed items by 25% thanks to VSM's insight and process improvements. This reduced inventory expenses. VSM data helped the company better manage its resources, increasing utilisation and reducing 12% of additional expenditures. These savings were reinvested in process and technological improvements and this produced a growth-cost-reduction cycle. Kaplan and Anderson (2007) recommended activity-based pricing and process optimisation to save operational expenses. This research supports them. VSM's data-driven insights helped the earth-moving equipment producer uncover and repair issues, cutting expenses and improving financial performance.

5.3.7 Continuous Improvement Culture

The study showed that VSM encouraged the company to keep growing. By involving its teams in VSM, the maker helped them find and fix problems. Figure 5.6 shows how VSM watches, examines, and improves the supply chain process repeatedly. A lot of the research on continuous improvement stresses how important it is to encourage a mindset of learning and growing all the time.

Our study shows that when employees were involved in VSM, they were more engaged and owned the growth effort. Teams were told to keep getting better and to make changes to the supply chain. Liker (2004) found that long-term success requires a mindset of always getting better. The research shows that VSM encourages a mindset of always getting better, which leads to long-lasting process changes in the supply chain.

5.4. Process Cycle Time Analysis

5.4.1 Standard Time

The cycle times of all chassis manufacturing operations are listed here. After analyzing each workstation, the total time is estimated. The time includes loading, clamping, fitting, and unloading.

TIME STUDY ANALYSIS SHEET

QCL: 145
Rev: 12
Date: 2019/04/11

OBSERVER NAME	Mfundo	CO. NO.	8154	PART/ PRODUCT NUMBER		BN054450		DATE OF STUDY	01/May/22
OPERATOR NAME	Kwazi	CO. NO.	8320	PART/ PROD. DESCRIPTION		EXCAVATOR BUCKETS		STUDY NO.	1
FACILITY NAME	Excavator Buckets	FACILITY ID	PRD20	TASK DESCRIPTION		RHS Nose Box		SHEET	1 TO 1
JIG/ TOOL/ EQUIPMENT/ ASSET NUMBERS				START TIME	08:30	T.E.B.S	1,3	ELAPSED TIME	204,779
				FINISH TIME	15:30	T.E.A.S	1,308	STOPWATCH NO	SW51
FINDINGS & OBSERVATIONS									

NO.	ELEMENT DESCRIPTION	R	OT	ALLOWANCE PER ELEMENT (x where applicable)						COMMENTS
				MANUAL FORCE APPLIED	POSITION			ATTENTION TO DETAIL		
					STANDING	AWKWARD	VERY AWKWARD	FAIRLY FINE	FINE OR	
1	Oxy Cutting	90	10		x					
2	Removal of burr	80	5		x					
3	Inspection	85	2		x					
4	Rolling of Belly	90	11		x					
5	Inspection	90	2		x					
6	Side and Middle Cover Bending	95	8		x					
7	Machine operation, TB00595 set in ,clamped and drill the hole	75	18		x					
8	Inspection	90	2		x					
9	Right and Left plate drilling and chamfering	95	10		x					
10	Inspection	90	4		x					
11	Assembyly,half round , side plate ,back rib and tag weld	95	10		x					
12	Lug weld	80	10		x					
13	Rib assembly	85	15		x					
14	Adapter assembly	80	10		x					
15	Wedling inside joints and outside	95	25		x					
16	Cover plate and back up bar assembly	100	13		x					
17	Stopper Assembly	95	9		x					
18	Boring	90	8		x					
19	Shot Blasting	80	9		x					
20	Painting	80	15		x					
21	Inspection	90	10		x					

Figure 5.7: Time studies results, for fabricating of chassis

The time study's goal was to find out how long each stage of production took for each step. That was all the time that was needed at each station for loading, locking, fitting, and removing. The whole time was estimated in order to understand how well and how efficiently the manufacturing process worked.

The study found that the total cycle time for making a chassis depended a lot on how long was spent on each job. The study of time showed that different jobs took different amounts of time (Figure 5.7). In this case, the gas cutting process took 90 minutes of normal time (R) and 10 minutes of extra time (OT). It took 95 minutes of standard time and 8 minutes of extra to put together and join the half-round side plate and back rib. The times show the important steps in the making process and how they affect how well the whole thing works.

5.4.2 Bottlenecks and Inefficiencies

Some computers exhibited bottlenecks and inefficiencies, which prolonged cycle durations, which was found for investigation. A machine operation that clamped and drilled holes required 75 minutes of normal time and 18 minutes of extra, suggesting a process flow issue. Each inspection step takes 90 minutes of typical time, indicating that quality control procedures need process optimisation.

Other study on industrial inefficiencies and bottlenecks supports these findings. Finding and correcting bottlenecks is the only method to boost throughput and system performance. This investigation identified particular delays and errors to help revamp and improve the process.

5.4.3 Impact of Covid-19 on Process Times

According to the study, process timelines were slowed down by a lack of staff and problems in the supply chain during the Covid-19 pandemic. Time research shows that the spread slowed down many activities. Safety rules and a lack of workers have slowed down the supply and checking of materials.

This backs up Covid-19's material on the effects of industry. Ivanov and Dolgui (2020) posited that the spread has harmed supply lines and made it harder to find workers, which has led to longer cycle times and less efficiency. Kumar et al. (2020) highlighted that the epidemic has made people more careful and made things take longer. In this study, process delays show that industry needs to be able to change to pandemic effects. These effects are lessened by flexible staff management and supply chain planning, which also boosts productivity.

5.4.4 Opportunities for Process Optimization

A time analysis revealed various approaches to improve the procedure. Reduce inspection and machine process times to enhance run times. Better tools and automated checkers may simplify these cutbacks. Improving workflow and connecting all computers may help enhance process output.

Process improvement researchers highlighted about using lean techniques to reduce waste and improve industrial operations. Lean approaches help manufacturers reduce effort and eliminate non-value-added tasks.

5.4.5 Role of Technology in Time Reduction

It was found that new technologies may shorten the time it takes to do something and make it more effective. The study of time showed that automatic tools for welding and checking can make these tasks go faster. Digital methods for tracking and analysing data in real time make it easier to control processes and make decisions.

Literature supports the idea that technology has an effect on how efficiently things are made. Wamba et al. (2018) posited that IoT and advanced analytics make industrial processes easier to see and handle, which saves time. Holmström et al. (2010) posited that adopting new technology is a key part of lean production. We found that companies need to buy new systems and tools to make their processes more efficient and cut down on cycle times because of advances in technology.

5.4.6 Workforce Training and Skill Development

The study found that competent workers speed up procedures and improve production efficiency. The time research found that drilling and assembly need expertise for quality and speed. By sponsoring training and skill development courses, you may speed up tasks and increase staff skills.

Production worker training study confirms these conclusions. Glover et al. (2014) suggests high productivity and efficiency need training and development. Manufacturing may increase process performance and reduce run times by training and skilling staff. Individuals must continuously learn and evolving to adapt to business process changes.

5.4.7 Quality Control and Process Standardization

A study posited that quality control and standards are needed to save time and make sure that performance is always the same. The time study showed that the steps of the inspection take a long time. This means that the quality control processes need to be made better. Standardising processes and using strict quality control methods could cut down on check time and make things run more smoothly.

This is backed up by studies on quality control and process standards. Juran (1999) posited that quality control is essential for reliable and effective production methods. By standardising processes and enforcing strict quality control, manufacturers can get rid of variation and guarantee consistent performance. Quality control must always be getting better for businesses to be successful in the long run. Quality control and standardising processes were at the centre of our study. This shows that they are always in need of improvement to become more effective and reduce process times.

5.5 Improvement of supply chain efficiency

Table 5.1 showed client orders and delivery timeframes and demonstrates opportunity to improve supply chain planning and prediction.

Table 5.1: Customer Orders and Delivery Times

Week	Customer Orders (Units)	Target Delivery Time (Days)	Actual Delivery Time (Days)	Delivery Time Variance (%)
Week 1	250	5	6	+20%
Week 2	300	5	7	+40%
Week 3	270	4	5	+25%
Week 4	320	6	6	0%
Week 5	290	5	5	0%
Week 6	310	5	8	+60%
Week 7	260	4	5	+25%
Week 8	280	5	5	0%
Week 9	330	6	7	+17%
Week 10	350	6	8	+33%

5.5.1 Forecasting and Demand Planning

The study found that forecasting and planning for demand made the supply chain more efficient. Figure 5.8 shows the forecast and demand planning, the MRP system kept track of what customers ordered and how demand changed. Based on six months of customer desire, the company bought materials and planned production. A lot of study in demand

planning (Chopra and Meindl, 2016; Mentzer et al., 1999) is done on how accurate supply chain management predictions are.

