INTEGRATING EFFECTIVE MRP WITH GREEN SUPPLY CHAIN PRACTICES TO ENHANCE SUSTAINABLE MANUFACTURING PERFORMANCE

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JULY 2025

INTEGRATING EFFECTIVE MRP WITH GREEN SUPPLY CHAIN PRACTICES TO ENHANCE SUSTAINABLE MANUFACTURING PERFORMANCE

BY
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Thesis Submitted
to College of Business
Universiti Utara Malaysia, in Partial Fulfilment of the Requirement
for the Master of Sciences
(Supply Chain Management

Kolej Perniagaan
(College of Business)
Universiti Utara Malaysia

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Tarikh: **29 Julai 2025**
Date:

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Tajuk Tesis / Disertasi : **Integrating Effective MRP with Green Supply Chain Practices to Enhance Sustainable Manufacturing Performance**
(Title of the Thesis / Dissertation)

Program Pengajian : **Master of Science (Supply Chain Management)**
(Programme of Study)

Nama Penyelia/Penyelia-penyelia : **Dr. Siti Norhasmaedayu Mohd Zamani**
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ACKNOWLEDGEMENT

First and foremost, I would like to express my sincere gratitude to the Almighty for granting me the strength, determination, and good health to complete this research successfully.

I am deeply thankful to my respected supervisor, **Dr. Siti Norhasmaedayu binti Mohd Zamani**, for her constant support, invaluable guidance, and encouragement throughout the course of this thesis. Her insightful feedback and patience helped me stay focused and motivated during every stage of this research journey.

I would also like to thank the faculty members and administrative staff of the Faculty of Technology Management and Business for their cooperation and assistance. My heartfelt thanks go to all the professionals and organizations who participated in the study and shared their valuable insights, making this research possible.

I am extremely grateful to my beloved parents and family for their endless love, understanding, and encouragement throughout this journey. Their support has been my pillar of strength.

Last but not least, I thank my friends and fellow researchers for their moral support, academic discussions, and the camaraderie that helped me remain positive and focused.

ABSTRACT

Malaysian manufacturing firms face increasing environmental regulations, rising demand for eco-friendly products, and operational challenges such as supply disruptions and cost pressures. Traditional practices often fail to balance efficiency with sustainability, highlighting the need to integrate effective Material Requirements Planning (MRP) with Green Supply Chain Practices (GSCP) to improve Sustainable Manufacturing Performance (SMP). Despite extensive use of MRP for inventory and production efficiency, limited research exists on its synergy with GSCP to achieve sustainability outcomes. This study addresses that gap by examining how dimensions of MRP effectiveness which are planning accuracy, inventory control, timeliness of materials, production scheduling, and operational impact influence SMP directly and indirectly through GSCP elements such as eco-design, green procurement, and reverse logistics. A structured questionnaire was distributed to 100 manufacturing firms registered under the Federation of Malaysian Manufacturers (FMM), using simple random sampling. Data was analyzed using SPSS version 27. Results reveal that MRP effectiveness significantly improves SMP and that this effect is amplified when mediated by GSCP. This research contributes to the Resource-Based View (RBV) theory by demonstrating how internal operational capabilities can serve as strategic assets for environmental and economic performance. Practically, the findings provide actionable insights for industry practitioners aiming to integrate digital planning tools with sustainable practices to achieve competitive and ecological benefits.

Keywords: *Material Requirement Planning, Green Supply Chain Practices, Sustainable Manufacturing Performance, Resource Based View, Federation Malaysian of Manufacturers*

ABSTRAK

Firma pembuatan di Malaysia berdepan dengan peningkatan peraturan alam sekitar, permintaan yang semakin tinggi terhadap produk mesra alam, serta cabaran operasi seperti gangguan bekalan dan tekanan kos. Amalan tradisional sering gagal mengimbangi kecekapan dengan kelestarian, sekali gus menekankan keperluan untuk menggabungkan keberkesanan MRP dengan GSCP bagi meningkatkan SMP. Walaupun penggunaan MRP secara meluas untuk kecekapan inventori dan pengeluaran telah lama wujud, kajian mengenai sinerginya dengan GSCP bagi mencapai hasil kelestarian masih terhad. Kajian ini menangani jurang tersebut dengan meneliti bagaimana dimensi keberkesanan MRP iaitu ketepatan perancangan, kawalan inventori, ketepatan masa bahan, pematuhan jadual pengeluaran, dan kesan operasi mempengaruhi SMP secara langsung dan tidak langsung melalui elemen GSCP seperti reka bentuk eko, perolehan hijau, dan logistik terbalik. Soal selidik berstruktur telah diedarkan kepada 100 firma pembuatan yang berdaftar di bawah FMM menggunakan persampelan rawak mudah. Data dianalisis menggunakan SPSS versi 27. Dapatan menunjukkan keberkesanan MRP secara signifikan meningkatkan SMP dan kesan ini diperkuatkan apabila dimediasi oleh GSCP. Kajian ini menyumbang kepada teori RBV dengan menunjukkan bagaimana keupayaan operasi dalaman boleh berfungsi sebagai aset strategik untuk prestasi alam sekitar dan ekonomi. Secara praktikal, dapatan ini memberikan panduan berguna kepada pengamal industri yang ingin menggabungkan alat perancangan digital dengan amalan lestari bagi mencapai kelebihan daya saing dan manfaat ekologi.

Kata Kunci: P*erancangan Keperluan Bahan, Amalan Rantaian Bekalan Hijau, Prestasi Pembuatan Lestari, Pandangan Berasaskan Sumber, Persekutuan Pengilang-Pengilang Malaysia.*

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
BDA	Big Data Analytics
CEO	Chief Executive Officer
ERP	Enterprise Resource Planning
FMM	Federation of Malaysian Manufacturers
GSCP	Green Supply Chain Practices
GSCP-ED	Green Supply Chain Practices – Eco-Design
GSCP-GP	Green Supply Chain Practices – Green Procurement
GSCP-RL	Green Supply Chain Practices – Reverse Logistics
IoT	Internet of Things
IMP	Industrial Master Plan
MRP	Material Requirements Planning
MRP-PA	Material Requirements Planning – Planning Accuracy
MRP-IC	Material Requirements Planning – Inventory Control
MRP-TM	Material Requirements Planning – Timeliness of Materials
MRP-PSA	Material Requirements Planning – Production Schedule Adherence
MRP-OI	Material Requirements Planning – Operational Impact
RBV	Resource-Based View
SDGs	Sustainable Development Goals
SEM	Structural Equation Modeling
SMEs	Small and Medium Enterprises
SMP	Sustainable Manufacturing Performance
SMP-ENV	Sustainable Manufacturing Performance – Environmental Outcomes
SMP-OP	Sustainable Manufacturing Performance – Operational Outcomes
SMP-EC	Sustainable Manufacturing Performance – Economic Outcomes
SPSS	Statistical Package for the Social Sciences
TBL	Triple Bottom Line

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CHAPTER 1

INTRODUCTION

1.0 Introduction

This chapter will outline the background, problem statement, research objectives, research questions, and scope. The study focused on how the effectiveness of material requirements planning (MRP) through planning accuracy, inventory control, timeliness of materials, production schedule adherence, and operational impact was integrated with green supply chain practices (GSCP) such as eco-design, green purchasing and cooperation with customers affect the implementation of sustainability in terms of environmental, operational, and economic outcomes on performance in Malaysian manufacturing firms.

1.1 Background of the Study

The integration of MRP with environmentally conscious supply chain practices has emerged as a vital strategy for achieving sustainable performance in manufacturing. As organisations seek to balance operational efficiency with ecological responsibilities, effective MRP ensures that materials are available at the right time while supporting waste reduction and resource optimisation critical to sustainable manufacturing (Gomaa, 2024). For example, the fast-moving consumer goods sector illustrates how strategic operations management can enhance efficiency while meeting consumer demand (Olutimehin et al., 2024). By linking MRP with environmentally sound practices, manufacturing industries can address the dual challenge of maintaining affordability and accessibility while advancing sustainability (Doroshenko, 2023; Luu, 2023).

Integrating MRP with GSCP is crucial to boosting sustainable manufacturing performance. MRP enhances production efficiency and inventory management by synchronising supply with demand, reducing waste from overproduction and excess stock. This aligns with GSCP's focus on minimising environmental impact through sustainable resource management and eco-friendly processes (Dias et al., 2021). Recent studies highlight MRP's role in enabling real-time data integration, improving decision-making, and resource allocation, particularly in developing economies (Mohammed et al., 2024). A well-functioning MRP that incorporates green practices supports long-term organisational success while fulfilling ecological responsibilities (Lambert et al., 2024; Wei et al., 2023).

When implemented effectively, MRP improves operational efficiency, ensures production matches actual demand, and reduces excess inventory costs, thereby improving cash flow (Lambert et al., 2024). Integrated with GSCP, it encourages manufacturers to adopt lean and environmentally responsible operations (Dias et al., 2021). This combination prioritises both economic and environmental performance, enabling manufacturers to respond swiftly to market demands while improving sustainability outcomes (Wei et al., 2023; Mohammed et al., 2024). Additionally, robust MRP systems manage inventory, schedules, and resource allocation with precision, streamlining processes, minimising waste, and enhancing resource usage is key to balancing profitability with environmental stewardship (Gupta & Sachan, 2024; Nweje & Taiwo, 2025).

GSCP plays a pivotal role in improving sustainability by integrating environmental considerations into supply chain management, enhancing operational efficiency, reducing waste, and lowering carbon emissions (Wang, 2023; Fu et al., 2024). These practices also strengthen competitiveness, customer satisfaction, and brand loyalty (Sutia, 2022; Esan et al., 2024). Furthermore, GSCP can drive innovation through new technologies and digital tools that improve transparency, adaptability, and responsiveness (Esangbedo et al., 2024; Reynolds, 2024). Beyond internal improvements, GSCP fosters stakeholder engagement, supplier collaboration, and community partnerships, delivering shared environmental benefits and resilience (Purvis & Fernandez, 2024; Yuan, 2024; Aminnaseri & Taleghani, 2023). Overall, integrating MRP effectiveness with GSCP is not merely a trend but a strategic imperative for sustainable manufacturing performance in today's eco-conscious and competitive global market (Causil & Morais, 2023; Zhu, 2024; Reynolds, 2024).

1.2 Problem Statement

In Malaysia's current manufacturing landscape, firms are increasingly challenged to meet both operational efficiency and environmental sustainability goals. As they strive to remain competitive in a dynamic global market, the pressure to reduce production waste, optimise inventory, and comply with environmental regulations has become more pressing. Yet, while many firms adopt Material Requirements Planning (MRP) systems to enhance production and inventory control, these systems often lack integration with environmental considerations such as carbon reduction, green procurement, or circular design (Al-Hussaini et al., 2023; Bataineh et al., 2025). This disconnects between operational tools and sustainability objectives has resulted in inefficiencies, missed cost-saving opportunities, and difficulties in aligning with national and international green targets.

However, Malaysian manufacturing industries are increasingly confronted with the complex challenge of reconciling operational efficiency with environmental stewardship. Traditional MRP, although initially designed to optimise production and inventory control, often fall short in addressing environmental impacts or incorporating green supply chain practices (Xu et al., 2023). This disconnect reveals a deeper structural issue, the lack of integration between MRP effectiveness and sustainable supply chain initiatives, which may lead to reduced manufacturing performance and a heightened ecological footprint. For example, Panasonic Malaysia, with its factory located in Shah Alam, effectively applies an integrated MRP system through SAP ERP to manage its complex production schedules for electronics and home appliances (Saidatul, 2023). The company uses MRP to align procurement, production, and inventory levels with customer demand and delivery timelines. Its MRP system enables accurate planning of materials and components across multiple product lines, reducing excess inventory and production delays. Another example is Top Glove, the world's largest glove manufacturer based in Klang, also utilises MRP modules within its enterprise planning system to handle large-scale production scheduling and raw material planning (Top Glove, 2024). The company's MRP system is designed to respond to fluctuating global demand, which became especially critical during the COVID-19 pandemic. By automating production forecasts, material purchasing, and inventory monitoring, the system reduces lead times and improves responsiveness.

Despite numerous sustainability initiatives introduced by the Malaysian government including the Industrial Master Plan (IMP) and carbon emission reduction frameworks many manufacturing firms still struggle to incorporate Green Supply Chain Practices (GSCP) into their daily operations (Cheng et al., 2023; Zahari et al., 2024). Traditional MRP systems were primarily developed for production planning and inventory accuracy, but their application rarely extends to sustainability metrics or environmental decision-making (Xu et al., 2023). This creates a significant practical challenge, especially for firms that operate under increasing pressure to meet corporate social responsibilities, regulatory compliance, and international sustainability certifications (Ong et al., 2022; Krishnan et al., 2024). Many small and medium enterprises (SMEs), in particular, lack the resources and strategic direction to effectively merge operational performance with environmental stewardship.

From a research standpoint, the literature remains limited in empirically examining the synergistic impact of MRP and GSCP on Sustainable Manufacturing Performance (SMP). While several studies discuss MRP's effect on scheduling and inventory outcomes, and others analyse GSCP’s role in environmental improvements, few have focused on the combined influence of these systems (Rajaratnam et al., 2023; Tsai et al., 2025). Furthermore, scholars highlight the absence of an integrative framework that examines how dimensions of MRP such as planning accuracy, timeliness of materials, production schedule adherence, and operational impact interact with green practices like eco-design, green procurement, and reverse logistics to enhance sustainability (Lee & Qi, 2021; Lim et al., 2021). This highlights a clear research gap in both theory and application, especially within the Malaysian context where sustainability has become a central policy concern.

Malaysian firms are now under increasing pressure to adopt more sustainable operational models as part of the country’s commitment to global and regional environmental goals. This transition is driven by national agendas such as the Twelfth Malaysia Plan (2021–2025) and the newly launched Industrial Master Plan 2030 (IMP 2030), both of which emphasize the urgent need to reduce carbon emissions, promote resource efficiency, and accelerate green industrial transformation. The government has pledged to reduce greenhouse gas (GHG) emissions intensity by 45% by 2030 compared to 2005 levels, as part of its commitment to the Paris Agreement. Despite these policy directions, Malaysia's manufacturing sector remains a significant contributor to carbon emissions, primarily due to its heavy reliance on energy-intensive production, inefficient resource use, and a lack of integration between production planning and environmental performance.

According to the Climate Transparency Report 2023, Malaysia's carbon emissions per capita stood at approximately 7.7 metric tons, which is above the global average. The industrial sector alone contributes to over 30% of the country's total emissions, underscoring the sector's pivotal role in driving or hindering national sustainability progress. In this context, manufacturing firms that fail to integrate sustainability into their operations risk facing regulatory penalties, market restrictions, and reputational harm, especially as international supply chains demand greater environmental accountability. As such, improving the effectiveness of Material Requirements Planning (MRP) systems and embedding them with Green Supply Chain Practices (GSCP) becomes not only a strategic necessity but also a compliance-driven imperative.

Integrating MRP with green practices such as eco-design, green procurement, and reverse logistics can help manufacturers minimise production waste, optimise energy usage, and improve supply chain transparency. These improvements support the broader goals of reducing environmental impact while maintaining or enhancing operational efficiency. When implemented effectively, this integration contributes to Sustainable Manufacturing Performance (SMP) by aligning internal operational processes with environmental objectives. Hence, the contributions of this study are multifaceted: it provides a pathway for Malaysian manufacturers to comply with national sustainability targets, reduce their ecological footprint, and improve long-term competitiveness in a rapidly greening global economy.

There are also operational risks to ignoring this integration. Firms that fail to adopt green practices risk increased costs from inefficiencies, non-compliance penalties, reputational harm, and weakened competitiveness in global markets (Handiyanto et al., 2024; Lee & Qi, 2021). Research shows that manufacturers that successfully integrate MRP with GSCP experience improved supply chain transparency, enhanced social capital, and better responsiveness to market changes (Khalila et al., 2024; Zailani et al., 2023). Moreover, SMP outcomes such as improved environmental performance, lower production costs, and higher customer satisfaction are more achievable when operational planning tools are aligned with green initiatives (Zahari et al., 2023).

This study therefore addresses both a theoretical and practical need to explore and validate how MRP effectiveness can be leveraged to support sustainability initiatives within manufacturing operations. Specifically, this research aims to empirically investigate the relationship between MRP effectiveness, GSCP, and SMP in Malaysian manufacturing firms registered under the Federation of Malaysian Manufacturers (FMM). Guided by the Resource-Based View (RBV) theory, the study contributes to understanding how internal operational capabilities like MRP can act as strategic resources to support green transformation. In doing so, this research supports Malaysia's ambition for a greener industrial sector and provides manufacturers with practical insights on how to integrate sustainability directly into their core operational systems (Shaharudin et al., 2022; Omotayo, 2023).

In conclusion, this problem statement underscores the pressing need for a synergistic relationship between MRP effectiveness and Green Supply Chain Practices

(GSCP) to elevate Sustainable Manufacturing Performance (SMP). MRP effectiveness reflected through accurate planning, timely material procurement, efficient inventory control, and adherence to production schedules plays a crucial role in reducing operational waste, preventing stockouts or overproduction, and improving resource utilisation. When such planning capabilities are integrated with environmentally responsible practices like eco-design and green procurement, the result is a more agile, cost-efficient, and sustainable production system. This study contributes by demonstrating how the internal operational strengths offered by an effective MRP system can be strategically aligned with green initiatives to achieve both environmental compliance and competitive performance. Ultimately, this integration is vital in guiding Malaysia's manufacturing sector toward a more resilient, environmentally responsible, and globally competitive future.

1.3 Research Questions

In this study, the effectiveness of MRP and their potential influence on GSCP and SMP were examined within manufacturing organizations registered under the Federation of Malaysian Manufacturers (FMM). The research questions were formulated to explore how the independent variable MRP process effectiveness affected SMP, and to what extent GSCP served as a mediating factor in this relationship. These questions were developed to address identified gaps in the literature and to align with the overall research objectives.

1. What is the relationship between MRP effectiveness and SMP?
2. What is the relationship between GSCP and SMP?
3. To what extent do GSCP mediate the relationship between MRP effectiveness and SMP?

1.4 Research Objectives

Based on the research questions, the study aims to establish clear and actionable objectives that will systematically address each aspect of sustainable manufacturing performance within FMM. These objectives are designed to explore the direct and indirect effects of various factors, providing a structured approach to understand and enhance GSCP through MRP effectives and SMP.

1. To investigate the relationship between MRP effectiveness and SMP.
2. To investigate the relationship between GSCP and SMP.
3. To investigate the mediating role of GSCP in the relationship between MRP effectiveness and SMP.

1.5 Scope of Study

The scope of this study critically examines the intersection of MRP effectiveness and GSCP in driving SMP within the Malaysian manufacturing industry. Specifically, the study targets medium to large-sized manufacturing firms registered under the Federation of Malaysian Manufacturers (FMM).

By targeting manufacturing firms registered under the FMM, the research situates its scope within an industry-representative setting that reflects the diversity of manufacturing sector.

To capture these complex dynamics, the research adopts a quantitative survey-based methodology. The researcher collected the data from key stakeholders in the Malaysian manufacturing industry, including one Chief Executive Officer (CEO), production managers, supply chain managers, and operations executives across FMM-member firms. This respondent mix ensures a balanced perspective across strategic, tactical, and operational levels of decision-making, allowing the study to assess both top-down and bottom-up insights into the implementation of integrated sustainable practices.

1.6 Limitation of Study

This study also bears the following limitations that can influence the scope, method used and findings in the study. Despite the efforts to reduce possible biases, the following limitations have been taken into consideration.

The research takes time which is limited and may not be enough to get proper data gathering and analysis. However, lack of resources may also limit the possibility to reach more manufacturing sector in Malaysia and or a diverse group of them.

In fact, the study sample is restricted only to manufacturing sector located in Malaysia, which can reduce the extendibility of the results to other countries or large firms. Moreover, it is also vital to take note that the disparity of results may vary across industries, therefore, data in the manufacturing sector considerably different from one another.

The data for the study is collected through online questionnaires, which often present a number of limitations including socially desirable responding, respondent's memory distortion or selective recalling of information or selective attention and comprehension by the respondent. Such biases can affect the internal and external validity of the data collected within the research area.

The survey explores concepts which can be generally comprehended as MRP and GSCP integration that is not comprehensively adopted by all participants. Lack of constancy in the understanding and experience of the respondents with regard to these concepts can hamper the accuracy of information provided. This research work will employ cross-sectional research design whereby the information to be collected is obtained at one point in time. This approach hampers facilitation of an evaluation of the future trends of MRP, GSCP, and SMP.

It is here that these limitations are acknowledged to offer a clear understanding of both the process and results of this study. However, due to these challenges the study intends to make significant contribution towards identifying and establishing the MRP factors for the SMP of manufacturing sector which could act as avenue for further research and as reference point for future use.

1.7 Significance of Study

The integration of MRP with GSCM represents a pivotal advancement in the pursuit of SMP. In the current era, where environmental concerns are increasingly influencing corporate strategy, manufacturers are compelled to adopt systems that balance economic efficiency with ecological responsibility. This study addresses a significant research gap by investigating how the synergistic relationship between MRP effectiveness and green supply chain initiatives can be strategically harnessed to enhance sustainability outcomes across operational, environmental, and economic dimensions.

The significance of this research lies in its potential to inform both theory and practice. From a theoretical standpoint, this study contributes to the emerging body of knowledge that intersects operations management, supply chain planning, and sustainability science. While prior studies have independently explored MRP and GSCP, the integrated perspective remains under-examined, especially within the context of developing economies such as Malaysia, where FMM dominate the industrial landscape (Lin et al., 2020). Many studies focus on manufacturing companies rather than service companies due to the tangible nature of products, which allows for easier measurement and standardization of key performance indicators (KPIs). Manufacturing also often represents a more substantial portion of a country's economy and offers readily observable impacts on employment and GDP. Furthermore, the historical dominance of manufacturing in industrial economies has led to a more established body of research and established best practices (Ettlie & Rosenthal, 2011). By examining this integration, the study responds to calls for a more holistic understanding of how effective MRP planning tools can support sustainability-oriented transformations within the manufacturing sector (Dias et al., 2021; Mohammed et al., 2024).

