FACTORS FOR THE ADOPTION OF DIGITAL TECHNOLOGIES IN THE MACHINERY AND METAL MANUFACTURING SECTOR IN KLANG VALLEY MALAYSIA

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A project report submitted in partial fulfilment of the requirements for the award of Master of Project Management

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"FACTORS FOR THE ADOPTION OF DIGITAL TECHNOLOGIES IN THE MACHINERY AND METAL MANUFACTURING SECTOR IN KLANG VALLEY MALAYSIA"** was prepared by **CHEW EE-ER** has met the required standard for submission in partial fulfilment of the requirements for the award of Master of Project Management at Universiti Tunku Abdul Rahman.

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ABSTRACT

The advancement of Industry 4.0 has accelerated the adoption of digital technologies in the machinery and metal manufacturing sector to improve efficiency, competitiveness, and sustainability. This study explores the key factors influencing digital technology adoption and its impact on manufacturing performance—specifically, time, cost, and quality improvements. Guided by the Technology-Organisation-Environment (TOE) framework, a structured questionnaire was distributed via email and social media, yielding 55 valid responses from small, medium, and large firms. Descriptive statistics and Principal Component Analysis (PCA) were used for analysis.

Findings show that perceived usefulness, top management support, compatibility, market demand, and competitive pressure are the most influential adoption factors. PCA identified three core dimensions: Perceived Technological Fit, Institutional and Organisational Readiness, and External Business Environment. Performance-wise, digital technologies notably improve time efficiency, quality control, and cost management.

The study concludes that successful digital transformation depends on aligning technological capabilities with organisational readiness and environmental drivers. Key recommendations include enhancing leadership support, upskilling the workforce, and expanding digital infrastructure—particularly for SMEs. These insights provide practical guidance for industry stakeholders and policymakers aiming to promote sustainable industrial digitalisation.

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LIST OF SYMBOLS / ABBREVIATIONS

c_p	specific heat capacity, J/(kg·K)
h	height, m
K_d	discharge coefficient
M	mass flow rate, kg/s
P	pressure, kPa
P_b	back pressure, kPa
R	mass flow rate ratio
T	temperature, K
v	specific volume, m^3
α	homogeneous void fraction
η	pressure ratio
ρ	density, kg/m^3
ω	compressible flow parameter
ID	inner diameter, m
MAP	maximum allowable pressure, kPa
MAWP	maximum allowable working pressure, kPa
OD	outer diameter, m
RV	relief valve

CHAPTER 1

INTRODUCTION

1.1 Introduction

Chapter 1 presents a summary of the research regarding the adoption of digital technology in the machinery and metal manufacturing sector. Digital transformation is altering global industries, with automation, artificial intelligence (AI), and the Internet of Things (IoT) serving as key drivers of operational efficiency, innovation, and competitiveness. The machinery and metal production industry in Malaysia's Klang Valley has both opportunities and challenges for the integration of advanced technologies. Notwithstanding the considerable benefits of digital adoption in enhancing production, improving decision-making, and increasing overall corporate performance, the pace of adoption differs markedly among businesses. Various factors, including technological infrastructure, organisational readiness, and environmental conditions, influence the sector's ability to effectively implement these technologies. Some organisations have embraced digital transformation to gain a competitive edge, while others face limitations in resources, skills, and finances. This report analyses the key factors influencing the adoption of digital technology in the machinery and metal manufacturing sector. The report provides valuable insights into how digital transformation can improve business development, efficiency, and sustainable competitiveness by analysing technological, organisational, and environmental factors.

1.2 Research Background

The swift progression of digital technology has profoundly transformed global manufacturing environments, heralding a new industrial epoch known as Industry 4.0. This digital revolution, marked by the integration of automation, artificial intelligence (AI), the Internet of Things (IoT), big data analytics, and cloud computing, has empowered manufacturers globally to augment operational efficiency, refine decision-making, elevate product quality, and decrease costs. Consequently, digital transformation has transitioned from a competitive advantage to an essential requirement for industrial companies seeking to maintain relevance in a rapidly expanding and complicated global economy.

In sophisticated industrial economies like Germany, the United States, China, and South Korea, the implementation of Industry 4.0 technology has been expedited by national goals, specific incentives, and robust public-private partnerships. Research in these contexts has thoroughly investigated the elements influencing or obstructing technological adoption in manufacturing, with frameworks like the Technology-Organisation-Environment (TOE) model proving essential for comprehending these dynamics. The TOE framework delineates three interconnected domains—technological readiness, organisational capabilities, and external environmental pressures—as fundamental factors influencing the decision to adopt new technologies. Research utilising this model has yielded significant insights into adoption behaviour across various sectors and national settings, guiding strategies for successful digital transformation.

Despite the increasing volume of international research, there has been limited empirical focus on emerging economies, whose adoption paths are frequently obstructed by structural, economic, and institutional impediments. In Southeast Asia, particularly Malaysia, the machinery and metal manufacturing sector is a vital component of industrial development, considerably contributing to GDP, exports, and employment. The Klang Valley in Malaysia functions as a principal industrial and manufacturing centre, with a high density of machinery and metal production enterprises, especially small and medium-sized enterprises (SMEs). However, the integration of digital technology in this industry is inconsistent and irregular, prompting apprehensions over sustained competitiveness and productivity.

National initiatives like Industry4WRD, introduced by the Malaysian government, seek to expedite digital transformation in manufacturing sectors; however, empirical evidence indicates that numerous firms, particularly SMEs, encounter ongoing challenges concerning cost, infrastructure, workforce preparedness, and regulatory intricacies. Furthermore, the current academic research has not adequately examined the distinct interplay of technological, organisational, and environmental elements that affect digital adoption in Malaysia's machinery and metal sector. This sector is comparatively underexplored relative to other industrial subsectors, especially in the Klang Valley, where specific industry dynamics and governmental frameworks necessitate detailed examination.

1.3 Problem Statements

The machinery and metal manufacturing sector in Klang Valley, Malaysia, is essential for bolstering the national industrial economy. In contrast to global trends that prioritise the integration of digital technologies—such as automation, artificial intelligence (AI), and the Internet of Things (IoT)—this sector exhibits low to negligible levels of adoption, especially among small and medium-sized enterprises (SMEs).

Despite the widespread acknowledgement of digital transformation as a catalyst for operational efficiency, productivity, and cost reduction in manufacturing, the rate of adoption in Malaysia's machinery and metal sector remains inconsistent and slow. This delay is particularly alarming given the swift global digitisation, which risks exacerbating the competitiveness disparity between Malaysian companies and their worldwide peers. A multitude of interconnected reasons contribute to this stalemate, including infrastructural constraints, substantial initial investment expenses, insufficient technical proficiency, and organisational inertia resulting from inadequate digital leadership and reluctance to change. External impediments, like governmental ambiguity, restricted access to digital financing, and unpredictable market conditions, exacerbate the situation. These issues collectively impede the digital growth of organisations, rendering many unable to properly utilise technological innovations for performance enhancement.

Although global literature has thoroughly examined digital adoption in manufacturing, there exists a notable deficiency in empirical research addressing the particular technological, organisational, and environmental problems encountered by Malaysia's machinery and metal manufacturing sector. There is a notable deficiency of research concentrated on the Klang Valley, a significant industrial centre, and an absence of context-specific frameworks to assist SMEs in managing digital transformation. This study aims to identify and examine the key factors affecting the adoption of digital technologies in the Klang Valley industry. The research seeks to establish a basis for formulating a comprehensive, context-specific strategy to expedite digital adoption, improve industrial competitiveness, and support Malaysia's overarching digital economy objectives by tackling both internal and external obstacles.

1.4 Research Questions

The subsequent enquiries of the study are as follows:

1. What are the factors for the adoption of digital technologies in the machinery and metal manufacturing sector?
2. What are the perceived performance effects of the adoption of digital technologies in the machinery and metal manufacturing sector for improved manufacturing performance?

1.5 Research Aims

This study aims to examine the elements facilitating the effective adoption and integration of digital technology in the machinery and metal production industry in the Klang Valley, Malaysia. The results will guide the creation of a framework to enhance production performance by integrating digital technologies into the machinery and metal manufacturing sector, driven by technological, organisational, and environmental factors.

1.6 Research Objectives

This research outlines objectives designed to achieve the stated study goal:

1. To investigate the factors for the adoption of digital technologies in the machinery and metal manufacturing sector.
2. To investigate the perceived performance effects of adopting digital technologies in the machinery and metal manufacturing sector for improved manufacturing performance.

1.7 Research Scopes

This research project examines the factors influencing the uptake of digital technology in Malaysia's Klang Valley's machinery and metal manufacturing sector. The study will analyse three primary dimensions: technological aspects, organisational factors, and environmental variables. The assessment will analyse the readiness and challenges faced by manufacturers, including infrastructure, employee skills, leadership support, and external influences such as market conditions and governmental restrictions. The study aims to identify key barriers and enablers of digital adoption and to provide a framework that aids manufacturers in leveraging digital technology to enhance operational efficiency and competitiveness.

1.8 Research Justifications

The rapid advancement of digital technologies has significantly transformed the global manufacturing industry, enhancing innovation, productivity, and competitiveness. The machinery and metal manufacturing sector in Malaysia is vital to the economy; however, it faces considerable challenges in embracing digitisation. While large manufacturers have advanced in adopting novel technology, small and medium-sized enterprises (SMEs), which represent the majority of the industry, face several technological, organisational, and environmental challenges. This research is justified for several essential reasons:

The Malaysian government has emphasised the need for digital transformation in the manufacturing sector via initiatives such as the Industry 4.0 policy to enhance technical capabilities. Notwithstanding these initiatives, a gap remains in understanding the specific factors that hinder or facilitate the use of digital technologies, particularly within the machinery and metal manufacturing sub-sector. This study analyses the technological, organisational, and environmental aspects influencing adoption decisions, providing essential insights into the challenges and opportunities encountered by local manufacturers.

Moreover, the study is crucial for informing corporate strategy within the industry. A multitude of manufacturers in Malaysia persist in employing traditional production methods, leading to inefficiencies, increased costs, and reduced competitiveness in the global market. This study will offer pragmatic guidance for surmounting obstacles to digital adoption and leveraging digital technology to enhance operational efficiency, product quality, and innovation through an analysis of the factors affecting digital adoption. This can ultimately aid businesses in achieving enhanced company performance and sustaining competitiveness in a rapidly evolving industry.

This study improves the comprehension of digital technology adoption in Malaysia, namely in the machinery and metal production sector. The research will provide valuable information for policymakers, corporate leaders, and technology developers, aiding the rapid digital change within the industry.

1.9 Research Design and Methodology

This research will adopt quantitative approach, utilising surveys to gather data from machinery and metal manufacturing companies in Klang Valley, Malaysia. The survey will collect insights on three key elements influencing digital technology adoption: technological, organisational, and environmental aspects. A Likert-scale questionnaire will be distributed to key stakeholders inside the selected businesses, including managers and decision-makers. The data analysis will utilise statistical methods to identify correlations and trends, including descriptive statistics and regression analysis. This methodology will produce factual data on the factors influencing digital adoption and provide ideas for improvement.

1.10 Chapters Organisation

The chapters must be arranged according to a logical and consistent structure. The study is divided into the following five major chapters:

Chapter 1: Introduction

An introduction outlining the project's historical context opens this chapter. The problem statement, research questions, research aim and objectives, research scope, research justification, research design and technique, study context, and the arrangement of the ensuing chapters are all included in this section.

Chapter 2: Literature Review

This chapter provides a thorough review of the literature on the application of digital technology in the metal and machinery manufacturing sector. Using the Technology-Organisation-Environment (TOE) paradigm, it examines influential factors, incorporates prior research, and looks into issues from a variety of crucial angles. It offers a comprehensive foundation for understanding the dynamics of adoption in the industry of machinery and metal manufacturing industry.

Chapter 3: Research Methodology
The research techniques used to accomplish the goals and objectives of the study are outlined in this chapter. This framework's components include the research methodology used, the rationale behind the sample size selection, the methods used for data collection, and the techniques used for data analysis..

Chapter 4: Results and Discussion
The data interpretation from the questionnaire surveys and the ensuing analytical findings are examined in this chapter. In order to accomplish the larger study goals, the findings are then evaluated in light of the research aim and objectives.

Chapter 5: Conclusions and Recommendations
The results of the study are carefully examined in this chapter, which also covers the accomplishment of the goals and the importance of the contributions made to the field. This study provided recommendations for future research attempts and outlined the limitations encountered during the research process..

1.11 Conclusion

In conclusion, the machinery and metal manufacturing sector in Klang Valley, Malaysia, is at a critical juncture where the incorporation of digital technology is vital for sustaining competitiveness and fostering growth. The industry faces global pressures to innovate, with contemporary technologies like as automation, AI, and IoT offering significant potential to improve operational efficiency, product quality, and cost-effectiveness. However, the pace of digital adoption is uneven, particularly among small and medium-sized enterprises (SMEs), which face several technological, organisational, and environmental challenges. These limitations hinder their ability to fully leverage the opportunities of digital transformation.