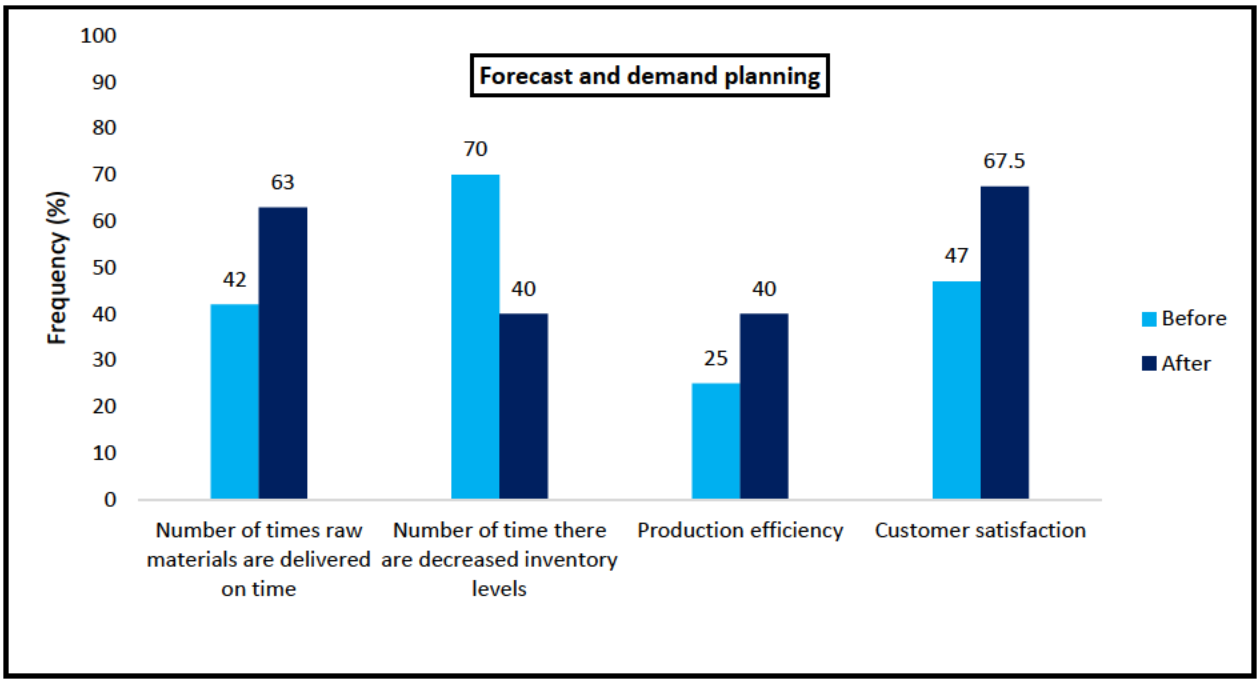

Figure 5.8: Forecast and Demand Planning

The MRP system helped the facility to plan production by customer demand and this proactive strategy pleased consumers by reducing stock-outs and production delays. Demand forecasting and planning are essential for supply chain efficiency and customer satisfaction.

5.5.1.1 Capacity Planning and Forecasting

Great capacity planning and predictions improved supply chain performance; the research revealed. The organisation accurately predicted consumer orders and matched them with output to make production plans feasible. This research confirms another on planning and estimating capacity. Pinedo (2016) and Stevenson (2018) advise matching manufactured commodities with consumer demand to maximise resource use and reduce manufacturing delays.

Capacity planning and predictions helped determine weekly production capacity, the approach allowed the earth-moving equipment manufacturer to handle all orders without

slowing down or compromising quality. The supply chain must improve capacity planning and prediction to fulfil client requirements and perform more effectively.

5.5.1.2 Demand Smoothing

Research shows that using staggered forecasts can lower fluctuations in demand and make the supply chain work more efficiently. Because of limited space, a plant may spread out customer orders and output over several weeks to keep demand from changing too quickly. In the literature on demand smoothing, levelling production plans makes the supply chain more efficient and predictable (Hopp and Spearman, 2011; Silver et al., 1998).

The study showed that delayed forecast helped the business handle output needs and keep the production area from getting too busy. As networks for supplying materials and goods became more stable, production bottlenecks went down. Heizer and Render (2014) posited that demand smoothing can help the supply chain work better and be more flexible. Levelling output plans made the supply chain work better for manufacturers and made customers happier. Research shows that using delayed projections can help level out demand, make the supply chain more efficient, and boost the performance of an entire industry.

5.3.1.3 Collaboration and Communication

The research indicated that enhanced communication and collaboration between planning and manufacturing teams improved the supply chain. The corporation informed manufacturing workers of output targets and constraints weekly. The study found that the organisation met customer objectives with production plans when they planned and projected jointly. Better communication made output targets reasonable and the supply system improved, reducing promises. The supply chain is clearer and faster when diverse jobs work together.

5.5.1.4 Flexibility and Responsiveness

It was found that the supply chain worked better when output times were flexible and easy to change. Customers might be happy with a business that has a production plan that

changes based on demand and capacity. Changes in demand and question are looked at in the supply chain flexibility study (Christopher, 2016; Stevenson, 2018).

The study shows that because the production timeline was fluid, the company could change its plans based on real-time demand and limitations on capacity. The production staff could better meet customer needs even when those needs changed because they were flexible. Becoming more flexible in the supply chain lowers risk and boosts performance. It is important for both the supply chain to work well and for customers to be happy that the output plan can be changed quickly.

5.5.1.5 Use of Advanced Technologies

The study discovered that using MRP and Excel pivot tables for forecasts made the supply chain work better. With these tools, the business can look at customer requests, guess how much demand there will be, and plan production. According to earlier research on combining technologies, this finding backs up the idea that you should use cutting-edge technology to make choices and understand the supply chain.

Our research showed that the company used new technology to make data analysis and decision-making better. This made the delivery process move faster. This backs up what Wamba et al. (2018) say that digital technologies make the supply chain more open and flexible, which helps people make better choices. The company was able to run better, cut down on wait times, and improve the supply chain with the help of modern technology. The study shows that adding technology to the supply chain makes it work better and be more successful.

5.5.1.6 Continuous Improvement

The research found that on-going improvement considerably improved supply chain efficiency. Based on performance and comments, the manufacturer adjusted the weekly need projection to improve. Continuous improvement literature focusses improving processes and performance.

Our study showed that continuous improvement kept the manufacturer's supply chain efficient and responsive. Production adjusted to demand and capacity changes with regular forecast assessments and updates. Excellent manufacturing performance

requires a culture of continual improvement. The research concludes that supply chain efficiency and long-term success need ongoing development.

5.5.2 Inventory Management

Research has shown that managing goods makes supply networks better. The company kept the most stock on hand by using MRP to guess what customers would want. This study on inventory management (Nahmias and Cheng, 2021; Silver et al., 1998) showed that keeping the right number of items in stock is important for keeping costs low and service levels high.

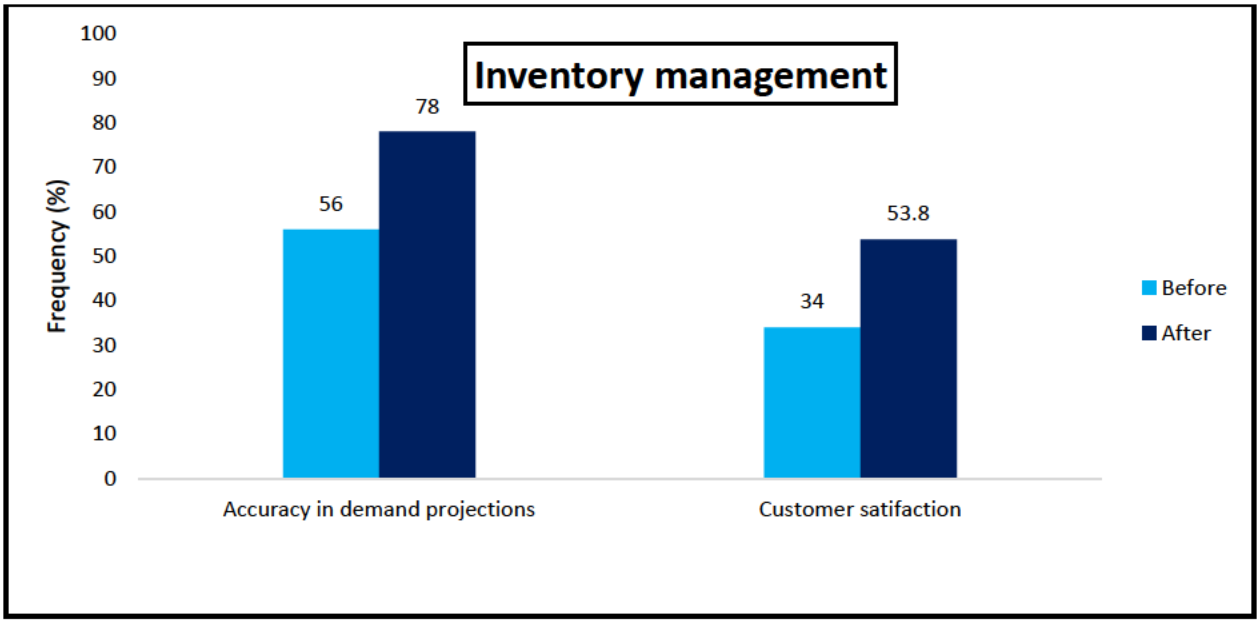

Figure 5.9: Inventory Management

Accurate demand estimates let the company save money on inventories. Tracking goods correctly decreases costs and increases supply chain flexibility, according to Chopra and Meindl (2016). The company retained adequate stock to assure supply and component availability. Less wait time made things quicker and smoother. The paper recommends inventory management to boost supply chain efficiency and save expenses.