From a practical perspective, the study offers actionable insights for supply chain professionals, policymakers, and industry leaders. MRP, traditionally used to optimize production scheduling and inventory management, have now become instrumental in supporting lean and green operations. When aligned with GSCP such as green eco-design, green purchasing, can reduce material waste, improve energy utilization, and promote circularity in supply chains (Alves et al., 2024; Vallés Fuster et al., 2024). Furthermore, the integration of advanced information and communication, including predictive analytics and real-time data sharing, enhances visibility across the supply network, enabling more agile and environmentally responsible decision-making (Silva et al., 2021).

The importantly, this study is situated within the context of GSCP and MRP transformation, where manufacturers are increasingly pressured to adopt smart technologies to remain competitive. The integration of MRP with GSCP supports this transition by providing a structured, data-driven foundation for achieving sustainability goals, optimizing resource utilization, and minimizing environmental externalities. As such, this research offers a roadmap for manufacturers especially FMM manufacturing firms in emerging markets to transition from reactive compliance-driven models to proactive, strategically aligned sustainable manufacturing systems.

Ultimately, this study contributes to sustainability discourse by articulating how integrated operational systems can generate long-term value for both the organization and the environment. In doing so, it advances the Sustainable Development Goals (SDGs), particularly those related to responsible consumption and production (SDG 12), climate action (SDG 13), and industry innovation (SDG 9). The findings will thus be instrumental in shaping industrial strategies that are not only efficient and cost-effective but also environmentally sustainable and socially responsible.

1.8 Conceptual Definitions

i. Material Requirements Planning (MRP)

MRP play a vital role in improving manufacturing efficiency by optimizing cost management, production scheduling, and resource utilization. Khumla and Sarawan (2023) note that effective MRP implementation enhances financial health, while Mourtzis et al. (2015) highlight the cost-saving benefits of cloud-based MRP for SMEs. The adaptability of MRP to production changes is essential, as emphasised by Lagos et al. (2023), and barriers such as limited technological skills must be addressed to boost productivity (Tamalika et al., 2024). Integrating real-time data further strengthens MRP performance, allowing for dynamic decision-making and improved responsiveness (Mourtzis et al., 2015; Yovita, 2020).

ii. Green Supply Chain Practices (GSCP)

GSCP refers to the integration of environmentally conscious methods throughout the supply chain, encompassing every phase from product design to end-of-life disposal. GSCP aims to minimize the ecological footprint of supply chains while simultaneously maximizing resource efficiency and operational performance. Khan et al. (2022) emphasize that effective GSCP practices lead to reduced waste and improved company performance, facilitating a transition toward greener business frameworks. Similarly, Indrianto and Kusmantini (2022) highlight the need to reconsider traditional supply chain practices to mitigate environmental impacts, positioning GSCP as a viable and strategic solution. In summary, GSCP serves as a vital mechanism for companies seeking to integrate environmental sustainability into their core operations, thereby contributing to broader societal and ecological benefits.

iii. Sustainable Manufacturing Performance (SMP)

SMP reflects a balance of economic, environmental, and social goals, driven by responsible production practices. Harikannan et al. (2023) highlight that sustainable manufacturing significantly influences all dimensions of sustainability. Expanding on this, Harikannan and Vinodh (2024) note that it includes both environmental tools and performance outcomes. Walisundara et al. (2022) affirm that green practices are positively linked to sustainable organizational performance. Alayón et al. (2022) define sustainable manufacturing through the triple bottom line framework, while Wassan et al. (2023) emphasize that adopting sustainability principles enhances economic, social, and environmental outcomes. Together, these studies underline that sustainable manufacturing performance is achieved through integrated practices that promote long-term value across all dimensions

1.9 Organization of the Thesis

This thesis was divided and organized into five chapters, each addressing a distinct component of the research. The structure was designed to systematically guide the reader through the research process, from the introduction of the problem to the conclusions drawn from the findings.

Chapter 1 provided an introduction to the research topic, outlining the research problem, questions, objectives, scope, limitations, and definitions of key terms. This chapter established the foundation for the entire thesis by setting the context and clarifying the research aims.

Chapter 2 reviewed the relevant literature, offering a comprehensive overview of previous studies and theoretical frameworks related to the research topic. It identified gaps in the existing body of knowledge and positioned the current study within the broader academic discourse.

Chapter 3 described the research methodology employed in the study, including the research design, data collection methods, sampling techniques, and data analysis procedures. This chapter ensured the research process was conducted in a transparent, systematic, and replicable manner.

Chapter 4 presented the findings derived from the data analysis. It provided a detailed account of the results, supported by relevant tables, figures, and statistical outputs. This chapter addressed the research questions and tested the hypotheses outlined in Chapter 1.

Chapter 5 discussed the findings in relation to the literature reviewed in Chapter 2. It interpreted the results, explored their theoretical and practical implications, and reflected on their relevance to the study's conceptual framework. This chapter also acknowledged the study's limitations and proposed recommendations for future research. Finally, it concluded the thesis by summarizing the key findings, highlighting their significance, and outlining the study's contributions to the field.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter critically reviews the existing literature on the effectiveness of MRP, the mediating role of GSCP, and their combined influence on SMP. The review aims to identify gaps in the current body of knowledge, explore relevant theoretical foundations, and justify the conceptual framework proposed for this study. It offers a comprehensive synthesis of how MRP planning tools and environmentally responsible practices can work synergistically to advance sustainability within the Malaysian manufacturing sector. By addressing research gaps, clarifying theoretical constructs, and supporting hypothesis development, this chapter establishes a solid foundation for the study's conceptual model. The subsequent chapter will detail the research methodology, including the data collection procedures and analytical techniques employed.

2.1 MRP Effectiveness and Sustainable Manufacturing Performance

MRP is a production planning and inventory control system designed to manage manufacturing processes by ensuring that materials and products are available for production and delivery in the right quantities and at the right time. Originally developed to improve operational efficiency and reduce inventory costs, MRP systems have evolved with digital technologies to enhance real-time planning, scheduling accuracy, and resource utilisation (Bataineh et al., 2025). Key dimensions of MRP effectiveness include planning accuracy, inventory control, timeliness of materials, and production schedule adherence (Shaharudin et al., 2022). These capabilities not only improve operational responsiveness but also support lean manufacturing principles by reducing waste and improving material flow across the supply chain. Despite its widespread adoption, research suggests that the full potential of MRP is yet to be realised when it comes to integrating environmental concerns and sustainability performance (Xu et al., 2023).

SMP represents the extent to which a manufacturing firm achieves its operational, environmental, and social goals simultaneously. It reflects a firm's ability to produce goods efficiently while minimising environmental harm, conserving resources, and supporting social well-being (Ong et al., 2022). Typical indicators of SMP include reductions in waste, energy and water use, improvement in product quality, cost savings, and adherence to environmental standards. SMP is increasingly viewed as a critical dimension of competitiveness in the global market, where firms are expected to align with frameworks like the United Nations Sustainable Development Goals (SDGs) and national sustainability targets (Selvaraju et al., 2022). Scholars have stressed that achieving high SMP requires not only green strategies but also internal capabilities, such as effective planning and scheduling systems like MRP, to ensure consistency and operational alignment (Zahari et al., 2024).

In the contemporary industrial landscape, the pursuit of both operational efficiency and sustainability has become increasingly central, driven by mounting regulatory pressures and consumer expectations for environmentally responsible production (Zohuri, 2023). In this context, Material Requirements Planning (MRP) systems have evolved from basic inventory control tools into dynamic platforms capable of advancing Sustainable Manufacturing Performance (SMP). MRP effectiveness encompasses several key dimensions, including planning accuracy, inventory control, timeliness of materials, production schedule adherence, and operational impact—each of which plays a crucial role in supporting sustainability outcomes across the manufacturing lifecycle (Singhal et al., 2024; Schelling et al., 2024).

Planning accuracy, the ability to forecast material needs with precision, is foundational to preventing overproduction, reducing waste, and minimizing unnecessary energy consumption. Accurate planning helps ensure the right materials are procured at the right time, aligning resource use with actual production demand—thus lowering the environmental burden of excess inventory and inefficient workflows (Yarali et al., 2024). Similarly, inventory control allows firms to manage stock levels efficiently, reducing material obsolescence, storage-related emissions, and energy usage. By limiting excess inventory, manufacturers not only lower costs but also contribute to a leaner, more sustainable production system (Miguel Núñez-Merino et al., 2024).

Timeliness of materials, another core dimension ensures that raw materials arrive just in time for production, avoiding delays, downtime, and the need for emergency shipments that often have a higher environmental footprint. Effective MRP systems help firms synchronise their procurement with production needs, thereby reducing idle capacity and energy waste (Alzahmi et al., 2025). Additionally, production schedule adherence supports operational stability, allowing firms to avoid last-minute changes that disrupt energy-efficient production processes. Reliable scheduling enhances process flow, quality control, and alignment with sustainability targets by reducing the carbon intensity of rescheduling or reworking operations (Gharibvand et al., 2024).

Finally, operational impact, which reflects the MRP system's influence on overall manufacturing efficiency, ties all dimensions together by measuring their combined effect on cost, productivity, and environmental outcomes. A well-integrated MRP system can drive positive ripple effects across resource planning, employee workload balancing, and machinery utilization, all of which contribute to sustainable performance (Kalogiannidis et al., 2023; Kumar et al., 2024). Studies have shown that when MRP effectiveness aligns with green objectives, firms experience reduced emissions, improved energy efficiency, and better alignment with sustainability standards such as ISO 14001 and the United Nations Sustainable Development Goals (Luo et al., 2024; Selvaraju et al., 2022).

From a theoretical standpoint, these relationships are justified through the Resource-Based View (RBV), which identifies effective MRP systems as strategic resources that can enhance both operational and environmental performance. The systems theory further highlights the interconnectedness of planning, procurement, and sustainability efforts, suggesting that improvements in MRP can trigger widespread improvements across a firm's ecological footprint. Lastly, stakeholder theory reinforces the idea that manufacturing firms must be accountable not only to shareholders but also to regulators, communities, and consumers, making MRP a lever for legitimacy and transparency (Salah et al., 2023; Jawad et al., 2024).

Given these considerations, the integration of MRP effectiveness into sustainability discourse is not merely a technical upgrade, it is a strategic imperative. Each dimension of MRP contributes uniquely and collectively to the achievement of sustainable manufacturing performance. Recognising and leveraging this potential can help Malaysian manufacturers transition toward environmentally responsible, resource-efficient, and globally competitive operations in alignment with national green agendas and international sustainability frameworks (Olajiga et al., 2024; Mabotja, 2025; Jiang, 2024).

2.2 Green Supply Chain Practices and Sustainability Manufacturing Performance

GSCP refer to the strategic incorporation of environmental considerations into supply chain activities, including product design, procurement, production, distribution, and end-of-life management. Common GSCP elements include eco-design, green purchasing, and reverse logistics, each aimed at reducing environmental impact while maintaining or improving supply chain performance (Rajaratnam et al., 2023). These practices are essential for helping firms comply with environmental regulations, meet consumer expectations for sustainable products, and achieve cost efficiencies through waste reduction and resource optimisation (Krishnan et al., 2024). The successful implementation of GSCP requires strong collaboration across supply chain partners and often depends on the availability of integrated planning systems like MRP to coordinate sustainable actions. However, GSCP adoption remains inconsistent in many developing economies due to limited awareness, financial constraints, and weak technological infrastructure (Handiyanto et al., 2024).

The bibliographic coupling map **Figure 1** provides a visual representation of the intellectual structure within the field of supply chain and sustainability research. At the core of the network are highly interconnected studies such as those by Zhang (2005), Yu (2013), Vickery (1999), and Fantazy (2009) which form a central cluster indicative of shared theoretical perspectives and methodological approaches. These foundational works predominantly focus on supply chain integration, agility, strategic alignment, and performance outcomes, reflecting the long-standing emphasis on operational excellence within the supply chain domain (Cinti et al., 2025).

Peripheral nodes in the network such as those by Khan (2020), Lim (2022), Rizvi (2023), and Huma (2023) represent emerging streams of research, particularly those emphasizing GSCP, sustainability, and environmentally responsible manufacturing. The relative distance of these studies from the central cluster suggests their novelty and the evolving nature of sustainability discourse in the supply chain context. Notably, Tipu (2014) occupies a strategic bridging position between traditional SCM paradigms and newer sustainability-focused studies, indicating a transitional contribution that aligns operational effectiveness with sustainable development goals.

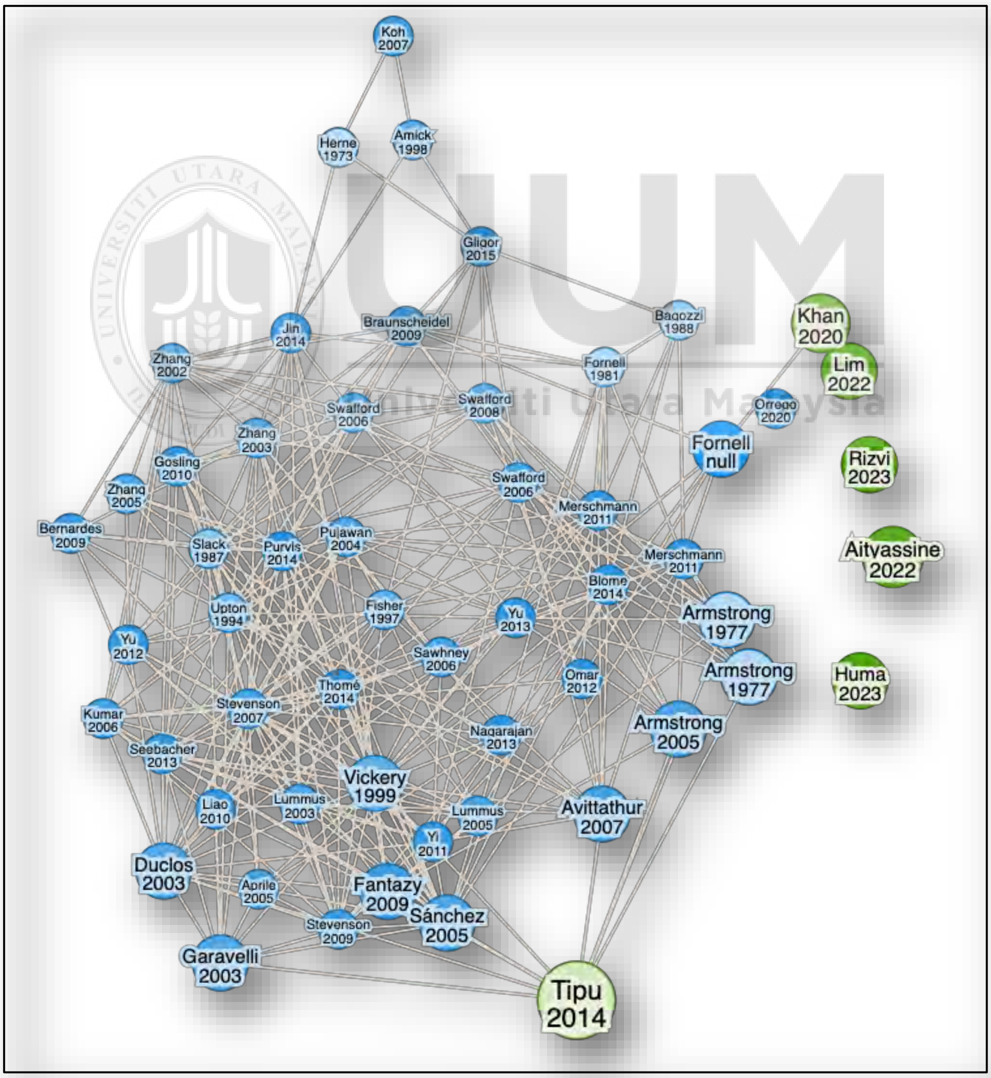

Figure 1: Green Supply Chain Practices (GSCP) and Sustainability Manufacturing Performance (SMP)

This structural mapping as **Figure 1** reveals that while the theoretical backbone of supply chain management remains grounded in established frameworks such as the Resource-Based View (RBV) and performance measurement models, there is a growing scholarly shift towards integrating ecological and socio-environmental considerations (Rahman et al., 2025). The divergence of newer studies underscores the relevance of this research in addressing underexplored intersections between MRP effectiveness and GSCP. By situating the present study within both foundational and contemporary research clusters, it contributes to expanding the discourse on sustainable manufacturing performance and bridging gaps between traditional supply chain efficiency and environmental sustainability imperatives (Feng et al., 2024).

Based on recent research by Xin (2024), the intersection between GSCP and SMP has garnered increasing scholarly and industrial attention, particularly as organizations confront complex environmental challenges while striving to maintain competitiveness. The literature reveals that GSCP plays a pivotal mediating role in translating operational efficiency tools such as MRP into broader sustainability outcomes. This section synthesizes critical findings from current research, elucidating key themes, implementation barriers, and the broader strategic significance of GSCP in enhancing SMP.

GSCP is conceptualized as an integrated approach to reducing environmental risks across the entire supply chain while maintaining cost-effectiveness and performance. According to Tronnebati and Jawab (2023), contemporary firms increasingly adopt holistic GSCP initiatives encompassing green purchasing, sustainable production, and eco-efficient distribution systems. These initiatives mark a fundamental departure from linear, resource-intensive models toward systems thinking rooted in ecological stewardship and economic resilience.

Recent scholarship has explored the synergy between GSCP and circular economy principles. Malhotra (2023) emphasizes that integrating circular practices into supply chains enhances flexibility, adaptability, and responsiveness capabilities that are essential in volatile and resource-constrained environments. These capabilities serve as enablers for manufacturing firms to improve sustainability performance while reinforcing resilience across value chains (Sharma et al., 2025).

Sustainable sourcing also emerges as a foundational GSCP element, with supplier selection and environmental compliance increasingly seen as strategic levers. As stated by Chen (2024) highlighted the alignment of sustainable sourcing decisions with environmental, social, and economic dimensions, suggesting that supplier relationships are instrumental in institutionalizing sustainability within supply chain networks. Leadership within supply chain governance frameworks plays a catalytic role in embedding GSCP across operations. According to Esangbedo et al. (2024), provide evidence that supply chain leadership, when synergized with corporate sustainability strategies can significantly enhance environmental and operational performance. Their findings imply that leadership not only facilitates change but also ensures continuity and alignment of sustainability goals across complex supply chains.

Nonetheless, the implementation of GSCP is fraught with structural and organizational challenges. In previous study by Wang and Wang (2023), assert that post-pandemic disruptions have intensified the need for resilient, lean, and green supply chains, exposing inefficiencies that hinder the adoption of sustainability strategies. In this context, MRP when adapted to integrate sustainability parameters may offer a systematic pathway for overcoming these constraints (Muyulema-Allaica et al., 2025). Not only that, the role of internal stakeholder engagement, particularly employee involvement and top management commitment, is frequently highlighted in the literature (Egila et al., 2025). Previous study by Shafqat et al. (2023), highlighted that top management support moderates the relationship between GSCP and SMP, indicating that cultural alignment and organizational buy-in are prerequisites for effective sustainability transformation. Similarly, Mushtaq (2023) explores how a green entrepreneurial orientation (GEO) shapes organizational behaviour toward GSCP adoption, with environmental performance mediating this relationship.

Implementation barriers remain a significant focus of recent inquiry. Sarin and Srivastava (2024) identify key inhibitors such as lack of technological infrastructure, resistance to change, and weak regulatory enforcement, which collectively obstruct the operationalization of green practices. Addressing these barriers calls for systemic shifts in governance, process design, and capability building. Additionally, the technology continues to redefine the contours of sustainable supply chain management. According to Rattan and Nair (2024), along with Bowen et al. (2024), highlight the role of emerging technologies such as artificial intelligence and blockchain in enhancing traceability, transparency, and accountability across green supply chains. These MRP tools not only optimize logistics and inventory but also provide real-time data to support sustainable decision-making. Moreover, the regulatory frameworks and governance mechanisms play an equally vital role in shaping GSCP outcomes. Reynolds (2024) argues that industry regulations and compliance standards act as institutional forces that either reinforce or hinder sustainability practices. The collaborative regulatory platforms and cross-sectoral partnerships are seen as essential for translating sustainability policy into tangible outcomes.

A persistent tension between sustainability and profitability is also evident across empirical studies. The previous study by Layode et al. (2024) and Ma (2024) reflect on industry-specific case studies that particularly in medical and fashion sectors that highlighting the complexities of balancing economic imperatives with ecological and social responsibilities. These insights emphasize the need for context-specific strategies that address both cost efficiency and ethical obligations. Human resource management (HRM) is increasingly recognized as a critical enabler of sustainable supply chain implementation. Furthermore, Eyo-Udo et al. (2024) advocate for the integration of sustainability principles into HR policies to cultivate a workforce that is aligned with organizational sustainability goals, thereby promoting collaborative green initiatives throughout the supply chain. The Triple Bottom Line (TBL) framework remains a dominant theoretical lens for assessing sustainability performance (Nogueira et al., 2025). Not only that as stated by Adeti (2023) mention that the utility of TBL in evaluating the interdependencies between economic viability, environmental protection, and social equity in supply chain contexts. This tri-dimensional focus enables organizations to adopt balanced strategies that extend beyond financial performance to include long-term stakeholder and societal value.

Sector-specific applications of sustainable supply chain practices further demonstrate the adaptability and breadth of GSCP principles. For example, Luo (2023) and Novijanto et al. (2023) examine GSCP frameworks in agriculture and food industries, where resource efficiency and waste minimization directly influence sustainability performance. These studies confirm that GSCP are not industry-exclusive but is highly contextualized depending on operational, cultural, and regulatory environments. Another study by Singh and Joshi (2024) highlight that from an operational standpoint, the adoption of GSCP can yield significant performance improvements, including enhanced process efficiency, waste reduction, and cost optimization. Other studies by Aminnaseri and Taleghani (2023) and Basuki (2024) reinforce the strategic relevance of sustainability initiatives by linking them to competitive advantage and manufacturing excellence. These findings align with the argument that sustainable practices are not merely compliance-driven but can serve as value-generating innovations. Importantly, the linkage between GSCP and SMP requires continued empirical validation across varying organizational settings. In additionally, scholars such as Potluri and Kilaru (2023), Li (2023), and Aminnaseri and Taleghani (2023) provide evidence that lean manufacturing, sustainable sourcing, and green innovation collectively contribute to both environmental and financial performance improvements. However, the degree of impact varies based on firm size, sector maturity, and market dynamics.