In order to close the current knowledge gap, this study looks at the major factors impacting the adoption of digital technology in the Malaysian machinery and metal production sector. The research will provide useful insights into the facilitators and barriers to digital adoption by a comprehensive analysis of technological, organisational, and environmental factors. The results will ultimately contribute to the development of a framework that aids producers in overcoming challenges, enhancing manufacturing performance, and competitiveness. This study seeks to offer specific recommendations to facilitate the industry's transition to a digitally enabled future, thereby advancing the overarching goals of Malaysia's digital economy.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The swift progression of digital technologies has transformed the manufacturing industry, signifying the shift to Industry 4.0. This change is propelled by automation, artificial intelligence (AI), big data analytics, the Internet of Things (IoT), and cloud computing, which together augment efficiency, productivity, and innovation. In the machinery and metal manufacturing sector, these technologies facilitate intelligent production systems, real-time data-driven decision-making, and predictive maintenance, resulting in enhanced operational efficiency and increased competitiveness. The adoption of digital technology differs among organisations, with major enterprises advancing more rapidly than small and medium-sized enterprises (SMEs) owing to disparities in resources, skills, and organisational preparedness.

The machinery and metal manufacturing sector in Malaysia is essential for industrial advancement and economic progress. Although several enterprises have effectively adopted digital manufacturing technologies, numerous SMEs encounter considerable obstacles in their shift towards smart factories and interconnected production systems. Financial limitations restricted digital literacy, while insufficient technological infrastructure obstructed the implementation of Industry 4.0 solutions. Furthermore, technological, organisational, and environmental elements impact the efficacy of digital transformation, necessitating a comprehensive strategy to evaluate the industry's preparedness for digital adoption.

This literature analysis examines the determinants affecting the adoption of digital technology in Malaysia's machinery and metal production industry. It analyses critical factors like technological competence, market demand, organisational preparedness, competitive pressure, and governmental assistance, utilising proven frameworks such as the Technology-Organization-Environment (TOE) model. This review synthesises current research to identify impediments, drivers, and best practices influencing the adoption of digital technologies, offering significant insights for industry stakeholders, policymakers, and researchers. Comprehending these elements is crucial for directing effective digital transformation plans, hence ensuring the competitiveness of Malaysia's manufacturing sector in the global digital economy.

2.2 Why Digital Technologies in the Machinery and Metal Manufacturing Sector?

The incorporation of digital machinery and modern metal production technologies is widely acknowledged as a strategic necessity for improving productivity, operational efficiency, and worldwide competitiveness. In the context of Industry 4.0, technologies including the Industrial Internet of Things (IIoT), artificial intelligence (AI), cloud computing, and cyber-physical systems (CPS) are utilised to enhance production systems and enable data-driven decision-making. While advanced economies have significantly advanced in the adoption of these technologies, manufacturers in developing nations, including Malaysia, face considerable obstacles in attaining extensive technical diffusion.(Shah et al., 2024).

Enhancing efficiency, reducing costs, and improving quality are fundamental catalysts of digital transformation in the manufacturing industry. For small and medium-sized organisations (SMEs), the adoption of IIoT facilitates real-time monitoring, predictive maintenance, and process automation—essential capabilities for agile responses to fluctuating market conditions and operational disturbances (Shah et al., 2024). Empirical research from Malaysian SMEs demonstrates that organisational capabilities, legislative support mechanisms, and dynamic market factors substantially affect enterprises' preparedness for Industry 4.0 adoption (Wong and Kee, 2022). Companies that effectively use smart manufacturing systems, comprising networked production lines and automated workflows, exhibit enhanced performance in reducing downtime and optimising supply chain efficiency (Shai et al., 2022).

However, the use of technology is still hindered by structural barriers, such as insufficient financial resources, worker skill gaps, and the intrinsic complexity of digital systems. Research highlights the crucial importance of leadership in Malaysia's electrical and electronics (E&E) sector for surmounting institutional barriers and facilitating the digital transition (Arumugam et al., 2022). Organisations with strategic leadership frameworks and well-defined digital roadmaps are more inclined to successfully implement sophisticated systems and allocate resources for workforce reskilling. Additionally, internal elements like digital literacy and communication infrastructure are essential facilitators of effective technology integration (Arumugam et al., 2022).

System compatibility has become a critical determinant in formulating companies' digital adoption plans. Recent research on Malaysian manufacturers indicates that compatibility with current technical infrastructure is the primary factor influencing adoption intent, outweighing the effects of relative advantage, complexity, and trialability (Shahir, Asis and Wahid, 2020). This highlights firms' preference for solutions that align with current operational frameworks, minimising the need for extensive retraining and structural overhaul.

Addressing these complex difficulties requires coordinated efforts from both governmental and industrial stakeholders. Targeted policy instruments, including financial incentives, capacity-building efforts, and strategic assistance, are crucial for assisting SMEs in managing digital transition. The Penang scenario exemplifies a feasible approach, where cooperation between local technology suppliers and government-supported training initiatives has enabled Industry 4.0 integration and stimulated high-value industrial endeavours (Shai et al., 2022). By consistently investing in digitalisation, automation, and advanced production systems, Malaysia's machinery and metal manufacturing sector can improve resilience, maintain global competitiveness, and safeguard against technological upheavals.

2.3 Technology-Organisation-Environment (TOE) Framework

The Technology–Organisation–Environment (TOE) framework is a fundamental approach for understanding the adoption of technological breakthroughs across sectors by assessing three critical dimensions: technological, organisational, and environmental aspects. This approach, initially developed by Tornatzky and Fleischer (1990), has been extensively utilised in research concerning Industry 4.0, cloud computing, and digital transformation, especially in small and medium-sized organisations (SMEs) (Baker, 2012). It offers a thorough framework for evaluating the readiness, limitations, and adoption patterns of companies undergoing digital transformation.

From a technological perspective, enterprises often face obstacles with the complexity, integration, and preparedness of digital technology. Integrating technology like automation, artificial intelligence (AI), and the Internet of Things (IoT) frequently presents difficulties, particularly for small and medium-sized enterprises (SMEs). Ramzul et al. (n.d.)emphasise that small and medium-sized enterprises encounter substantial installation and maintenance expenses, cybersecurity issues, and an absence of digital culture in the realm of cloud computing adoption. Nevertheless, cloud-based solutions are considered economical options that alleviate infrastructure demands and facilitate a progressive transition to Industry 4.0. Likewise, Qerul Barriah Muhamad and Jamal Abdul Nasir Bin Syed Mohamad (n.d.) indicate that technological preparedness, perceived advantages, and financial investment substantially impact the adoption of digital transformation among Malaysian SMEs.

The organisational dimension highlights internal competencies like leadership, strategic vision, and workforce proficiency. Organisations governed by management teams that emphasise digital transformation are more inclined to effectively implement Industry 4.0 technology (Amin et al., 2024). Nonetheless, deficiencies in skills and internal opposition to change continue to be enduring impediments. In their 2024 study on e-commerce adoption, Wasudawan and Sim (2024) discovered that 65.5% of Malaysian SMEs continue to favour traditional business models due to insufficient qualified workers and cultural resistance to digital tools. These findings highlight the significance of workforce development, ongoing training, and change management strategies in facilitating effective digital transitions.

The environmental context encompasses external factors, including regulatory frameworks, market dynamics, and government incentives. Government support is essential for addressing adoption barriers, particularly in developing economies. Amin et al. (2024) researched the manufacturing sector in Bangladesh, revealing that policy incentives and market competition play a significant role in firms' adoption of digital technologies. In Malaysia, the National Policy on Industry 4.0 (Industry4WRD) serves as a strategic initiative aimed at offering financial assistance and guidance to SMEs for the adoption of automation and smart manufacturing (Qerul Barriah Muhamad & Jamal Abdul Nasir Bin Syed Mohamad, n.d.). Challenges, including bureaucratic inefficiencies, lack of standardisation, and ambiguous regulatory procedures, frequently obstruct the effective implementation of these policies.

The framework of TOE provides an extensive strategy to studying the complex dynamics of technology adoption in the contexts of cloud computing, e-commerce, and Industry 4.0. Organisations with advanced technology preparedness, strong internal leadership, and operating within favourable external conditions are more likely to succeed in their digital transformation initiatives. Ongoing problems, including financial constraints, talent shortages, and organisational resistance, necessitate collaborative efforts by governmental entities, industry stakeholders, and educational institutions to cultivate a digitally proficient workforce and foster an innovation-conducive environment.

2.4 Factors for the Adoption of Digital Technologies in the Machinery and Metal Manufacturing Sector

The integration of digital technologies in the machinery and metal manufacturing sector is essential for improving productivity, optimising resource use, and maintaining competitiveness in the framework of Industry 4.0. Technologies including artificial intelligence (AI), collaborative robots (cobots), digital twins, and systems that facilitate a circular economy are being increasingly utilised to enhance operational performance, especially within small and medium-sized enterprises (SMEs) and publicly listed manufacturing companies. The Technology–Organisation–Environment (TOE) framework serves as a comprehensive analytical tool for examining the various factors influencing digital technology adoption, encompassing technological, organisational, and environmental aspects (Ghani, Ariffin, and Sukmadilaga, 2022).

Industry 4.0 technologies, including AI, the Internet of Things (IoT), and collaborative robots (cobots), enable automation, improve precision, and enhance predictive maintenance capabilities. Studies have identified significant barriers to adoption, including integration complexities, limited IT infrastructure, and cybersecurity vulnerabilities (Neto et al., 2020). Research suggests that, contrary to the assumed significance of technical capacity, IT capability plays a less critical role in Malaysian manufacturing firms. Instead, top management support and external incentives, such as government funding, are identified as more robust predictors of AI adoption (Ghani, Ariffin and Sukmadilaga, 2022). Digital twin technology presents considerable potential via real-time monitoring and virtual asset modelling; however, its adoption is limited by elevated implementation costs, security concerns, and a lack of specialised human resources (Neto et al., 2020).

Organisational determinants such as leadership commitment, workforce competence, and financial capacity are equally crucial. Correia Simões, Lucas Soares and Barros (2020) note that the intention of management to adopt cobots is positively affected by strategic alignment, workforce readiness, and adherence to regulatory standards. Many SMEs encounter constraints in digital literacy and budgetary flexibility, which hinder the adoption of emerging technologies (Rojas-Berrio et al., 2022). The shift towards circular economy practices increases organisational requirements, necessitating enhanced data management, automation systems, and real-time analytics to minimise waste and optimise resource efficiency. Challenges related to operational scalability and uncertain regulatory environments persistently hinder progress (Hariyani et al., 2024).

Environmental factors, such as public policy, competitive pressures, and institutional infrastructure, significantly influence technology adoption. Market demand and government-supported initiatives, including tax incentives and upskilling programs, have been demonstrated to expedite digital transformation in emerging economies, especially within capital-intensive sectors (Rojas-Berrio et al., 2022). Digital technologies, including blockchain, AI, and IoT, play a significant role in the implementation of the circular economy by improving supply chain transparency, facilitating life-cycle analysis, and enabling sustainability monitoring. The regulatory ecosystem has not yet fully adapted to the requirements presented by these technological advancements (Hariyani et al., 2024).

The successful adoption of digital technologies in the machinery and metal manufacturing sector depends on technological readiness, leadership engagement, financial viability, and the presence of supportive policy mechanisms. Technologies like AI, cobots, and digital twins offer significant transformative potential; however, their widespread adoption is hindered by challenges related to system integration, cybersecurity threats, and workforce readiness. Addressing these constraints requires collaborative efforts among industry stakeholders, policymakers, and educational institutions to develop a digitally proficient workforce, simplify regulatory frameworks, and create incentive structures that support the transition to smart and sustainable manufacturing practices.

2.4.1 Technological Dimension

Technology is a vital facilitator in the implementation of digital transformation (DT) and Industry 4.0 technologies across several manufacturing sectors. In Malaysia, industries such as machinery and equipment (M&E), furniture manufacturing, and general industrial production are increasingly integrating automation, robotics, artificial intelligence (AI), and smart manufacturing systems to enhance operational efficiency and maintain global competitiveness. However, the successful adoption of these technologies is shaped by several interrelated technological factors, including technological readiness, cost, integration complexity, and workforce capability.

Technological readiness, defined as an organisation’s capacity to deploy and integrate advanced systems, is among the most influential determinants of Industry 4.0 adoption. Within Malaysia’s M&E sector, firms are increasingly leveraging automation, machine-to-machine (M2M) communication, and intelligent handling systems to streamline production processes and reduce operational downtime. These innovations contribute to improved production quality and resource efficiency. Nevertheless, widespread adoption remains constrained by the persistence of legacy systems that are often incompatible with new digital infrastructures, thus impeding seamless integration.

Cost also constitutes a significant barrier, particularly for small and medium-sized enterprises (SMEs). High initial investment requirements—including expenditures on digital infrastructure, licensing, cybersecurity, and employee training—often deter firms from undertaking large-scale technological upgrades. Chin and Sadeh (2024) report that cost remains a primary factor discouraging digital transformation in Malaysian manufacturing firms. In the furniture manufacturing industry, in particular, the continued reliance on manual processes is attributed to financial constraints that limit the adoption of automation and intelligent technologies (Yi et al., 2021). These findings underscore the necessity of financial incentives, tax exemptions, and public funding mechanisms to support SMEs in their transition toward Industry 4.0.

