A Conceptual Framework for Manufacturing Flexibility and New Product Performance: The Strategic Role of Sustainable Competitive Advantage

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ABSTRACT

This conceptual paper proposes a framework that investigates the role of manufacturing flexibility (MF) in enhancing new product performance (NPP), with sustainable competitive advantage (SCA) as a mediating factor, within Malaysia's Electrical and Electronics (E&E) industry. Drawing on the Resource-Based View (RBV) and Dynamic Capabilities Theory (DCT), the framework highlights five core MF dimensions lkke labour, machine, operational, new product, and material handling flexibility which has been critical enablers for adapting to technological change, market uncertainty, and sustainability demands. The paper posits that MF enhances NPP by enabling faster product launches, customization, and efficient resource utilization, while SCA reinforces this link by supporting differentiation, innovation, and long-term competitiveness. This model addresses key gaps in existing literature by contextualizing MF within a high-mix, low-volume manufacturing environment typical of Malaysia's E&E sector. The study contributes theoretically by integrating strategic and operational perspectives of MF and offers practical insights for managers aiming to build resilient, innovation-driven operations. The proposed framework also aligns with Malaysia's MADANI strategy and the United Nations Sustainable Development Goals (SDGs 9 and 17). Future empirical studies are encouraged to validate and extend the framework across diverse industrial contexts

Keywords: Manufacturing Flexibility, New Product Performance, Sustainable Competitive Advantage, E&E Industry, 4.0 industry

INTRODUCTION

A significant component of Malaysia's economic, social, and technological development is the E&E manufacturing sector. In comparison to industrialized nations, Malaysia's GDP benefited from the E&E sector at an average annual rate of 6.1% between 1970 and 2018 (Hashim and Fahmy-Abdullah, 2024). Therefore, to guarantee long-term sustainability and resilience to market volatility, the E&E industry must create manufacturing flexibility. Manufacturing flexibility is a multifaceted concept that describes a company's capacity to adapt or respond to environmental uncertainty with minimal sacrifice in terms of performance, cost, time, or effort (Mishra, 2021).

Since the days of inflexible mass production systems like Fordism, manufacturing flexibility has clearly changed. Traditional systems, which were initially created for uniform high-volume output, started to demonstrate its limitations in the 1960s and 1970s. As a result, more flexible production techniques like job shops and batch production were developed. The development of Flexible Manufacturing Systems (FMS) in the 1980s marked a significant advancement by combining automation, robots, and sophisticated material handling to facilitate quick changes in production. In addition to integrating flexibility into strategic supply chains and corporate planning, the 1990s and 2000s extended flexibility into dimensions including volume, mix, and product flexibility (Vokurka & O'Leary-Kelly, 2000).

In recent years, manufacturing procedures are become more dynamic due to Industry 4.0 technologies like robotics, artificial intelligence (AI), and the Internet of Things (IoT). This allows for improved efficiency and real-time responsiveness (Margherita & Braccini, 2020). In an unpredictable global marketplace, these intelligent systems enable machines to modify their settings on their own, promoting adaptability and operational effectiveness. However, emerging markets like Malaysia are still in the early stages of integration, whereas mature economies have long recognized the value of manufacturing flexibility (Hossain et al., 2024).

Additionally, there are still difficulties in spite of these developments. Businesses find it challenging to strike a balance between cost and adaptability when implementing flexible manufacturing since it necessitates a significant capital investment and continuous technical advancements (Castiglione et al., 2024). Apart from that, the impact of manufacturing flexibility on new product performance (NPP), especially in the Malaysian setting, is not well explored in the literature (Zahari et al., 2023). Furthermore, nothing is known about how sustainable competitive advantage (SCA) mediates this link (Hong Loong et al., 2023).

As a way to close these gaps, this study suggests a conceptual model that combines sustainable competitive advantage as a mediator to improve the performance of new products with important manufacturing flexibility dimensions, including labor, operational, and material handling flexibility. The framework, which is based on the Resource-Based View (RBV) and Dynamic Capabilities (DC) Theory, offers an organized method for enhancing innovation and adaptability in Malaysia's E&E industry.