The reviewed literature demonstrates a compelling interdependence between GSCP and SMP, mediated by technological advancements, organizational culture, regulatory compliance, and strategic alignment (Xin, 2024). As firms seek to integrate MRP effectiveness with GSCP to achieve SMP, the discourse highlights the need for holistic frameworks that transcend operational silos and embed sustainability into every layer of supply chain architecture. Future research should deepen its exploration into this integration, particularly through longitudinal and cross-sectoral studies, to establish empirically grounded models that drive both performance excellence and sustainable impact (Sadri et al., 2025).

Recent literature underscores the strategic importance of GSCP in enhancing SMP, particularly as firms adapt to environmental regulations, growing consumer eco-awareness, and global sustainability imperatives. GSCP, which include eco-design, green procurement, energy-efficient operations, reverse logistics, and waste minimization, have been shown to improve operational efficiency and sustainability metrics such as emissions reduction, resource efficiency, and lifecycle optimisation (Mathur et al., 2025; Singhal et al., 2024). They also strengthen regulatory compliance, manage reputational risks, and enhance competitiveness (Masokoameng et al., 2023; Tambuskar et al., 2023). However, significant gaps remain, including limited empirical research on the influence of organisational factors like behavioural readiness and strategic commitment, insufficient exploration of contextual variables such as industry type and supply chain maturity (Li, 2025; Songkhwan et al., 2025), and a lack of longitudinal studies on long-term impacts like innovation capacity and resilience. Addressing these gaps through integrative, cross-sectoral, and longitudinal approaches is essential for developing scalable, context-sensitive sustainability strategies that align with the evolving global sustainability landscape.

2.3 MRP Effectiveness and Green Supply Chain Practices

The evolution of MRP, alongside their integration with GSCP, reflects the dynamic transformation of manufacturing and logistics operations in response to contemporary environmental and operational challenges (Nazir et al., 2024). According to Bag and Pretorius (2022), this literature review aims to critically examine the effectiveness of MRP when implemented in tandem with GSCP, that drawing on a diverse body of empirical and theoretical studies to elucidate the interrelationship between these components and their collective impact on SMP.

As stated by Opoku (2024), the integration of MRP effectiveness with GSCP has emerged as a strategic response to the growing need for SMP. This literature review critically explores the intersection of MRP functionalities and green practices, assessing their collective impact on environmental performance, operational efficiency, and economic outcomes. The discussion draws upon empirical studies, theoretical perspectives, and industry trends to establish a strong foundation for the proposed research framework (Stroumpoulis & Kopanaki, 2022).

Furthermore, MRP serve as a strategic mechanism for aligning production schedules with inventory requirements, thereby enabling organizations to reduce material waste, manage operational costs, and optimize resource utilization (Malindzakova et al., 2022). Khumla and Sarawan (2023) extend this understanding by demonstrating that MRP considerably enhance operational transparency and cost-efficiency among small and medium-sized enterprises (SMEs) in Thailand. The scholars suggest that MRP platforms offers substantial performance gains, especially for resource-constrained firms. The recent study by Bahauddin and Syed (2025) reinforces this view by asserting that the core value of MRP lies in its capability to provide precise demand forecasting, efficient production scheduling, and effective inventory control three pillars that are vital for sustaining operational performance in dynamic manufacturing environments. In a similar vein, Reis (2023) underscores the integration of a catalyst for improving MRP responsiveness and accuracy, highlighting the value of real-time data processing in achieving agile and adaptive production planning.

An essential component of MRP effectiveness lies in its capacity for real-time inventory management, which ensures seamless synchronization between material availability and production schedules. As stated by Robbani et al. (2023) emphasize that well-implemented MRP enable firms to maintain optimal stock levels by leveraging accurate demand forecasts, thereby reducing instances of both stockouts and overstocking. This precision not only minimizes inventory holding costs but also enhances production flow efficiency, contributing to leaner operations.

However, maintaining static planning parameters is insufficient in today's volatile manufacturing landscape. Zhang et al. (2023) argue that the evolving complexities of global supply chains such as fluctuating customer demands, supplier uncertainties, and transportation disruptions necessitate MRP to be dynamically adaptable. The incorporation of agile methodologies into MRP frameworks enables firms to rapidly adjust procurement and production plans in response to real-time operational changes. This level of responsiveness is critical for maintaining continuity, resilience, and competitive advantage in increasingly unpredictable market conditions.

According to Yao et al. (2024), beyond traditional role in production planning and inventory control, MRP are increasingly being re-examined through the prism of sustainability. This paradigm shift reflects the broader imperative for manufacturing firms to pursue operational excellence without compromising environmental stewardship (Duffour & Pattanaik, 2025). Additionally, Zhai and Wang (2024) argue that environmentally responsive MRP those designed to integrate carbon footprint reduction, energy-efficient scheduling algorithms, and sustainable sourcing criteria that represent a significant evolution in MRP planning tools. These features are no longer peripheral add-ons but are becoming central to MRP design, particularly as regulatory pressures and stakeholder expectations around corporate sustainability intensify.

Critically, the integration of sustainability objectives into MRP functionalities reinforces the strategic alignment between operational efficiency and environmental performance (Ilori & Majiyagbe, 2024). When MRP are configured to factor in emissions metrics, energy consumption profiles, and supplier eco-credentials, they can support decision-making that contributes directly to green supply chain goals (Lerman et al., 2022). This not only enables firms to meet environmental compliance standards but also enhances their reputation and competitiveness in markets increasingly influenced by ESG (Environmental, Social, and Governance) criteria. However, such integration is not without challenges (Argelaguet et al., 2021) and as recent study by Andrei and Johnsson (2025) many firms lack the technological maturity or organizational readiness to embed sustainability metrics into their core planning systems. This gap underscores the need for comprehensive frameworks that facilitate the convergence of MRP design with GSCP, enabling a more holistic and sustainable approach to manufacturing performance.

The GSCP are essential in mitigating environmental degradation while sustaining competitiveness. These practices encompass green purchasing, eco-design, reverse logistics, and environmentally responsible manufacturing processes (Guan et al., 2025). Underpinned by the Life Cycle Assessment (LCA) approach, GSCP enables organizations to assess environmental impacts across the product life cycle, thereby supporting informed decision-making (Zaib et al., 2023). The adoption of LCA not only fosters compliance with environmental regulations but also enhances energy efficiency and resource conservation in industrial operations.

Moreover, the innovative environmental practices, such as sustainable water use and waste management, further amplify the strategic value of GSCP. As stated by Saad et al. (2024) examine wastewater reuse technologies and their role in sustainable irrigation systems within food production sectors, highlighting the broader applicability of GSCP across industries. Besides that, Khokhar et al. (2023) discuss how integrating safety stock and lead time buffers into green supply strategies helps minimize overproduction and waste critical concerns in MRP planning.

Recent literature emphasizes that the synergy between green supply principles and MRP elements is fundamental to achieving sustainable manufacturing performance.

For instance, Cocco et al. (2023) demonstrate that integrating MRP with renewable energy systems substantially reduces greenhouse gas emissions, positioning manufacturing systems as environmentally resilient. Huang et al. (2023) reinforce this view by advocating for strategic shifts in energy sourcing within production systems to fulfil sustainability mandates. The intersection of MRP effectiveness and GSCP represents a transformative shift in supply chain management toward holistic sustainability. Strategic alignment between these components allows for simultaneous achievement of operational efficiency and environmental stewardship. According to Soni et al. (2023), the use of MRP facilitates improved forecasting and smarter logistics decisions, directly contributing to lower waste and higher sustainability outcomes.

However, despite growing interest in this integration, challenges persist. Gomez and Grady (2023) argue that the absence of collaborative frameworks and performance measurement standards inhibits the full realization of green supply goals within traditional MRP. Accurate benchmarking and cross-functional integration remain vital to transforming sustainability from a peripheral concern into a core operational objective. According to Haweel (2024), to address the multifaceted challenges of sustainable manufacturing, future research should adopt interdisciplinary frameworks that integrate technological innovation, sustainability science, and operations management. Embedding sustainability considerations directly into MRP and supply chain configurations offers a strategic pathway for organizations to simultaneously enhance operational competitiveness and fulfill escalating stakeholder and regulatory demands (Kareem et al., 2025).

The studies of literature reviewed in this study underscores the strategic importance of integrating MRP effectiveness with green supply chain practices to elevate sustainable manufacturing performance (Muthuswamy & Sudhakar, 2023). A recent study by Mhaskey (2024) highlights that while MRP offer foundational capabilities such as planning precision, inventory control, and production agility, green supply chain practices contribute to environmental accountability and long-term resource stewardship. The convergence of these two domains presents a transformative opportunity for manufacturing firms to achieve balanced outcomes across economic, operational, and ecological dimensions.

SMP integrates environmental preservation, economic viability, and social responsibility, with MRP systems playing a central role in aligning production scheduling, inventory control, and material availability to sustainability objectives (Hossain et al., 2025). Environmentally, effective MRP reduces waste, energy use, and overproduction, supporting carbon reduction and circular economy goals (Kroculick, 2025; Qin et al., 2024). Economically, it improves lead times, lowers costs, and enhances responsiveness, contributing to competitiveness and risk mitigation (Abobakr et al., 2024; Afolabi et al., 2025). Socially, MRP promotes transparency, better workflow coordination, and ethical supply chain practices, indirectly enhancing stakeholder trust and corporate reputation (Chachu et al., 2021). However, empirical research validating MRP's impact on all three sustainability pillars remains limited, with gaps in understanding the mechanisms linking MRP to tangible sustainability gains and in gathering practitioner insights (Safdar et al., 2024; Qureshi et al., 2024; Liu et al., 2022). This review underscores the need for integrated, empirical approaches to explore how operational planning systems like MRP can advance sustainability performance in manufacturing, informing both academic discourse and practical strategies (Prütz et al., 2023; Comparative et al., 2023).

Looking ahead, empirical inquiry into this integration remains essential. Specifically, future studies should focus on validating the interdependencies between

MRP-driven operational enhancements and the mediating role of green practices in achieving sustainability outcomes such as research will be instrumental in guiding the development of resilient, adaptive, and environmentally sustainable manufacturing systems capable of thriving in complex global markets.

In the context of this study, the literature review plays a pivotal role in examining the relationships between MRP effectiveness, GSCP, and SMP. It provides a structured foundation to explore how digital planning systems and sustainability-oriented practices interact, and to what extent they contribute to the achievement of sustainable outcomes in the manufacturing sector. This review also guides the identification of theoretical models and research gaps, thereby informing the study's conceptual framework and methodological design. Below is **Table 1** of summary of literature review based on current studies:

Table 1: Literature Review Summary of MRP System Efficiency and Sustainable Manufacturing Performance

Author	Year	Title	Main Focus	Findings
Tejendra Singh Singhal et al.	2024	Eco-Design of Products and Processes: A Review on Principles and Tools for Sustainable Manufacturing	Reviewing eco-design principles and tools to support MRP systems in boosting SMP.	Integrating eco-design with MRP can lower environmental impact and enhance resource efficiency, leading to improved SMP.
Ammar Salah et al.	2023	The Impact of Production and Operations Management Practices in Improving Organizational Performance: The Mediating Role of Supply Chain Integration	Examining how management practices influence organizational performance through supply chain integration.	Effective management practices are positively linked to improved organizational performance, with supply chain integration

				acting as a key mediator.
Stavros Kalogiannidis et al.	2023	Smart Sustainable Marketing and Emerging Technologies: Evidence from the Greek Business Market	Investigating the relationship between emerging technologies and smart sustainable marketing.	Emerging technologies are crucial in enhancing the effectiveness of smart sustainable marketing strategies.
João Reis	2023	Exploring Applications and Practical Examples by Streamlining Material Requirements Planning (MRP) with Python	Examining how Python can optimise Material Requirements Planning (MRP) processes.	Python-based frameworks can significantly enhance MRP processes, improving efficiency and integration with ERP systems.
Zainab Nadhim Jawad et al.	2024	Machine learning-driven optimization of enterprise resource planning (ERP) systems: a comprehensive review	Evaluating the integration of machine learning with ERP systems.	ML integration enhances ERP efficiency by enabling real-time data-driven decisions, impacting operational success.
Thanh Van Luu et al.	2023	A model of industry 4.0 and a circular economy for green logistics and a sustainable supply chain	Investigating the interplay between Industry 4.0 and circular economy principles in logistics.	Integrating Industry 4.0 technologies with circular economy practices can enhance SMP
Li Jiang	2024	The Past, Present and Future of Enterprise Resource Planning	Examining the evolution of ERP systems, focusing on advancements through cloud computing.	ERP systems have transformed significantly, driven by cloud technology, enhancing operational efficiency.
Tshepo Mabotja	2025	Impact of automated picking systems on operational	Examining the impact of warehouse management	Adopting integrated and automated warehouse

		efficiency in South Africa's manufacturing warehouses	systems on operational efficiency in steel manufacturing.	management systems is essential for improving efficiency in the sector.
Oladiran Kayode Olajiga et al.	2024	Intelligent Monitoring Systems in Manufacturing: Current State and Future Perspectives	Reviewing the role of Intelligent Monitoring Systems (IMS) in manufacturing efficiency and quality control.	IMS which related to MRP enhance production efficiency and quality by integrating advanced technologies like IoT and AI.
Rizad et al (Malaysia)	2018	The Effectiveness of MRP System to Forecast the Accuracy Inventory Requirement	The study investigates the capability of a Material Requirements Planning (MRP) system in accurately forecasting inventory requirements within a multinational company using a qualitative case study approach.	The MRP system is effective as the core tool for managing inventory and ensuring customer service, but it requires valid data and pre-set parameters. For better adaptability to external changes, integration with supporting software like a stock model is recommended.
Zainal (Malaysia)	2023	Appropriate inventory level through material requirement planning measures in manufacturing industry	The study focuses on implementing Material Requirements Planning (MRP) to determine optimal inventory levels in the manufacturing industry, specifically	By applying MRP along with tools like the Ishikawa diagram and Why-Why Analysis, the study identifies key factors influencing inventory management and proposes

			examining supplier sourcing, system implementation, and inventory control.	practical strategies to optimize inventory levels, offering actionable insights for Company X Sdn Bhd and the wider manufacturing sector.

Recent literature between 2023 and 2024 as in Table 2, highlighted the growing role of digital technologies particularly artificial intelligence (AI), big data analytics (BDA), and machine learning (ML) in advancing GSCP and enhancing SMP. Studies by Huynh et al. (2023) and Ansari & Ghasemaghaei (2023) reveal that BDA enables real-time monitoring, predictive analytics, and waste reduction, aligning operational efficiency with environmental objectives. Yadav et al. (2024) and Alhasawi et al. (2023) further emphasize that AI applications enhance supply chain resilience by supporting decision-making in eco-design, sustainable sourcing, and lifecycle management. Despite challenges such as digital infrastructure gaps and integration complexity, these technologies are increasingly viewed as enablers of transformative sustainability.

Collectively, the findings suggest that the strategic integration of AI and BDA into GSCP fosters not only operational agility but also measurable sustainability outcomes in manufacturing.

Table 2: Based on Recent Studies between 2021–2025

Title	**Authors**	**Year**	**Citations**	**References**	**Similarity to origin**
Big data analytics-artificial intelligence and sustainable	Rashid et al (Malaysia)	2024	115	122	3.6

performance through green supply chain practices in manufacturing firms of a developing country					
Green supply chain management practices in Malaysia manufacturing industry	Sundaram et al (Malaysia)	2017	48	28	3.8
Big data analytics capabilities: Patchwork or progress? A systematic review of the status quo and implications for future research	Minh-Tay Huynh, Michael Nippa, T. Aichner	2023	28	185	3.5
Artificial intelligence applications for information management in sustainable supply chain management: A systematic review and future research agenda	Alok Yadav, R. K. Garg, A. Sachdeva	2024	5	56	3.2
Big Data Analytics Capability and Firm Performance: Meta-Analysis	Kimia Ansari, Maryam Ghasemaghaei	2023	14	87	3
A Review of Artificial Intelligence (AI) and Machine Learning (ML) for Supply Chain Resilience: Preliminary Findings	Enjoud Alhasawi, Mahmood Hajli, Denis Dennehy	2023	2	42	2.7

Catalyzing Supply Chain Evolution: A Comprehensive Examination of Artificial Intelligence Integration in Supply Chain Management	Sarthak Pattnaik, Natasya Liew, Ali Ozcan Kures, Eugene Pinsky, Kathleen Park	2024	1	19	2.6
Big data analytics capabilities and supply chain sustainability: Evidence from the hospitality industry	N. Alzboun	2023	1	30	2.5
Big data driven supply chain innovative capability for sustainable competitive advantage in the food supply chain: Resource-based view perspective	Mukesh Kumar, Rakesh D. Raut, S. Mangla, Jonathan D. Moizer, Jonathan Lean	2024	14	65	2.5
The Influence of Digital Technologies on Sustainable Supply Chain Performance in Public Procuring Entities: A Moderating Effect of Legal Frameworks	Deus N. Shatta	2024	3	53	2.4
The use of artificial intelligence to advance sustainable supply chain: retrospective and future avenues explored through bibliometric analysis	Ibtissam Zejjari, Issam Benhayoun	2024	4	28	2.3
A systematic review of the literature on the use	Moayad Al-Talib, W. Al-Saad, Anan	2024	1	99	2.3

of information technologies in supply chain management	Alzoubi, Anthony I. Anosike				
The Effects of E-Procurement Tools on Supply Chain Performance of Procuring Entities in Tanzania: Mediation Effect of Behavioral Intention	Deus N. Shatta, Bahati K Mabina, B. Myamba	2024	4	47	2.3
Big Data Analytics and AI for Green Supply Chain Integration and Sustainability in Hospitals	Mahmoud Allahham, A. Sharabati, Heba Hatamlah, A. Y. B. Ahmad, S. Sabra, Mohammad Khalaf Daoud	2023	23	46	2.2
Enhancing resilience in supply chains through resource orchestration and AI assimilation: An empirical exploration	Xingwei Lu, Xianhao Xu, Yi Sun	2025	3	106	2.2
Exploring firm and individual-level determinants of IFRS for SMES adoption in Morocco, a diffusion of innovations' perspective	Issam Benhayoun, Ibtissam Zejjari	2024	6	38	2.2
Theorized model for e-procurement system in developing countries	Deus N. Shatta, Bahati K Mabina	2024	6	77	2.2

Examining the Influence of E-Payment System on LGAs' Public Procurement Performance: A Case of Kasulu District Council, Kigoma Tanzania	Begarving Arthur, Nicodemas Mwaseba, Haji M. Mnasi	2023	2	32	2.2
The determinants of use behavior of e-procurement system in developing countries	Deus N. Shatta, Bahati K Mabina	2024	3	66	2.2
Adaptive Cloud-Based Big Data Analytics Model for Sustainable Supply Chain Management	N. Stefanović, Miloš Radenković, Z. Bogdanović, Jelena Plasic, Andrijana Gaborovic	2025	3	26	2.1
Exploring the motivations behind artificial intelligence adoption for building resilient supply chains: a systematic literature review and future research agenda	Laxmi Pandit Vishwakarma, R. Singh, Ruchi Mishra, Mani Venkatesh	2024	2	60	2.1
Generative AI-enabled supply chain management: A coordination theory perspective	Lixu Li, Yaoqi Liu, Yong Jin, T. Cheng, Qianjun Zhang	2024	5	62	2.1
Adoption of ISSB standards in emerging markets – insights from Moroccan companies'	Issam Benhayoun, Mehdi El Amrani, Aya Barhdadi, Walid Azzaoui	2025	3	87	2.1

organizational readiness					
Determinants Of Adoption Of E-Procurement Practices: A Critique Of Literature Review	Robert Kariuki Waithaka, J. Kimani	2021	7	0	2.1
The influence of performance expectancy on e-procurement adoption model in developing countries: Tanzanians perception	Deus N. Shatta	2021	5	0	2.1
The Effects of Digital Technologies on Green Logistics Performance in Tanzania: A Moderation and Mediation Analysis Using PLS-SEM	Deus N. Shatta, Benjamin Mwakyeja, Nicholaus Mgawe, B. Myamba	2024	1	43	2.1
Digital learning, big data analytics and mechanisms for stabilizing and improving supply chain performance	Aziz Barhmi, Fahd Slamti, Soulaimane Laghzaoui, Mohamed Reda Rouijel	2024	1	67	2
Influence Of E-Selection On Performance Of Evaluation Committee In County Government Of Turkana	Francis Edapal Esimit, Dr. Yusuf Kibet		4	24	2
Effect Of E-Procurement Practices On Supply Chain Performance	Robert Kariuki Waithaka, J. Kimani	2021	9	0	2

2.4 Hypotheses Development

Formulating hypotheses is a critical component of empirical research, serving as a bridge between theoretical foundations and practical analysis. Hypotheses are developed based on extensive literature review and established theories such as the Resource-Based View (RBV), which emphasize the strategic value of internal capabilities and interdependent processes in driving sustainable performance (Barroga & Matanguihan, 2022; Misra & Agarwal, 2020). This study explores how the internal capability of Material Requirements Planning (MRP) effectiveness and the adoption of Green Supply Chain Practices (GSCP) influence Sustainable Manufacturing Performance (SMP). The following hypotheses are proposed based on empirical evidence and theoretical reasoning:

MRP effectiveness encompasses several critical operational dimensions, including planning accuracy, inventory control, timeliness of materials, production schedule adherence, and operational impact. Past studies demonstrate that these capabilities significantly enhance operational efficiency and resource optimization. For instance, Singhal et al. (2024) and Shaharudin et al. (2022) found that accurate planning and timely materials flow reduce waste and improve production stability. Moreover, inventory control and schedule adherence contribute to leaner operations and reduced environmental impact, which are essential to sustainable manufacturing outcomes (Schelling et al., 2024; Gharibvand et al., 2024). Therefore, the first hypothesis is:

- H1: MRP effectiveness positively affects SMP.