Integration complexity further impedes digital transformation. Many firms face technical challenges in harmonising new Industry 4.0 technologies with existing legacy systems due to interoperability issues, a lack of standardised protocols, and insufficient technical roadmaps. Yi et al. (2021) note that Malaysian SMEs in the furniture sector encounter significant difficulties during implementation, stemming from ambiguous technology standards and fragmented digital ecosystems. Similarly, the M&E sector requires coordinated integration between hardware components, software platforms, and cloud-based systems, a process that is both technically demanding and resource-intensive.

Workforce capability also plays a pivotal role in determining the success of technological adoption. Even where infrastructure and digital tools are available, the absence of a skilled workforce can hinder implementation. According to Chin and Sadeh (2024), organisational agility and workforce readiness are critical for the effective deployment of Industry 4.0 technologies. In the context of furniture manufacturing, Yi et al. (2021) highlight that a shortage of personnel trained to operate automated systems significantly slows digital progress. To address these challenges, strategic investments in upskilling, vocational training, and digital literacy programmes are required to build a workforce capable of managing advanced industrial technologies.

In summary, technological readiness, financial feasibility, system integration, and workforce competence are central to the adoption of Industry 4.0 technologies in the Malaysian manufacturing landscape. While smart manufacturing, robotics, and automation offer considerable opportunities for productivity gains and competitive advantage, numerous technological barriers continue to constrain progress. Addressing these challenges will require coordinated action from policymakers, educational institutions, and industry stakeholders to ensure the successful and sustainable implementation of digital transformation initiatives.

2.4.1.1 Perceived Usefulness

Perceived usefulness is a pivotal determinant in the adoption of digital technologies across diverse industries, particularly among small and medium-sized enterprises (SMEs) within the manufacturing sector. In the context of Industry 4.0, businesses are increasingly recognising the potential of artificial intelligence (AI), advanced manufacturing technologies (AMT), automation, cloud computing, and intelligent manufacturing systems to enhance productivity, streamline operations, and support data-driven decision-making. However, the extent to which organisations perceive these technologies as beneficial directly influences their adoption behaviour.

One of the primary ways in which perceived usefulness manifests is through improvements in efficiency and productivity. In a study of Malaysian dairy SMEs, automation and innovative manufacturing systems were shown to significantly reduce operational costs, increase process efficiency, and enhance output quality (Saeedi, Juwaidah and Kelly, 2022). Similarly, intelligent manufacturing systems—leveraging the integration of IoT, AI, and cloud computing—enable real-time monitoring, predictive maintenance, and supply chain optimisation, thereby providing firms with a competitive edge in increasingly digitalised markets (Yang et al., 2023).

Despite the apparent advantages, numerous SMEs face challenges in fully realising the potential of these technologies due to internal and external constraints. Chan, Mohd Yusuff and Zulkifli (n.d.) identify key barriers to AMT adoption, including inadequate employee training, resistance to organisational change, and financial limitations. These obstacles diminish the perceived usefulness of digital tools, as firms may fail to generate value from technologies, they are ill-prepared to implement or sustain. Thus, while digital solutions offer significant potential, the lack of readiness and capacity impedes their effective deployment.

The perceived value of AI in enhancing decision-making and managing operational risks further illustrates this concept. Lada et al. (2023) found that top management commitment and organisational preparedness are critical enablers of AI adoption in Malaysian SMEs. Firms that proactively invest in digital infrastructure and transformation strategies tend to perceive AI as a valuable asset for improving analytical capacity, automating workflows, and generating customer insights. Interestingly, external factors such as market competition and institutional support were found to exert less influence on AI adoption, suggesting that internal perceptions of utility outweigh external pressures in determining technology uptake.

Additionally, perceived usefulness extends to the application of emergent technologies in managing risk. As noted by Rodriguez-Espíndola et al. (2022), digital tools such as AI, blockchain, cloud platforms, and big data analytics are increasingly employed to enhance cybersecurity, regulatory compliance, and supply chain resilience. Organisations that recognise the risk-mitigation potential of these technologies are more inclined to integrate them into their operational models, particularly in high-risk industries where data security and regulatory demands are pronounced.

In summary, perceived usefulness plays a central role in shaping digital technology adoption in the manufacturing sector. While the advantages of Industry 4.0 tools—such as automation, intelligent systems, and AI—are widely acknowledged, SMEs often struggle with capability limitations, financial constraints, and internal resistance. Addressing these issues through strategic support, including government incentives, targeted training programmes, and organisational change initiatives, is essential to improving technology perceptions and accelerating digital transformation.

2.4.1.2 Perceived Ease of Use

A key factor in the acceptance and long-term use of digital technology in the context of Industry 4.0, smart manufacturing, and automation-intensive environments is perceived ease of use, or PEOU. The degree to which users perceive digital tools as intuitive, accessible, and seamlessly integrable into existing workflows directly influences the success of digital transformation initiatives, operational efficiency, and workplace safety. Multiple studies have identified user-friendly system design, organisational support, and system reliability as key enablers of successful technology adoption within intelligent manufacturing settings.

In the context of small and medium-sized enterprises (SMEs), PEOU is closely linked to digital preparedness, change management, and structured adoption planning. Ghobakhloo and Iranmanesh (2021) argue that SMEs often face significant barriers such as limited financial and technical resources, which heighten risk aversion and complicate the implementation of complex digital solutions. However, firms that proactively invest in workforce training, cross-platform integration, and external technical support are more likely to achieve smoother transitions and higher user acceptance of Industry 4.0 technologies.

User engagement within smart factory environments is also highly dependent on PEOU. Jo (2023), through a survey of 167 smart factory employees, found that the combination of perceived usefulness, ease of use, and a strong commitment to continuous learning significantly contributes to long-term technology adoption. Facilities equipped with intuitive user interfaces, automated data processing systems, and seamless machine-software interoperability were associated with higher engagement levels. Moreover, the quality of both system functionality and support services played a pivotal role in reducing perceived technological complexity and cognitive overload among users.

The relevance of PEOU extends to the adoption of automation and robotics.Cao et al. (2020), in a study of 258 manufacturing firms in China employing the Technology Acceptance Model (TAM), demonstrate that organisational efficacy and normative perceptions significantly influence the uptake of robotic technologies. Manufacturers that offer accessible training modules, intuitive robotic interfaces, and consistent technical support report elevated adoption rates and operational performance. Furthermore, institutional support—through government incentives and industry-wide digitalisation strategies—has been shown to mitigate perceived complexity and foster greater confidence in automation adoption.

Beyond productivity enhancement, PEOU plays a crucial role in the implementation of digital solutions for workplace safety. Cagno et al. (2024) found that the adoption of Industry 5.0 safety technologies—such as AI-based hazard detection, wearable sensors, and predictive analytics—in Italian metalworking SMEs was significantly influenced by ease of integration and user intuitiveness. Nevertheless, barriers such as high deployment costs, privacy concerns, and implementation challenges remain prevalent. The study emphasises that clear communication of benefits and alignment with operational workflows are essential to overcoming resistance and enhancing technology acceptance.

In summary, perceived ease of use is a foundational element in the successful deployment and continued use of Industry 4.0 technologies. Organisations that prioritise user-centric design, intuitive automation systems, and comprehensive training resources tend to experience greater employee engagement, smoother implementation processes, and enhanced safety outcomes. Strategic investment in PEOU-enhancing mechanisms—including change management frameworks, digital support systems, and stakeholder communication—can substantially accelerate digital transformation and secure long-term benefits in efficiency, productivity, and technological resilience.

2.4.1.3 Technology Optimism

Technology optimism refers to the belief that digital technologies have the potential to drive industrial progress, enhance efficiency, and address critical operational challenges. Within the context of digital transformation and smart manufacturing, this optimism is reflected in the increasing adoption of Industry 4.0 technologies—including artificial intelligence (AI), the Internet of Things (IoT), cloud computing, and automation—across both small and medium-sized enterprises (SMEs) and large industrial firms. These organisations pursue digitalisation as a pathway to improved competitiveness, sustainability, and economic resilience. Although adoption barriers persist, evidence suggests that strategic investments, infrastructure development, and targeted government interventions can mitigate these challenges and accelerate the realisation of digital technology benefits.

A central driver of technology optimism is the expectation that digitalisation can empower SMEs by improving operational agility and supporting broader economic development goals. Empirical studies demonstrate that SMEs leveraging digital transformation report enhanced customer engagement, more efficient operations, and greater adaptability to market fluctuations. Tools such as enterprise resource planning (ERP) systems, AI-enabled analytics, and automation technologies allow SMEs to narrow the performance gap with larger firms, despite limited resources. However, persistent constraints—including limited capital, organisational inertia, and infrastructure deficits—hinder widespread adoption. Public-sector support through funding schemes, digital literacy training, and incentive-based regulatory frameworks remains essential in enabling SMEs to fully participate in the digital economy (- et al., 2024).

In the realm of smart manufacturing, optimism is further sustained by its transformative potential for industrial productivity. The transition from traditional to digital manufacturing paradigms enables firms to adopt data-driven decision-making models, predictive maintenance protocols, and mass customisation capabilities. Technologies such as 3D printing, industrial robotics, and real-time performance monitoring contribute to waste reduction, operational efficiency, and product innovation. A systematic review of 229 industry case studies highlights the tangible benefits of digital manufacturing adoption, including productivity gains, cost efficiencies, and improved product quality. Nevertheless, the literature indicates a significant gap in standardised frameworks for evaluating performance outcomes and cost-benefit dynamics, limiting broader generalisability (Maretto, Faccio and Battini, 2023).

Beyond productivity, technology optimism also encompasses the environmental and social dimensions of manufacturing. Digital technologies are widely viewed as enablers of sustainable production and circular economy practices. IoT-based monitoring systems, AI-driven resource optimisation tools, and blockchain-enabled supply chain transparency are instrumental in reducing emissions and enhancing traceability. However, the success of these initiatives is contingent upon the availability of robust digital infrastructure, supportive policy environments, and socio-economic alignment. Ahmadi-Gh and Bello-Pintado (2024) emphasise that disparities between developed and developing regions—in terms of digital readiness—impede equitable access to the sustainability benefits of digitalisation, necessitating a context-sensitive approach that harmonises digital policy with environmental objectives.

Furthermore, technology optimism is evident in its perceived role in enhancing risk management. Digital technologies such as AI, blockchain, and big data analytics enable improved supply chain resilience, cybersecurity protocols, and regulatory compliance. Firms adopting these tools demonstrate superior capacity to anticipate market disruptions, mitigate operational risks, and adapt to evolving standards. Nonetheless, the rise in system connectivity introduces vulnerabilities related to data privacy and cybersecurity. Addressing these risks requires not only the deployment of robust digital security architectures but also sustained investment in infrastructure and workforce development (- et al., 2024).

Despite the prevailing optimism, research underscores the need for a nuanced and strategic approach to digital technology adoption. Ghobakhloo and Ching (2019) argue that digital transformation is not a universal remedy but must be tailored to sector-specific conditions, economic constraints, and workforce capabilities. To bridge the gap between technological potential and real-world implementation, policymakers and industry leaders must foster enabling environments through integrated efforts in education, funding, infrastructure, and regulation.

In summary, technology optimism in the context of digital transformation and smart manufacturing is supported by the potential for enhanced productivity, sustainability, and economic development. While SMEs and large enterprises alike stand to benefit, significant barriers—such as financial limitations, skill shortages, and technological integration issues—must be addressed. Achieving the full promise of Industry 4.0 requires coordinated action among governments, industry stakeholders, and academic institutions to design scalable, inclusive, and evidence-based transformation strategies. By cultivating a culture of innovation, continuous learning, and policy alignment, technology optimism can be converted into tangible industrial advancement, shaping the trajectory of global manufacturing.

2.4.1.4 Technological Capability

International competitiveness, innovative capacity, and manufacturing performance are all significantly influenced by technological competency (TC). It encompasses a firm's ability to acquire, assimilate, and deploy technology to enhance productivity, operational efficiency, and responsiveness to dynamic market demands. In the context of Industry 4.0, TC is foundational to digital transformation, automation, and the deployment of smart manufacturing systems, enabling firms to maintain competitive advantage in increasingly digitised and globalised markets.

Developing technological capabilities involves more than the mere acquisition of advanced technologies; it requires sustained investment in research and development (R&D), workforce training, and the cultivation of an innovation-oriented organisational culture. Empirical evidence from Malaysian manufacturing firms demonstrates that companies with well-developed TC exhibit superior operational efficiency, quality assurance, and cost reduction outcomes (#1 et al., 2019). These benefits are manifested in enhanced production flexibility, agile supply chains, and product innovation. Nonetheless, firms in developing economies continue to face significant barriers, particularly skills shortages and technological infrastructure gaps, which constrain their ability to fully leverage Industry 4.0 technologies (Ahmad, Othman and Lasim, n.d.).