Since Covid-19 broke out, customers would have to wait a lot longer for supplies and the earth-moving equipment manufacturer's suppliers had a hard time getting the parts they needed from their suppliers on time. Because backhoe buckets were in high demand, it was imperative that the earth-moving equipment manufacturer order supplies ahead of

time and concurrently keep inventory level at 40% and make sure they had enough to meet customer needs.

5.5.3 Production Scheduling

It was found from the study that scheduling output based on predicted customer orders improved supply chain efficiency. The MRP system lets the company schedule production based on consumer demand and material availability. Production scheduling literature suggests aligning production plans to demand projections to maximise resource usage and reduce lead times (Pinedo, 2016; Stevenson, 2018).

A detailed production schedule helps the organisation allocate resources and avoid bottlenecks. Synchronising production plans with client order estimations enhanced delivery times and customer satisfaction. The research found that production scheduling improves supply chain efficiency and customer satisfaction. In Figure 5.10, the manufacturing schedule shows product output levels over time. This chart shows the resource allocation and timescales for each production step, emphasising milestones and possible bottlenecks.

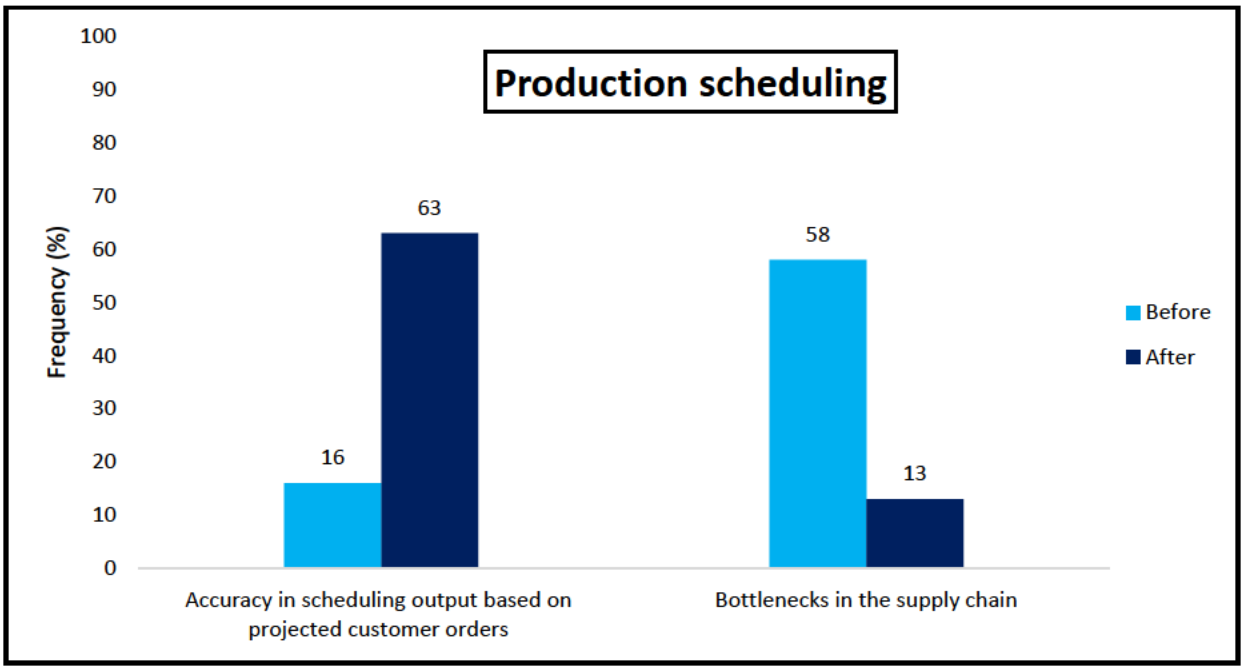

Figure 5.10: Production Schedule

5.5.4 Lead Time Reduction

The study found that cutting down on wait times made the supply system better. The MRP method helped the company figure out what customers wanted and when to make it. This found and fixed problems in the supply line. Cutting down on wait times has been shown in other studies to make the supply chain more flexible and lower product prices (Christopher, 2016; Hopp and Spearman, 2011). The effects of different methods used to cut down on wait times in the production process are shown in Figure 5.11 which shows the percentage drops in wait times that was caused by certain actions, like improving source teamwork and process optimisation.

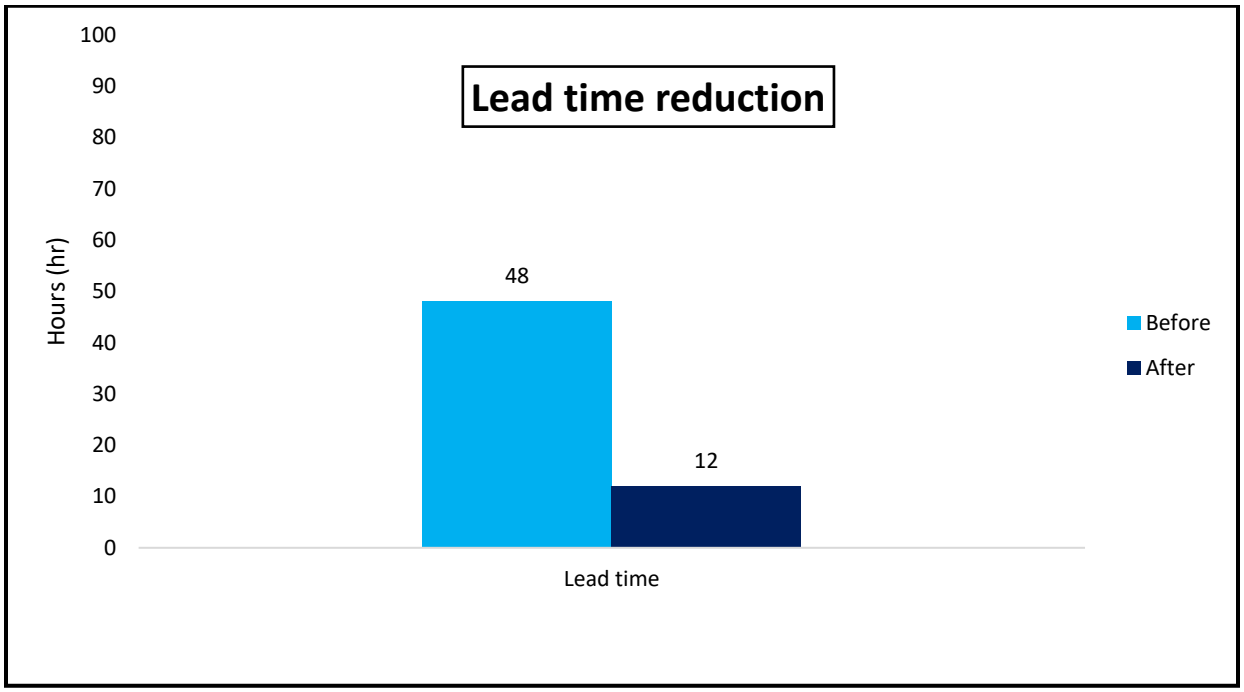

Figure 5.11: Lead Time Reduction

This study showed that lowering wait times boosted the firm's supply chain and productivity. Harrison and Van Hoek (2011) suggest minimising wait times to improve supply chain flexibility and efficiency. It fits their findings. Removing flaws and bottlenecks lowered wait times and enhanced the supply chain. The study shows that lowering wait times improves supply chains and matches customer needs.

5.5.5 Supplier Collaboration

The supply chain worked much better when providers worked together, the study found. The company made it easier to get supplies and work together by giving makers estimates of demand and plans for output. It has been found that having good ties with providers makes the supply chain work better (Monczka et al., 2015). Figure 5.12 shows how working together with suppliers can improve the efficiency of the whole supply chain. It does this by showing measures like better delivery times, lower costs, and higher quality. This graph shows the link between having strong relationships with providers and better business results.