Green Supply Chain Practices (GSCP) such as eco-design, green purchasing, and reverse logistics are increasingly adopted by firms to address sustainability concerns. According to Krishnan et al. (2024) and Rajaratnam et al. (2023), these practices not only enhance environmental performance but also support operational improvements and cost savings, contributing to long-term competitiveness. Zailani et al. (2023) further support the idea that GSCP implementation yields positive economic, environmental, and operational outcomes. Thus, the second hypothesis is:

- H2: GSCP positively affect SMP.

At the same time, the literature also suggests that GSCP may act as a mediating mechanism between MRP and sustainability outcomes. Although MRP enhances material flow and planning, its sustainability impact is magnified when integrated with green practices. Alzahmi et al. (2025) argue that MRP-supported scheduling and procurement can create synergies with GSCP, particularly in areas such as reducing overproduction, supporting closed-loop supply chains, and improving eco-efficiency. However, there remains a lack of empirical validation on how GSCP bridges MRP effectiveness and SMP. Therefore, this research proposes:

- H3: GSCP mediate the relationship between MRP effectiveness and SMP.

Together, these hypotheses provide a structured pathway for examining how operational and environmental strategies combine to enhance sustainability performance in Malaysian manufacturing firms. The next section presents the conceptual framework underpinning these relationships.

Table 2.1: Research Hypotheses Development

Hypotheses	**Statement**
Hypotheses 1 (H1)	MRP effectiveness positively affects SMP.

Hypotheses (H2)	2	GSCP positively affect SMP.
Hypotheses (H3)	3	GSCP mediate the relationship between MRP effectiveness and SMP.

2.5 Conceptual Framework

In the context of sustainability-oriented manufacturing research, the conceptual framework serves as a foundational scaffold for systematically examining the intricate relationships between key constructs namely, MRP effectiveness, GSCP, and SMP. The utility of a conceptual framework lies in its ability to distils complex, multifaceted issues into an organized theoretical model that facilitates empirical inquiry. It not only aligns the research objectives with methodological design but also enables scholars to anchor their work within established theoretical paradigms while addressing current gaps in the literature.

As emphasized by Dikobe et al. (2023), a conceptual framework visually and theoretically maps the hypothesized relationships between critical variables. In this study, MRP effectiveness represents the independent construct, GSCP functions as a mediating construct, and SMP is positioned as the dependent outcome. This triadic structure aligns with emerging research calling for integrative approaches that capture both technological and environmental dimensions of SCM such as frameworks are not merely illustrative but serve to unify diverse theoretical perspectives, including operations strategy, resource-based theory, and sustainability science.

As stated by Deroncele-Acosta et al. (2024) assert that the process of constructing a conceptual framework enhances epistemological rigour by compelling researchers to systematically synthesize prior research, define constructs, and clarify causality. In the case of MRP-GSCP-SMP integration, this approach allows for an in-depth exploration of how operational planning tools MRP can be leveraged to facilitate green initiatives across the supply chain, ultimately enhancing long-term environmental and organizational performance. Moreover, Plessis et al. (2024) further elaborate that conceptual frameworks, when grounded in systematic literature reviews and empirical synthesis, facilitate the refinement of variables and identification of moderating or mediating pathways that might otherwise be overlooked.

In applied research domains such as manufacturing, conceptual frameworks must also support practical implementation. As Gresh et al. (2023) argue, a well-developed framework serves as a tool for both assessment and intervention, especially in dynamic industrial contexts where sustainability goals must align with performance imperatives. This aligns with the present study's aim to provide a roadmap through which manufacturing firms can operationalize MRP effectiveness and GSCP integration in pursuit of enhanced SMP.

The flexibility of conceptual frameworks also permits adaptation to specific research environments. For example, Khumalo and Saurombe (2023) demonstrate the relevance of context-specific frameworks by applying conceptual modeling to the gender-digital divide, underscoring the capacity of such tools to elucidate contextually grounded phenomena. In a similar vein, this study contextualizes MRP and GSCP within the Malaysian manufacturing sector, where digital maturity, regulatory drivers, and environmental pressures uniquely shape sustainability outcomes.

Gause et al. (2024) emphasize that conceptual frameworks facilitate stakeholder communication by simplifying complex systems and providing a shared reference point. This is particularly crucial in sustainability research, which often involves multidisciplinary teams and diverse stakeholders, including policymakers, industry leaders, and environmental regulators. A coherent framework enhances the interpretability and applicability of research findings across these domains.

Nevertheless, developing a conceptual framework is not without challenges. Runeson et al. (2024) caution that the translation of abstract theoretical constructs into measurable variables risks oversimplification or misrepresentation, particularly when constructs span multiple disciplines. In this study, ensuring clarity in the operationalization of MRP effectiveness and GSCP dimensions is critical for maintaining both theoretical and empirical integrity.

In conclusion, the conceptual framework proposed in this study as below **Figure 2.1** provides a strategic lens through which the interactions between MRP systems, GSCP, and SMP can be critically analysed. It offers a platform for empirical validation, policy relevance, and organizational learning, thereby contributing to both academic scholarship and practical transformation within the manufacturing sector. The framework's development reflects the growing imperative to integrating the digital operational tools with sustainability goals an agenda that is central to future-ready industrial strategies.

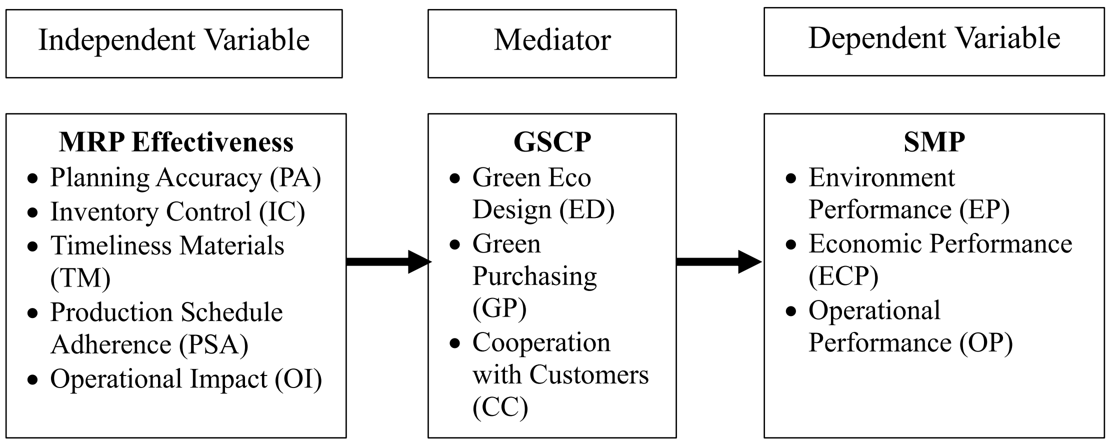

Figure 2.1: Conceptual Framework

The conceptual framework of this study was adopted and adapted from prior empirical research that examined the intersection between operational planning systems and sustainability performance within the manufacturing sector. Rooted in the Resource-Based View (RBV) theory, which emphasizes internal capabilities as strategic assets, the framework incorporates MRP System Effectiveness as the independent variable, Green Supply Chain Practices (GSCP) as the mediating variable, and Sustainable Manufacturing Performance (SMP) as the dependent variable. This framework was adopted from established models in the literature that have examined similar constructs (e.g., Singhal et al., 2024; Krishnan et al., 2024), while adapted to the Malaysian manufacturing context by refining the specific dimensions and indicators of each variable.

The development of the framework was guided by extensive literature review. For the independent variable, MRP System Effectiveness was decomposed into five core components: Planning Accuracy (PA), Inventory Control (IC), Timeliness of Materials (TM), Production Schedule Adherence (PSA), and Operational Impact Control (OI). These dimensions reflect how well a firm's MRP system manages resources, schedules production, and responds to operational demands. For the mediating variable, GSCP was defined through Green Eco-Design (ED), Green Purchasing (GP), and Cooperation with Customers (CC), aligning with widely recognized green practices that directly influence supply chain sustainability. Lastly, SMP was operationalized through Environmental Performance (EP), Economic Performance (ECP), and Operational Performance (OP), reflecting the triple bottom line approach.

The rationale behind this framework is to empirically explore how internal planning capabilities (MRP) contribute to sustainability outcomes, and to what extent this relationship is enhanced by the integration of green practices. While the structure of the framework was adopted from existing studies, the specific indicators and the relationships among variables were adapted to suit the objectives, context, and scope of the present study. This adaptation ensures that the model is both theoretically grounded and practically relevant for analyzing sustainability strategies in Malaysian manufacturing firms.

2.6 Underpinning Theory

The significance of underpinning theory is widely acknowledged across various academic disciplines, where theoretical frameworks form the foundation for both analytical exploration and practical application. A recurring theme in the literature is the critical role of theory in guiding research design and methodological choices. Scholars assert that a well-developed theoretical foundation enables researchers to articulate clear objectives, position their studies within the broader studies of existing knowledge, and enhance the methodological rigor and relevance of their findings (Tibert, 2025; Arifinsyah et al., 2025). Conceptual models, in particular, are frequently highlighted as essential tools for navigating complex phenomena, as they support the systematic identification and analysis of variables and the relationships among them (Alemu, 2023; Dionigi et al., 2022). In this study will explore only Research Based View (RBV).

The Resource-Based View (RBV) was selected as the underpinning theory for this study due to its strong alignment with the internal operational and environmental capabilities under investigation specifically MRP effectiveness and Green Supply Chain Practices (GSCP) and their impact on Sustainable Manufacturing Performance

(SMP). While alternative theories such as Stakeholder Theory or Institutional Theory focus on external pressures and compliance motivations, RBV uniquely emphasizes the strategic value of internal resources and their configuration in achieving long-term competitive advantage. In this context, MRP systems and green supply chain practices are not merely responses to external forces but are considered valuable, rare, inimitable, and non-substitutable (VRIN) resources that, when integrated effectively, can lead to superior sustainability outcomes. This internal-focused lens is particularly relevant in the Malaysian manufacturing landscape, where firms are increasingly seeking to leverage their technological and process capabilities for both efficiency and environmental performance. Therefore, RBV provides a more appropriate theoretical foundation to examine how internal capabilities rather than external obligations can be strategically harnessed to drive sustainable manufacturing outcomes. This internal resource-driven focus makes RBV more fitting than other frameworks in analyzing the synergy between operational planning and environmental strategy.

2.6.1 Resource-Based View (RBV)

This research critically examines how the Resource-Based View (RBV) provides a theoretical to analyse the integration of MRP effectiveness with GSCP in pursuit of SMP. It addresses the increasing demand for environmentally responsible operations while maintaining competitive advantage in manufacturing. Studies such as Chukwudi (2024), Yasmin (2024), and Pinheiro et al. (2024) emphasize that leveraging internal resources like advanced MRP enables organizations to streamline production planning and inventory control while aligning operations with sustainability goals. This alignment strengthens a firm's adaptability, resource efficiency, and long-term viability in a sustainability-driven market.

Previous models based on the Resource-Based View (RBV) have consistently emphasized the importance of leveraging internal capabilities both tangible and intangible to achieve sustained competitive advantage, particularly in manufacturing and supply chain contexts. For example, studies by Barney (1991) and later refined by Wernerfelt (1995) laid the theoretical groundwork by asserting that firms must develop resources that are valuable, rare, inimitable, and non-substitutable (VRIN) to outperform competitors. In the context of sustainability, more recent models such as those proposed by Hart (1995) and Aragón-Correa and Sharma (2003) extended RBV by incorporating environmental capabilities as strategic assets. These models argue that environmental practices, like green procurement or eco-design, when integrated with operational systems, become core capabilities that enhance firm performance. Similarly, Lopez-Gamero et al. (2011) developed an RBV-based framework linking internal environmental resources to business performance, highlighting the mediating role of green practices. These evolving RBV models serve as the foundation for this study's framework, where MRP effectiveness and GSCP are viewed as integrated internal capabilities that, when properly aligned, can drive superior sustainable manufacturing performance.

The RBV is a strategic management theory that emphasizes the importance of internal resources and capabilities as key drivers of an organization's competitive advantage and long-term performance. According to RBV, firms can achieve sustained success when they possess resources that are valuable, rare, inimitable, and non-substitutable (VRIN) (Mansour et al., 2022). These resources can be tangible (such as technology and infrastructure) or intangible (such as knowledge, processes, and organizational capabilities). The theory suggests that it is not merely the possession of resources that matters, but how effectively these resources are utilized and integrated within the firm's strategy to deliver superior performance outcomes (Lubis, 2022).

The RBV theory is highly relevant to this study, which examines how the effectiveness of MRP when integrated with GSCP can enhance SMP in Malaysian manufacturing firms. In this context, the MRP represents a core internal capability of the organization. Its effectiveness in planning accuracy, inventory control, timeliness of materials, and production schedule adherence can be seen as a strategic operational resource (Fathara et al., 2023). Similarly, GSCP such as eco-design, green purchasing, and reverse logistics can also be considered internal capabilities that reflect an organization's commitment to sustainability. The RBV framework supports the idea that when these resources are strategically developed and properly managed, they can drive superior sustainable performance outcomes across environmental, operational, and economic dimensions (Malik et al., 2020). Therefore, RBV provides a theoretical lens through which the integration and performance implications of these internal systems and practices can be critically analyzed.

The development of this study's conceptual framework is firmly grounded in the principles of the Resource-Based View (RBV), which emphasizes that an organization's sustained competitive advantage stems from its ability to strategically utilize internal resources and capabilities. Drawing from this theoretical foundation, the framework was successfully developed by identifying two core internal capabilities—MRP system effectiveness and Green Supply Chain Practices (GSCP) that reflect the firm's operational and environmental strengths. These were selected based on their alignment with the RBV criteria of being valuable, rare, inimitable, and non-substitutable (VRIN). The integration of MRP and GSCP within the framework was guided by extensive literature review, which highlighted the potential for these capabilities to collectively influence Sustainable Manufacturing Performance (SMP). Unlike existing models that examine these variables in isolation, this study's framework strategically bundles them to reflect the RBV's concept of capability configuration, wherein combining complementary resources can yield superior outcomes. Therefore, this framework not only aligns conceptually with RBV but also fills a theoretical and empirical gap by offering a holistic model tailored to the Malaysian manufacturing context.

The variables in this study MRP effectiveness (independent variable), GSCP (mediator), and SMP (dependent variable) are directly aligned with the RBV framework. MRP effectiveness embodies the firm's operational capability, which is a strategic resource that can improve performance if effectively utilized. GSCP acts as a complementary resource that enhances the value of the MRP system by embedding environmental responsibility into operational processes. The integration of MRP and GSCP represents a bundling of organizational capabilities, which according to RBV, can lead to enhanced performance outcomes. In this case, SMP, which includes environmental impact reduction, improved resource efficiency, and economic competitiveness. The theory underlines that these internal resources must be configured and deployed strategically to maximize their contribution to sustainability goals, thereby creating a competitive advantage that is difficult for competitors to replicate.

2.7 Chapter Summary

This chapter has critically reviewed the relevant literature to provide a comprehensive understanding of the interplay between MRP efficiency, GSCP, and SMP within organization under FMM. It examined the mediating roles of key variables and identified notable gaps in the existing studies of knowledge, particularly the limited empirical research on the integrated impact of these constructs and the industry-specific challenges they entail. Furthermore, the chapter introduced the RBV as the underpinning theoretical frameworks, aligning them with the study's conceptual model and research hypotheses. This literature review not only contextualizes the research but also underscores its contribution in addressing critical gaps in the implementation and impact of green supply chain practices in the Malaysian manufacturing sector.

CHAPTER 3

METHODOLOGY

3.0 Introduction

This chapter presents the methodological framework adopted for the study. It elaborates on the research design, target population, sampling techniques, questionnaire development, and data collection procedures. As the foundation of the research, this chapter ensures that the study is conducted in a systematic and rigorous manner. A quantitative research approach was employed, utilizing a cross-sectional survey targeting organizations registered under the FMM. Through this methodology, the study seeks to examine the relationship between MRP effectiveness, GSCP, and SMP.

3.1 Research Design

The intricacies of research design have garnered significant attention across various academic disciplines, as it constitutes a foundational element that underpins the integrity and effectiveness of research outcomes. In recent years, scholarly discourse surrounding optimal research methodologies has intensified, driven by the increasing complexity and diversity of academic inquiries (Longo et al., 2024; Allioui et al., 2023). The evolution of disciplines, in tandem with rapid technological advancements and shifting paradigms in knowledge production, underscores the critical need for research designs that not only align with disciplinary standards but also adapt to the unique requirements of specific contexts (Feuerriegel et al., 2023; Stahl et al., 2023). Despite these advancements, the selection of appropriate research designs remains a considerable challenge, particularly in achieving a balance between methodological rigor and practical applicability (Burden et al., 2024; Chang et al., 2024). A central issue emerging from this complex landscape is the absence of standardized guidelines to assist researchers in navigating the nuanced process of designing studies that produce valid and reliable results. This gap raises essential questions about how different research designs influence outcomes and the broader implications for knowledge transfer and application, particularly in domains such as healthcare and education (Muteeb et al., 2023; Keng-Ooi et al., 2023).

This study uses a quantitative research design to examine the relationship between MRP effectiveness, GSCP, and SMP of organisation under FMM. A cross-sectional survey approach will be used to gather primary data from supply chain managers, logistics officers, production managers and procurement managers in various industries.

3.2 Population

In research methodology, the term *population* refers to the complete set of individuals or entities that a researcher aims to investigate. This group comprises all members who exhibit specific characteristics pertinent to the research question or hypothesis under examination. Populations may be delineated according to demographic variables such as age, gender, geographical location, or shared experiences (Willie, 2024; Willie, 2022).

Identifying the population of interest is essential for ensuring both the validity and reliability of research findings. Researchers commonly distinguish between the general population and the target population the latter being a defined subset of the broader population that is the principal focus of the study. This distinction is crucial for developing appropriate sampling strategies that can yield meaningful and generalizable insights about the wider population (Willie, 2024; Willie, 2022). Furthermore, alignment between the defined population and the research objectives enhances the applicability of the study's outcomes.

Ethical considerations are of paramount importance when conducting research involving specific populations, particularly vulnerable or marginalized groups. Researchers are ethically obligated to safeguard the rights and well-being of participants throughout the research process (Castañeda & Smith, 2022). The use of culturally sensitive and inclusive methodologies not only promotes ethical integrity but also contributes to the overall credibility and contextual relevance of the research (Castañeda & Smith, 2022). Additionally, population dynamics play a significant role in the interpretation of research findings. A nuanced understanding of the defining characteristics and challenges faced by the target population can provide deeper insight into the results, especially in studies focused on health disparities or social inequality (Willie, 2024).

The target population for this study consists of as of 2024, Malaysia's manufacturing sector comprises approximately 4000 companies, according to data from the FMM and Malaysian Investment Development Authority (MIDA). The notable growth in the number of manufacturing enterprises underscores the effectiveness of Malaysia's strategic industrial initiatives, particularly those outlined under the New Industrial Master Plan (NIMP) 2030. This national policy framework aims to modernize and transform the country's industrial base through the adoption of innovation, digitalization, and enhanced integration into global value chains. Key geographical contributors to this industrial expansion include the states of Selangor, Penang, Johor, and the Klang Valley region, all of which are recognized for their established and emerging high-value manufacturing hubs.

Despite the pivotal role Malaysia's federal manufacturing sector plays in national economic development particularly within the electrical and electronics (E&E) industry its progress toward adopting sustainable and digital supply chain practices remains significantly constrained. Structural challenges, including limited financial capital, insufficient technological capabilities, and restrictive regulatory environments, present critical barriers to transformation. These systemic limitations impede the implementation of MRP effectiveness and GSMP, both of which are essential to improving operational efficiency, environmental performance, and long-term industrial sustainability.

Given that Malaysia is among the world's foremost exporters of semiconductors, electrical equipment, and ICT products, the country's manufacturing ecosystem is strategically positioned to lead regional sustainability transitions. As of 2023, the E&E sector alone contributed 5.8% to Malaysia's GDP and accounted for 40% of total exports, underscoring its national and global significance. The sector also produces 13% of the global supply of back-end semiconductors, highlighting Malaysia's critical integration into global value chains.

However, this global prominence is juxtaposed with internal stagnation in sustainability practices, particularly among domestic firms and SMEs that lack access to high-end technologies and responsive policy support. Multinational corporations (MNCs) such as Intel, AMD, and Infineon, alongside local champions like Silterra and Globetronics, drive much of the industry's high-value output. Yet, the diffusion of best practices in green manufacturing remains uneven across the sector.

This research is therefore essential to bridging the empirical gap between Malaysia's industrial potential and its practical constraints. By examining how MRP and GSCP interact under local contextual pressures, this study aims to generate actionable insights to enhance manufacturing resilience, economic competitiveness, and environmental stewardship. It addresses an urgent need for evidence-based policy interventions and technological capacity-building strategies that can enable a more inclusive and adaptive industrial transformation in Malaysia.

3.3 Sample

A sample is defined as a subset of a population selected to participate in a research study (Ajithakumari, 2024). Sampling is fundamental to the research process, as it directly influences the reliability, validity, and generalizability of the study's findings (Galevska, 2023). Sampling techniques are generally classified into two main types: probability sampling, which involves the random selection of participants, and non-probability sampling, which involves selection based on specific criteria such as convenience, accessibility, or purposive characteristics (Ajithakumari, 2024). The selection of an appropriate sampling method depends on the research objectives, study design, and characteristics of the target population (Galevska, 2023).

For this study, the Krejcie and Morgan (1970) Table is utilized to determine the appropriate sample size for the target population of 4,000 member organizations under the FMM. According to this model, a population of 4,000 requires a minimum sample size of 351 respondents to ensure a 95% confidence level with a ±5% margin of error. This level of precision is widely accepted in social science research and is considered sufficient for generating statistically valid and generalizable findings (Bukhari, 2021).

As reported by the FMM as of June 30, 2024, the organization comprises 4000 member firms representing a diverse range of manufacturing and industrial service sectors across various organizational scales (FMM, 2024). The application of Krejcie and Morgan's method therefore ensures methodological rigor in the sampling process and supports the study's aim to produce valid conclusions regarding the adoption of sustainable and digital supply chain practices within Malaysia's manufacturing landscape.

Accordingly, a sample size of 368 organizations is deemed both adequate and statistically representative of the FMM population. This sampling determination is further illustrated in Table 3.1, which presents the Krejcie and Morgan Sample Size Determination Table for reference.