Sector-specific studies reveal disparities in technological advancement within manufacturing sub-sectors. For instance, Ratnasingam et al. (2020) report that panel-based and metal furniture manufacturers in Malaysia demonstrate higher levels of technological integration compared to their solid-wood and leather counterparts. These technologically advanced firms utilise automation, computer-aided design (CAD) tools, and robotics to scale production and maintain price competitiveness. However, widespread adoption is hindered by limited digital literacy and a shortage of skilled personnel, highlighting the need for targeted workforce development and educational initiatives aligned with Industry 4.0 competencies (Ahmad, Othman and Lasim, n.d.).

Technological capability also underpins global market performance. Firms with strong internal R&D capacity and knowledge management systems are better positioned to innovate, expand internationally, and enhance export performance. Conversely, over-reliance on imported technologies without concurrent investments in local knowledge absorption and innovation infrastructure limits long-term competitiveness. Evidence from Indonesia's manufacturing sector illustrates that firms failing to develop endogenous technological competencies struggle to sustain their market positions (Kumar, Kumar and Persaud, n.d.).

Beyond productivity and cost optimisation, TC contributes to strategic agility, customer satisfaction, and operational resilience. Al-Mamary et al. (2022) note that technologically mature firms are more adaptable to shifting market demands and more effective in managing supply chain and operational risks. However, realising these benefits requires a long-term commitment to continuous learning, collaborative R&D, and inter-firm knowledge exchange. In this regard, policymakers and government agencies play an instrumental role by facilitating access to innovation grants, establishing technology incubators, and improving digital infrastructure to support the technological upgrading of manufacturing firms.

In summary, technological capability is a cornerstone of industrial competitiveness in the digital era. While the adoption of Industry 4.0 technologies offers transformative potential, firms must overcome persistent challenges—such as skills shortages, financial constraints, and integration complexity—to fully realise these gains. Strengthening R&D ecosystems, promoting industry-academia collaboration, and advancing supportive policy frameworks are essential to building resilient, technologically advanced manufacturing sectors capable of sustained growth and global integration.

2.4.1.5 Compatibility

Compatibility is a critical factor influencing the success of technology adoption and digital transformation initiatives across diverse industrial contexts. It refers to the extent to which new technologies are aligned with existing infrastructure, organisational processes, and business models. The literature on small and medium-sized enterprises (SMEs), Additive Manufacturing (AM), digital strategy implementation, and Industry 4.0 integration consistently underscores the importance of compatibility as a facilitator—or barrier—to effective technological assimilation. High compatibility can enhance adoption rates, operational efficiency, and long-term sustainability, whereas poor compatibility often results in elevated implementation costs, internal resistance, and integration challenges.

Despite this theoretical significance, empirical findings on compatibility yield mixed results. Ramayah et al. (2013), applying the Innovation Diffusion Theory (IDT) to Malaysian SMEs, found that compatibility did not exert a statistically significant influence on technology adoption. Instead, factors such as relative advantage and observability were more salient drivers. This suggests that SMEs may prioritise direct and measurable benefits—such as cost savings and efficiency improvements—over seamless integration when evaluating new technologies.

In the context of Additive Manufacturing, compatibility remains a notable constraint. Handfield et al. (2022), in a study of seven AM implementation cases, observed that while AM's customisation potential and perceived advantages promote adoption, integration difficulties related to cost, system complexity, and lack of standardisation hamper widespread use. Many firms experience challenges in embedding AM into existing workflows, particularly in aligning software platforms, production line configurations, and supply chain logistics. Aligning AM with targeted business strategies and niche applications was proposed as a practical approach to enhance technological fit and mitigate these issues.

Compatibility concerns are similarly evident in the adoption of metal AM technologies within the Dutch manufacturing sector. A study utilising the Technology–Organisation–Environment (TOE) framework revealed that although relative advantage, trialability, and vendor marketing positively influence adoption decisions, barriers such as financial cost, low observability, and poor interoperability with legacy systems generate uncertainty (Nollet and Henseler AH van Reekum Onno Ponfoort, n.d.). This finding underscores the need for robust integration strategies and the development of industry-wide standards to support interoperability and technological convergence.

At a strategic level, compatibility also plays a decisive role in shaping digital transformation pathways. Cheng and Cui (2024), examining Chinese high-tech manufacturing firms, identified four dominant transformation strategies: searching, enhancing, grafting, and integrating.. Each strategy reflects a different approach to reconciling new digital solutions with existing systems. Firms employing search and enhancement strategies aim to identify or extend technologies compatible with legacy infrastructure, while grafting and integrating strategies involve deeper integration or full system convergence. The research demonstrates that higher levels of compatibility correlate with smoother transformation processes and improved innovation performance.

Furthermore, compatibility is crucial in aligning Industry 4.0 tools with Lean Production methodologies. While Industry 4.0 enables automation, intelligent networking, and real-time analytics, integrating these capabilities into lean environments presents structural and cultural challenges. Yürekli and Schuls (2022) highlight key barriers, including employee resistance, cybersecurity risks, and the high costs associated with digital-lean integration. The study advocates for structured frameworks that guide the alignment of lean principles with digital technologies to maximise synergy and minimise disruption.

In summary, compatibility is a foundational determinant of successful digital transformation and technological adoption. Across various contexts—including SMEs, advanced manufacturing, and Industry 4.0 integration—the degree of technological alignment with existing systems significantly influences the effectiveness of implementation efforts. Firms that proactively manage compatibility through strategic planning, standardisation, and capacity-building initiatives are better positioned to achieve smooth transitions, operational efficiency, and sustained competitive advantage.

2.4.1.6 Relative Advantage

Digital manufacturing, artificial intelligence (AI), and the industry as a whole are heavily influenced by relative advantage, which is the idea that a new technology is better than old techniques. Technologies 4.0. It encompasses tangible benefits such as cost savings, operational efficiency, improved decision-making, and access to real-time analytics—factors that increasingly influence firms to transition from conventional to advanced manufacturing systems.

A prominent illustration of relative advantage is observed in the deployment of Additive Manufacturing (AM), particularly Direct Metal Laser Sintering (DMLS). Baumers et al. (2016) demonstrate that, when machine capacity is optimally utilised, DMLS delivers significantly lower unit costs and improved operational efficiency compared to traditional machining and welding techniques . AM technologies enable greater production flexibility, support complex design geometries, and reduce material consumption through optimised build volume and waste minimisation. Moreover, advances in build failure risk management and design optimisation contribute to long-term economic viability, reinforcing the comparative benefits of AM over conventional manufacturing processes.

In addition to cost and efficiency gains, the integration of AI into AM systems offers substantial performance enhancements. Seo et al. (n.d.) explore the use of Convolutional Neural Networks (CNNs) and embedded strain gauges to create self-cognitive mechanical components capable of real-time monitoring and predictive maintenance. These systems detect malfunctions, loosening, and external impacts with an accuracy rate of 89.1%, thus improving component reliability and machine uptime while reducing maintenance costs and unplanned downtime. This application of AI exemplifies the growing utility of smart systems in delivering predictive capabilities and operational resilience.

The socio-technical implications of Industry 4.0 further underscore its relative advantage. A case study by Margherita and Braccini (n.d.) of an Italian manufacturing firm highlights how automation and AI-based decision-making transform production workflows by reallocating repetitive, labour-intensive tasks to machines. This shift enhances precision, increases speed, and reduces human error. However, the authors also emphasise the need for workforce retraining and human–machine collaboration to achieve optimal outcomes. Organisations that strategically invest in both digital technologies and human capital are more likely to realise the full spectrum of benefits associated with digital transformation.

Further evidence of relative advantage is found in semiconductor manufacturing, where AI-driven process optimisation significantly enhances industrial performance. Ghahramani et al. (2020) demonstrate how the integration of Genetic Algorithms (GAs) and Artificial Neural Networks (ANNs) facilitates advanced fault detection, feature selection, and predictive analytics. Combined with Industrial Internet of Things (IIoT) sensors, these technologies enable dynamic process control and real-time decision-making, resulting in increased production efficiency and cost-effectiveness.

In summary, the relative advantage of Industry 4.0 technologies—particularly digital manufacturing and AI-driven solutions—is evident across multiple dimensions, including cost efficiency, process optimisation, predictive maintenance, and workflow automation. While these benefits make advanced technologies increasingly attractive, successful adoption depends on strategic planning, workforce adaptation, and financial commitment. As organisations continue to integrate intelligent manufacturing systems, the long-term economic and operational benefits will further entrench Industry 4.0 as the prevailing paradigm in modern production.

2.4.1.7 Trialability

Trialability plays a significant role in adopting digital technologies, innovation, and Industry 4.0 solutions. It refers to the degree to which a new technology can be tested or experimented with on a limited basis before full adoption. Studies on Malaysian manufacturing SMEs, Virtual Reality (VR), and B2B e-business adoption highlight trialability as a critical factor in reducing perceived risk, improving user confidence, and facilitating technology diffusion. However, while trialability can positively impact adoption, its effectiveness depends on industry-specific factors, risk perceptions, and technological readiness.

Within the Malaysian manufacturing sector, trialability has emerged as one of the principal determinants of innovation diffusion, alongside relative advantage, compatibility, complexity, and observability. Mamun (2018), in a survey of 360 SMEs, found that firms demonstrating a higher propensity for experimentation and strategic innovation were significantly more likely to adopt new technologies. Trialability provides these firms with a mechanism to assess technological viability, evaluate potential returns, and mitigate uncertainty, thereby facilitating informed decision-making and enhancing competitive positioning in evolving markets.

In the realm of Virtual Reality (VR), trialability is a particularly salient barrier. Laurell et al. (2019), through the analysis of over 6,000 user-generated social media posts using machine learning, identified that high initial costs, limited application diversity, and inadequate accessibility deter widespread adoption. Crucially, the study found that the inability to trial VR technologies before purchase substantially reduced user engagement and willingness to adopt. Enhancing accessibility through demonstrations, low-cost entry options, and free trial experiences is therefore essential to overcoming this adoption barrier and promoting broader market penetration.

In high-risk environments, such as B2B e-business contexts, trialability functions as a strategic risk-mitigation tool. Banerjee, Wei and Ma (2012), in a qualitative study involving two case studies, demonstrated that trialability in these settings is not merely a passive perception but an active process involving controlled pilot implementations. Firms engaging in trial transactions with limited scope and resources were better positioned to evaluate vendor reliability, system performance, and contextual fit. This proactive approach enabled businesses to reduce uncertainty, build trust, and make evidence-based adoption decisions. The study challenges traditional Diffusion of Innovation (DOI) assumptions by reframing trialability as a necessary condition for adoption in risk-averse environments.

In summary, trialability serves as a critical bridge between initial interest and full-scale adoption across various technological domains. By allowing organisations to experiment, validate performance, and reduce uncertainty, trialability enhances the likelihood of successful digital transformation. However, its efficacy is contingent on contextual variables, including perceived risk, cost structures, and organisational readiness. As such, increasing access to trial opportunities—whether through pilot projects, demonstrations, or phased rollouts—can significantly accelerate innovation diffusion and support the broader integration of Industry 4.0 technologies.

2.4.1.8 Observability

Observability—the degree to which the benefits of a technology are visible and demonstrable to potential adopters—is a key determinant of digital transformation and Industry 4.0 adoption. When technological advantages are tangible and readily perceived, individuals and organisations are more inclined to embrace innovation. Technologies such as Digital Twins (DTs), the Internet of Things (IoT), and AI-enabled systems exhibit high observability, thereby enhancing user confidence and accelerating adoption processes. Nonetheless, barriers such as high implementation costs, inadequate infrastructure, and limited opportunities for experimentation may hinder the visibility of these technologies and slow their diffusion.

In the domain of Intelligent Environments (IEs)—including smart homes, offices, and context-aware systems—observability has been found to significantly influence user acceptance. FakhrHosseini et al. (2024) note that users who can perceive direct, real-time benefits such as energy savings, enhanced security, and improved automation are more likely to adopt intelligent technologies. The study critiques existing technology adoption models for their limited capacity to explain user behaviour in AI-augmented environments, advocating for more comprehensive frameworks that emphasise real-time feedback and demonstrability.

Observability is particularly salient in metal Additive Manufacturing (AM), where Digital Twins facilitate real-time monitoring and predictive analytics. Gunasegaram et al. (2021) demonstrate that the integration of DTs into AM processes enhances visibility by providing virtual replicas of production environments, enabling manufacturers to pre-empt defects, optimise workflows, and reduce material waste. These observable improvements reinforce the perceived value of DTs and foster broader industrial adoption.

Similarly, in the context of digital transformation within the mining sector, Litvinenko (2020) highlights how the digital economy—through AI-driven exploration, real-time data monitoring, and platform-based decision-making—improves transparency and operational efficiency. The case of Russia's mineral industry illustrates how observable benefits such as improved sustainability and faster data processing strengthen organisational confidence in digital adoption. However, persistent cybersecurity risks and infrastructural constraints limit the full realisation of observability in such settings.