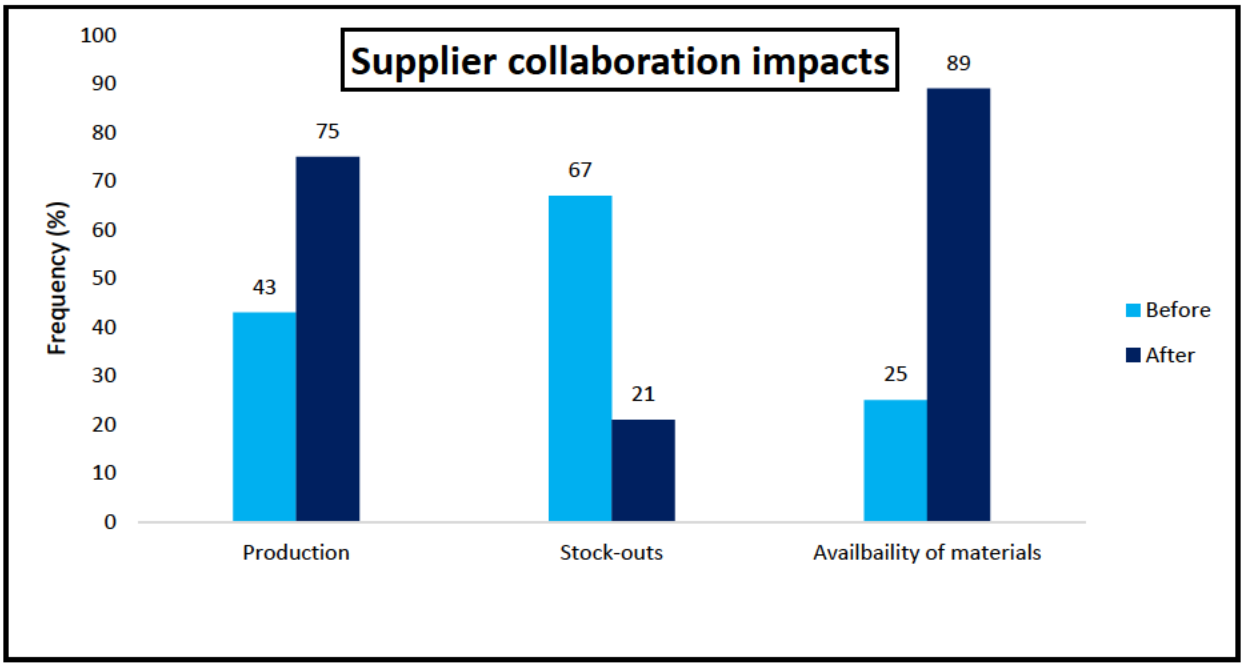

Figure 5.12: Supplier Collaboration Impacts

Supplier involvement increased material availability, reduced stock-outs, and accelerated production, according to our data. Lambert and Cooper (2000) found that supplier cooperation improves supply chain performance and reliability. Working closely with suppliers to assure material and component availability increased production and delivery efficiency. The research found that supplier cooperation improves supply chain efficiency and commodity accessibility.

5.5.6 Technology Integration

The study discovered that using MRP and Excel pivot tables for forecasts made the supply chain work better. With these tools, the company can look at customer orders, guess how much demand there will be, and plan production. Gunasekaran et al. (2017) and Waller and Fawcett (2013) posited that new technologies make the supply chain more open and help with making decisions.

Based on lessons learnt, the business was able to use new tools to get more information and make smarter choices. This made the delivery queue work better. In line with what Wamba et al. (2018) posited, this fact shows that digital technologies help people make better choices by making the supply chain more adaptable and clearly. By using cutting-edge technologies, the company was able to make its operations more efficient, cut down on wait times, and make the supply chain work better. So, the study shows that putting technology together is needed to make the supply chain work better and get to high levels of success. Figure 5.13 shows how integrating technology has improved the performance of the supply chain, showing gains in important areas like speed, accuracy, and adaptability. This graph shows data that shows how using new technologies like robotics and data analytics has improved the results of operations.

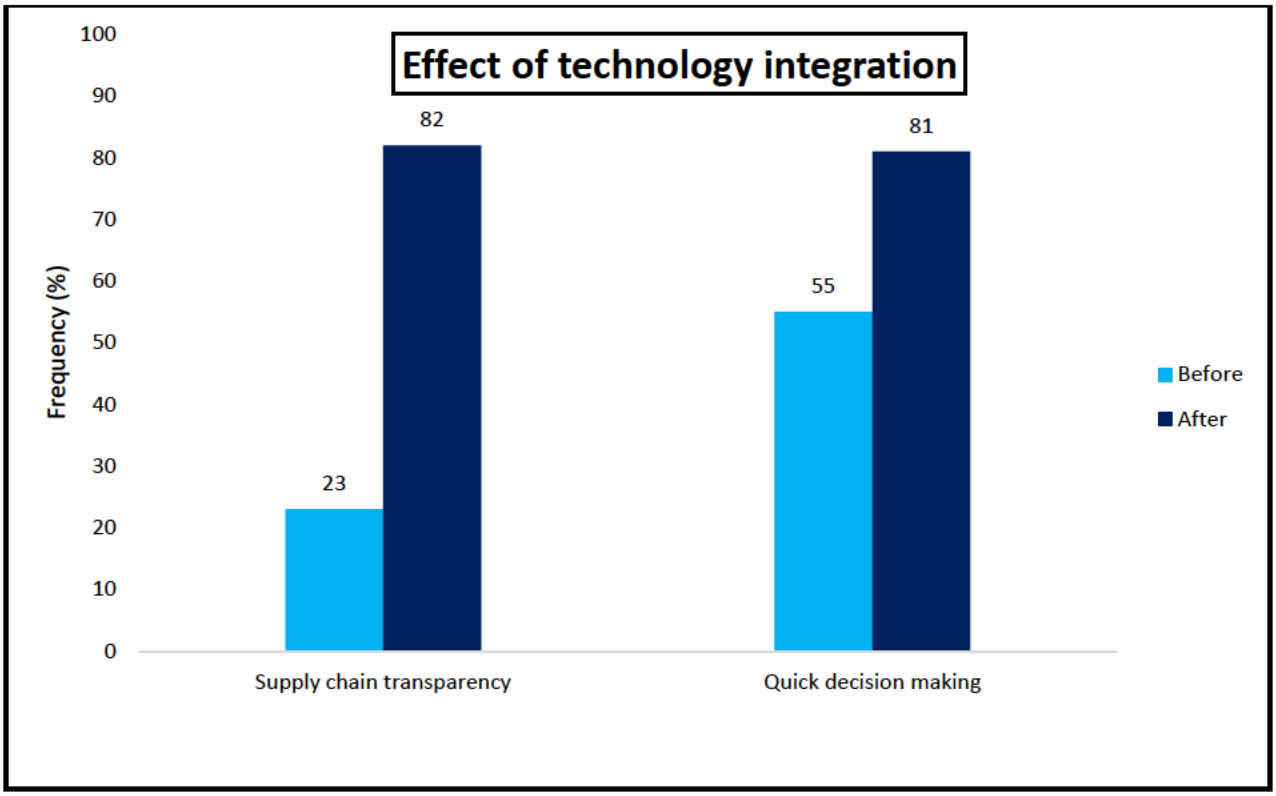

Figure 5.13: Effect of Technology Integration

5.6 Business model for supply chain optimization

The earth-moving equipment manufacturer's supply chain business model was vulnerable to the Covid-19 pandemic, requiring a full re-evaluation and optimisation approach. The pre-pandemic supply chain's JIT inventory system and lean manufacturing procedures were unable to manage the pandemic's widespread disruptions. A more robust and adaptive company model resulted.

Resilient supply chains integrate various strategic components to reduce future risks. Risk management emphasises on identifying possible disruptions and establishing effective mitigation strategies. This involves identifying essential supply chain relationships and proactively resolving weaknesses. According to Sheffi and Rice (2005), redundancies improve crisis resilience, to avoid single points of failure, numerous suppliers and different delivery routes are essential.

Implementing resilience metrics such as Time to Recover (TTR) and Time to Survive (TTS) helps analyse the supply chain's resilience to disturbances. TTR measures supply

chain recovery time, whereas TTS measures supply chain reliability under pressure. These measures help evaluate resilience and identify improvement areas, according to Pettit et al. (2019).

5.6.1 Resilient Sourcing and Procurement

Resilient sourcing and procurement is an important part of the suggested supply chain model. Using this method means coming up with two or more buying strategies, making flexible contracts, and building long-term relationships with important providers. The goal is to make a buying system that is fluid enough to let sourcing decisions be changed quickly when supply conditions change (Choi & Cheng, 2021). Ivanov and Dolgui's (2020) research back up this approach by showing how important it is to have flexible sources to make the supply chain more flexible during outages.

5.6.2 End-to-End Visibility and Real-Time Tracking

Supply chain optimisation requires end-to-end visibility and real-time tracking. IoT, RFID, and blockchain provide real-time supply chain inventory, shipping, and production monitoring. By offering full insights into supply chain operations, these technologies enhance decision-making and enable quick reactions to disturbances (Queiroz et al., 2020).

5.6.3 Agile Logistics and Distribution Networks

Another important part of the supply chain optimisation plan is the agile logistics and distribution networks. The plan encourages creating a flexible shipping network that can reroute packages and switch between different types of transportation as needed. By using cross-docking, decentralised warehouse, and delayed production methods, you can make the transportation network more flexible. This will cut down on wait times and improve the time to market (Christopher & Peck, 2020). Christopher (2016) posited that transport networks need to be flexible in order to deal with uncertainty well, which is in line with this agile method.

5.6.4 Data-Driven Decision-Making and Advanced Analytics

The optimised business model concludes with data-driven decision-making and advanced analytics. Big data analytics, predictive models, and machine learning

algorithms help firms make procurement, manufacturing, and logistical choices. Pattern recognition, disruption prediction, and operational process optimisation are possible with advanced analytics. Kache and Seuring (2017) found that data-driven solutions improve supply chain agility by offering actionable insights and predictive capabilities.

The case study supply chain optimisation model shows how integrating many tactics may help the earth-moving equipment company, as shown in Figure 5.14. A schematic shows how supply chain variables are linked in the supply chain optimisation model. To show how independent factors like forecasting and demand planning, inventory management, production scheduling, lead time reduction, and supplier cooperation affect technology integration, this graphic shows them.