Table 3.1: Krejcie and Morgan Table, 1970

N	S	N	S	N	S
10	10	220	140	1200	291
15	14	230	144	1300	297
20	19	240	148	1400	302
25	24	250	152	1500	306
30	28	260	155	1600	310
35	32	270	159	1700	313
40	36	280	162	1800	317
45	40	290	165	1900	320
50	44	300	169	2000	322
55	48	320	175	2200	327
60	52	340	181	2400	331
65	56	360	186	2600	335
70	59	380	191	2800	338
75	63	400	196	3000	341
80	66	420	201	3500	346
85	70	440	205	4000	351
90	73	460	210	4500	354
95	76	480	214	5000	357
100	80	500	217	6000	361
110	86	550	226	7000	364
120	92	600	234	8000	367
130	97	650	242	9000	368
140	103	700	248	10000	370
150	108	750	254	15000	375
160	113	800	260	20000	377
170	118	850	265	30000	379
180	123	900	269	40000	380
190	127	950	274	50000	381
200	132	1000	278	75000	382
210	136	1100	285	1000000	384

N is population size *S* is sample size

3.3.1 Sampling Technique

To ensure the validity and relevance of this quantitative study, a simple random sampling technique was employed, targeting manufacturing firms that are registered under the Federation of Malaysian Manufacturers (FMM). Simple random sampling was selected because it provides every member of the population an equal and independent chance of being chosen, which minimizes selection bias and enhances the generalizability of findings (Sharma et al., 2024; Polas, 2024). This approach aligns with the statistical assumptions underlying the Krejcie and Morgan (1970) sample size determination method, which recommends using random sampling to maintain representativeness when estimating population parameters.

The study focused on respondents who have direct involvement in material planning, supply chain operations, procurement, or sustainability roles within their organizations. These individuals are considered knowledgeable and capable of accurately assessing the impact of Material Requirements Planning (MRP) and Green Supply Chain Practices (GSCP) on Sustainable Manufacturing Performance (SMP) (Haryaningsih et al., 2023; Willie, 2024). A structured online questionnaire was distributed using Google Forms, enabling cost-effective and broad geographical coverage across Malaysian states, which is crucial for obtaining diverse insights from firms with different operational scopes (Galevska, 2023).

A total of 100 valid responses were collected from manufacturing firms. The minimum required sample size was calculated using Krejcie and Morgan's (1970) sample size formula, assuming a 95% confidence level and a 5% margin of error, which are standard thresholds for ensuring statistical significance in social science research (Sharma et al., 2024). Data were processed using the Statistical Package for the Social

Sciences (SPSS) version 27, incorporating reliability tests such as Cronbach's Alpha, descriptive statistics, and exploratory factor analysis to ensure consistency and validity.

To guide sample selection and ensure relevance to the study's objectives, the following inclusion criteria and justifications were established:

Table 3.2: Criteria

Inclusion Criteria	Justification
Firm must be a registered member of FMM	Ensures formal recognition within Malaysia's manufacturing sector (Ghazali et al., 2021).
Respondent must work in the supply chain, planning, procurement, or sustainability department	Ensures subject-matter relevance and operational knowledge (Chachu et al., 2021).
Firm must be involved in manufacturing activities	Aligns with the study's focus on sustainable manufacturing (Zahari et al., 2024).
Firm must have used or currently use MRP systems	Confirms the respondent's familiarity with MRP effectiveness (Kroculick, 2025).
Firm must be located in Malaysia	Ensures contextual and geographical consistency (Omotayo, 2023).

By meeting these criteria, the sample accurately reflects the targeted population and ensures the credibility of the findings. The rigorous sampling strategy, supported by relevant literature and statistical best practices, reinforces the methodological robustness and relevance of the study's exploration into how MRP effectiveness and GSCP contribute to SMP in Malaysia's manufacturing industry.

3.4 Questionnaire Design

The questionnaire was designed as a structured instrument to collect quantitative data aligned with the study's research objectives and hypotheses. It was administered via Google Forms to ensure broad accessibility and efficient data collection across various regions in Malaysia. The design focused on closed-ended items and five-point Likert scale statements, as recommended by Taherdoost (2022) and Wu (2021), to ensure reliability, neutrality, and statistical suitability.

The instrument consists of four main sections:

1. **Demographics** – capturing firm size, ownership, sector, and respondent's role, which help contextualize responses (McMaster Research Ethics Board, 2024; Drive Research, 2024).

2. **MRP Effectiveness** – items measure planning accuracy, inventory control, timeliness of materials, production scheduling, and operational impact.

3. **Green Supply Chain Practices (GSCP)** – covering eco-design, green purchasing, and reverse logistics.

4. **Sustainable Manufacturing Performance (SMP)** – focused on environmental, operational, and economic outcomes.

To ensure content validity, a pilot test was conducted with a small sample of manufacturing professionals. Feedback was used to refine the structure, clarity, and logical flow of the questionnaire. Tables 3.2 and 3.3 outline item distributions based on the constructs adapted from validated prior studies (Mahar et al., 2025; Seiringer et al., 2024; Setyadi et al., 2025).

In line with current trends, MRP effectiveness is measured by its capacity to enhance scheduling precision and adapt to supply chain changes (First Resonance, 2024), while GSCP items capture the firm's ability to integrate sustainability into operational planning. The final instrument ensures that data supports rigorous testing of relationships between MRP, GSCP, and SMP using SPSS.

Table 3.3: Questionnaire Design Section

Section	Explanation
Demographic Questions (Section 1)	This section gathers essential background information about the respondents and their respective organizations within the Federation of Malaysian Manufacturers (FMM). It includes details such as the type of organization, size, ownership structure, and the respondent's role. These demographic variables help contextualize the findings and ensure that the sample represents a diverse cross-section of FMM member organizations.
MRP Effectiveness (Section 2)	This section comprises items designed to evaluate the effectiveness of Manufacturing Resource Planning (MRP) systems within FMM member organizations. Planning Accuracy, Inventory Control, Timeliness of Materials, Production Schedule Adherence, and Operational Impact.
Green Supply Chain Management Practices (Section 3)	This section assesses the mediating role of green supply chain practices in the relationship between MRP system effectiveness and sustainable manufacturing outcomes. Eco-Design, Green Purchasing and Cooperation with Customers
Sustainable Manufacturing Performance	The final section measures sustainable manufacturing performance, focusing on outcomes aligned with environmental, economic, and operational sustainability.

(Section 4)	The questions assess how effectively organizations integrate sustainability into manufacturing activities, resource usage, production outputs, and compliance with sustainability standards.

Table 3.4: Summary of Previous Studies that aligns on MRP Effectiveness, Green Supply Chain Practices, and Sustainable Manufacturing Performance

Types of Variables	Question	Authors
IV:MRP Effectiveness	PA1: In our company, MRP helps us generate accurate material plans	Malindzakova, Malindzak, & Mervart, 2022
	PA2: Material forecasting in our company is more reliable since we started using MRP	
	PA3: Our MRP process aligns well with our actual production schedules.	
	PA4: Inventory records in our company have become more accurate due to improved material planning through MRP	
	IC1: In our company, MRP helps reduce excess inventory	Reis, 2023
	IC2: Inventory turnover in our company has improved since we adopted MRP	
	IC3: We experience fewer stockouts due to the use of MRP.	
	IC4: Our inventory records have become more accurate as a result of MRP-based material planning	
	TM1: In our company, MRP ensures materials are available on time for production.	Khumla & Sarawan, 2023
	TM2: The MRP system helps us detect material shortages early enough to take corrective action	
	TM3: MRP planning allows our company to place purchase orders at the right time	
	TM4: MRP has helped reduce procurement lead times in our company	

	PSA1: MRP has helped our company adhere more closely to the master production schedule PSA2: Unplanned changes in our production schedule have decreased since we implemented MRP. PSA3: MRP supports the timely completion of production orders in our company PS4: The production team in our company follows MRP-generated plans because they are realistic and achievable	Mohd & Aziz, 2021;
	OI1: MRP has improved the overall operational efficiency in our plant. OI2: Since implementing MRP, our customer delivery performance has improved OI3: MRP has strengthened coordination between departments such as production, procurement, and planning. OI4: Our company experiences fewer disruptions from material shortages due to MRP.	First Resonance, 2024; Seiringer et al., 2024
Mediator: Green Supply Chain Management Practices	ED1: Design of products for reduced consumption of material/energy ED2: Design of products for reuse, recycle, recovery of material, component parts ED3: Design of products to avoid or reduce use of hazardous products and/or their manufacturing process	Jayant, Azhar, & Vikas, 2017; Komal & Khandare, 2024
	GP1: Eco-labelling of products GP2: Cooperation with suppliers for environmental objectives GP3: Environmental audit for suppliers' internal management GP4: Suppliers' ISO14000 certification GP5: Second-tier supplier environmentally friendly practice evaluation	Logistics Editorial Board, 2023; Mahar et al., 2025

	CC1: Cooperation with customers for eco-design CC2: Cooperation with customers for cleaner production CC3: Cooperation with customers for green packaging	Nazir, Zhaolei, Mehmood, & Nazir, 2024; Primadasa et al., 2024
DV: Sustainable Manufacturing Performance	EP1: Reduction of air emission EP2: Reduction of waste water EP3: Reduction of solid wastes EP4: Decrease of consumption for hazardous/harmful/toxic materials EP5: Decrease of frequency for environmental accidents EP6: Improvement of an enterprise's environmental situation	Huang & Badurdeen, 2017; LineView, 2025
	ECP1: Decrease of cost for materials purchasing ECP2: Decrease of cost for energy consumption ECP3: Decrease of fee for waste treatment ECP4: Decrease of fee for waste discharge ECP5: Decrease of fine for environmental accidents	Mukhopadhyay & Jayaraman, 2025;
	OP1: Increase amount of goods delivered on time OP2: Decrease inventory levels OP3: Decrease scrap rate OP4: Promote products' quality OP5: Increase product line OP6: Improve capacity utilization	Setyadi et al., 2025; Zailani, Iranmanesh, & Foroughi, 2017

3.5 Research Measurement

In quantitative research, the research measurement questionnaire serves as a fundamental tool for systematically gathering empirical data (Zheng, 2021). The construction of such a questionnaire demands rigorous design procedures to minimize measurement errors and maximize both reliability and validity (Taherdoost, 2022). According to methodological guidelines, the development process encompasses the identification of required information, determination of survey structure and question formats, careful phrasing of items, and logical sequencing in the final instrument (Taherdoost, 2022).

This study adopts a dual-scale approach by integrating nominal and interval measurement scales, in alignment with established measurement theory (Blasco, 2021). Nominal scales are employed to categorize respondents based on non-numeric variables such as industry sector, job designation, organizational size, and years of experience. These variables, although not numerically ranked, provide critical demographic context for interpreting patterns within the data. The nominal data will be analysed using frequency distributions and descriptive statistics, offering an essential overview of respondent characteristics and enabling cross-tabulation where appropriate.

The core section of the questionnaire measures the study's principal constructs, namely, MRP effectiveness, GSCP, and SMP that using interval scales via a 5-point Likert Scale. This scale allows respondents to indicate their level of agreement with a set of standardized statements. MRP effectiveness uses "Strongly Disagree" (1) to "Strongly Agree" (5). The GSCP uses "Not considering it" (1), "Planning to consider it" (2), "Considering it currently" (3), "Initiating implementation" (4) and

"Implementing successfully" (5). The SMP uses "Not at all" (1), "A little bit" (2), "To some degree" (3), "Relatively significant" (4), and "Significant" (5). The Likert scale, widely regarded as a robust psychometric tool, is frequently employed in survey-based research to quantify attitudes, perceptions, and behavioural tendencies (Anjaria, 2022; Maruf, 2023). While some academic debate exists regarding the ordinal versus interval treatment of Likert responses, this study treats the scale as an interval measure to facilitate parametric statistical analysis, including mean comparison, standard deviation, and regression modelling. The integration of both nominal and interval measurement scales ensures that the collected data are both categorically descriptive and statistically analysable, thereby enhancing the study's analytical rigor and the validity of its conclusions.

3.6 Unit of Analysis

The unit of analysis is a foundational element in research methodology, as it defines the principal entity being observed and analysed throughout the study. It plays a critical role in formulating hypotheses, structuring research questions, and aligning data collection and analysis methods (Morin et al., 2021). In the context of this research, the unit of analysis is company/organization managers are the respondents. Specifically, this includes individuals holding key decision-making roles such as supply chain managers, operations managers, logistics managers, and production or procurement managers. These individuals are strategically positioned to provide informed perspectives on the effectiveness of MRP, the implementation of GSCP, and SMP.

By focusing on managerial-level respondents, the study ensures access to individuals with comprehensive operational oversight and strategic insight into the challenges and initiatives related to sustainability and resource planning in the Malaysian manufacturing sector. This approach enhances the validity and relevance of the data collected, as these managers are directly involved in system implementation, sustainability integration, and performance measurement. Thus, the selected unit of analysis enables the research to reflect experiential knowledge, strategic decision-making, and operational realities critical to achieving the study's objectives within the FMM context.

3.7 Data Collection

Data collection is a core aspect of research methodology, involving systematic procedures for gathering information that directly addresses research questions and hypotheses (Sukmawati et al., 2023; Mazhar, 2021). It encompasses various approaches such as questionnaires, interviews, observations, and database searches depending on the research design and objectives. In this quantitative study, there are 2 type of data which are primary data, obtained through structured online questionnaires, and secondary data, sourced from previously published academic literature and reports (Ganesha & Aithal, 2022). Primary data enables the direct measurement of variables, while secondary data supports theoretical framing and contextualization of findings.

The primary data have been collected from manufacturing organizations listed under the FMM, using online distribution via email and WhatsApp. Contact information for potential respondents will be accessed through the official FMM website (https://www.fmm.org.my/default.aspx), ensuring that the sample is relevant, reliable, and representative. This method targets professionals in decision-making roles such as operations managers, supply chain manager, production manager, logistics manager and executives who possess the operational insight necessary to answer the questionnaire. Leveraging email and WhatsApp as data collection platforms provides several advantages due it is cost-effective, time-efficient, and user-friendly, allowing respondents the flexibility to participate at their convenience. This digital approach is expected to improve response rates and enhance participation from diverse sectors within the Malaysian manufacturing landscape, thereby strengthening the generalizability and robustness of the study's findings.

3.7.1 Primary Data

Primary data refers to firsthand information collected directly by researchers to address specific research questions, distinct from secondary data that originates from existing sources (Mazhar, 2021; Ganesha & Aithal, 2022). In this study, primary data will be obtained through a structured online questionnaire, specifically designed to collect quantifiable insights from managerial-level respondents within FMM-affiliated manufacturing organizations. This data collection method is both efficient and scalable, allowing for a broad geographical reach and diverse representation of respondents from various sectors within the Malaysian manufacturing industry. The digital format of the survey administered via Google Forms enables respondents to participate at their own convenience, increasing the likelihood of response accuracy and completeness. This approach is especially suitable for engaging professionals such as production, logistics, and supply chain managers, whose availability may be limited. Moreover, online questionnaires reduce human error in data entry and ensure uniformity in administration, thereby enhancing the reliability and validity of the data (Hamzani et al., 2023). The collected primary data will serve as the empirical basis for examining the hypothesized relationships between MRP system effectiveness, green supply chain practices, and sustainable manufacturing performance, thereby contributing original, real-world insights to the field of sustainable industrial operations.

3.7.2 Secondary Data

Secondary data analysis is a well-established research methodology that entails the re-examination of existing data to address new or extended research questions (Kelly et al., 2024). This approach is recognized for its cost-effectiveness, efficiency, and potential to enrich the scope of empirical inquiry, particularly within fields such as healthcare, management, and sustainability (Moore et al., 2021). Secondary data may originate from a variety of sources, including large-scale research databases, digital repositories, electronic records, and publicly accessible qualitative content such as online interviews and previously published articles (Moore et al., 2021; Cheong et al., 2023).

In this study, secondary data sourced from peer-reviewed journal articles and scholarly publications that explore themes related to MRP, green supply chain practices, and sustainable manufacturing performance. These articles serve as a critical theoretical foundation, offering empirical findings, conceptual frameworks, and methodological precedents that inform the present investigation. The insights drawn from secondary data will not only contextualize the primary data but also guide the construction of the conceptual framework and the formulation of testable hypotheses.

By engaging with past research, this study ensures academic continuity and theoretical robustness. The incorporation of secondary data enhances the study's validity by aligning its primary data analysis with existing scholarly discourse. Moreover, it enables the researcher to build upon established knowledge, thereby contributing meaningfully to the broader academic conversation on sustainable practices and digital integration in manufacturing.

3.8 Pilot Test

Pilot testing is a crucial step in ensuring the validity, clarity, and reliability of a research instrument before full-scale data collection (Tate et al., 2023; Wilson et al., 2022). In this study, a pilot test was conducted involving five experts, comprising three academic researchers specializing in supply chain and sustainability and two industry practitioners from the manufacturing sector who are familiar with Material Requirements Planning (MRP) systems and Green Supply Chain Practices (GSCP).

These validators reviewed the questionnaire for item clarity, content relevance, and construct alignment with the study's variables MRP effectiveness, GSCP, and Sustainable Manufacturing Performance (SMP). Special attention was given to the appropriateness of the 5-point Likert scale, wording of each item, and the logical flow of sections. The reviewers also evaluated the technical deployment of the questionnaire using Google Forms to ensure accessibility, smooth navigation, and correct branching logic in an online environment.

Feedback was collected and analysed thematically. Necessary refinements were made to remove ambiguity, redundancy, and inconsistencies, ensuring the instrument was well-calibrated to collect reliable and valid data for the main study.

Table 3.5: 30 Samples Pilot Test Cronbach's Alpha

	Variable	**Cronbach's Alpha**
MRP SYSTEM EFFECTIVENESS (IV)	Planning Accuracy (IV1)	0.810
	Inventory Control (IV2)	0.897
	Timeliness of Materials (IV3)	0.855

	Production Schedule Adherence (IV4)	0.779
	Operational Impact (IV5)	0.702
GREEN SUPPLY CHAIN MANAGEMENT PRACTICES (MEDIATOR)	Eco-Design (MED1)	0.890
	Green Purchasing (MED2)	0.943
	Cooperation with Customers (MED3)	0.821
SUSTAINABLE MANUFACTURING PERFORMANCE (DV)	Environment Performance (DV1)	0.935
	Economic Performance (DV2)	0.914
	Operational Performance (DV3)	0.931

3.9 Data Analysis Technique

Data analysis techniques are essential components of research methodology, as they offer structured approaches to collect, interpret, and validate data for meaningful conclusions. In this study, which investigates how the integration of Material Requirements Planning (MRP) effectiveness and Green Supply Chain Practices (GSCP) contributes to Sustainable Manufacturing Performance (SMP) among Federation of Malaysian Manufacturers (FMM) member organizations, data analysis plays a pivotal role in testing the conceptual framework and confirming hypotheses.

The statistical analysis will be conducted using Statistical Package for the Social Sciences (SPSS) version 27. The analysis begins with a normality test, using both graphical methods (histograms and Q-Q plots) and statistical methods (Shapiro-Wilk and Kolmogorov-Smirnov tests) to determine whether parametric tests are appropriate

(Jaramillo et al., 2023). Following this, reliability testing will be conducted using Cronbach's Alpha to ensure the internal consistency of constructs such as MRP effectiveness, GSCP, and SMP (Malapane & Ndlovu, 2024).

Next, Pearson correlation analysis will assess the strength and direction of relationships among the variables, while multiple linear regression will test the predictive influence of MRP effectiveness and GSCP on SMP. These techniques are essential to verify the direct and mediating effects proposed in the study's hypotheses (Asha, 2022). This multi-layered approach ensures analytical rigor and enhances the empirical strength of the study.

Table 3.6: Table of the summary for proposes Data, RQ, RO & Hypotheses

Research Question (RQ)	**Research Objective (RO)**	**Hypothesis (H)**	**Variables Involved**	**Analysis Technique**
RQ1: What is the relationship between MRP effectiveness and SMP?	RO1: To investigate the relationship between MRP effectiveness and SMP.	H1	IV: MRP Effective nessDV: GSCP	Pearson Correlation & Regression
RQ2: What is the relationship between GSCP and SMP?	RO2: To investigate the relationship between GSCP and SMP.	H2	IV: GSCPDV : SMP	Pearson Correlation & Regression
RQ3: To what extent do GSCP mediate the relationship	RO3: To investigate the mediating role of GSCP in the relationship	H3	IV: MRP Effective nessMV: GSCPDV : SMP	Mediation Analysis using Regression

Research Question (RQ)	Research Objective (RO)	Hypothesis (H)	Variables Involved	Analysis Technique
between MRP effectiveness and SMP?	between MRP effectiveness and SMP.			

3.10 Chapter Summary

This chapter has detailed the quantitative methodological framework adopted for this study, which investigates the relationships between MRP effectiveness, green supply chain practices, and sustainable manufacturing performance among member organizations of the FMM. The research employed a structured questionnaire distributed via Google Forms, targeting managerial-level respondents such as supply chain, operations, and procurement managers individuals directly engaged in planning and sustainability initiatives. The questionnaire was designed based on the research objectives and conceptual model, incorporating nominal and interval scales, with key constructs measured using a 5-point Likert scale. To ensure validity and reliability, the instrument underwent expert review and pilot testing. A sample size of 368 respondents was determined using Krejcie and Morgan's table, with simple random sampling ensuring representativeness across the manufacturing sector. Data analysis was conducted using SPSS, employing descriptive statistics, reliability testing (Cronbach's alpha), and inferential techniques, including multiple linear regression, to evaluate the hypothesized relationships among variables. Ethical considerations such as voluntary participation, informed consent, and data confidentiality were observed throughout the study. This methodological approach provides a statistically sound foundation for the analysis and interpretation of findings presented in the subsequent chapters.

CHAPTER 4

DATA ANALYSIS

4.1 Introduction

This chapter discusses about the response rate of survey, demographic analysis, data screen and cleaning, normality analysis, reliability analysis, hypothesis test, Pearson correlation, regression and result analysis hypothesis.