The importance of observability is also evident in IoT adoption among small and medium-sized manufacturers in Thailand. Wungcharoen (n.d.), using multiple case studies, finds that trialability and business partner influence significantly enhance the visibility of IoT benefits, making the technology more appealing to SMEs. Nevertheless, concerns regarding security, system compatibility, and high costs continue to obscure the full range of IoT advantages, resulting in slower adoption. The study recommends targeted policy support, demonstration projects, and financial incentives to improve the visibility and accessibility of IoT technologies, particularly in resource-constrained environments.

In summary, observability plays a pivotal role in the successful adoption of digital technologies, particularly within Industry 4.0 domains such as AI, IoT, Digital Twins, and intelligent manufacturing systems. Technologies that provide real-time feedback, measurable efficiency improvements, and visible cost advantages are more likely to be adopted and sustained. To maximise the diffusion of observable technologies, stakeholders must address underlying cost, security, and infrastructure barriers through coordinated policy interventions, strategic investment, and cross-sector collaboration.

2.4.2 Organisational Dimension

For digital transformation and Industry 4.0 technologies to be successfully adopted and implemented, the organisational dimension is essential. Key organisational factors—including digital culture, structural readiness, knowledge acquisition, workforce agility, and managerial adaptation—substantially influence a firm’s capacity to embrace technological innovations. Existing research demonstrates that both SMEs and large enterprises must develop robust digital strategies, foster leadership commitment, and invest in continuous skill development to facilitate effective technology integration and realise long-term business value.

Digital culture and organisational readiness are fundamental enablers of successful technological adoption. Jewapatarakul and Ueasangkomsate (2024), applying the Technology–Organisation–Environment (TOE) framework to Thai food manufacturing SMEs, found that organisational readiness mediates the relationship between digital culture and technology adoption. Firms with strong knowledge-sharing mechanisms, a digitally supportive culture, and allocated resources for employee upskilling demonstrated significantly higher rates of digital integration. This finding underscores the importance of aligning internal processes and capabilities before embarking on full-scale digital transformation initiatives.

Organisational structure also influences the effectiveness of advanced technology adoption. In the context of Indian manufacturing firms, Ghani, Jayabalan and Sugumar (n.d.) report that mechanistic, hierarchical structures can inhibit productivity and impede the assimilation of Advanced Manufacturing Technologies (AMTs). Despite investments in cutting-edge technologies, rigid decision-making hierarchies limit the organisational flexibility required for digital workflows. Transitioning to more organic structures—characterised by decentralised authority, cross-functional collaboration, and adaptive processes—is critical for enhancing both technological adoption and operational performance.

Beyond structural readiness, IT capability and organisational intelligence are key drivers of digital business value. Riera and Iijima (2019), in a study of Japanese SMEs, reveal that firms with robust IT infrastructure and strong knowledge management systems are better positioned to leverage digital investments. Organisational intelligence, encompassing the effective management of internal knowledge and strategic foresight, contributes to superior risk mitigation, agile planning, and sustained learning—all of which are essential for navigating the complexities of digital transformation.

Organisational agility and workforce adaptability are also essential for responding to evolving digital environments. Faisal and Naim (n.d.) examine Saudi Arabian enterprises and find that technological integration, coupled with targeted skill development initiatives, enhances organisational agility. Agile firms respond more effectively to market fluctuations and technological shifts. However, the study also identifies organisational trust as a critical barrier; low trust can inhibit employee engagement with digital processes. As such, cultivating a transparent, trust-based culture is vital for encouraging openness to technological change and fostering successful transformation outcomes.

In summary, the organisational dimension of digital transformation encompasses a wide array of interrelated factors, including digital culture, structural flexibility, IT competence, and workforce agility. Firms that prioritise leadership engagement, organisational readiness, and continuous learning are more likely to derive a competitive advantage from Industry 4.0 technologies. By fostering adaptive organisational structures, nurturing digital mindsets, and investing in workforce development, companies can ensure a smooth transition into the digital era, promoting innovation, resilience, and sustainable business growth.

2.4.2.1 Organisational Scale

In many industrial areas, an organization's size has a significant impact on its readiness, adoption, and implementation of digital transformation. Large corporations typically have greater financial resources, institutional backing, and sophisticated technology frameworks, allowing them to more efficiently implement Industry 4.0 solutions, sustainable production methods, and intricate management systems. Conversely, small and medium-sized firms (SMEs) frequently face structural and financial limitations, aversion to change, and restricted access to regulatory support, which collectively impede their ability to fully adopt digital transformation projects. An increasing volume of research has investigated the impact of organisational size on technological preparedness, innovation implementation, and information and communication technology (ICT) integration.

Empirical research from the Chinese manufacturing sector highlights the importance of business size in preparedness for Industry 4.0 and the adoption of sustainable manufacturing practices. Ali and Johl (2023) illustrate that larger SMEs, owing to their superior access to institutional support and resources, are more adept at investing in sustainable and digital technologies. Utilising institutional theory and the resource-based view (RBV), the research demonstrates that institutional forces positively influence enterprises' tangible and intangible resource reservoirs, facilitating the enhancement of circular economy capabilities. In contrast, smaller enterprises sometimes lack essential financial and technical competence, highlighting the necessity for focused governmental and industry-led support systems.

The magnitude of an organisation similarly influences its ability to accept innovations inside the manufacturing sector. Rehman, Au Yong and Choong (2021) ascertain that larger enterprises gain advantages from decentralised architectures that promote information dissemination and enable the execution of knowledge-centric leadership methods. These companies are more proficient at incorporating AI-driven analytics, electronic human resource management (E-HRM) systems, and workforce innovation tactics. In contrast, smaller organisations frequently function within strict hierarchies and possess limited management depth, which hinders their capacity to adopt and implement emerging technology.

In Malaysia, numerous SMEs recognise the advantages of digital transformation but are reluctant to initiate implementation. Kai Wen and Anisah Atan (2021) indicate that infrastructural deficiencies, cybersecurity threats, and insufficient leadership commitment are significant impediments, based on a survey of 200 SMEs in Perak. Their findings indicate that public sector intervention—via financial incentives, awareness campaigns, and collaborative initiatives—is crucial for closing the gap between digital awareness and operational transformation.

In addition to manufacturing, organisational size also affects ICT adoption in service-oriented sectors like hospitality. Ahmad and Scott (2019) observe that larger hotel chains are more inclined to adopt sophisticated automation solutions, including Property Management Systems (PMS) and AI-driven HR platforms, to enhance service efficiency. Smaller hotels frequently oppose automation in customer-facing roles, such as self-service kiosks, due to apprehensions around service quality and consumer expectations. This underscores the significance of context-specific digital transformation methods that correspond with organisational size and industry standards.

The inequity in digital adoption is also apparent within the Nigerian SME landscape. Irefin et al. (2012) highlight cost, insufficient government assistance, and inadequate ICT infrastructure as principal obstacles to adoption. Although large corporations have progressively invested in Enterprise Resource Planning (ERP) systems and e-commerce platforms, smaller enterprises continue to face financial and technical constraints, hence confirming the relationship between organisational size and digital transformation capacity.

In summary, organisational scale is a crucial structural element that impacts the direction and efficacy of digital transformation initiatives. Large enterprises exhibit comparative advantages in technology implementation owing to their resource richness and structural adaptability, while SMEs encounter enduring obstacles that restrict their digital capabilities. To foster a more inclusive digital transition, governments and industry leaders must boost support mechanisms for SMEs through targeted finance, skill development, and infrastructure improvement, thereby facilitating equal participation in the digital economy.

2.4.2.2 Organisational Readiness

For Industry 4.0 and artificial intelligence (AI) technologies to be implemented successfully in the manufacturing sector, organisational readiness is a crucial component. Readiness denotes an organization's ability to incorporate digital initiatives, allocate technology resources, enhance worker skills, and execute structural changes that facilitate digital transformation. A burgeoning corpus of research indicates that financial acumen, strategic foresight, and governmental assistance are essential facilitators of digital preparedness, but impediments such as substantial investment expenditures, organisational inertia, and insufficient technological proficiency persist in hindering adoption initiatives.

In the Malaysian context, the organisational readiness of SMEs is influenced by managerial, operational, and technological factors. Kee, Cordova and Khin (2023) ascertain that financial capabilities and perceived benefits are the principal determinants affecting SMEs' capacity to embrace Industry 4.0 technology. Notwithstanding these incentives, SMEs sometimes face considerable obstacles, such as resource limitations, deficiencies in digital expertise, and immature ecosystems. The research highlights the imperative of legislative incentives, governmental action, and ecosystem development to promote SME digitisation.

Strategic planning serves as a crucial tool for improving preparedness. Trstenjak and Opetuk (2020) present a readiness factor framework for the deployment of Industry 4.0, emphasising the significance of organised investment and digital process design in mitigating operational risk. Their study promotes the utilisation of predictive analytics and tailored planning models to assist enterprises in the progressive integration of technology, facilitating a more seamless transition into smart manufacturing.

Readiness levels differ among industry sectors and geographic regions. Moreira and Vidor (2024) note that, in their study of metalworking enterprises in Brazil, although these firms recognise the advantages of digital transformation, most are still in the initial phases of implementation. Prevalent obstacles encompass substantial initial expenditure, restricted availability of proficient labour, and cultural opposition to transformation. The report emphasises the necessity for tailored Industry 4.0 maturity models to assist companies in evaluating their digital advancement and developing specific intervention tactics.

In addressing these problems, Pacchini et al. (2019) differentiate between organisational readiness and digital maturity, contending that readiness is essential for achieving maturity. Their research presents an eight-factor assessment model utilised in a Brazilian auto parts firm to gauge readiness for Industry 4.0 implementation. The report indicates that companies must create structured review frameworks and phased plans to prevent financial instability and operational interruptions during digital transitions.

In addition to Industry 4.0, organisational preparedness is crucial for enabling AI implementation. Roszelan and Shahrom (2025) illustrate, through the Technology–Organisation–Environment (TOE) paradigm, that organisational preparedness is the paramount element affecting AI integration in Malaysian manufacturing enterprises. The research highlights leadership support, resource availability, regulatory clarity, and competitive pressures as essential facilitators of AI implementation. Organisations with well-defined digital strategies and dedicated leadership demonstrated a greater capacity to integrate AI-driven decision-making, automation, and intelligent technology into their operational frameworks.

In summary, organisational readiness is a vital facilitator of both Industry 4.0 and AI adoption, determining the success of digital transformation efforts and impacting organisations' long-term competitiveness. Despite ongoing challenges such as financial constraints, workforce skill deficiencies, and internal opposition, organisations that implement strategic planning, utilise systematic evaluation techniques, and cultivate leadership dedication are more likely to attain successful digital integration. Furthermore, collaborative efforts among multiple stakeholders, inclusive governmental policies, and focused workforce development initiatives are crucial for facilitating a sustainable and equitable transition into the digital age.

2.4.2.3 Absorptive Capacity

An essential organisational trait that enhances creative performance, permits digital transformation, and increases competitiveness in high-tech trade is absorptive ability. It signifies an organization’s capacity to recognize, obtain, integrate, and utilize external information to foster innovation and facilitate commercial expansion. Recent research suggests that absorptive ability acts as a mediating factor connecting digitalisation, R&D investment, and collaborative networks to firm performance, especially in manufacturing, service sectors, and small to medium-sized firms (SMEs).

At the macroeconomic level, absorptive ability is crucial for improving national innovation and trade competitiveness. Lam et al. (2023) utilise ARDL and FMOLS econometric models to illustrate that in Malaysia, trade openness, foreign direct investment (FDI), and infrastructure development are essential elements of national absorptive capacity. These characteristics substantially impact high-tech commerce and economic growth by facilitating the integration of external knowledge and advanced technology into local production systems.

In the manufacturing sector, absorptive capacity is closely linked to process and product innovation. A study of 248 Malaysian manufacturing enterprises reveals that both internal R&D initiatives and external sources—such as contractual R&D and collaborative knowledge-sharing—enhance firms' capacity to transform information into concrete breakthroughs. Ramayah et al. (2020) assert that companies possessing strong absorptive capacities are more adept at adapting, innovating, and maintaining competitiveness in fluctuating market conditions.

In the service sector, especially within SMEs, absorptive capability alleviates deficiencies in technical and managerial skills. Anisa Osman and Abas (2016) demonstrate that open innovation approaches, external collaborations, and engagement in knowledge exchange platforms enable SMEs to surmount internal resource limitations. These collaborative networks enhance organisations' capacity to assimilate and leverage external knowledge efficiently, hence augmenting innovation results and organisational learning.

The relationship between digital capability and innovative performance is mediated by absorptive capacity. Kastelli et al. (2024) examined over 1,000 Greek manufacturing enterprises and found that digital transformation initiatives—such as AI integration, big data analytics, and IoT adoption—do not automatically result in innovation unless firms have the necessary absorptive capacities. Organisations with elevated absorptive ability may more effectively process and utilise digital insights, hence optimising the strategic advantages of Industry 4.0 technology.

Moreover, absorptive capacity influences the correlation between digital platforms and the performance of SMEs. Ramdan et al. (2024) demonstrate that in Malaysian SMEs, contextual ambidexterity—defined as the capacity to balance exploration and exploitation—along with the utilisation of digital platforms, results in improved performance when combined with robust absorptive capacities. Companies that strategically invest in digital technologies, engage in continuous learning, and collaborate externally are more proficient at adapting to market fluctuations and maintaining competitive advantage.