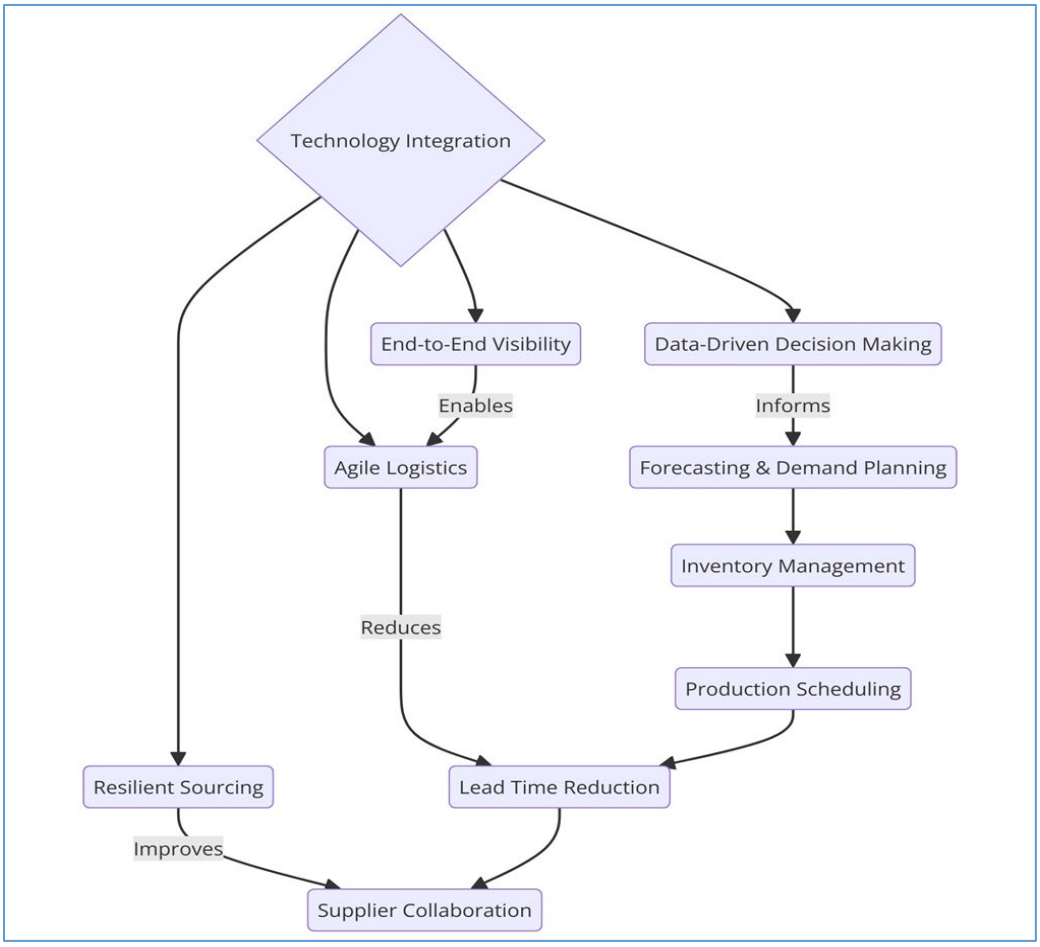

Figure 5.14: Schematic for key linkages between supply chain variables

In response to pandemic problems, a new supply chain optimisation model was created to show critical variable interactions. Figure 5.14 shows these variables' relationships.

The graphic shows technological integration as the dependent variable and resilient sourcing, end-to-end visibility, agile logistics, and data-driven decision-making as independent variables. These independent factors strengthen supply chain resilience and adaptation.

Restructured forward links show logical evolution in the model. Resilient sourcing improves supplier relationships and risk diversification, which improves coordination and end-to-end visibility. The organisation can dynamically adapt to supply chain shocks with agile logistics, and data-driven decision-making informs all elements of the model with sophisticated analytics and predictive insights.

The earth-moving equipment maker had a supply chain optimization model made for them. It shows the important connections between different supply chain factors and how they work together to improve total performance. Forecasting and planning for demand, managing supplies, planning production, cutting down on wait times, and working together with suppliers are all shown on the diagram as independent variables. Technology integration is shown as a dependent variable that is affected by these independent variables. This approach is the basis for figuring out how changes in these areas can make the supply chain work better as a whole.

Forecasting and Demand Planning - The investigation found that the company's MRP system recorded client orders and tracked demand fluctuations. The research found that the company's Material Requirements Planning (MRP) system better logged client orders and monitored demand. The company aligned supplier ordering and production planning using a six-month client demand projection. This strategy increased supply chain efficiency, enabling quick market reactions. The MRP system helped predict consumer demands, change production schedules, reduce surplus inventory, and prevent stockouts. Modern supply chain management best practices emphasises precise demand forecasting, which these advancements support. The company's proactive use of data analytics for demand forecasting has reduced demand fluctuation risks, stabilizing production flows and improving customer satisfaction.

Inventory Management - The study found that the company's inventory management, which was based on the MRP system's ability to predict demand, helped them keep the

right amount of stock on hand. The study showed that the company's inventory management, which was based on the MRP system's ability to predict demand, was very important in keeping the right amount of stock on hand. The company was better able to balance costs and service levels by keeping the right amounts of supplies based on what they thought customers would want. By taking this strategy approach, keeping costs went down and there were fewer cases of overstocking or running out of stock, both of which can hurt business efficiency. The case study showed that inventory change rates were looked at in a planned way and that things got a lot better after better inventory control measures were put in place. Just-In-Time stocking methods were used by the company. These made the supply chain more flexible so it could respond quickly to changes in customer demand.

Production Scheduling - The study found that arranging production based on expected customer orders improved the performance of the supply chain. Improving the production schedule was very important for the supply chain to work well. The company planned production based on what they thought customers would order and what they thought MRP demand would be. This arrangement made the best use of resources and cut down on waste for the maker. According to the study, these changes to the schedule cut down on idle time and increased productivity. The company also used adaptable production methods that let them quickly change plans to meet changing customer needs. Adapting to quickly changing customer needs is important in today's market.

Lead Time Reduction - Lead time reduction improved the company's supply chain, according to studies. MRP helped the company understand consumer demand and schedule production, resolving supply chain challenges. The study showed that lowering lead times improved supply chain performance. The MRP system helped the company assess client demand and synchronize production plans. This synchronization helped detect supply chain bottlenecks and prevent delays. Strategic actions including simplifying department communication and improving supplier response cut lead times, according to the report.

Supplier Collaboration - The schematic image shows that the last step in the organisation's supply chain management plans is for suppliers to work together. Even

though the text did not go into specifics about how the company worked with its suppliers, it seems likely that their efforts to improve forecasting, inventory management, production scheduling, and lead time reduction would have helped them work together better with their suppliers and make the most of their supply chain performance.

The diagram shows that working together with suppliers is an important part of the company's supply chain management plans. Even though the original study did not go into specifics about how the company worked with its suppliers, it seems likely that the better forecasting, inventory management, production scheduling, and shorter lead times all made it easier for the company to work together with its suppliers. The study showed that better contact and sharing of information with providers led to more reliable shipping dates and a better match between supply and production needs. The company started using shared planning methods, which let them do forecasts and inventory management with their main providers together. This teamwork not only improved the performance of the supply chain, but it also built stronger relationships with suppliers, which led to better terms for negotiations and better service levels.

Technology Integration - The schematic design shows Technology Integration as a cross-cutting facilitator supported by all supply chain optimization factors. The graphic shows technology integration as a key enabler impacted by supply chain optimization factors. The company improved its supply chain strategy by incorporating technology. Advanced technologies include data management systems, automation tools, and real-time visibility software improved function coordination and communication. The research found that these technology advances enhanced data accuracy and availability, enabling better decision-making. Technology in the supply chain optimised procedures and enabled innovation and ongoing development. Thus, the company became a competitive earth-moving equipment provider by improving its capacity to adapt quickly to market needs. The diagram shows how different supply chain factors are interrelated, providing a complete framework for understanding how changes in one area might benefit others.

5.7 Conclusion

The Covid-19 pandemic caused a lot of problems in the supply chain for a company that makes earth-moving equipment. This showed how important it is to have a more flexible

business plan. Just-in-time (JIT) and lean production supply chains did not work well enough to handle pandemics. It was important to use a supply chain model that is stronger, more flexible, and lasts longer in order to improve efficiency and ensure long-term success.

The results back up literature on supply chain security, digital change, joint work, speed, and sustainability. The company was able to solve problems and run easily thanks to a strong supply chain. Digitising the supply chain made it easier to see what was going on, make decisions, and run operations more efficiently.

Companies can quickly adapt to changes in supply and demand when they use flexible supply chain methods. The study suggests that sustainability should be a part of the supply chain business plan in order to make it more resilient and improve long-term success. The research discovered that the supply chain business model needs to be strong, able to react to digital transformation, work together, be flexible, and last a long time. These strategies helped the company that makes earth-moving equipment meet customer goals, make the supply chain work better, and still do well during the Covid-19 outbreak.