4.2 Response Rate of Survey

In research, the percentage of people who fill out and return a survey or questionnaire relative to the total number of people who were invited or qualified to participate is known as the response rate of survey. It is used to determine the efficacy and representativeness of the survey sample and is commonly reported as a percentage (Wu et al., 2022). For this study, the researcher distributed 350 questionnaires and only 100 respondents completed the questionnaires. The data is in percentage form.

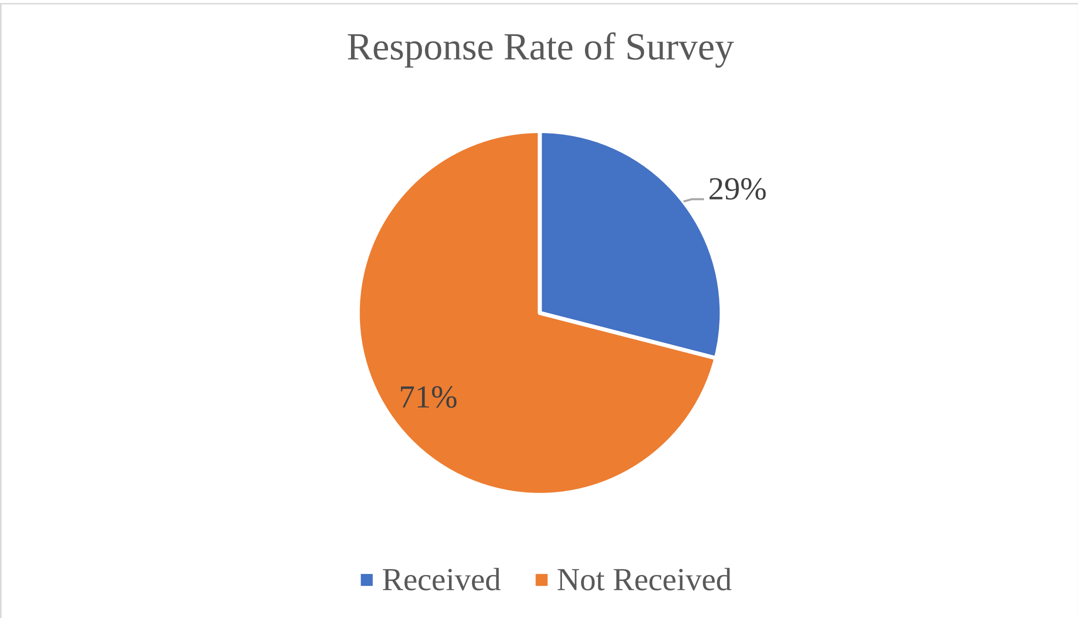

Figure 4.1 Response Rate of Survey

The survey achieved a response rate of 29%, indicating a weak level of participation from the targeted respondents. This minority response reflects a significant level of interest and relevance of the research topic within the manufacturing sector, providing a moderate foundation for data analysis and meaningful insights into the integration of MRP with GSCP.

4.3 Demographic Analysis

Demographic analysis in research refers to the study and interpretation of data related to the characteristics of a population or sample group, such as age, gender, education level, occupation, income, and geographic location. It helps researchers understand the background and diversity of respondents, identify patterns or trends, and assess how these characteristics may influence behaviours, perceptions, or outcomes relevant to the research objectives.

For this research, the demographic questions consist of 7 which are type of organization, years in operation, industry sector, respondent's position, annual revenue, educational background, years of experience and number of employees. This facilitates the analysis and interpretation of data by researcher in relation to various demographic groupings, which can spot trends and draw more precise conclusions about the population.

4.3.1 Type of Organization

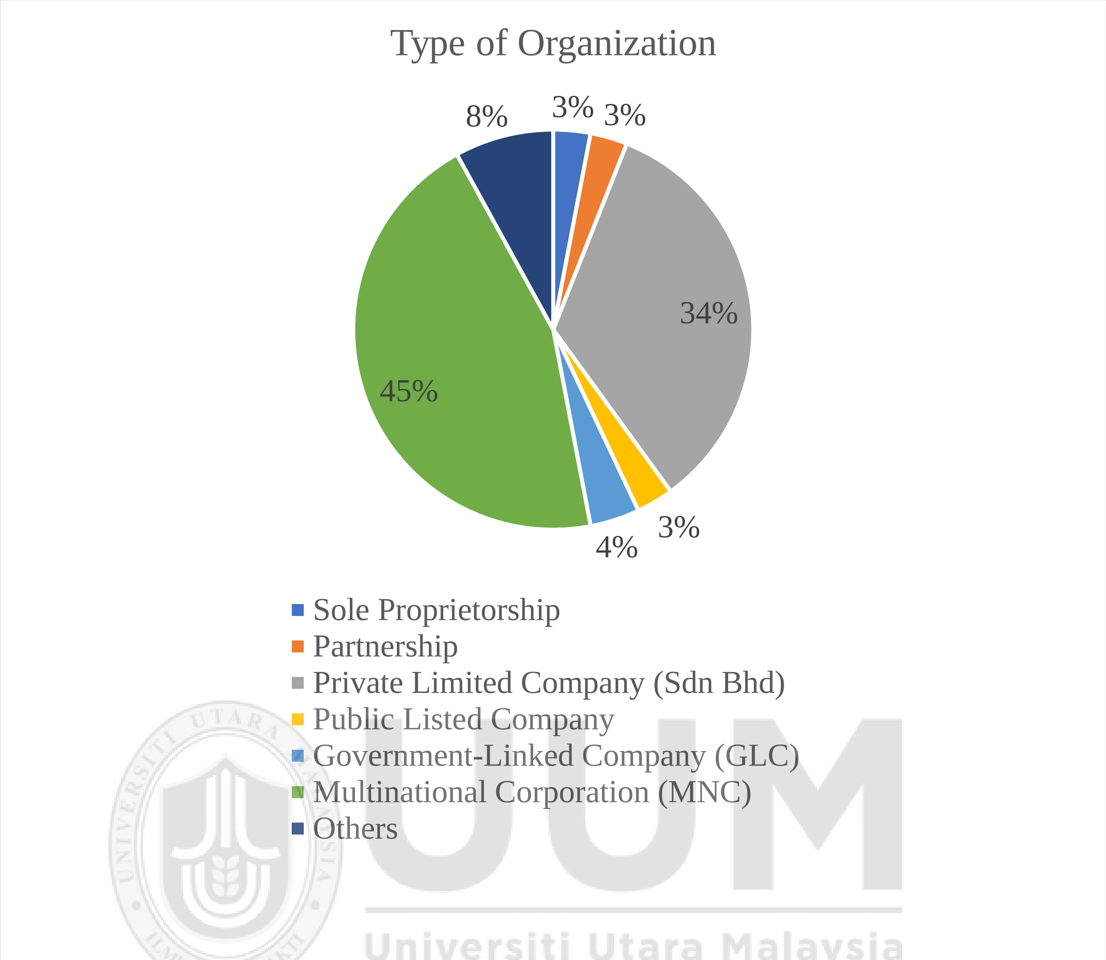

Figure 4.2 Type of Organization

The respondents in this study predominantly represent larger and more complex organizational structures, with Multinational Corporations (MNCs) accounting for 45% and Private Limited Companies (Sdn Bhd) making up 34%. This indicates that the sample includes businesses with significant operational capacity, resources, and likely more structured supply chain practices. Smaller forms like sole proprietorships and partnerships are marginal (3% each), reflecting that advanced manufacturing practices such as MRP and green supply chain integration are more prevalent in established firms. The presence of Government-Linked Companies (4%) and Public Listed Companies (3%) also suggests institutional influence in sustainable manufacturing initiatives.

4.3.2 Years in Operation

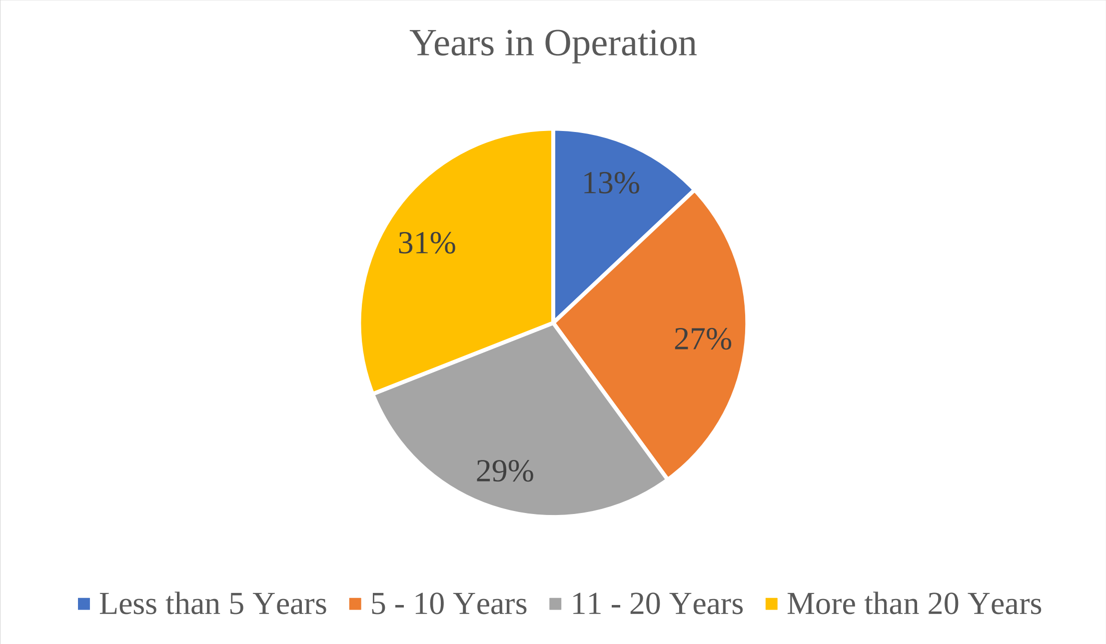

Figure 4.3 Years in Operation

The data shows that a majority of the organizations surveyed are well-established, with 60% operating for more than 11 years (29% between 11–20 years and 31% for more than 20 years). This suggests maturity in business processes, including potential long-term investment in sustainability and advanced planning systems like MRP. Only 13% of firms are relatively new (less than 5 years), implying that most respondents likely have had sufficient time to adopt or consider integrating sustainable practices into their operations.

4.3.3 Industry Sector

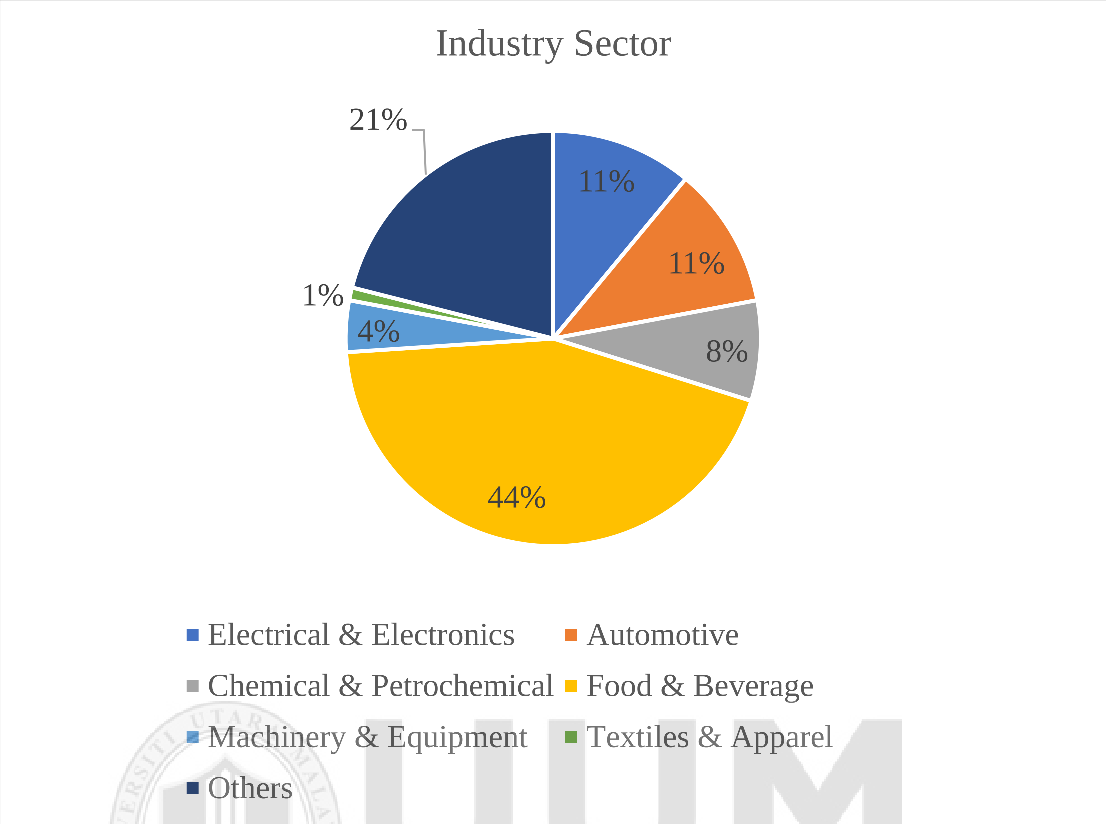

Figure 4.4 Industry Sector

The largest portion of respondents comes from the Food & Beverage sector (44%), followed by Electrical & Electronics and Automotive, each at 11%. The diversity in sectors highlights the cross-industry relevance of integrating MRP with green supply chain practices. The strong representation of F&B may reflect growing environmental concerns and regulatory pressures in consumable goods production, while the inclusion of sectors like Automotive and Chemical & Petrochemical suggests a high environmental impact potential, where sustainable manufacturing practices are crucial.

4.3.4 Respondent's Position in the Organization

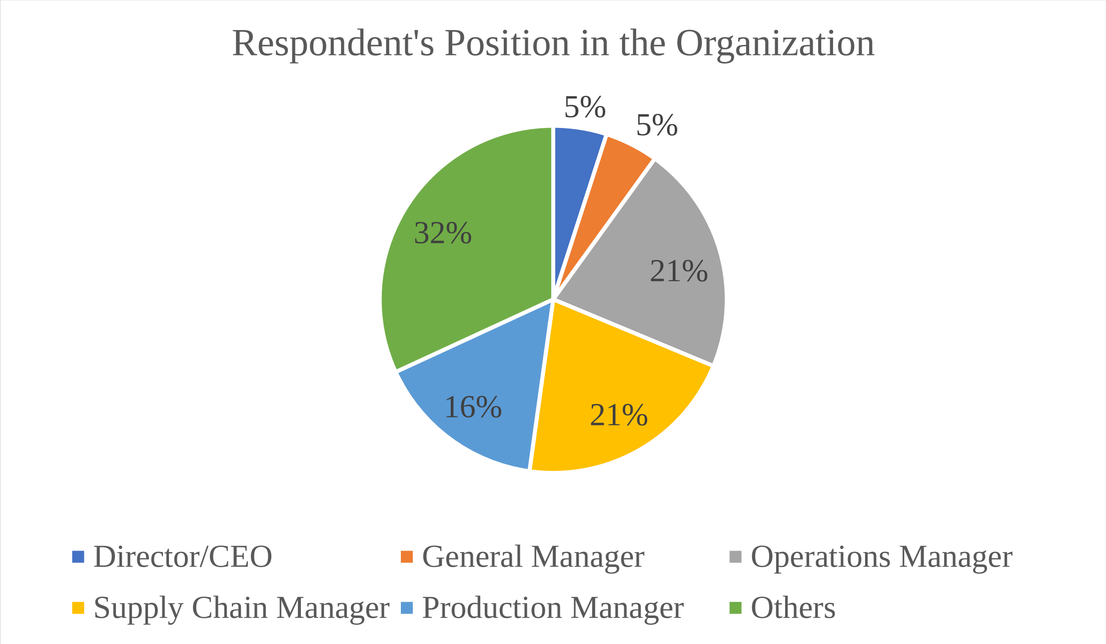

Figure 4.5 Respondent's Position in the Organization

Respondents mainly hold middle to upper-management roles such as Operations Manager and Supply Chain Manager (both at 21%), followed by Production Managers (16%). These roles are directly responsible for implementing MRP systems and overseeing supply chain and manufacturing processes, making their input highly relevant. The inclusion of senior-level roles (Director/CEO and General Manager at 5% each) indicates strategic oversight, while the 32% in "Others" may consist of technical experts or sustainability officers, broadening the perspective of the data collected.

4.3.5 Annual Revenue (Last Fiscal Year)

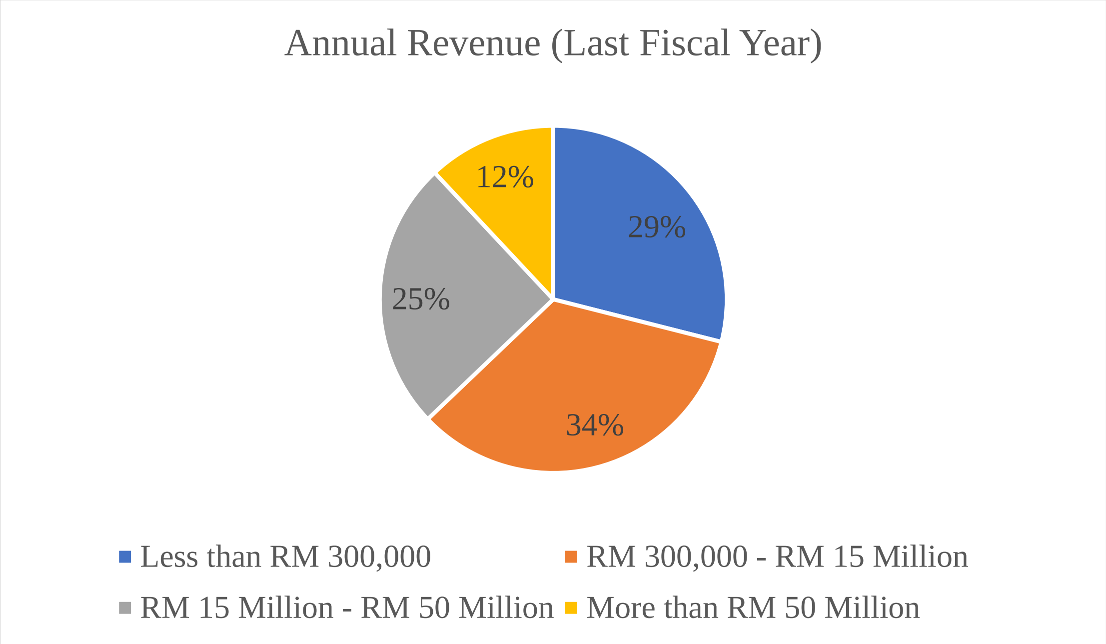

Figure 4.6 Annual Revenue (Last Fiscal Year)

A balanced distribution of annual revenue indicates that the study encompasses a range of business sizes, with 34% earning between RM 300,000 and RM 15 million, and 25% between RM 15 million and RM 50 million. Notably, 29% of companies report less than RM 300,000 in revenue, possibly indicating smaller players or departments within larger organizations. The 12% earning more than RM 50 million represent high-performing firms that likely have more capacity to implement green and digital manufacturing systems.

4.3.6 Educational Background of Respondent

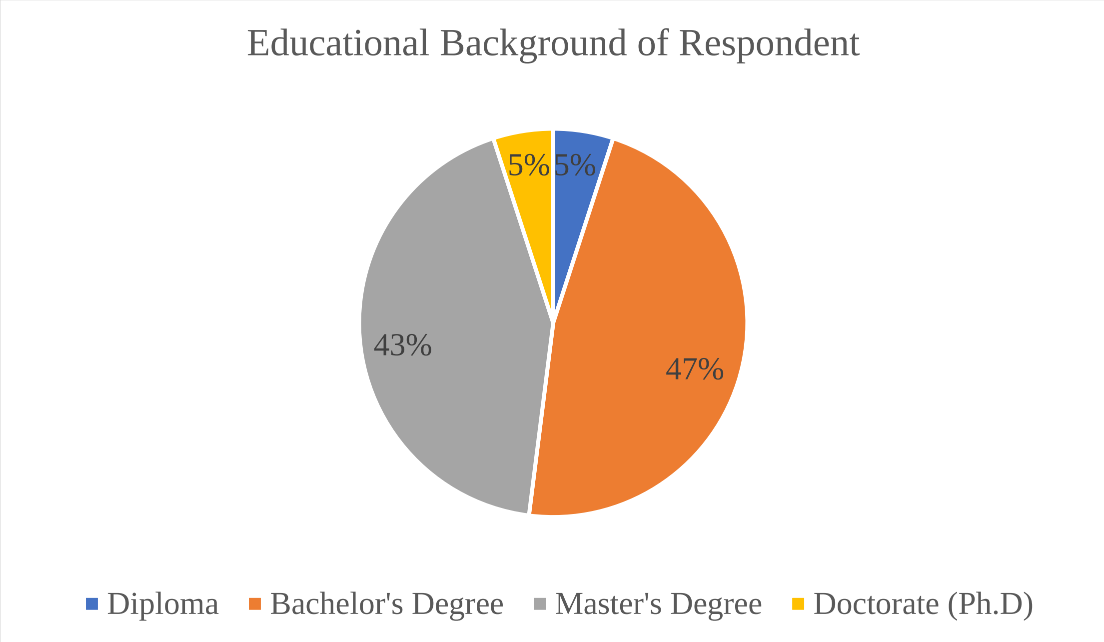

Figure 4.7 Educational Background of Respondent

An impressive 90% of respondents possess Master and Degree (43% Master's and 47% Degree), which implies a highly knowledgeable sample with strong academic and professional grounding in manufacturing and sustainability issues. This enhances the credibility and reliability of the responses, as participants are likely to have a solid understanding of complex topics such as MRP integration, green practices, and sustainability performance.