In compliance with Malaysia's MADANI strategy and the Sustainable Development Goals (SDGs 9 and 17) of the UN, the research offered here supports efforts to generate inclusive, sustainable development, foster innovation, and build resilient industrial infrastructure. By providing theoretical and empirical insights, the study aims to support practitioners and policymakers in enhancing manufacturing skills and ensuring long-term competitiveness in an increasingly dynamic market context.

LITERATURE REVIEW

New Product Performance

New Product Performance (NPP) refers to the extent to which a new product meets its intended business and market outcomes, serving as a key indicator of a firm's innovation success and market responsiveness (Qin, Zheng & Wang, 2024). It incorporates both financial measurements, such ROI and profit margins (Bertolotti, Gavazza & Lanteri, 2023), as well as innovation metrics, including market uniqueness and customer happiness (Li, Liu & Boadu, 2023). Simple market measurements like market share and failure rates have given way to data-driven techniques like sentiment analysis and user-generated content (Ma et al., 2024) and analytical tools like the fuzzy AHP model (Cui et al., 2022) for measuring NPP. For outcomes, new product performance (NPP) can be measured using sales growth, market share of new products, and customer acceptance (Cooper & Kleinschmidt, 1995; Griffin & Page, 1996; Henard & Szymanski, 2001).

According to Qin, Zheng, and Wang (2024), customer involvement in the development process enhances product-market fit and cultivates loyalty, while long-term market growth is driven by a balanced innovation strategy that combines radical and incremental improvements (Obal et al., 2023; Li, Liu & Boadu, 2023). In the words of Zhang, Hou, and Guo (2023), digital transformation facilitates proactive innovation and real-time decision-making by accelerating product development using technologies like artificial intelligence (AI), big data, and cloud computing.

Notwithstanding these facilitators, NPP is frequently hampered by a lack of capital, unpredictability in the market, and quick changes in technology (Bertolotti, Gavazza & Lanteri, 2023; Obal et al., 2023). However, these obstacles can be lessened by cooperative tactics, adaptable manufacturing, and digital integration (Castiglione et al., 2024; Lu, Qi & Yu, 2024).

Innovation, sustainability, and technological integration have a significant impact on Malaysia's E&E sector. While data-driven methods support decision-making and responsiveness (Chong et al., 2024), eco-innovation improves operational efficiency and product appeal (Mukhtar, Shad & Lai, 2024; Sukri et al., 2023). Because manufacturing flexibility facilitates faster design modifications, customisation, and timely market entry, it has a direct impact on NPP (Yu & Lee, 2023; Zhang et al., 2023). For this reason, NPP is an essential element in assessing the efficacy of flexibility strategies in high-tech, dynamic industries like E&E.

Sustainable Competitive Advantage

From the inflexible mass production systems typical of Fordism in the early 20th century to the sophisticated and flexible manufacturing settings common today, the idea of manufacturing flexibility has undergone significant change. By the 1960s and 1970s, these systems which had been initially intended for high-volume, uniform production had become limited, leading to the creation of more adaptable setups like job shops and batch production to meet changing market demands.

The introduction of Flexible Manufacturing Systems (FMS) in the 1980s brought about a dramatic change by combining cutting-edge technology like robots, automated material handling, and computer numerical control (CNC) to allow for dynamic changes in production processes. Product, mix, and volume flexibility were among the many elements of manufacturing flexibility that had been added by the 1990s (Vokurka & O'Leary-Kelly, 2000).

Businesses started incorporating flexibility into more comprehensive strategic supply chain frameworks in the 2000s in order to handle the increasing unpredictability of the market. More recently, real-time responsiveness, operational productivity, and sustainable performance have been further improved by the incorporation of Industry 4.0 technologies, such as robotics, artificial intelligence (AI), and the Internet of Things (IoT) (Margherita & Braccini, 2020).

It is commonly acknowledged that manufacturing flexibility (MF) is a fundamental skill that allows production systems to adapt to environmental instability and uncertainty. At first, MF was described as a manufacturing system's capacity to quickly adjust to shifting market conditions (Castiglione et al., 2024).