CHAPTER 6 : CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

Some worldwide supply networks were poor during the Covid-19 epidemic, thereby necessitating the need for reconfiguring supply chain strategies. This chapter presents research conclusions, summarises the recommendations from the study, and suggests future steps to conclude the study. This research examined how the Covid-19 epidemic impacted an earth-moving equipment manufacturer's supply chain, what affected its performance, how to make it more effective, and how to create a business strategy to minimise future pandemic consequences.

6.2 Research conclusions

6.2.1 Characterising supply chain elements

The first study goal was to outline the earth-moving equipment manufacturer's supply chain procedures and components. The results show a well-structured and integrated supply chain with four major departments, that is sales and operations, procurement, production, and dispatch, which are crucial to earth-moving equipment manufacture and delivery.

The sales and operations section handles key demand, sales, and production planning. The master scheduler in this department consolidates unit needs from subsidiaries and third-party clients into a Forecast Report (FCR), which is subsequently converted into a production plan called the Master Schedule. This ensures the material requirements planning (MRP) system generates work orders to meet demand.

The procurement department, often known as the buying department, purchases materials, equipment, and supplies for production. The department's buyer source, handle purchase orders, and communicate with suppliers to get the correct items at the greatest price. The department's buying application boosts efficiency and streamlines order-to-invoice processes.

Raw materials become completed earth-moving equipment in the manufacturing department, the supply chain's heart. Key manufacturing subtasks include machining, fabrication, painting, assembling, and inspection, according to the report. Pareto analysis

revealed significant supply chain inefficiencies during the Covid-19 pandemic, with 91% of ADT machines delivered 21 to 200 days late. Finally, dispatch manages the distribution, transportation, and delivery of completed items to consumers, warehouses, and other distribution sites. This department provides efficient forward and reverse products and information flow to fulfil client needs.

6.2.2 Factors affecting supply chain performance

The second study goal shed important light on the many factors that had a big effect on the earth-moving equipment manufacturer's supply chain performance during the Covid-19 pandemic. The results demonstrated that the company was facing problems that are complex and linked to each other. This shows how important it is to use methods for supply chain management that look at the whole system. At the heart of the problems in the supply chain was the problem of how reliable the suppliers were. An important reason why the maker took so long to fill customer orders for ADT machines was that providers could not keep their delivery promises. This shows that the business needs to improve how it manages its relationships with its suppliers so that everyone in the network is more open, works together better, and is held accountable.

How the maker managed their goods was closely linked to how reliable their suppliers were. Just-in-time inventory management worked well during normal times, but the company did not have enough extra stock to handle the problems in the supply chain caused by the pandemic. This result shows how important it is for inventory management to find the right mix between being efficient and being able to handle changes. One way to do this could be to use blend strategies that have parts of both lean and agile.

The study also showed that problems with the workers have a big effect on how well the supply chain works. Safety concerns, a lack of staff, lockdowns, and quarantine rules all slowed down production and delivery. This made it clear that the company needs to come up with strong workforce management strategies that put the health and safety of its employees first while keeping operations running smoothly.

During the outbreak, problems with transportation and handling also became a big factor in how well the supply chain worked. Things going wrong with transportation, like ports

closing, shipping being limited, and prices going through the roof, made it harder for the maker to get its goods to customers on time. This shows how important it is to use a variety of transportation methods, build stronger logistics relationships, and spend money on supply chain monitoring and optimization tools to make the logistics and transportation processes more resilient.

The study's results also showed how important it is for businesses to adopt new technologies to make their supply chains more resilient during the pandemic. Companies that had put money into digital supply chain technologies like blockchain, advanced analytics, and the Internet of Things (IoT) were better able to deal with the problems and keep their operations running smoothly. This makes it even more important for the maker to keep looking at and using new technologies that can make its supply chain more flexible, clear, and quick to act.

Changes in demand turned out to be another important factor affecting how well the manufacturer's supply chain worked. Customers' changing tastes and buying habits because of the pandemic made it very hard to match changing supply with changing demand. This shows how important it is to have good demand predicting and planning skills, as well as to learn more about how customers' wants and needs change over time.

The study also found that the manufacturer's inability to respond effectively to problems in the supply chain was hampered by a lack of money. Companies that did not have a lot of money had a hard time buying the tools, technologies, and tactics they needed to deal with the effects of the crisis. This shows how important it is to be financially stable and how important it is for the company to keep their finances in good shape so they can handle surprise costs and spend on supply chain optimization projects.

6.2.3 Deployment of value stream mapping

The third study aim was to deploy value stream mapping to identify areas for improving supply chain efficiency. It was concluded that some benefits were driven by the MRP system, which helped the organisation estimate and plan client demand. By properly estimating weekly needs and synchronizing manufacturing capacity, the firm reduced stock-outs and delays, improving customer satisfaction. It was also concluded that

capacity planning and demand forecasts are crucial. The organisation avoided production bottlenecks and overburdening the production department by precisely forecasting client demand and aligning it with actual production capabilities, according to the report. This proactive strategy enabled the organisation to adapt to demand fluctuations and preserve supply chain stability. Demand smoothing with staggered forecasts worked well too. The corporation stabilized material and product supply networks and reduced demand volatility by dividing manufacturing over weeks. This improved production efficiency and reduced disruptions.

Another element to supply chain efficiency was planning-production collaboration and communication. By aligning everyone with production objectives and restrictions, the organisation created realistic and feasible output plans. This collaborative strategy improved supply chain performance by building trust and responsibility. The company's supply chain optimization required flexibility and reactivity. By having a flexible manufacturing schedule, the firm could swiftly respond to demand fluctuations and better serve customers. This adaptability enables the organisation to respond faster to market changes, improving supply chain efficiency. The integration of modern technology like MRP systems and Excel pivot tables helped the organisation succeed. These technologies helped the organisation improve data analysis, decision-making, and supply chain optimization. The study shows that technology solutions enhance supply chains.

6.2.4 Concluding remarks on development of a supply chain model

In reaction to the problems caused by the Covid-19 pandemic, the fourth study goal is to rethink and improve the supply chain through development of a supply chain model. Because of the global health crisis, the standard supply chain approach of JIT inventory and lean production techniques did not work well when there were problems and uncertainty in the supply chain.

To deal with these problems and make its supply chain more reliable and effective, the maker used a complex strategy that included several important parts. Firstly, implementing a strong supply chain strategy turned out to be a major strategic change. This framework focused on making things more flexible, setting up backup and redundancy systems, and handling supply chain risks effectively. The maker was better

able to handle the pandemic and keep operations running smoothly by expanding its relationships with suppliers, keeping more important goods on hand, and using digital tools to improve supply chain monitoring.

The digitalization of the supply chain was also a key part of making the business plan work better. The maker was able to see more of the supply chain when they combined IoT, AI, and blockchain technologies. This made it possible to keep an eye on goods and resources in real time, predict demand, and handle transactions safely. These digital features made the supply chain much more reliable and efficient, which cut down on wait times and speed up delivery times.

The study also showed how important it is to work together with providers and other people involved in the supply chain. The company was able to match output and demand planning by building better relationships and keeping the lines of communication open with its key providers. They set common goals and worked together to solve problems. This way of working together made the supply chain more stable and quicker, which helped meet the needs of the end customers better.

When the maker used flexible supply chain methods, they were also able to respond quickly to changes in supply and demand. The company was able to respond quickly to changing market conditions and customer needs by using flexible methods like shorter wait times, longer order cycles, and better communication and teamwork. This made the supply chain work better overall.

Lastly, it became clear that a key long-term plan was to include environmental concerns in the supply chain business model. The case study's schematic model does a good job of showing how the manufacturer's different supply chain optimization methods are connected and depend on each other. It shows how combining demand forecasts, inventory management, production scheduling, lowering wait times, working together with suppliers, and combining technology all helped make the supply chain business model better. The fact that technology integration is a key factor in all these different supply chain variables shows how important digital transformation is for making the supply chain more resilient and better able to handle new challenges.

6.3 Recommendations

This analysis outlines several ways the earth-moving equipment manufacturer might strengthen its supply chain during Covid-19. The research identified key components, actors, and approaches these ideas address. The sales and operations planning (S&OP) process should be improved to increase demand forecasting and production planning accuracy and responsiveness. Advanced forecasting, improved communication with subsidiaries and clients, and real-time market data might help predict and adjust to shifting demand trends.

Supplier Relationship Management (SRM) in the Procurement Department should be optimised. This may need stronger supplier assessment and selection criteria, strategic alliances with key suppliers, and coordinated supply planning and inventory management. The firm should improve SRM by increasing openness, cooperation, and responsibility. To guarantee dependable and timely supply of vital components and supplies, strong supplier certification and monitoring systems and strategic collaborations with key suppliers should be implemented.

Customer service and assistance should be improved by the firm. The data shows several consumer complaints about high wait times and trouble contacting staff. Improved timeliness and customer service might alleviate these issues and boost customer satisfaction.

The organisation should prioritise data-driven decision making. The investigation illuminated consumer behaviour and market trends. The corporation may respond to shifting market dynamics by investing in data collecting, analytics, and strategic decision-making. The company should invest in and enhance supply chain digital transformation. The effective integration of IoT, AI, and block chain technology has improved visibility, real-time data analysis, and safe transaction management.