4.3.7 Years of Experience in the Manufacturing Sector

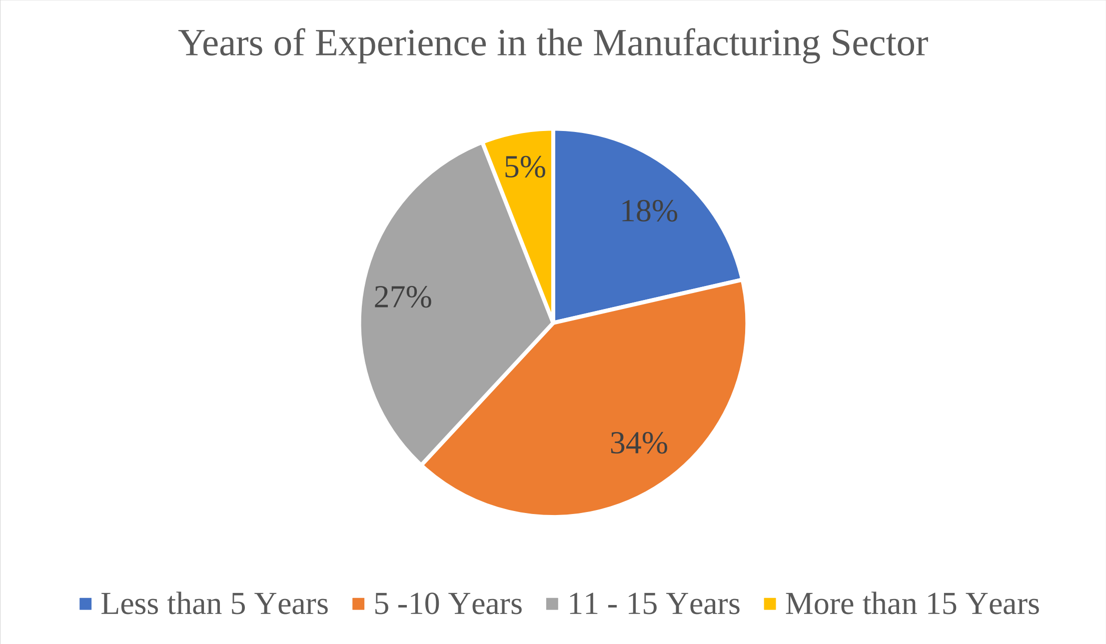

Figure 4.8 Years of Experience

The majority of respondents (61%) have between 5 and 15 years of experience in manufacturing, which indicates that they possess adequate industry exposure and practical knowledge to provide informed insights. Interestingly, only 5% have more than 15 years of experience, suggesting that the study mostly captures the perspectives of mid-career professionals who are actively involved in current operational and strategic decisions related to sustainability.

4.3.8 Number of Employees

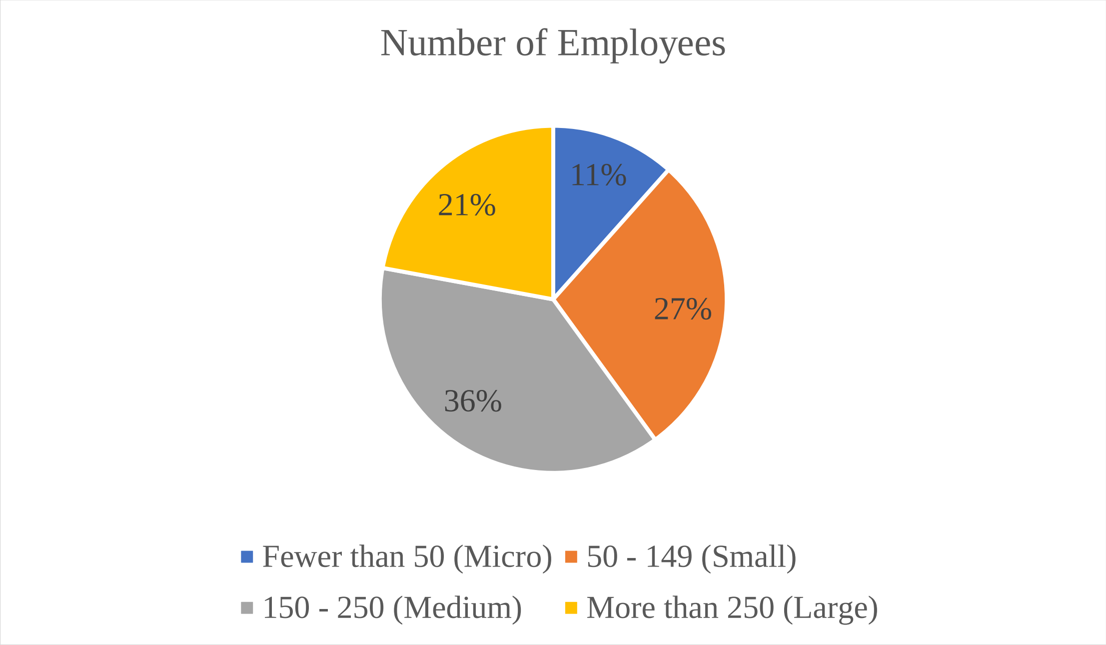

Figure 4.9 Number of Employees

The distribution shows that medium-sized enterprises (150–250 employees) form the largest group at 36%, followed by small (27%) and large organizations (21%). Only 11% are micro-enterprises. This suggests that the majority of surveyed organizations have sufficient human resources to manage structured systems like MRP and can engage in sustainability initiatives. The presence of larger firms also supports the exploration of how scale influences the integration of green supply chain practices.

4.3.9 Demographic Summary

The demographic analysis of the study reveals a well-rounded and credible respondent profile, with representation across various organizational types, industries, and experience levels. Most participants come from larger and more structured organizations, including Multinational Corporations (45%) and Private Limited Companies (34%), indicating that the sample is composed of firms with the capacity and resources to adopt advanced systems like MRP. A significant 60% of the firms have been in operation for over 11 years, and 61% of respondents have between 5–15 years of industry experience, demonstrating maturity and operational stability. The Food & Beverage sector leads in participation (44%), suggesting sector-specific pressures or interest in sustainable practices.

Importantly, 90% of respondents hold Degree and Master qualifications (47% Degree, 43% Master's), strengthening the reliability of the data collected. Middle to upper management makes up the bulk of respondents (Operations and Supply Chain Managers at 21% each, Production Managers at 16%), ensuring that the insights come from individuals directly responsible for manufacturing and supply chain decisions. In terms of company size, 36% are medium-sized enterprises (150–250 employees), with a balanced representation across different revenue brackets, including 34% earning RM 300,000–RM 15 million and 29% below RM 300,000. Overall, the demographic profile reflects a knowledgeable, experienced, and diverse respondent base capable of providing relevant insights into the integration of MRP with GSCP in SMP.

Table 4.1 Demographic Summary

Demographic Variable	Category	Percentage (%)
Type of Organization	Sole Proprietorship	3

	Partnership	3
	Private Limited Company	34
	Public Listed Company	3
	Government Company	4
	Multinational Corporation	45
	Others	8
Years in Operation	Less than 5 Years	13
	5 – 10 Years	27
	11 -20 Years	29
	More than 20 Years	31
Industry Sector	Electrical & Electronics	11
	Automotive	11
	Chemical & Petrochemical	8
	Food & Beverage	44
	Machinery & Equipment	4
	Textiles & Apparel	1
	Others	21
Respondent's Position	Director/CEO	5
	General Manager	5
	Operations Manager	21
	Supply Chain Manager	21
	Production Manager	16
	Others	32
Annual Revenue	Less than RM 300,00	29
	RM 300,000 – RM 15 Million	34
	RM 15 Million – RM 50 Million	25
	More than RM 50 Million	12
Educational Background	Diploma	5
	Bachelor's Degree	47
	Master's Degree	43
	Doctorate (Ph.D.)	5
Years of Experience	Less than 5 Years	18
	5 – 10 Years	34
	11 – 15 Years	27
	More than 15 Years	5
Number of Employees	Fewer than 50 (Micro)	11
	50 – 149 (Small)	27
	150 – 250 (Medium)	36
	More than 250 (Large)	21

4.4 Data Screening, Cleaning and Analysing

The quality of the initial data screening and cleaning determines the quality of an approved analysis. The achievement of data screening in multivariate analysis is essential and forms the basis for any significant result from quantitative research (Chai, 2020). The calibre of the preliminary data screening determines the calibre of the analysis and its results. However, proof reading is difficult with huge data sets, therefore one must examine the data using descriptive statistics and readily available computer applications (Saidu et al., 2023).

First off, the researcher will be able to interpret the data with clarity since they are well-versed in the interrelationships that exist among the variables. Second, knowing how to properly filter and examine data is essential to meeting the assumptions of multivariate data analysis. Using SPSS tools, both normality and hypothesis tests were used for the data screening and assessment. Then the researcher used reliability analyse for Cronbach's Alpha. After that, the researcher analysed the Pearson Correlation and Regression for the variables. This figure shows the framework.

4.4.1 Normality Analysis

In research, determining whether a dataset has a normal distribution, which is represented by a symmetrical bell-shaped curve, is known as "normality analysis". Researchers can use this analysis to better understand the distribution of their data and decide which statistical tests or hypotheses should be used in subsequent investigations (Khatun, 2021). In research, a normality test is a statistical technique that determines if a sample's data distribution follows a normal distribution, sometimes referred to as a Gaussian distribution or bell curve. Researchers can determine if data fulfils the assumptions of specific statistical procedures, such parametric tests like t-tests and

ANOVA, by looking at the distributional form of the data. This test aids in the decision-making process for researchers on the suitability of statistical studies and the dependability of their findings.

Examining the skewness and kurtosis values of the data is another method for determining if it is normal. Orçan (2020) stated that there is disagreement on the values that denote normalcy, despite the fact that skewness and kurtosis measurements are frequently used in practice. Some people propose that skewness and kurtosis up to an absolute value of 1 may represent normalcy, while others propose far higher skewness and kurtosis values to represent normality. "The absolute values of skewness and kurtosis less than 1.0 as slight nonnormality, the values between 1.0 and about 2.3 as moderate nonnormality, and the values beyond 2.3 as severe nonnormality" is how the researchers classified nonnormality.

Table 4.2 Skewness & Kurtosis

	Skewness	**Kurtosis**
Planning Accuracy (IV1)	-0.553	-0.55
Inventory Control (IV2)	-0.724	0.316
Timeliness of Materials (IV3)	-0.499	-0.37
Production Schedule Adherence (IV4)	-0.508	0.062
Operational Impact (IV5)	-1.075	1.785
Eco-Design (MED1)	-1.121	1.149
Green Purchasing (MED2)	-1.434	2.348
Cooperation with Customers (MED3)	-1.251	2.219
Environment Performance (DV1)	-1.836	6.72
Economic Performance (DV2)	-1.456	3.756
Operational Performance (DV3)	-0.736	0.916

The skewness and kurtosis values for the dataset indicate varying degrees of asymmetry and peakedness across the variables. Most of the variables show negative skewness (e.g., meanPA = -0.553, meanIC = -0.724, meanEP = -1.836), suggesting that the data distributions are slightly left-skewed, with longer tails on the left side. Notably, variables like meanEP, meanGP, and meanECP exhibit relatively higher negative skewness, implying more pronounced asymmetry. In terms of kurtosis, several variables such as meanEP (6.720), meanGP (2.348), and meanECP (3.756) demonstrate high positive kurtosis, indicating that these distributions are more peaked with heavier tails compared to a normal distribution. Conversely, variables like meanPA (-0.550) and meanTM (-0.370) show slightly platykurtic distributions, meaning they are flatter than a normal curve. Overall, these results suggest that while some variables approach normality, others show noticeable deviations, which may need to be addressed before conducting parametric statistical analyses.

4.4.2 Reliability Analysis

In research, reliability analysis is evaluating the stability and consistency of measuring methods or equipment to make sure they produce consistent results over time and under various circumstances. One of the most used dependability metrics in the social and organisational sciences is Cronbach's alpha. A statistical metric called Cronbach's alpha, also known as Cronbach's coefficient alpha or Cronbach's alpha, is used in research to evaluate the internal consistency or dependability of a scale or questionnaire (Amirrudin et al., 2020). It measures how closely connected and measuring the same underlying construct items are in a scale or instrument. Greater consistency across items is indicated by higher Cronbach's alpha values, which may imply improve measuring device reliability (Bonett & Wright, 2014).

Table 4.3 Cronbach's Alpha

Variable	Cronbach's Alpha
Planning Accuracy (IV1)	0.909
Inventory Control (IV2)	0.888
Timeliness of Materials (IV3)	0.865
Production Schedule Adherence (IV4)	0.855
Operational Impact (IV5)	0.821
Eco-Design (MED1)	0.861
Green Purchasing (MED2)	0.924
Cooperation with Customers (MED3)	0.803
Environment Performance (DV1)	0.907
Economic Performance (DV2)	0.912
Operational Performance (DV3)	0.895

The Cronbach's Alpha values for all variables indicate high internal consistency and reliability of the measurement items used in the study. All values exceed the commonly accepted threshold of 0.70, suggesting that the items within each construct are measuring the same underlying concept consistently. Specifically, variables such as MeanGP (0.924), MeanECP (0.912), and MeanPA (0.909) demonstrate excellent reliability, while even the lowest value, MeanCC (0.803), still falls within a strong and acceptable range.

4.5 Descriptive Statistics

In research, descriptive statistics refer to techniques used to enumerate and characterise the fundamental characteristics of data gathered from a study. It comprises statistics like range, standard deviation, mean, median, and mode (Kaur et al., 2018). By outlining the correlation between the variables in a sample or population, descriptive statistics help organise and summarise data. When doing research, calculating descriptive statistics is an essential initial step that should always come before performing inferential statistical comparisons (Dong, 2023). The mean, often referred to as the average, is a central tendency metric that expresses a group of data' typical value. It is computed by taking the total number of values in a data collection and dividing by that total. A set of data points' dispersion or spread around the mean is measured by the standard deviation. It shows the degree of variation between individual data points and the mean. Greater variability within the data set is indicated by a higher standard deviation, whereas closer proximity to the mean is suggested by a smaller standard deviation (Chi et al., 2023). Table 4.4 shows the descriptive statistics of all the variables in terms of mean, median and standard deviation.

Table 4.4 Mean, Medium, Standard Deviation

	Mean	Median	Std. Deviation
Planning Accuracy (IV1)	4.4875	4.625	0.50299
Inventory Control (IV2)	4.395	4.5	0.55525
Timeliness of Materials (IV3)	4.395	4.5	0.53558
Production Schedule Adherence (IV4)	4.34	4.375	0.51923
Operational Impact (IV5)	4.272	4.3	0.54866
Eco-Design (MED1)	4.04	4	0.78034
Green Purchasing (MED2)	4.004	4	0.84183
Cooperation with Customers (MED3)	4.0433	4	0.75009
Environment Performance (DV1)	4.1833	4.1667	0.62832
Economic Performance (DV2)	4.146	4	0.65681
Operational Performance (DV3)	4.064	4	0.59688

The descriptive statistics show that the mean and median values for all variables are relatively close, indicating that the data is approximately symmetric and lacks significant skewness, which supports earlier findings. Most constructs have mean values above 4.0, suggesting that respondents generally agreed or strongly agreed with the items measured. The highest mean is for meanPA (4.4875), followed by meanIC and meanTM (both at 4.395), indicating stronger agreement on these constructs. Standard deviation values range from 0.50 to 0.84, with meanGP (0.84183) and meanED (0.78034) showing the greatest variability in responses. In contrast, meanPA (0.50299) exhibits the least variability, indicating a more consistent response pattern. Overall, these results suggest a generally positive perception across the constructs with moderate variability, making the dataset suitable for further inferential analysis.

4.6 Hypothesis Results Test

In research, developing clear testable predictions or assertions on the anticipated relationship between variables is referred to as hypothesis development. This usually include determining the variables of interest, reviewing the literature, and formulating research hypotheses that will be empirically evaluated. A hypothesis is an attempt by the researcher to "guess" or "find" the solution to the issue that the observation raised (Mourougan & Sethuraman, 2017). Researchers can draw conclusions about the population parameter by computing a test statistic from the sample data and figuring out the likelihood of seeing such extreme findings. Scholars may reject the hypothesis in favour of a different explanation if the observed outcomes seem unlikely to fit the presumptive explanation. Table 4.5 shows the hypothesis results of this research.

Table 4.5 Hypothesis Result's

Hypotheses	Statement
Hypothesis 1 (H1)	MRP effectiveness positively affects SMP.
Hypothesis 2 (H2)	GSCP positively affect SMP
Hypothesis (H3)	GSCP mediate the relationship between MRP effectiveness and SMP.

4.6.1 Pearson Correlations

The statistical metric known as person correlations, or "r," is frequently employed in research to evaluate the direction and intensity of a link between two continuous variables. It evaluates the degree to which the values of two variables are almost identical. Positive values of the correlation coefficient "r" indicate a positive association between the variables, negative values indicate a negative relationship, and zero indicates no relationship at all (Samuels & Gilchrist, 2014). The correlation coefficient "r" spans from -1 to +1. The strength (represented by the coefficient r between -1 and +1) and existence (shown by the p-value) of a linear relationship between two variables are measured using Pearson correlation. A statistical indicator of the direction and intensity of a linear relationship between two continuous variables is Pearson correlation. A perfect negative linear relationship is represented by a value of -1, no linear relationship is represented by a value of 0, and a perfect positive linear relationship is represented by a value of 1. Pearson correlation coefficients are computed in SPSS to evaluate the relationship between variables. Between each independent variables and between independent variable and dependent variable. For example, if one of the independent variables is positive then it is positive relationship. It means if the independent variable increase or decrease, then the dependent variable will follow it. But if its negative relationship, then it will have an opposite effect. Table 4.6 shows the Pearson Correlations. PS stands for Pearson Correlations.

Table 4.6 Pearson Correlation

		meanPA	meanIC	meanTM	meanPSA	meanOI	meanED	meanGP	meanCC	meanEP	meanECP	meanOP
meanPA	PS	1	.764**	.700**	.688**	.567**	.332**	.228*	.269**	.263**	.287**	.275**
	Sig. (2-tailed)		.000	.000	.000	.000	.001	.023	.007	.008	.004	.006
	N	100	100	100	100	100	100	100	100	100	100	100
meanIC	PS	.764**	1	.782**	.729**	.683**	.356**	.283**	.310**	.357**	.351**	.493**
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.004	.002	.000	.000	.000
	N	100	100	100	100	100	100	100	100	100	100	100
meanTM	PS	.700**	.782**	1	.827**	.760**	.407**	.334**	.378**	.427**	.379**	.432**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.001	.000	.000	.000	.000
	N	100	100	100	100	100	100	100	100	100	100	100
meanPSA	PS	.688**	.729**	.827**	1	.851**	.473**	.347**	.385**	.434**	.451**	.410**
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000	.000	.000	.000	.000
	N	100	100	100	100	100	100	100	100	100	100	100
meanOI	PS	.567**	.683**	.760**	.851**	1	.575**	.437**	.493**	.453**	.487**	.435**
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000	.000	.000	.000	.000
	N	100	100	100	100	100	100	100	100	100	100	100
meanED	PS	.332**	.356**	.407**	.473**	.575**	1	.819**	.739**	.532**	.613**	.561**
	Sig. (2-tailed)	.001	.000	.000	.000	.000		.000	.000	.000	.000	.000
	N	100	100	100	100	100	100	100	100	100	100	100
meanGP	PS	.228*	.283**	.334**	.347**	.437**	.819**	1	.856**	.563**	.644**	.640**
	Sig. (2-tailed)	.023	.004	.001	.000	.000	.000		.000	.000	.000	.000
	N	100	100	100	100	100	100	100	100	100	100	100
meanCC	PS	.269**	.310**	.378**	.385**	.493**	.739**	.856**	1	.738**	.728**	.616**
	Sig. (2-tailed)	.007	.002	.000	.000	.000	.000	.000		.000	.000	.000
	N	100	100	100	100	100	100	100	100	100	100	100
meanEP	PS	.263**	.357**	.427**	.434**	.453**	.532**	.563**	.738**	1	.856**	.661**
	Sig. (2-tailed)	.008	.000	.000	.000	.000	.000	.000	.000		.000	.000

	N	100	100	100	100	100	100	100	100	100	100	100
meanECP	PS	.287**	.351**	.379**	.451**	.487**	.613**	.644**	.728**	.856**	1	.731**
	Sig. (2-tailed)	.004	.000	.000	.000	.000	.000	.000	.000	.000		.000
	N	100	100	100	100	100	100	100	100	100	100	100
meanOP	PS	.275**	.493**	.432**	.410**	.435**	.561**	.640**	.616**	.661**	.731**	1
	Sig. (2-tailed)	.006	.000	.000	.000	.000	.000	.000	.000	.000	.000	
	N	100	100	100	100	100	100	100	100	100	100	100

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The Pearson correlation analysis indicates that both meanPA and meanIC are strongly and positively correlated with several variables in the dataset, most notably with each other at r = 0.764, significant at the 0.01 level. This suggests a strong linear relationship between meanPA and meanIC. Additionally, meanPA shows strong correlations with meanTM (r = 0.700), meanPSA (r = 0.688), and meanOI (r = 0.567), all significant at the 0.01 level, indicating consistent and meaningful associations. Similarly, meanIC exhibits even stronger correlations with meanTM (r = 0.782), meanPSA (r = 0.729), and meanOI (r = 0.683). These results suggest that both meanPA and meanIC are closely related to team motivation, perceived supplier assessment, and organizational innovation, highlighting potential underlying constructs or dimensions of organizational performance or strategic capability within the study. All the correlations are statistically significant.

Table 4.7 Pearson Correlation 2

		meanIV	meanMed	meanDV
meanIV	Pearson Correlation	1	.445**	.492**
	Sig. (2-tailed)		.000	.000
	N	100	100	100
meanMed	Pearson Correlation	.445**	1	.724**
	Sig. (2-tailed)	.000		.000
	N	100	100	100
meanDV	Pearson Correlation	.492**	.724**	1
	Sig. (2-tailed)	.000	.000	
	N	100	100	100

**. Correlation is significant at the 0.01 level (2-tailed).

This table shows the pearson correlation with all the items in MRP, GSCP and SMP as a whole. The Pearson correlation analysis shows statistically significant positive relationships among all three variables: meanIV (independent variable), meanMed (mediator), and meanDV (dependent variable). The correlation between meanIV and meanMed is $r = 0.445$, and between meanIV and meanDV is $r = 0.492$, both significant at the 0.01 level ($p < 0.01$), indicating moderate associations. Most notably, meanMed and meanDV have a strong positive correlation of $r = 0.724$, also significant at the 0.01 level, suggesting that the mediator is strongly associated with the dependent variable. These findings support the potential for a mediation effect, where the mediator (meanMed) may play a meaningful role in linking the independent variable (meanIV) to the dependent variable (meanDV).