This conception has developed over time to highlight flexibility in using the same production infrastructure for a variety of products. According to Rama Murthy et al. (2024), MF is the ability of systems to adapt to changes without sacrificing effectiveness, especially in component variety, customization, and product design. In today's industrial environment, the ability to adapt to changes in the product mix, shorten lead times, and enhance customer responsiveness is essential (Moin et al., 2024). In order to accommodate varying operational contexts and degrees of uncertainty, businesses are increasingly customizing their flexibility strategies.

In modern times, advanced manufacturing systems are purposefully made to be flexible by integrating essential elements like reconfigurability, scalability, and modularity. While scalability permits changes in production capacity without requiring a large amount of reinvestment, modularity permits quick reconfiguration of system components in response to changing production requirements (Habib et al., 2023) (Castiglione et al., 2024).

Reconfigurable manufacturing systems preserve operational efficiency and agility by adjusting to changes in technology, batch size, and product design (Hofmeester, 2023). Furthermore, customization-driven flexibility reduces expenses and maximizes output for particular product lines. This strategic agility supports manufacturers in responding to evolving customer preferences, technological disruption, and competitive pressures.

The positive outcomes of MF go beyond responsiveness; they also feature notable cost and operational savings. Highly adaptable systems increase efficiency by decreasing setup times, allocating resources optimally, and minimizing production interruptions (Castiglione et al., 2023). Global competitiveness and overall performance can be improved by flexible systems, according to simulation tests conducted with the use of programs like Tecnomatix. By permitting small-batch and customized outputs without the capital constraint of traditional manufacturing setups, flexibility also helps to make production through additive manufacturing technologies more affordable (Hofmeester & Eyers, 2023). sustainable competitive advantage (SCA) may be captured through long-term profitability, customer loyalty, and innovation capability (Porter, 1985; Barney, 1991; Teece, Pisano, & Shuen, 1997; Lawson & Samson, 2001).

Manufacturing flexibility is essential for tackling the fast-paced technology improvements and unstable market conditions in Malaysia's Electrical and Electronics (E&E) sector. It promotes modular production techniques and makes integration with Industry 4.0 technologies easier, both of which are essential for preserving

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operational resilience and cost effectiveness (Yeap et al., 2024; Ang et al., 2024). During the COVID-19 pandemic, businesses with greater flexibility maintained stable operations and financial results, thus highlighting the significance of MF (Zahari et al., 2023). In a high-mix, low-volume setting, Malaysian manufacturers may also fulfill customized orders with little resource loss thanks to modular manufacturing designs (Habib et al., 2023).

The present research, which draws from the literature, outlines five important aspects of manufacturing flexibility that are pertinent to Malaysia's E&E sector: labor flexibility, machine flexibility, operational flexibility, new product flexibility, and material-handling flexibility. Table 1 provides a summary of these dimensions, which stand for the fundamental characteristics of MF as used in this study.

Table 1: Dimension selection table

articles	New product flexibility	Operation flexibility	machine flexibility	labour flexibility	matherial handling flexibility	volume	routing flexibility	Mix Flexibility	Process flexibility	Expansion flexibility	Automation flexibility	Product diferentiation flexibility	Strategic flexibility	Tactical flexibility
(Al-obaidy, Ismael and Alshammary, 2023)				x										
(Raouf and Iswadi, 2020)	x		x											
(Sarote, Samuel and Kumar Yadav, 2021)		x	x	x	x				x	x	x			
(Moin et al., 2024)				x		x			x			x		
(Singh, 2024)		x											x	x
(UDOFIA et al., 2023)	x	x				x		x						
(Habib et al., 2023)	x													
(El Ghoul *et al.*, 2024)		x												
(Blalević Dević, 2024)				x										
(Zhu and Topaloglu, 2022)	x													
(Angelici *et al.*, 2020)				x										
(Li, Eshragh and Ebufegha, 2023)	x													
(Willebrand *et al.*, 2024)		x												
(Pérez-Pérez, Serrano-Bedia and López-Fernández, 2022)	x		x	x	x		x							
(Khalaf and El Mokadem, 2019)			x	x	x	x								
(Woun Tan and Teong Lim, 2019)	x		x	x	x		x	x						

RESULTS AND DISCUSSION

New Product Flexibility

New Product Flexibility (NPF) is the ability of a company to quickly introduce new products by adapting manufacturing systems to meet changing market demands and customer needs (Larso, Doolen, and Hacker, 2009). Customized items can be produced more quickly and affordably thanks to technologies like additive manufacturing (Castiglione et al., 2023). Businesses may control demand variations, cut expenses, and effectively handle product changes with the help of modular designs and flexible layouts (Habib et al., 2023; Li and Eshragh, 2023).