6.4 Area for future research

There is a lot of useful information in this study about how the Covid-19 pandemic affected the supply chain of a company that makes earth-moving equipment. But there are still some things that need more study. Long-term effects of digital change on supply chain

success should be looked at in future research. This study showed the short-term benefits of digital technology; however, it is very important to look at how they will affect stability and efficiency in the long run. Digital technologies should be tested to see how well they can grow and adapt to changes in the supply chain.

It is getting more and more interesting that sustainability is a part of supply chain management, hence, green practices, such as reducing carbon impacts and supporting ethical sources, should be studied more in the future to see how they affect the supply chain's security and efficiency.

AI could change how the supply line is managed. In the future, researchers should look into how AI could improve tasks in the supply chain, such as planning transportation, predicting demand, and managing stockpiles.

Future research work should focus on investigating how manufacturers are adapting their supply chains to prepare for future pandemics or similar disruptions. Studies may focus on examining strategies implemented for post-pandemic recovery and their effectiveness by exploring how manufacturers can better prepare for and mitigate the effects of global disruptions. Further studies may focus on assessing the trade-offs between nearshoring and globalization for heavy equipment manufacturers, as well as exploring how policy and regulatory changes could improve supply chain resilience in the heavy equipment industry.

6.5 Conclusion

The COVID-19 pandemic had a negative impact of the supply chain performance of an earth-moving equipment manufacturer. The study put emphasis on competitiveness and sustainability to mitigate Covid-19's impacts on the industry and its supply chains. A systematic research framework guided data gathering and analysis, yielding definitive results and meaningful suggestions for research and industry.

The findings emphasise on diversifying suppliers, improving inventory management, investing in workforce development, optimizing transportation and logistics, adopting digital technologies, improving demand planning and forecasting, strengthening financial stability, and ensuring regulatory compliance.

The business model that was developed attempted to decrease pandemic risks and increase supply chain resilience. The recommendations form the study strived to improve operational stability, meet customer demand, and boost long-term success. Future research should focus on digital transformation, sustainable supply chain practices, resilience metrics, geopolitical concerns, AI, and humanitarian supply chain issues.

References

Acar, Y., Kadipasaoglu, S. and Schipperijn, P., 2010. A decision support framework for global supply chain modelling: an assessment of the impact of demand, supply and lead-time uncertainties on performance. *International Journal of Production Research*, *48*(11), pp.3245-3268.

Adhikari, N. C. D., Domakonda, N., Chandan, C., Gupta, G., Garg, R., Teja, S., Das, L. and Misra, A. 2019. An intelligent approach to demand forecasting. In: Proceedings of *International Conference on Computer Networks and Communication Technologies: ICCNCT 2018*. Springer, 167-183.

Ahmed, W. and Huma, S., 2021. Impact of lean and agile strategies on supply chain risk management. *Total Quality Management & Business Excellence*, *32*(1-2), pp.33-56.

Alzoubi, H. M., Elrehail, H., Hanaysha, J. R., Al-Gasaymeh, A. and Al-Adaileh, R. 2022. The role of supply chain integration and agile practices in improving lead time during the Covid-19 crisis. *International Journal of Service Science, Management, Engineering, and Technology (IJSSMET)*, 13 (1): 1-11.

Amade, B., Akpan, E., Ubani, E., Amade and Amaeshi, F. 2016. Supply Chain Management and Construction Project Delivery: Constraints to its Application. *PM World Journal*, 5.

Anastasiadis, F., Liontakis, A. and Tsoulfas, G.T., 2024. End-to-End Mapping Towards Sustainability: The Case of the Cretan Vegetable Supply Chain. In *Value Chain Dynamics in a Biodiverse Environment: Advances in Biodiversity, Sustainability, and Agri-food Supply Chain Development* (pp. 1-14). Cham: Springer Nature Switzerland.

Arunkumar, J. and Gnanaprakasam, T. 2017. The Application Of Fishbone Diagram Approach For Improving The Poor Academic Performance In Secondary Schools. *Thiagarajar College Of Preceptors*, Article ID: 12.

Aslam, H., Khan, A.Q., Rashid, K. and Rehman, S.U., 2020. Achieving supply chain resilience: the role of supply chain ambidexterity and supply chain agility. *Journal of Manufacturing Technology Management*, *31*(6), pp.1185-1204

Blome, C., & Schoenherr, T. (2011). Supply chain risk management in financial crises—A multiple case-study approach. International Journal of Production Economics, 134(1), 43-57.

Bogiqi, S. and Palmgren, E., 2024. Navigating Through Turbulent Waters: Examining the Long-Term Impact of COVID-19 on global Supply Chains: Insights into the Resilience and Adaptation Strategies of Multinational Enterprises.

Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management: moving toward new theory. International Journal of Physical Distribution & Logistics Management, 38(5), 360-387.

Caridi, M., Cavalieri, S. and Dotti, S., 2010. Assessing the benefits of RFID technology in improving logistics performance. *International Journal of Production Economics*, 124(2), pp.447-458.

Carvalho, H., Naghshineh, B., Govindan, K. and Cruz-Machado, V. 2022. The resilience of on-time delivery to capacity and material shortages: An empirical investigation in the automotive supply chain. *Computers & Industrial Engineering*, 171: 108375.

Centobelli, P., Cerchione, R. and Esposito, E., 2020. Lean supply chain management in healthcare: A systematic literature review. *International Journal of Production Research*, 58(1), pp.87-109.

Chae, B. K. (2009). Developing key performance indicators for supply chain: an industry perspective. Supply Chain Management: An International Journal, 14(6)

Chang, W.S. and Lin, Y.T., 2019. The effect of lead-time on supply chain resilience performance. *Asia Pacific Management Review*, *24*(4), pp.298-309.

Chopra, S., & Sodhi, M. S. (2004). Managing risk to avoid supply-chain breakdown. MIT Sloan Management Review, 46(1), 53-61.

Chang, W.-S. and Lin, Y.-T. 2019. The effect of lead-time on supply chain resilience performance. *Asia Pacific Management Review*, 24 (4): 298-309.

Chopra, S. and Meindl, P., 2016. *Supply Chain Management: Strategy, Planning, and Operation*. Pearson.

Christopher, M., & Holweg, M. (2011). "Supply chain 2.0": managing supply chains in the era of turbulence. International Journal of Physical Distribution & Logistics Management, 41(1), 63-82.

Christopher, M., 2016. Logistics & supply chain management. Pearson UK.

Cousins, P. D., & Menguc, B. (2006). The implications of socialization and integration in supply chain management. Journal of Operations Management, 24(5), 604-620.

Cox, A. 1997. *Business success: A way of thinking about strategy, critical supply, chain assets and operational best practice*. Earlsgate Press.

Croom, S., Romano, P. and Giannakis, M. 2000. Supply Chain management: An analytical framework for critical literature review. *European Journal of Purchasing & Supply Management*, 6 (1): 67-87.

Esmizadeh, Y. and Mellat Parast, M. 2021. Logistics and supply chain network designs: incorporating competitive priorities and disruption risk management perspectives. *International Journal of Logistics Research and Applications*, 24 (2): 174-197.

García, S.G., Reyes, R.R. and García, M.G., 2018. Design of a Conceptual Model for improving company performance based on lean management applying the viable system model (VSM). European Journal of Engineering and Formal Sciences, 2(2), pp.49-63.

Gattinoni, S. 2022. Supply chain planning: inventory optimization through the demand forecasting tools and algorithm. Article ID.

Gereffi, G. (2020). What does the COVID-19 pandemic teach us about global value chains? The case of medical supplies. Journal of International Business Policy, 3, 287-301.

Glover, W.J., Farris, J.A., Van Aken, E.M. and Doolen, T.L., 2014. Critical success factors for the sustainability of kaizen event human resource outcomes: An empirical study. *International Journal of Production Economics*, 155, pp.216-226.

Gunasekaran, A., Subramanian, N., & Papadopoulos, T. (2017). Information technology for competitive advantage within logistics and supply chains: A review. Transportation Research Part E: Logistics and Transportation Review, 99, 14-33.

Gultom, G. D. P. and Wibisono, E. 2019. A framework for the impact of lean six sigma on supply chain performance in manufacturing companies. In: Proceedings of *IOP Conference Series: Materials Science and Engineering*. IOP Publishing, 012089.

Handfield, R. B., Graham, G., & Burns, L. (2020). Corona virus, tariffs, trade wars and supply chain evolutionary design. International Journal of Operations & Production Management, 40(10), 1649-1660.

Harrison, A. and Van Hoek, R., 2011. *Logistics Management and Strategy: Competing Through the Supply Chain*. Pearson Education.

Hasibuan, A., Arfah, M., Parinduri, L., Hernawati, T., Harahap, B., Sibuea, S.R. and Sulaiman, O.K., 2018, April. Performance analysis of supply chain management with supply chain operation reference model. In *Journal of Physics: Conference Series* (Vol. 1007, No. 1, p. 012029). IOP Publishing.

Haun, S., Sheoran, S. and Wang, G. 2004. Supply Chain Management: An International Journal. *A research and analysis of supply chain operations reference (SCOR) model*, 9 (1).

Heizer, J. and Render, B., 2014. *Operations Management: Sustainability and Supply Chain Management*. Pearson Education.