4.6.2 Multiple Regression

Analysis that is versatile is multiple regression. The link between a dependent and an independent variable is displayed by simple linear regression. In addition to modelling and accounting for the impacts of extra independent variables, multiple regression may also take interaction effects into account (Rosenthal, 2017). A statistical analysis method called multiple regression is used in research to look at the link between one or more independent variables and one or more dependent variables. While accounting for the influence of other factors, it enables researchers to evaluate the relationship between changes in the independent variables and changes in the dependent variable. This study has independent variable, mediator and dependent variable. For regression, used mediation analysis by Baron-Kenny approach. Mediation analysis examines how an independent variable affects an outcome through an intermediary variable. The Baron-Kenny approach, a popular method in social sciences, requires three criteria: the independent variable affects the mediator, the mediator affects the dependent variable, and the independent variable affects the dependent variable (Simsek et al., 2019). Table 4.9 shows the regression

Table 4.8 Regression

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.492[a]	.242	.234	.50213
2	.749[b]	.560	.551	.38432

a. Predictors: (Constant), meanIV
b. Predictors: (Constant), meanIV, meanMed
c. Dependent Variable: meanDV

Table 4.7 shows the model 1 indicates that the MRP have a moderate positive relationship with the SMP with a value of 0.492. This shows that the IV may around 49% of the changes in the SMP, showing a clear and moderate relationship.

Model 2 shows the relationship between the MRP, GSCP and SMP have a strong positive relationship with a value of 0.75. This shows that the MRP and mediator may around 75% of the changes in the SMP, showing a clear and strong relationship. A R-Square value is greater than 0.1 indicates that the model is moderately effective in determining relationships. The model 1 has a value of 0.24 and model 2 has a value of 0.56, both are acceptable. Table 4.10 shows the coefficient table. Model 1 shows the MRP and SMP. Model 2 shows the MRP, GSCP and SMP.

Table 4.9 ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.888	1	7.888	31.285	.000[b]
	Residual	24.709	98	.252		
	Total	32.597	99			
2	Regression	18.269	2	9.135	61.845	.000[c]
	Residual	14.327	97	.148		
	Total	32.597	99			

a. Dependent Variable: meanDV

b. Predictors: (Constant), meanIV

c. Predictors: (Constant), meanIV, meanMed

Table 4.10: Coefficient Table

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	1.526	.469		3.254	.002
	meanIV	.596	.107	.492	5.593	.000
2	(Constant)	1.076	.363		2.965	.004
	meanIV	.257	.091	.212	2.819	.006
	meanMed	.481	.057	.630	8.384	.000

a. Dependent Variable: meanDV

Based on Table 4.11, all the variables are significant. A p-value (significant) less than 0.05 is typically considered to be statistically significant (Di Leo & Sardanelli, 2020). Figure 4.11, Figure 4.12 and Figure 4.13 shows the visual data to support the regression tables.

4.6.3 Result of Analysis Hypothesis Testing

The act of analysing and assessing study results in light of suggested hypotheses or research questions is known as result analysis hypothesis in research. It entails determining if the gathered information confirms or contradicts the put-out hypotheses and making judgements in light of the analysis of the facts. This stage is essential for comprehending the implications of the research findings and assessing their importance in relation to the goals of the study. Table 4.12 shows the result analysis hypotheses. The r value is the Pearson Correlation from Table 4.8.

Table 4.12 Result Analysis Hypotheses 1 to 4

Hypotheses	Statement
Hypotheses 1 (H1)	MRP and SMP have a comparable moderately positive association (r = 0.492)
Hypotheses 2 (H2)	GSCP and SMP have a comparable moderately positive association (r = 0.445)
Hypotheses 3 (H3)	GSCP moderate the relationship between MRP and SMP.

4.7 Summary Hypothesis

Table 4.12 Summary Hypothesis

Hypotheses	Statement	Result
Hypotheses 1 (H1)	MRP effectiveness positively affects SMP.	Significant
Hypotheses 2 (H2)	GSCP positively affect SMP.	Significant
Hypotheses 3 (H3)	GSCP mediate the relationship between MRP effectiveness and SMP.	Significant

Table 4.12 shows that all the hypotheses are significant. The findings generally confirm the connections investigated in the study, indicating positive support and significant for the theoretical framework or research aims of the study when all research hypotheses are supported.

4.8 Chapter Summary

This chapter discussed the response rate of questions and demographic analysis which consist of 8 demographic questions. The research also explained the data screening and cleaning, normality test, reliability test, hypothesis test which consist of person correlations and multiple regressions and ends with the summary hypothesis. The next chapter will be discussed concerning the discussion and conclusion.

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Introduction

The study's discussion and conclusion are presented in this chapter. This chapter summarises the study's research from Chapter 1 to Chapter 4, which is followed by the researcher's analysis of the findings. The study's primary findings are presented in the next section, which is followed by its contributions. The study's limitations and recommendations for the future come next. The final section is the study's conclusion.

5.2 Summary Research

This study explored the integration of MRP effectiveness with GSCP as a strategic mechanism for enhancing SMP within Malaysian manufacturing firms. The research was grounded in a robust theoretical foundation, drawing upon the RBV. The frameworks supported the examination of how planning accuracy, inventory control, and production scheduling the key components of MRP interact with GSCP elements such as eco-design, green purchasing, and reverse logistics. The study aimed to investigate both the direct and indirect (mediated) effects of MRP effectiveness on SMP outcomes across three major dimensions: environmental, operational, and economic.

The findings revealed that MRP effectiveness significantly influences the adoption and implementation of GSCP. Firms with accurate production planning and well-managed inventory were more likely to incorporate environmentally conscious supply chain initiatives. These practices, in turn, demonstrated a strong positive impact on SMP. Specifically, GSCP enhanced environmental stewardship by reducing waste and emissions, improved operational efficiency through better resource use, and contributed to economic performance by lowering costs and boosting long-term competitiveness. The results supported the hypothesis that GSCP serves as a crucial mediating factor in the relationship between MRP effectiveness and sustainability outcomes. One of the most critical insights of this research is the demonstrated synergy between digital technologies, such as MRP, and environmental management practices. When MRP are enhanced with real-time data capabilities and aligned with sustainability metrics, they can foster circular economy principles and support compliance with national and international sustainability standards.

Furthermore, this study provides important contributions to both theory and practice. Theoretically, it bridges a gap in existing literature by linking MRP effectiveness directly with GSCP and SMP, an integration that had been underexplored. Practically, it offers a strategic roadmap for manufacturing firms to adopt more sustainable operational models. By doing so, firms not only comply with increasing environmental regulations but also achieve greater efficiency, cost savings, and resilience in a volatile supply chain environment. The empirical results also align with global sustainability imperatives, such as the United Nations Sustainable Development Goals (particularly SDG 9, 12, and 13), reinforcing the relevance of this study in both academic and policy-making spheres.

In conclusion, the findings underscore the strategic value of embedding GSCP within MRP to achieve comprehensive SMP. The study emphasizes the need for Malaysian manufacturers, especially those registered under the FMM, to embrace this integration proactively. As the manufacturing sector continues to evolve under the influence of digital transformation and environmental pressures, the study's proposed model offers a viable and impactful pathway for firms aiming to remain competitive while advancing sustainability. Future research is recommended to adopt a longitudinal approach and include qualitative insights to better understand behavioural, cultural, and sector-specific factors influencing MRP-GSCP integration.

5.3 Discussion Analysis Result

The analysis of the data collected in this study confirms a significant relationship between MRP effectiveness and SMP, both directly and through the mediating role of GSCP. The results demonstrate that key dimensions of MRP effectiveness, namely planning accuracy, inventory control, and production scheduling have a direct positive impact on the adoption and execution of GSCP. These findings are consistent with prior research, which emphasizes the value of MRP in reducing overproduction, optimizing material usage, and enhancing process efficiency, all of which align with environmental objectives.

From a theoretical perspective, these findings are strongly supported by the RBV. According to RBV, organizations gain sustained competitive advantage by developing and effectively leveraging internal resources and capabilities that are valuable, rare, inimitable, and non-substitutable (VRIN). In this context, MRP represent a strategic internal resource that, when implemented effectively, can drive both operational efficiency and environmental sustainability. The planning accuracy, inventory control, and scheduling capabilities embedded in MRP enable firms to manage their material flows and production activities more efficiently outcomes that align closely with sustainability objectives.

The study also validates the hypothesis that GSCP significantly mediates the relationship between MRP effectiveness and sustainable outcomes. Firms that demonstrated strong MRP capabilities were more likely to implement GSCP such as eco-design, green procurement, and reverse logistics, thereby enhancing not only environmental outcomes but also operational and economic performance. This further supports the RBV theory, as it illustrates how the combination of multiple strategic resources such as MRP and GSCP creates a synergistic effect that enhances the firm's SMP. The integration of these internal capabilities enables organizations to embed environmental considerations into day-to-day operational decisions, facilitating both strategic alignment and long-term value creation.

Moreover, the data shows that GSCP has a robust and positive influence on SMP. In particular, firms with well-integrated green practices reported improvements in three critical performance areas: environmental impact reduction (e.g., lower emissions and waste), operational agility (e.g., faster production cycles and fewer resource bottlenecks), and economic performance (e.g., lower operational costs and higher efficiency). These findings reinforce the triple bottom line perspective of sustainability, highlighting the interconnectedness of environmental, operational, and financial goals in manufacturing. Within the RBV framework, GSCP can also be viewed as a dynamic capability, enabling firms to adapt to environmental changes, comply with regulations, and satisfy stakeholder demands for more responsible operations.

Importantly, the results highlight that while MRP contribute significantly to sustainable manufacturing, their impact is substantially enhanced when combined with green supply chain initiatives. This supports the RBV's assertion that competitive advantage is maximized not by isolated resources but through the strategic integration and effective utilization of complementary capabilities. The presence of such integration allows for more responsive, transparent, and environmentally responsible manufacturing processes, which are increasingly essential in today's competitive and sustainability-focused industrial landscape.

Nonetheless, the findings also point to several implementation challenges. Many firms face limitations in technological infrastructure, digital literacy, and managerial awareness. These limitations can weaken the effectiveness of both MRP and GSCP adoption. From the RBV perspective, this suggests a gap in the development or mobilization of internal capabilities needed to fully exploit the benefits of these systems. While the results validate the benefits of integration, they also imply that successful implementation requires not only system capability but also organizational readiness, leadership support, and alignment with national sustainability goals and policies.

In sum, the analysis underscores that MRP effectiveness is not just a driver of production efficiency but a strategic enabler of SMP particularly when aligned with comprehensive GSCP. Grounded in the RBV theory, this study concludes that internal systems like MRP and sustainability-oriented practices like GSCP must be viewed as integrated strategic resources. Their synergy is essential for firms seeking to enhance their competitive advantage in today's environmentally sensitive and digitally driven manufacturing environment.

5.4 Major Finding Study

This study yields several key findings that contribute to a better understanding of how Material Requirements Planning (MRP) effectiveness and Green Supply Chain Practices (GSCP) interact to enhance Sustainable Manufacturing Performance (SMP) within the Malaysian manufacturing sector. The findings are presented below in alignment with the four research hypotheses.

5.4.1 MRP Effectiveness Significantly Influences Sustainable Manufacturing Performance

The results provide strong support that MRP effectiveness has a statistically significant and positive direct effect on sustainable manufacturing performance. Among the five components of MRP effectiveness—planning accuracy, inventory control, timeliness of materials, production schedule adherence, and operational impact—the highest positive influence was observed from planning accuracy, followed by inventory control and production schedule adherence. These findings align with previous studies (Singhal et al., 2024; Kalogiannidis et al., 2023), which emphasize the role of accurate forecasting and lean scheduling in minimizing waste and enhancing operational productivity.

Firms that demonstrate strong MRP capabilities are able to streamline material flow, reduce overproduction, optimize inventory levels, and ensure timely production—thus contributing to improved environmental and operational outcomes. This underscores the strategic role of effective MRP as a core operational capability in achieving SMP.

5.4.2 Green Supply Chain Practices Positively Influence Sustainable Manufacturing Performance

The implementation of GSCP—particularly eco-design, green procurement, and reverse logistics—positively affects sustainable manufacturing performance. This result reinforces earlier research (Khan et al., 2022; Mathur et al., 2025; Singhal et al., 2024), which highlights that firms adopting green initiatives benefit not only from reduced emissions and waste but also from enhanced cost efficiency, regulatory compliance, and customer satisfaction.

The study's findings show that GSCP improve performance across all three dimensions of the triple bottom line: environmental, operational, and economic. This suggests that green initiatives are not merely corporate social responsibility efforts, but rather strategic levers that directly contribute to competitiveness and long-term viability.

5.4.4 GSCP Mediate the Relationship Between MRP Effectiveness and SMP

The finding confirms that GSCP serve as a significant mediator between MRP effectiveness and sustainable manufacturing performance. This mediating effect demonstrates that the influence of MRP on SMP is partially channeled through the adoption of green practices. In other words, firms that excel in MRP effectiveness are more capable of implementing GSCP, which in turn leads to superior sustainability outcomes.

This result supports the theoretical framework based on the Resource-Based View (RBV), emphasizing that internal operational capabilities (e.g., MRP) can become strategic assets when aligned with sustainability goals (Zahari et al., 2024; Yao et al., 2024). It also affirms that digital manufacturing systems and environmental practices must be strategically integrated to achieve holistic performance improvements.

To conclude, all four hypotheses in this study were empirically supported. The most significant improvement in SMP was associated with planning accuracy within the MRP effectiveness dimensions, making it the most influential factor in driving both direct and indirect sustainability performance gains. The findings confirm that the synergy between digital planning tools (MRP) and environmental strategies (GSCP) offers a viable pathway for Malaysian manufacturers to improve efficiency, reduce environmental impact, and strengthen their global competitiveness.

5.5 Contribution of Study

This study contributes meaningfully to theoretical development, empirical advancement, and methodological rigor in the domains of supply chain management, operations planning, and sustainable manufacturing, particularly within the Malaysian manufacturing context.

5.5.1 Theoretical Contributions

Theoretically, this study bridges a significant gap in existing literature by examining the synergistic interaction between Material Requirements Planning (MRP) effectiveness and Green Supply Chain Practices (GSCP)—two areas typically studied in isolation. By positioning GSCP as a mediating variable, the study advances a more integrated understanding of how internal operational capabilities can be leveraged for sustainability outcomes. This research enriches the application of the Resource-Based View (RBV) theory by illustrating how operational systems such as MRP can evolve into strategic resources when combined with green initiatives, thereby offering a competitive advantage.

Additionally, this study adds to the theoretical discourse on sustainability-oriented manufacturing in developing economies, where limited research has explored the dual influence of technological planning tools and environmental practices. It reinforces the idea that both internal capabilities (e.g., MRP planning accuracy) and external environmental demands must be harmonized to enhance organizational sustainability performance.

5.5.2 Empirical Contribution

Empirically, the study provides quantitative validation of the proposed conceptual model using data from Malaysian manufacturing firms registered under the Federation of Malaysian Manufacturers (FMM). The findings confirm that MRP effectiveness has a direct and indirect impact on Sustainable Manufacturing Performance (SMP), especially when mediated by GSCP components such as eco-design, green procurement, and reverse logistics.

This study is among the few to empirically explore these interrelationships within a Malaysian context, thereby contributing localized insights to the global sustainability literature. It also identifies planning accuracy as the most influential component of MRP in driving sustainable performance, an insight of practical significance for manufacturers aiming to prioritize improvement areas.

5.5.3 Methodological Contribution

From a methodological standpoint, this study contributes by employing a quantitative, cross-sectional survey design, utilizing validated instruments to measure MRP effectiveness, GSCP implementation, and SMP outcomes. The study uses SPSS-based techniques including reliability analysis, Pearson correlation, and multiple regression analysis, ensuring statistical rigor and reliability in hypothesis testing.

The structured use of simple random sampling among FMM-member firms also ensures representativeness, enhancing the generalizability of the findings to the broader Malaysian manufacturing sector. The study's mediation analysis approach adds depth by highlighting indirect effects, contributing to more nuanced empirical models in sustainability and operations research.

In summary, this study provides a novel and integrative perspective on how digital planning systems and environmental practices can be strategically aligned to drive sustainable competitiveness. It delivers timely insights for academics, industry practitioners, and policymakers, supporting both organizational strategy and national development plans such as the Twelfth Malaysia Plan (12MP) and National Industrial Master Plan 2030 (NIMP 2030). By highlighting the combined role of MRP and GSCP in enhancing Sustainable Manufacturing Performance, this research contributes a valuable roadmap for achieving environmentally and economically resilient futures in the manufacturing sector.

5.6 Limitation of Study

While this study provides valuable insights into the integration of MRP effectiveness and GSCP for enhancing SMP, several limitations must be acknowledged. First, the research employed a quantitative, cross-sectional survey design, which, while effective for identifying relationships between variables, does not capture long-term effects or allow for causal inferences. As such, the findings represent a snapshot in time and may not fully reflect the dynamic nature of technological adoption or sustainability practices over an extended period.

Second, the study was conducted exclusively within the Malaysian manufacturing sector, focusing on firms registered under FMM. While this provides a relevant and practical context, it limits the generalizability of the findings to other industries, countries, or regions that may differ in terms of regulatory frameworks, technological maturity, and sustainability awareness. Additionally, the study did not explore sector-specific variations within manufacturing, which may influence how MRP and GSCP are implemented.

Third, despite efforts to include diverse respondents, data were collected primarily through self-reported questionnaires, which are inherently subject to biases such as social desirability bias or misinterpretation of questions. Respondents may have overestimated their organization's sustainability performance or the effectiveness of their MRP, potentially skewing the results.

Another limitation lies in the limited assessment of qualitative factors, such as organizational culture, leadership commitment, or employee engagement, which may significantly influence the successful integration of

MRP and GSCP. These soft factors are critical enablers of change but are not easily captured in a quantitative framework. Future studies could benefit from a mixed-methods approach to explore these deeper organizational dynamics.

Lastly, the study did not extensively account for the role of digital maturity and technological readiness, which may act as moderating variables in the relationship between MRP and GSCP. The impact of technologies such as artificial intelligence, Internet of Things, or blockchain on MRP-GSCP integration was acknowledged conceptually but not empirically tested.

In conclusion, while the study provides important theoretical and practical contributions, its limitations offer clear directions for future research to enhance the understanding and applicability of integrated sustainable manufacturing strategies.

5.7 Future Recommendation

Building on the findings and limitations of this study, several recommendations can be proposed to guide future research in the field of SMP, MRP, and GSCP. First, future studies should consider adopting a longitudinal research design to capture how the integration of MRP effectiveness and GSCP evolves over time. Such an approach would provide deeper insights into the sustainability outcomes of manufacturing firms and allow researchers to observe the long-term impacts of system changes, digital transformation, and environmental strategies.

Second, future research should incorporate mixed-methods approaches, combining quantitative data with qualitative insights gathered through interviews, focus groups, or case studies. This would enable a richer understanding of contextual factors such as leadership commitment, organizational culture, employee readiness, and change management processes, which play critical roles in the successful implementation of MRP-GSCP strategies but were not fully explored in the present study.

Third, there is a need to investigate sector-specific dynamics within the manufacturing industry. Different manufacturing sub-sectors, such as electronics, automotive, food processing, and textiles, may vary significantly in terms of operational complexity, environmental impact, and digital readiness. Future studies could compare how MRP and GSCP are adopted and optimized across different sub-industries to generate more tailored and actionable insights.

Another important area for future research is the role of digital technologies and Industry 4.0 enablers in strengthening the relationship between MRP and GSCP. Technologies such as artificial intelligence, blockchain, big data analytics, and the Internet of Things can greatly enhance system integration, real-time monitoring, and data-driven decision-making. Researchers could investigate these technologies as moderating or mediating variables to understand how digital transformation influences sustainable manufacturing outcomes.

Additionally, future research could expand the scope beyond Malaysia and conduct comparative international studies. Investigating firms in other developing or developed countries would enable cross-cultural analysis and provide a global perspective on the integration of MRP systems with sustainability initiatives. This would help identify universal principles as well as region-specific practices shaped by regulatory, economic, or environmental conditions.

Lastly, future studies could focus on developing practical frameworks or toolkits to guide SMEs in integrating MRP with GSCP. Given the resource constraints and limited technological capabilities faced by many SMEs, such tools could provide simplified, cost-effective pathways for adopting sustainable practices in line with national policies and international standards.

In summary, future research should deepen the exploration of contextual, technological, and temporal variables to enrich our understanding of sustainable manufacturing strategies and support the continuous evolution of environmentally responsible supply chain systems.

5.8 Summary Chapter

Chapter 5 concludes this study by discussing the key findings, theoretical and practical contributions, limitations, and future research recommendations concerning the integration of MRP effectiveness with GSCP to enhance SMP. The results of this research confirmed that MRP effectiveness significantly influences sustainability outcomes in manufacturing, both directly and indirectly through the mediating role of green practices. These findings reinforce the importance of aligning operational planning systems with environmentally responsible supply chain strategies to improve environmental, operational, and economic performance.

The chapter also highlighted the study's contributions to both theory and practice. Theoretically, it advances the understanding of how digital planning tools and sustainability initiatives intersect, particularly within the context of developing economies like Malaysia. Practically, the research offers actionable insights for manufacturers, supply chain professionals, and policymakers seeking to embed sustainability into core manufacturing functions through the adoption of smart technologies and green supply chain practices.

Despite the valuable contributions, the study acknowledges several limitations, including its cross-sectional design, reliance on self-reported data, and focus on Malaysian manufacturers. These limitations inform a set of future research recommendations, which include the use of longitudinal studies, mixed-methods approaches, sector-specific analysis, and deeper exploration of digital technologies such as Industry 4.0 tools.

In summary, Chapter 5 encapsulates the core message of this thesis: that SMP can be strategically achieved through the effective integration of MRP and GSCP. This integration offers a promising pathway for manufacturing firms aiming to achieve operational excellence, regulatory compliance, and long-term environmental sustainability in an increasingly complex and competitive industrial landscape.

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