In summary, absorptive capacity is a fundamental facilitator of digital innovation, organisational learning, and economic advancement. In high-tech commerce, manufacturing, service industries, and SMEs, companies with enhanced absorptive capacities are more proficient at assimilating external knowledge, optimising digital technologies, and attaining sustainable growth. Policymakers and corporate leaders must emphasise capacity building via R&D incentives, collaborative innovation ecosystems, and digital skills development to guarantee sustainable and inclusive advancement in the digital economy.

2.4.2.4 Top Management Support

Successful acceptance of digital technologies, Industry 4.0 implementation, and overall organisational transformation strongly depend on top management support. Executive leadership is pivotal in formulating digital strategy, promoting innovation, and alleviating opposition to change. Effective leadership aligns digital activities with organisational objectives, improves staff adaptation, and allows companies to manage technological unpredictability. In contrast, ineffective leadership frequently leads to disjointed digital initiatives, employee doubt, and operational inefficiency.

Veeraya et al. (2024) emphasise the crucial roles of digital leadership (DL) and digital culture (DC) in enabling successful digital business transformation (DBT) among Malaysian SMEs. The study underscores the significance of strategic alignment—specifically service-level alignment (SLA)—among leadership vision, operational processes, and digital technology. SLA significantly affected DBT outcomes, whereas other alignment variables, including technology transformation alignment (TTA) and competitive potential alignment (CPA), exerted minimal influence. These findings indicate that leadership must not only support digital efforts but also cultivate an organisational culture that promotes technological flexibility.

Leadership qualities, including emotional intelligence and transformative behaviours, significantly impact the adoption of Industry 4.0.

Van Dun and Kumar (2023) conducted a comparative case study of Dutch manufacturing organisations, revealing that emotionally intelligent leaders who articulate a clear strategic vision enhance employee acceptance of modern technology, including cyber-physical systems and augmented reality. The research finds psychological impediments to transformation, such as fear of job loss and apprehensions over surveillance, and emphasises that clear communication and participatory leadership are crucial for alleviating resistance and cultivating trust.

The importance of senior management support is further demonstrated in the adoption of digital technology by Malaysian SMEs. Lee, Falahat and Sia (2021) establish four strategic drivers of digital adoption—sales, marketing, process improvement, and product development—through numerous case studies of low- and high-tech businesses. Companies exhibiting proactive leadership and well-defined digital strategy showed elevated levels of adoption and integration. Conversely, companies devoid of leadership commitment encountered resource constraints and organisational conservatism, leading to a protracted digital adoption.

The implementation of deep learning technologies in manufacturing is increasingly contingent upon executive endorsement. Chatterjee et al. (2024) demonstrate, through Partial Least Squares Structural Equation Modelling (PLS-SEM) applied to 473 enterprises, that top management support considerably moderates the link between deep learning adoption and firm performance. Leaders who emphasise AI-driven solutions like predictive maintenance, quality assurance, and anomaly detection enhance process efficiency and secure a competitive edge. The absence of executive commitment leads to postponed technology implementation and lost possibilities for digital optimisation.

Omrani et al. (2024) conducted a comprehensive quantitative analysis comprising 15,346 SMEs from both EU and non-EU countries, which underscores the primacy of internal organisational variables over environmental influences in digital transformation. Grounded on the Technology–Organisation–Environment (TOE) framework, the study demonstrates that leadership vision, IT infrastructure, and financial resources have a more significant impact on digital adoption than external factors like regulatory pressure or market rivalry. These findings indicate that SMEs ought to focus on leadership development and internal strategy planning as essential facilitators of digital preparedness and execution.

In summary, executive endorsement is essential for successful digital transformation and the integration of Industry 4.0. Leadership commitment fosters strategy coherence, nurtures a digital culture, and mitigates organisational opposition, consequently augmenting the success of innovation efforts. Companies aiming to expedite digital adoption must engage in leadership development, institutionalise change management methods, and enhance digital literacy throughout all organisational tiers. These endeavours are crucial for attaining sustainable change and preserving competitiveness in the digital economy.

2.4.2.5 Human Resources Support

The successful incorporation of Industry 4.0 technology, all-encompassing digital transformation initiatives, and workforce readiness are all contingent upon the support of human resources (HR). As companies progressively adopt automation, artificial intelligence (AI), and smart manufacturing, HR departments have a crucial role in mitigating skills shortages, managing employee opposition, assuring regulatory compliance, and integrating digital systems. Efficient human resource management (HRM) enhances workforce development and aids in adapting to evolving labour requirements. Nonetheless, obstacles like as an ageing workforce, restricted digital skill pools, and inadequate governmental assistance persist in hindering the complete implementation of Industry 4.0 advantages.

In Malaysia, HR-driven human capital development has been a vital component of the nation's industrial growth initiatives. Al-Huda, Karim and Ahmad (n.d.) analyse Malaysia's First, Second, and Third Industrial Master Plans (IMPs), emphasising employment growth, labour productivity, and educational investment as fundamental determinants of industrial competitiveness. Their findings indicate that measures aimed at job development and skills training have enhanced production efficiency and lowered costs. However, the rapid advancement of Industry 4.0 necessitates a more agile and proactive strategy for workforce development.

The difficulties of human resource management are most pronounced in small and medium-sized organisations (SMEs). Ismail et al. (2019) conducted a study with 100 HR experts from 50 SMEs in Perak, identifying three principal barriers to Industry 4.0 adoption: inadequate skills training, an ageing workforce, and resistance to change. Small and medium-sized enterprises frequently lack the ability to attract and retain technologically proficient staff, thereby hindering the adoption of automation, robots, and data-driven technologies. The study emphasises the necessity for proactive HR policies that focus on ongoing employee development and the enhancement of digital competencies.

Regulatory adaptation constitutes a significant concern. Suppiah (2024), in an extensive analysis of 395 Malaysian SMEs, discovers that a substantial percentage stay at the Industry 3.0 phase, hindered by obsolete skillsets and minimal interaction with developing technology. The study advocates for further governmental action via policy incentives, financial assistance, and organised training initiatives. In the absence of HR-driven regulatory alignment and institutional preparedness, companies may find it challenging to maintain competitiveness in technologically sophisticated markets.

Fauziah et al. (2023) offer additional insights into the industrial industry through interviews with 15 HR managers in Johor. Their findings identify four primary difficulties confronting HR departments: a deficiency of skilled labour, employment instability, the risk of job displacement due to automation, and opposition to technological advancement. The research finds that sustained workforce adaptability relies on ongoing training, employee involvement, and effective human resource planning to alleviate transformation-related apprehensions.

The technological maturity of HRM systems, alongside capability development, also impacts digital transformation outcomes. Kadir Hussein and Hasana Abdullah (2023) examine the implementation of Smart HRM in Malaysian companies and identify insufficient digital infrastructure, poor system integration, and employee mistrust regarding automation as significant obstacles. The study advocates for strategic investments in AI-driven HR tools, cloud-based workforce management systems, and internal training on Smart

HRM applications to enhance operational efficiency and facilitate change management.

In summary, human resource assistance is essential for the successful execution of Industry 4.0. Organisations that engage in worker training, digital infrastructure, and regulatory alignment are more adept at managing the intricacies of automation, AI integration, and digital manufacturing. Cooperative initiatives involving industry leaders, legislators, and educational institutions are crucial for developing flexible, future-oriented HRM systems that guarantee long-term industrial sustainability and equitable growth in the digital era.

2.4.2.6 Managerial Support

A key enabler of Industry 4.0 adoption, digital transformation, and organisational sustainability is managerial support. It includes leadership commitment, strategic decision-making, and the advancement of digital readiness, all of which are crucial for the effective execution of modern manufacturing practices such as smart production systems, Lean 4.0, and digital supply chain integration. Without proactive managerial involvement, companies frequently face significant obstacles, such as technological integration problems, employee resistance, and reduced returns on digital expenditures.

Evidence from Ghana's pharmaceutical sector highlights the significance of top management in enabling Lean 4.0 integration. Grace Tetteh et al. (2024) analyse data from 181 employees and demonstrate that Lean 4.0 implementation enhances operational efficiency; however, this does not necessarily lead to improved corporate performance. The research highlights the necessity of ongoing managerial commitment to consistently align digital initiatives with strategic objectives. Leadership should prioritise employee training, iterative process improvement, and long-term vision setting to ensure the effective integration of Industry 4.0 tools into the organisational framework.

Research on Pakistan’s textile industry examines the influence of transformational leadership on organisational sustainability. Nasir, Sakaria and Sien Yusoff (2022) investigate ISO-certified firms, revealing that managerial support plays a crucial role in enhancing innovation and adaptability. Leaders advocating for the integration of emerging technologies and the reconfiguration of traditional business models exhibit enhanced alignment with Industry 4.0 principles. This strategic adaptability enhances competitive advantage and bolsters long-term organisational resilience in volatile market conditions.

In summary, managerial support is a crucial factor influencing the success of digital transformation and the establishment of sustainable competitive advantage. Effective leadership necessitates more than mere support for technology adoption; it demands active strategic alignment, ongoing investment in workforce development, and the fostering of an innovation-driven organisational culture. Organisations without robust managerial commitment face inadequate technology utilisation, diminished employee engagement, and lost growth opportunities in the fast-changing digital economy.

2.4.3 Environmental Dimension

The environmental aspect of Industry 4.0 and digital transformation is essential for promoting sustainable manufacturing, enhancing resource efficiency, and achieving industrial decarbonisation. The incorporation of advanced technologies, including artificial intelligence (AI), the Internet of Things (IoT), digital twins, and cloud computing, has facilitated industries in decreasing emissions, minimising waste, and optimising energy consumption. Research increasingly demonstrates that the integration of digitalisation with environmental strategy can lead to improved sustainability outcomes, strengthened supply chain resilience, and enhanced compliance with environmental regulations. Challenges such as digital obsolescence, increased energy demands from digital infrastructure, and insufficient environmental policies continue to pose significant barriers to achieving the full sustainability potential of Industry 4.0 technologies.

The integration of circular economy principles with digital technologies represents a promising avenue. Berg (2021) emphasises the significance of digital product passports (DPPs) and digital twins in facilitating real-time monitoring of product life cycles, which improves resource efficiency and aids in waste reduction. These technologies enable closed-loop systems through the enhancement of transparency and traceability. Nevertheless, the study cautions about the unintended consequences linked to digitalisation, such as the rise in electronic waste and elevated energy consumption resulting from the growth of cloud computing infrastructure and data centre operations.

Digitalisation can also improve industrial sustainability through the implementation of intelligent technologies. Demartini, Evans and Tonelli (2019) assert that artificial intelligence, the Internet of Things, and machine learning can enhance energy efficiency, decrease production expenses, and augment manufacturing adaptability. These features facilitate data-driven decision-making and allow for real-time modifications to reduce material waste and enhance process efficiency. However, the authors observe a deficiency of longitudinal and conceptual studies that rigorously assess the enduring environmental effects of digital transformation across many industries.

Javaid et al. (2022) offer additional empirical evidence regarding the influence of Industry 4.0 technology on enhancing environmental sustainability. Their examination of twenty pivotal applications reveals that AI-driven automation, cloud computing, Big Data analytics, and smart energy management markedly improve operational efficiency, minimise waste, and facilitate sustainable supply chain practices. The optimisation of logistics and production processes using these technologies leads to quantifiable decreases in material consumption and carbon emissions.

Case studies from resource-intensive industries underscore the significance of digital-environmental alignment. Guan et al. (2023) assert that in China's rare earth metals business, digital transformation can mitigate resource depletion and industrial emissions when directed by clear environmental goals. Companies that establish explicit environmental objectives—such as reducing emissions and conserving resources—attain more advantageous sustainability results, illustrating that environmental strategy (ES) is crucial in mitigating the ecological effects of digitalisation.

Additional endorsement for digital integration in environmental management is provided by the creation of digital life-cycle frameworks for energy-intensive industries (EIIs). Kaniappan Chinnathai and Alkan (2023) suggest a five-tier paradigm that integrates data collecting, process management, simulation, artificial intelligence, and visualisation to improve energy efficiency and material utilisation. Their methodology combines digital twins and Big Data analytics to enhance sustainability performance, ensure compliance with environmental requirements, and minimise industrial waste via integrated digital resource management.

In summary, the environmental aspect of Industry 4.0 presents significant potential for advancing sustainable industrial practices, especially within manufacturing and resource-intensive industries. To optimise environmental advantages and mitigate negative effects like digital waste and high energy consumption, digital adoption should be deliberately directed by ecological policy, long-term planning, and focused investment in sustainable technology. Organisations that integrate AI-driven efficiency models, real-time monitoring systems, and circular economy strategies into their digital transformation initiatives will be more effectively positioned to attain ecological resilience and industrial competitiveness within the global green economy.

2.4.3.1 Market Demand

The adoption trajectory and progression of smart manufacturing and industry are significantly influenced by market demand. Technologies of the fourth generation. As businesses progressively shift towards automation, digitalisation, and data-driven decision-making, the demand for intelligent manufacturing solutions, such as AI-driven analytics, cyber-physical systems, and smart factories, continues to grow. The rate and extent of adoption depend on factors including technology preparedness, infrastructural availability, financial accessibility, and regulatory support, especially for small and medium-sized firms.