Hobbs, J.E., 2020. Food supply chains during the COVID-19 pandemic. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, 68(2), pp.171-176.

Hohenstein, N. O., Feisel, E., Hartmann, E., & Giunipero, L. (2014). Research on the phenomenon of supply chain resilience: A systematic review and paths for further

investigation. International Journal of Physical Distribution & Logistics Management, 45(1/2), 90-117.

Holmström, J., Ketokivi, M. and Hameri, A.P., 2010. Bridging practice and theory: A design science approach. *Decision Sciences*, 40(1), pp.65-87.

Ivanov, D., Dolgui, A., Sokolov, B., Ivanova, M., & Rozhkov, M. (2019). Literature review on disruption recovery in the supply chain. International Journal of Production Research, 57(8), 2757-2772.

Hopp, W.J. and Spearman, M.L., 2011. *Factory Physics*. Waveland Press.

Ishikawa, K., 1985. *What Is Total Quality Control? The Japanese Way*. Prentice Hall.

Ivanov, D. and Dolgui, A., 2020. Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. *International Journal of Production Research*, 58(10), pp.2904-2915.

Ivanov, D., 2020. Predicting the impacts of epidemic outbreaks on global supply chains: A simulation-based analysis on the coronavirus outbreak (COVID-19/SARS-CoV-2) case. *Transportation Research Part E: Logistics and Transportation Review*, 136, p.101922.

Ivanov, D., Dolgui, A., Sokolov, B., Ivanova, M. and Rozhkov, M., 2019. Literature review on disruption recovery in the supply chain. *International Journal of Production Research*, 57(8), pp.2757-2772.

Juran, J.M., 1999. *Juran's Quality Handbook*. McGraw Hill.

Jüttner, U., Peck, H., & Christopher, M. (2003). Supply chain risk management: Outlining an agenda for future research. International Journal of Logistics Research and Applications, 6(4), 197-210.

Kaplan, R.S. and Anderson, S.R., 2007. *Time-driven activity-based costing: A simpler and more powerful path to higher profits*. Harvard Business Press.

Karia, N., & Asaari, M. H. A. H. (2016). Innovation capability: the impact of e-collaboration and e-communication on supply chain performance. Journal of Industrial Engineering and Management, 9(2), 495-517.

Kehinde Busola, E., Ogunnaike Olaleke, O. and Adegbuyi, O. 2020. Analysis of inventory management practices for optimal economic performance using ABC and EOQ models. *International Journal of Management (IJM)*, 11 (7).

Khan, A.U., Huang, L., Onstein, E. and Liu, Y., 2022. Overview of emerging technologies for improving the performance of heavy-duty construction machines. *Ieee Access*, *10*, pp.103315-103336.

Kumar, A., Luthra, S., Mangla, S.K., and Kazançoğlu, Y., 2020. COVID-19 impact on sustainable production and operations management. *Sustainable Operations and Computers*, 1, pp.1-7.

Lambert, D. M. and Cooper, M. C. 2000. Supply Chain Management. *Industrial Marketing Management*, 29: 65-83.

Lee, H.L. and Whang, S., 2001. Winning the last mile of e-commerce. *MIT Sloan Management Review*, 42(4), p.54.

Masoudipour, E., Amirian, H. and Sahraeian, R. 2017. A novel closed-loop supply chain based on the quality of returned products. *Journal of cleaner production*, 151: 344-355.

Liker, J.K., 2004. *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*. McGraw-Hill.

McCaffer, R. and Root, D. 2000. *Supply Chain management in Construction*. Hong Kong

Mentzer, J., Dewitt, W., Keebler, J., Min, S., Nix, N., Smith, C. and Zacharia, Z. 2001. Defining Supply Chain Management. *Journal of Business Logistics*, 22.

Miranda, P., Silva, R., Da Silva, A. F. and Ferreira, C. 2020. *Kaizen Costing: Systematic Literature Review*.

Mishra, N.K., Pande Sharma, P. and Chaudhary, S.K., 2024. Redefining agile supply chain practices in the disruptive era: a case study identifying vital dimensions and factors. *Journal of Global Operations and Strategic Sourcing*.

Monczka, R.M., Handfield, R.B., Giunipero, L.C. and Patterson, J.L., 2015. *Purchasing and Supply Chain Management*. Cengage Learning.

Nahmias, S. and Cheng, Y., 2021. *Production and Operations Analysis*. Waveland Press.

Notteboom, T., Pallis, A., & Rodrigue, J. P. (2021). Disruptions and resilience in global container shipping and ports: A critical review. Maritime Economics & Logistics, 23(2), 269-297.

Odulaja, B.A., Oke, T.T., Eleogu, T., Abdul, A.A. and Daraojimba, H.O., 2023. Resilience in the face of uncertainty: a review on the impact of supply chain volatility amid ongoing geopolitical disruptions. *International Journal of Applied Research in Social Sciences*, *5*(10), pp.463-486.

Patel, A.R., Vyas, D.R., Markana, A. and Jayaraman, R., 2022. A conceptual model for integrating sustainable supply chain, electric vehicles, and renewable energy sources. *Sustainability*, *14*(21), p.14484.

Pettit, T. J., Fiksel, J., & Croxton, K. L. (2013). Ensuring supply chain resilience: Development and implementation of an assessment tool. Journal of Business Logistics, 34(1), 46-76.

Pinedo, M., 2016. *Scheduling: Theory, Algorithms, and Systems*. Springer.

Purwanto, J., Nasution, R.A. and Anggoro, Y., 2023. Gaining competitive advantage through corporate foresight value creation—The evidence from ASEAN automotive local affiliate companies. *Journal of Open Innovation: Technology, Market, and Complexity*, *9*(4), p.100143.

Queiroz, M.M., Ivanov, D., Dolgui, A. and Fosso Wamba, S., 2020. Impacts of epidemic outbreaks on supply chains: mapping a research agenda amid the COVID-19 pandemic through a structured literature review. *Annals of Operations Research*, pp.1-38.

Romero, D., Gaiardelli, P., Wuest, T., Powell, D. and Thürer, M. 2020. New forms of Gemba walks and their digital tools in the digital lean manufacturing world. In: Proceedings of *Advances in Production Management Systems. Towards Smart and Digital Manufacturing: IFIP WG 5.7 International Conference, APMS 2020, Novi Sad, Serbia, August 30–September 3, 2020, Proceedings, Part II*. Springer, 432-440.

Sengupta, K., Heiser, D. R. and Cook, L. S. 2006. Manufacturing and Service Supply Chain Performance: A Comparative Analysis. *Journal of Supply Chain Management*, 42: 4-15.

Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. Journal of Cleaner Production, 16(15), 1699-1710.

Sheffi, Y., & Rice, J. B. (2005). A supply chain view of the resilient enterprise. MIT Sloan Management Review, 47(1), 41-48.

Sheffi, Y., 2020. *The new (ab) normal: Reshaping business and supply chain strategy beyond Covid-19*. MIT CTL Media.

Shou, W., Wang, J., Wu, P., Wang, X. and Chong, H.-Y. 2017. A cross-sector review on the use of value stream mapping. *International Journal of Production Research*, 55 (13): 3906-3928.

Sidor, A. and Rzymski, P. 2020. Dietary choices and habits during COVID-19 lockdown. 12: 1657.

Silver, E.A., Pyke, D.F. and Peterson, R., 1998. *Inventory Management and Production Planning and Scheduling*. Wiley.

Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. (2014). Designing and managing the supply chain: Concepts, strategies and case studies. McGraw-Hill Higher Education.

Stevenson, W.J., 2018. *Operations Management*. McGraw-Hill Education.

Sudirjo, F. 2023. Marketing Strategy in Improving Product Competitiveness in the Global Market. *Journal of Contemporary Administration and Management (ADMAN)*, 1 (2): 63-69.

Swafford, P.M., Ghosh, S. and Murthy, N., 2006. The antecedents of supply chain agility of a firm: Scale development and model testing. *Journal of Operations Management*, 24(2), pp.170-188.

Tang, O. and Musa, S.N., 2011. Identifying risk issues and research advancements in supply chain risk management. *International Journal of Production Economics*, 133(1), pp.25-34.

Waller, M.A. and Fawcett, S.E., 2013. Data science, predictive analytics, and big data: A revolution that will transform supply chain design and management. *Journal of Business Logistics*, 34(2), pp.77-84.

Wamba, S.F., Akter, S., Coltman, T. and Ngai, E.W., 2018. The performance impact of big data analytics and supply chain ambidexterity: The moderating effect of environmental dynamism. *International Journal of Production Economics*, 203, pp.68-83.

Womack, J. P., & Jones, D. T. (2003). Lean thinking: Banish waste and create wealth in your corporation. Free Press.

Wong, W. and Wong, K. 2007. *Supply chain performance measurement system using dea modeling*. Available: http://emeraldinsight.com/Insight/ViewContentServlet;jsessionid=E57B39C6CE4796DA8D44590D80E6077B?File (Accessed

Zaidi, S.M.R., Alam, A. and Khan, M.Y., 2024. Enhancing Efficiency in Advanced Manufacturing through IoT Integration. *Engineering Headway*, *11*, pp.55-61.