In besides enhancing operations, NPF promotes sustainability through waste reduction and product life extension (Habib et al., 2023). According to He and Smith (2023) and Miti, Sultan, and Shah (2023), NPF is essential for maintaining competitiveness in Malaysia's Electrical and Electronics industry through quicker product introductions, customisation, and environmentally friendly production. NPF can be assessed through indicators such as the time required to introduce a new product and the percentage of successful product launches (Suarez, Cusumano, & Fine, 1996; Calantone, Chan, & Cui, 2003)

Operation Flexibility

The aptitude of a manufacturing system to swiftly and effectively adjust to shifting production demands, such as shifting product sequences and flexible planning to reduce transition penalties, is known as operational flexibility (OF) (Koste and Malhotra, 1999). It includes resource adaptability and scalability, which enable businesses to modify output and procedures in response to shifting consumer demands and market dynamics (Castiglione et al., 2024; Dias, 2022).Operational flexibility may be measured through production lead time and order fulfillment adaptability (Slack, 1987; Gerwin, 1993) In sectors like Malaysia's Electrical and

Electronics (E&E) industry, where demand and product variety fluctuate frequently, this adaptability is crucial for handling complexity.

Operational flexibility also supports sustainability by optimizing resource use and reducing waste, as flexible systems facilitate the integration of green technologies and practices (Wu et al., 2024; El Ghoul et al., 2024). Furthermore, it facilitates dynamic reactions to uncertainties and disruptions, which enhances decision-making and cost efficiency (Früh et al., 2023; Misaghian et al., 2023). Operational flexibility is a crucial component of competitiveness, innovation, and sustainable manufacturing performance in Malaysia's E&E sector, and it fits in nicely with Industry 4.0 developments and strategic objectives (Früh and Müller, 2023).

Machine Flexibility

Machine flexibility (MF) is vital for resilient and flexible production systems, especially in Malaysia's E&E sector. It describes how machines can multitask or switch between jobs with little interruption, allowing businesses to react quickly to shifts in market conditions, demand, and product design (Koste and Malhotra, 1999; Castiglione et al., 2024). This type of flexibility improves operational agility but may necessitate careful system capacity balance, as demonstrated by Hofmeister (2023). Machine flexibility can be gauged by the number of operations a machine can perform and its reconfiguration ease (Browne et al., 1984; Koste & Malhotra, 1999).

Real-time decision-making and process optimization are strengthened by integrating technologies like digital twins and reconfigurable machine tools (RMTs) (Ullah & Younas, 2024; Song et al., 2023). Additionally, by decreasing downtime, energy consumption, and per-unit costs, machine flexibility promotes innovation, product customisation, and sustainability (Lindner et al., 2023). Therefore, in dynamic manufacturing contexts, machine adaptability is a major enabler of new product performance and ongoing competitive advantage.

Labour Flexibility

In Malaysia's E&E sector, labor flexibility plays a major role in attaining responsive and sustainable manufacturing. Working time, functional, numerical, and geographic flexibility allow businesses to adjust labor deployment to changing production demands (Chowdhury et al., 2023; Dević, 2024). This adaptability enhances productivity, minimizes absenteeism, and supports cost-efficient labour management, especially during demand fluctuations or crises (Angelici & Profeta, 2023; Kapitsinis & Gialis, 2023). This flexibility can be measured by may be captured by the proportion of multi-skilled employees and their adaptability to new tasks (Upton, 1994; Mishra, 2021).

In line with the objectives of the industry 4.0 revolution, flexible arrangements like remote work and multiskilled roles also foster creativity and resilience in industrial processes (Edmans et al., 2023). Additionally, labor flexibility improves the performance of new products and sustains competitive advantage by retaining talented workers and sustaining operations amid disruptions. Labor flexibility is therefore still a key component of manufacturing flexibility and a strategic tool for raising competitiveness in the fast-paced E&E industry.