Strategic industry roadmaps have highlighted the influence of competitive pressure, governmental incentives, and pervasive digitalisation trends in expediting market demand for Industry 4.0 technologies. Research examining the computer and electronic product manufacturing sector identified nineteen novel manufacturing technologies, categorised into sensor, integration, intelligent, and response layers. Companies that strategically invest in these technologies get improved market positioning and global competitiveness. The study underscores that effective implementation necessitates a strong digital infrastructure, policy coherence, and industry preparedness (Khairi Ismail, Muhamad and Vija Kumaran, n.d.).

In Malaysia, the increasing market demand for digital transformation faces considerable obstacles, especially among SMEs. Kusiak (2018) indicates that SMEs in Terengganu encounter significant obstacles in adopting Industry 4.0 technology, such as financial limitations, insufficient technical expertise, and regulatory intricacies. Survey results from 102 entrepreneurs reveal that although numerous SMEs recognise the advantages of digitisation, insufficient financial and human resources impede its adoption. The report promotes enhanced digital infrastructure, more governmental assistance, and specialised workforce development programs to encourage SME engagement in smart manufacturing ecosystems.

Wider trends in smart manufacturing highlight the increasing imperative for data-driven operations. Mittal et al. (2018) emphasise that predictive analytics, machine learning, and intelligent industrial networks are essential for sustaining competitiveness. Nonetheless, cybersecurity threats, workforce constraints, and the absence of standardisation persist as considerable impediments. The report advocates for extensive legislative frameworks, improved cybersecurity protocols, and systematic training to facilitate widespread adoption.

Market demand is increasingly oriented towards the creation of adaptive Industry 4.0 maturity models, especially those designed for small and medium-sized enterprises (SMEs). An analysis of current frameworks indicates that the majority are tailored for large corporations and insufficiently accommodate the specific limitations encountered by smaller businesses. Researchers have developed maturity models tailored for SMEs that consider budgetary constraints, deficiencies in digital skills, and strategy misalignment. This signifies an increasing market demand for adaptable Industry 4.0 solutions that accommodate diverse organisational capabilities and sector-specific difficulties.

The emergence of Industry 4.0 and smart manufacturing is propelled by increasing market demand, technology advancements, and policy-driven incentives. Nonetheless, attaining widespread acceptance necessitates tackling enduring obstacles associated with digital infrastructure, human capital, and financial capacity—particularly for small and medium-sized enterprises (SMEs). Future advancements must emphasise the development of flexible, size-sensitive maturity models, focused regulatory changes, and continuous investment in digital competencies to address the changing requirements of the industrial market environment.

2.4.3.2 Competitive Pressure

The implementation of Industry 4.0 and the use of digital technologies are significantly accelerated by competitive pressure. It necessitates that firms sustain market relevance, improve operational efficiency, and attain strategic differentiation within a progressively digitalised economy. Organisations that postpone the adoption of advanced manufacturing technologies, automation systems, and data-driven decision-making tools jeopardise their competitive advantage. Research indicates that both small and medium-sized enterprises (SMEs) and large corporations are influenced by competitive forces, yet their responses differ significantly. Larger firms typically possess a more advantageous position for substantial investments in digital transformation, while SMEs frequently encounter structural, financial, and strategic limitations.

Khin and Hung Kee (2022) develop a digital readiness model within the Malaysian SME context by integrating the Dynamic Capability Theory (DCT), Resource-Based View (RBV), and Unified Theory of Acceptance and Use of Technology (UTAUT). Their findings suggest that market competition, especially from larger firms and multinational corporations (MNCs), significantly pressures SMEs to expedite the adoption of Industry 4.0. Despite acknowledging the strategic importance of digital transformation, many SMEs face constraints due to limited financial resources and insufficient digital literacy, hindering their competitiveness in high-tech environments.

In the European process industry, Blichfeldt & Faullant (2021) observe that firms facing increased competitive pressure tend to adopt more advanced digital technologies, thereby enabling radical innovations in products and services. Product innovation demonstrates a positive correlation with profitability, while service innovation shows comparatively less significant financial returns. This divergence indicates that in low-tech industries, firms primarily adopt digital technologies to enhance efficiency, whereas in high-tech sectors, digitalisation facilitates innovation-driven differentiation and quality improvements.

Albukhitan (2020) emphasises the strategic importance of digital transformation in sustaining competitive positioning. In his examination of manufacturing firms, productivity gains, cost efficiencies, product customisation, enhanced quality control, and improved workplace safety are identified as significant performance outcomes associated with digital adoption. Companies that align digital transformation strategies with their fundamental business goals are more capable of enduring market fluctuations and competitive challenges.

Somohano-Rodriguez and Madrid-Guijarro (2022) note that Industry 4.0 technologies, specifically Big Data, Cloud Computing, and the Internet of Things (IoT), are transforming competitive dynamics within Spain's Cantabrian manufacturing sector. The findings indicate that the adoption of Big Data substantially enhances labour productivity, whereas the effect of Advanced Robotics on sales growth is relatively limited. Larger firms, facing greater competitive pressure, are more likely to invest in these technologies, thereby strengthening their market leadership and enhancing long-term operational efficiency.

In summary, competitive pressure serves as a significant catalyst for digital transformation within various industries. Larger enterprises utilise digital investments to strengthen their market position, whereas SMEs often face challenges in responding due to constraints in resources and capabilities. Ensuring equitable participation in Industry 4.0 ecosystems necessitates addressing barriers associated with digital literacy, enhancing financial support mechanisms for SMEs, and cultivating innovation-driven ecosystems that enable firms of all sizes to adapt and succeed in the digital era.

2.4.3.3 Government Support

Accelerating digital transformation, advancing Industry 4.0 adoption, and fostering policy-driven innovation in the public and private sectors all require government support. Empirical research highlights the significance of financial incentives, strategic policy frameworks, and investments in digital infrastructure for facilitating the transition of businesses, especially small and medium-sized enterprises (SMEs), towards smart manufacturing, sustainable operations, and digital public services. Challenges, including cybersecurity risks, workforce skill shortages, and regulatory fragmentation, must be systematically addressed to ensure the long-term success of these initiatives.

Ratnasingam et al. (2021) identify that in Malaysia’s wood products industry, government-backed incentives and funding schemes play a significant role in influencing firms' decisions to adopt digital technologies, including computer-aided design (CAD), computer numerical control (CNC), and enterprise resource planning (ERP) systems. Businesses that employed these technologies observed enhancements in production efficiency and market competitiveness. In contrast, SMEs lacking financial assistance encountered significant obstacles in the adoption of digital tools, a disparity that was intensified during the COVID-19 pandemic.

The national Industry 4.0 roadmap, known as Industry4WRD, illustrates Malaysia's strategic commitment to enhancing technological adoption via government intervention. Wong (2022) indicates that this initiative seeks to improve the intelligence, resilience, and competitiveness of the manufacturing sector through the promotion of technologies, including artificial intelligence (AI), the Internet of Things (IoT), cloud computing, and robotics. The study highlights that skill shortages and cybersecurity vulnerabilities continue to pose significant challenges, requiring enhanced governmental initiatives in digital education, workforce reskilling, and the establishment of comprehensive cybersecurity frameworks.

Government support for digitalisation is apparent in the public sector, especially regarding sustainable vehicle policy. Che Kasim et al. (2024) examine Malaysia's End-of-Life Vehicle (ELV) policy, advocating for a centralised digital platform to enhance coordination among automotive manufacturers, recycling facilities, and regulatory authorities. Digital tools, including AI and IoT, can enhance the efficiency of ELV deregistration and disposal processes; however, the research highlights persistent challenges related to data security risks and fragmented regulatory environments. This highlights the necessity for increased government intervention to guarantee data integrity, regulatory harmonisation, and technological alignment across sectors.

In summary, government support is essential for facilitating digital transformation and the adoption of Industry 4.0. Policy interventions must prioritise comprehensive financial support mechanisms, the development of national digital infrastructure, targeted workforce development programs, and the enforcement of cybersecurity standards. Addressing these multidimensional factors enables governments to establish a resilient and competitive digital economy that can meet the demands of a rapidly evolving global industrial landscape.

2.4.3.4 Trading Partner Readiness

One of the most significant variables affecting the effective implementation of Industry 4.0, the transformation of digital supply chains, and the integration of IT across companies is the readiness of trading partners. Firms' reliance on interconnected digital ecosystems, facilitated by technologies like the Internet of Things (IoT), blockchain, and cloud-based platforms, means that the technological alignment and digital maturity of trading partners significantly affect operational efficiency, transactional transparency, and competitive advantage. The ability of supply chain stakeholders, especially SMEs and manufacturers, to adapt to digital platforms, comply with interoperability standards, and engage in collaborative innovation is crucial for achieving seamless digital integration.

Khalifa and Davison (2006) examine the adoption of electronic trading systems (ETS) by SMEs in Hong Kong, revealing that external pressures from customers and trading partners frequently drive IT adoption. Although large firms often spearhead digital transformation initiatives, small and medium-sized enterprises must adjust to these changing expectations to maintain their competitive edge. This study combines institutional theory with rational decision-making models, emphasising that trading partner readiness serves as both a facilitator and a limitation within the wider context of digital adoption. Companies that fail to comply with the digital standards established by their partners face the potential of being excluded from efficient supply chain operations.

Readiness of trading partners is critical in IoT-enabled supply chains. Mastos et al. (2020) demonstrate, via a case study on IoT-driven scrap metal management, that interoperable technologies among trading partners enhance waste collection processes, decrease carbon emissions, and increase resource utilisation. The findings emphasise the importance of technology compatibility and real-time data sharing throughout the supply chain to enhance process efficiency and sustainability outcomes.

The integration of blockchain in supply chain management highlights the significance of partner readiness. Korpela, Hallikas and Dahlberg (n.d.) assert that blockchain-based platforms provide improved traceability, trust, and decentralisation for B2B transactions. The successful implementation of blockchain technologies necessitates the establishment of common technical standards and preparedness among all stakeholders. Organisations with obsolete IT systems or restricted digital capabilities frequently encounter significant obstacles in participating in decentralised, real-time networks. The research suggests conducting readiness assessments and engaging in collaborative planning to address these capability gaps.

The Smart and Sustainable Supply Chain Readiness and Maturity (S3RM) model introduced by Akif et al. (n.d.) offers a systematic framework for assessing the preparedness of trading partners. The model includes indicators like technology availability, adaptability, environmental performance, and economic efficiency. A case study in the automotive sector utilising the S3RM framework indicates that companies exhibiting elevated readiness and alignment among trading partners attain enhanced long-term resilience, innovation capacity, and adherence to environmental standards.

In summary, the preparedness of trading partners is essential for the success of supply chains enhanced by Industry 4.0 technologies. Companies must verify that their supply chain partners have compatible digital infrastructures, standardised data protocols, and adequate digital capabilities. Organisations can enhance transparency, efficiency, and collaboration by fostering technological alignment, investing in IT infrastructure, and promoting digital literacy throughout the supply network, thereby securing their competitive position in the digital economy.

2.5 Improved Manufacturing Performance

2.5.1 Improved Time Performance

Time performance is a critical dimension of manufacturing efficiency, directly influencing productivity, cost-effectiveness, and organisational competitiveness. With the emergence of Industry 4.0, the integration of advanced digital technologies, Lean Manufacturing methodologies, and Digital Twin (DT) systems has significantly improved time management across production workflows. These innovations have been instrumental in reducing setup times, cycle durations, and defect rates, thereby accelerating throughput and enhancing overall operational agility. Contemporary research underscores the roles of technical efficiency, process optimisation, and real-time predictive systems in enabling faster, more accurate manufacturing operations.

Ismail (2006), in a study of total factor productivity (TFP) growth in Malaysian manufacturing, identifies technical efficiency as a principal determinant of enhanced time performance. The research indicates that industries such as food processing, wood manufacturing, and chemical production exhibit stronger efficiency gains relative to sectors like textiles, which face slower technological advancement. The findings suggest that sustained improvements in time performance require productivity-centred strategies, rather than relying solely on capital investments.

Lean Manufacturing has also proven effective in optimising time-related metrics in production environments. Ramires-Losano and Estefano Avilés-Solano (2024) examine the implementation of Lean tools—such as Poka Yoke, Single-Minute Exchange of Die (SMED), 5S, Kanban, and A3 reports—in metalworking SMEs. Their study documents a 30.11% reduction in setup times, a 28.00% increase in productivity, and a 23.77% decrease in cycle times. These improvements are attributed to the elimination of non-value-added activities and the streamlining of production processes, which collectively enhance resource utilisation and workflow efficiency.

Digital Twin (DT) systems further augment time performance by integrating real-time virtual models with physical manufacturing processes. Sun et al. (n.d.) investigate the application of multi-task learning (MTL)-enabled DT frameworks in metal tube bending operations. The study reveals that real-time prediction of spring-back and defect formation significantly improves manufacturing accuracy and reduces the need for rework. By synchronising simulation data with live operational feedback, DT systems enable proactive defect management, minimise downtime, and optimise process precision.