Material Handling Flexibility

In Malaysia's E&E manufacturing sector, material handling flexibility is essential to increasing operational efficiency, adaptability, and sustainability. Using flexible machinery, adjustable procedures, and scalable systems it helps businesses to handle changing production layouts, changing product requirements, and variable demand (Castiglione et al., 2024; Yıldız et al., 2024). Important enablers that help reduce material waste, optimize energy consumption, and promote cost-effective operations include automated guided vehicles (AGVs), sustainable equipment, and green material handling techniques (Chatterjee & Chakraborty, 2023; Bairagi, 2023). Material handling flexibility can be evaluated based on the range of materials handled and the speed of transfer across processes (Sethi & Sethi, 1990; Narasimhan & Das, 1999).

Furthermore, by facilitating quick reactions to shortages or spikes in demand, material handling flexibility improves supply chain resilience and guarantees continuity during disruptions (Kouvelis et al., 2023).

Additionally, this adaptability facilitates bulk customisation, enabling producers to satisfy a wide range of client demands without sacrificing product quality or delivery. According to this study, material handling flexibility directly promotes manufacturing adaptability and is consistent with the objectives of attaining outstanding new product performance and a lasting competitive advantage in the Malaysian E&E sector.

Conceptual Framework and Hypotheses

From the standpoint of the Resource-Based View (RBV), manufacturing flexibility (MF) can be viewed as a valuable, rare, and difficult-to-copy capability that contributes to long-term competitiveness. Similarly, the Dynamic Capabilities Theory (DCT) suggests that flexible manufacturing systems allow firms to reconfigure resources and adapt quickly to new opportunities, which is especially critical in high-mix, low-volume industries like electrical and electronics (E&E). Manufacturing flexibility (MF) has long been recognized as a strategic capability that allows firms to respond effectively to changing market conditions, customization demands, and technological advancements.

Based on these theoretical foundations, it is logical to assume that greater MF levels will enhance operational responsiveness and fortify Sustainable Competitive Advantage (SCA) by facilitating innovation, cost effectiveness, and differentiation. Because flexibility makes it easier to introduce innovative products efficiently while still satisfying market demands, companies with stronger SCA are also more likely to improve New Product Performance (NPP). Thus following hypotheses:

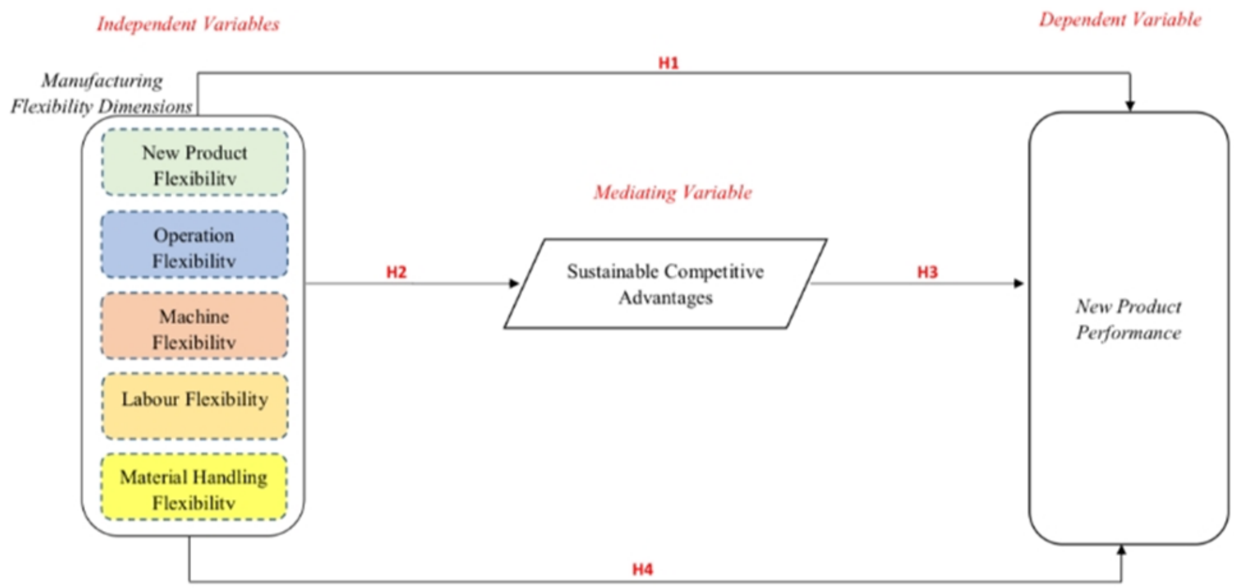

Figure 1: Research Framework

Hypothesis 1: There is a positive and significant relationship between Manufacturing Flexibility and New Product Performance:

Hypothesis 1 (a): There is a positive and significant relationship between New Product Flexibility and New Product Performance.

Hypothesis 1 (b): There is a positive and significant relationship between Operation Flexibility and New Product Performance.

Hypothesis 1 (c): There is a positive and significant relationship between Machine Flexibility and New Product Performance.

Hypothesis 1 (d): There is a positive and significant relationship between Labour Flexibility and New Product Performance.

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Hypothesis 1 (e): There is a positive and significant relationship between Material Handling Flexibility and New Product Performance.

Hypothesis 2: Manufacturing Flexibility has a significant and positive effect on Sustainable Competitive Advantages:

Hypothesis 2(a): New Product Flexibility has a significant and positive effect on Sustainable Competitive Advantages.

Hypothesis 2(b): Operation Flexibility has a significant and positive effect on Sustainable Competitive Advantages.

Hypothesis 2(c): Machine Flexibility has a significant and positive effect on Sustainable competitive advantages. Hypothesis 2(d): Labour Flexibility has a significant and positive effect on Sustainable Competitive Advantages. Hypothesis 2(e): Material Handling Flexibility has a significant and positive effect on Sustainable Competitive Advantages.

Hypothesis 3: There is a positive and significant relationship between Sustainable Competitive Advantages and New Product Performance.

Hypothesis 4: Sustainable competitive advantages positively and significantly mediate the relationship between Manufacturing Flexibility and New Product Performance

CONCLUSION

This conceptual paper has proposed a comprehensive framework that positions manufacturing flexibility (MF) encompassing machine, labour, and material handling flexibility as a critical strategic resource in driving sustainable competitive advantage (SCA) and enhancing new product performance (NPP) within Malaysia's Electrical and Electronics (E&E) industry. Anchored in the Resource-Based View (RBV) and Dynamic Capabilities Theory (DCT), the study highlights that MF enables firms to respond dynamically to technological changes, market volatility, and sustainability demands. The integration of advanced technologies such as digital twins, reconfigurable machine tools, and green material handling systems facilitates greater operational agility, workforce adaptability, and supply chain resilience. The framework further argues that SCA mediates the relationship between MF and NPP by enabling firms to sustain differentiation, optimize resource utilization, and foster innovation. This relationship is especially pertinent to the Malaysian E&E sector, where rapid innovation cycles and high customer expectations demand flexible and sustainable manufacturing capabilities. This study contributes to theory by extending the conceptual boundaries of MF research and offers practical implications for managers seeking to enhance firm performance through strategic flexibility. Future empirical studies are encouraged to validate the proposed framework and explore its application across different manufacturing contexts.

However, several limitations, such as the relationship between manufacturing flexibility (MF) and new product performance (NPP) are assumed to be generally positive in this study. However, diminishing returns could result from too much or badly managed flexibility. High degrees of flexibility, for instance, can overextend organizational resources and staff capabilities, raise operating costs, or complicate scheduling. Potential performance improvements could be outweighed by these unforeseen consequences. Future research should therefore look into the ideal degrees of flexibility and the situations in which MF turns from a source of competitive advantage to one of inefficiency. Contextual moderators that could improve or worsen the MF–SCA–NPP relationship, such as organizational culture, employee competencies, and regulatory environments, are not fully taken into consideration in this study. These factors should be investigated in future studies to offer a more complex understanding.

This framework may be expanded in future research to include other high-mix, low-volume industries like aerospace, medical devices, and specialty machinery in addition to the electrical and electronics (E&E) sector. These sectors are appropriate settings to test the generalizability of the framework because they deal with comparable issues in managing product variety, innovation speed, and operational flexibility.

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