In summary, time performance in manufacturing is being redefined through the integration of technical efficiency strategies, Lean Manufacturing techniques, and Digital Twin technologies. Organisations that invest in automation, predictive analytics, and continuous process improvement are well-positioned to achieve sustained reductions in production time and operational waste. These advancements contribute not only to enhanced efficiency but also to long-term competitiveness in the evolving Industry 4.0 landscape.

2.5.2 Improved Cost Performance

The adoption of Industry 4.0 technologies—including digital manufacturing, automation, and smart production systems—has significantly enhanced cost performance across multiple industrial sectors. By leveraging tools such as digital twins, predictive analytics, digital fabrication, and integrated cost modelling, organisations can optimise resource allocation, streamline operational expenditures, and improve production efficiency. Empirical studies examining Malaysia's digital economy, industrial cost optimisation frameworks, and robotics-based construction automation underscore the transformative impact of digitalisation on cost reduction, productivity enhancement, and financial. Nonetheless, the realisation of these cost benefits is contingent upon addressing systemic challenges, including digital integration complexities, infrastructural deficits, and workforce preparedness.

One of the most influential enablers of cost efficiency in manufacturing is the integration of digital design processes with advanced cost modelling systems. Curran et al. (2007) highlight that simulation-driven design, knowledge-based engineering (KBE), and digital twin technologies facilitate life cycle cost reductions while preserving production quality and scalability—particularly in capital-intensive sectors such as aerospace and automotive manufacturing. Similarly, Tierney et al. (2023) introduce the Connected Digital Factory Cost Models (CDFCMs), which integrate predictive analytics and digital twin simulations with financial planning tools. These models enhance forecasting accuracy, optimise capital expenditure, and provide a dynamic decision-making framework that aligns operational activities with cost-performance goals.

At the macroeconomic level, Nee et al. (n.d.) investigate Malaysia's digital transformation and find that Industry 4.0 implementation has positive implications for national productivity, innovation capacity, and cost efficiency.

However, the study also identifies digital infrastructure disparities, skill gaps, and an uneven digital adoption landscape as major obstacles. To harness the full cost-saving potential of digital transformation, the study advocates for targeted government incentives, public-private partnerships, and national upskilling programmes.

Cost performance is further influenced by the concept of cost stickiness in labour-intensive and complex manufacturing environments. Hui, Xie and Chen (2024) show that the adoption of Industry 4.0 technologies—including the Industrial Internet—enables firms to reduce cost stickiness by improving labour flexibility, optimising resource deployment, and minimising operational redundancies. While business complexity remains a barrier, firms that integrate digital cost control frameworks and enterprise-wide transformation strategies report substantial financial gains and improved cost responsiveness.

In the construction industry, robotic automation and digital fabrication technologies offer substantial cost-saving opportunities. Agustí-Juan and Bryan T (2018) compare conventional and robotically fabricated wall systems and find that robotic construction reduces material waste, increases precision, and expedites project completion. Despite these benefits, the study highlights high initial investment costs, digital tool accessibility challenges, and skill shortages as persistent barriers. To overcome these, it recommends workforce training initiatives, financial subsidies, and expanded access to robotic fabrication technologies.

In summary, Industry 4.0 and digital transformation have emerged as key drivers of improved cost performance by enhancing process efficiency, reducing operational waste, and strengthening financial forecasting capabilities. However, maximising these advantages necessitates addressing integration challenges, capital constraints, and skill development needs. Firms that adopt simulation-driven design, advanced cost modelling, and robotic automation will be better positioned to achieve sustainable cost efficiency, bolster competitiveness, and ensure financial resilience in an increasingly digital global economy.

2.5.3 Improved Quality Performance

The integration of Industry 4.0 technologies, Lean Manufacturing methodologies, and Six Sigma practices has significantly enhanced quality performance in manufacturing by reducing defects, optimising material utilisation, and enabling predictive quality management. The convergence of smart factory technologies, digital tools, and real-time analytics plays a critical role in improving product quality, operational transparency, and customer satisfaction. As digital transformation accelerates, manufacturing systems are increasingly characterised by cyber-physical integration and data-driven decision-making that support higher standards of quality control.

Ammar et al. (2021) demonstrate that advanced technologies—such as data analytics, the Internet of Things (IoT), robotics, and additive manufacturing—enable manufacturers to enhance production efficiency by reducing material waste and defects. The study highlights that smart factories equipped with automated quality control systems and real-time monitoring platforms ensure greater product consistency and reduced process variability. Furthermore, the integration of cybersecurity protocols and digital traceability systems contributes to supply chain transparency, improved compliance, and increased customer trust.

Kannan et al. (n.d.) emphasise the evolving role of quality professionals in adapting to the demands of Industry 4.0. A case study involving Malaysian electronics manufacturers reveals that contemporary quality management requires competencies in real-time data analytics, augmented reality (AR) applications, and intelligent quality management systems (QMS). The study advocates for ongoing training, interdisciplinary collaboration, and digital literacy programs as necessary conditions for improving quality assurance and achieving conformity with international manufacturing standards.

Despite these advancements, challenges persist among small and medium-sized enterprises (SMEs), particularly in the context of digital readiness. Ibikunle, Rajemi and Sahari (2024) report that while 86% of Malaysian SMEs have implemented Lean and Six Sigma practices, only 32.5% intend to adopt Industry 4.0 technologies for quality management. The study identifies key barriers, including limited financial resources, a lack of awareness, and insufficient governmental support, which hinder SMEs from executing comprehensive digital quality transformation.

In summary, enhancing quality performance in Industry 4.0 environments requires the integration of digital technologies, Lean Six Sigma methodologies, and sustained workforce development. Firms that invest in intelligent quality management systems, real-time monitoring, and employee upskilling are better positioned to achieve higher process accuracy, reduce non-conformance rates, and strengthen competitive positioning in a rapidly evolving industrial landscape.

2.6 Theoretical Framework

A theoretical framework offers a structured perspective for systematically understanding and managing the complexities of digital transformation in the manufacturing sector. Organisations can successfully handle the complex issues related to the adoption of intelligent systems, artificial intelligence (AI), and automation technologies by incorporating well-known models such as the Technology Acceptance Model (TAM), Business Process Management (BPM), and strategic principles from Industry 4.0. Research consistently indicates that leadership effectiveness, organisational strategy, business process optimisation, and digital infrastructure development are essential factors for successful digital transformation.

Arumugam, Bhaumik and Khazei (2023) conduct a study on Electronics and Electrical (E&E) manufacturing firms, utilising the TAM and DOI frameworks to illustrate that leadership effectiveness, which includes leadership styles and psychological traits, serves a crucial mediating role in technology acceptance. Their findings indicate that proactive and transformational leadership styles enhance organisational readiness for digital adoption, thereby providing a competitive advantage in Industry 4.0 contexts.

Serey et al. (2023) present a strategic framework derived from a systematic review of 160 academic sources, highlighting seven essential strategic objectives for the integration of Industry 4.0. These encompass the transformation of business models, the development of talent, and the interconnection of ecosystems. The framework highlights the necessity of a comprehensive approach that aligns AI-driven automation with organisational goals, workforce development, and the formulation of a long-term digital strategy.

Abdallah, Shehab and Al-Ashaab (2021) offer a four-dimensional framework that includes People, Strategy & Leadership, Business Processes, and Enabling Technologies for further refinement. This model emphasises that digital transformation is an ongoing organisational evolution instead of a singular event. The research emphasises that cultural transformation, leadership adaptation, and ongoing workforce upskilling are critical for achieving long-term digital maturity. Firms that fail to synchronise these four elements often experience implementation failures and restricted digital scalability.

Findings from Sichoongwe (2024), derived from an econometric analysis of 516 South African manufacturing firms, underscore the importance of a systematic adoption strategy. The research indicates that firm size, capital investment, and innovation capacity have a significant impact on the probability of adopting Industry 4.0 technologies. Firms focused on exports that have enhanced access to digital infrastructure exhibit increased adoption rates, indicating that institutional support and regulatory alignment are essential elements in national strategies for digital industrialisation.

In addition to these strategic and structural perspectives, Butt (2020) presents a BPM-based theoretical model specifically designed for digital transformation. This framework identifies and addresses operational gaps frequently observed in digital initiatives, such as fragmentation, insufficient standardisation, and inadequate evaluations of return on investment. The integration of process optimisation, structured change management, and human capital development is advocated to enable a smooth transition to data-driven manufacturing enterprises.

Theoretical frameworks provide critical guidance for manufacturing firms engaged in digital transformation. The synthesis of TAM, DOI, BPM, and Industry 4.0 paradigms establishes a solid framework for aligning technological integration with leadership, strategic intent, and organisational capability. To fully realise the benefits of digitalisation, manufacturers must adopt continuous learning, prioritise workforce development, and integrate transformation initiatives within overarching business objectives. The evolving digital manufacturing landscape necessitates the use of structured theoretical models to enhance productivity, foster innovation, and ensure long-term competitiveness. Figure 2.6 demonstrates the TOE framework for this study.

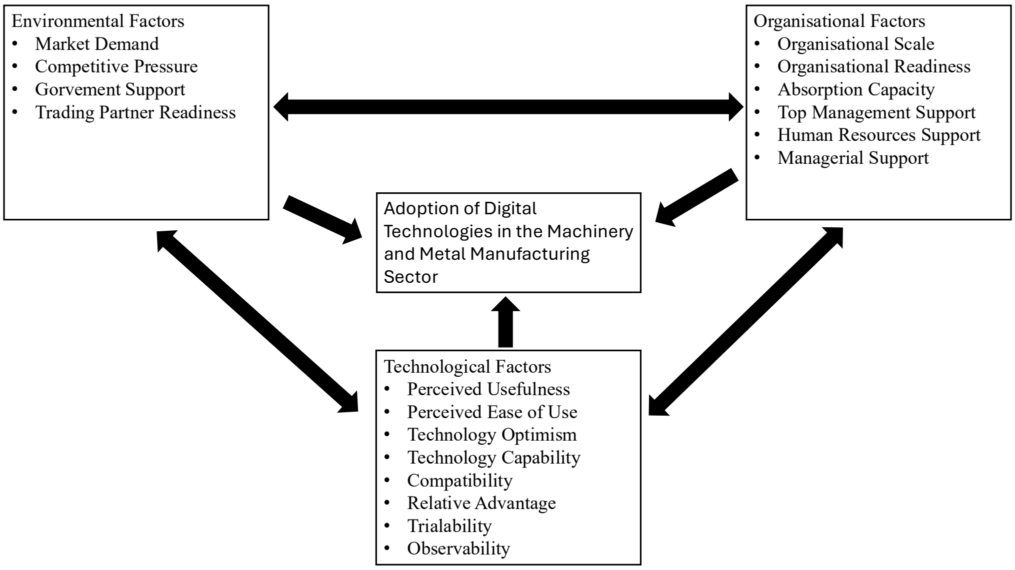

Figure 2.6: TOE Framework for Factors for the Adoption of Digital Technologies in the Machinery and Metal Manufacturing Sector.

2.7 Conclusion

In conclusion, the integration of digital technologies in the machinery and metal manufacturing sector offers significant potential for improving business performance across essential operational areas, such as quality, time efficiency, cost reduction, workplace safety, and environmental sustainability. This study, grounded in the Technology–Organisation–Environment (TOE) framework, highlights the various factors that affect the successful implementation of digital transformation initiatives.

From a technological standpoint, factors such as perceived usefulness, perceived ease of use, and system compatibility are essential determinants of digital tool adoption. Organisational factors, including absorptive capacity, top management support, and human resource readiness, significantly impact a firm's capacity to implement and sustain digital initiatives. Simultaneously, environmental factors such as market demand, competitive pressure, and governmental support significantly influence the landscape of broader adoption.

The implementation of advanced digital technologies, including automation, the Internet of Things (IoT), artificial intelligence (AI), and data analytics, facilitates real-time monitoring, predictive maintenance, and process optimisation. These capabilities lead to decreased operational inefficiencies, improved decision-making, and greater responsiveness to changing market conditions. They enhance the competitiveness and resilience of manufacturing firms in a progressively digital global economy.

This research presents actionable insights for manufacturing executives, policymakers, and industry stakeholders seeking to enhance digital transformation in the sector. Investments in digital infrastructure, leadership development, and workforce upskilling are essential for optimising the return on digital technologies. The effective integration of Industry 4.0 solutions will enhance operational performance, promote innovation, and facilitate long-term industrial growth and environmental sustainability.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This chapter outlines the methodology used for the study, highlighting the techniques adopted for data gathering and analysis. The essay begins by differentiating between quantitative and qualitative research approaches, providing a rationale for the selected design. The chapter outlines the research objectives, literature review process, data collection instruments, and criteria for participant selection. It proceeds by delineating the statistical approaches employed and validating their relevance to the research objectives and overall analytical framework.

3.2 Quantitative versus Qualitative Research

Quantitative and qualitative research are two primary paradigms in empirical inquiry, each providing unique epistemological and methodological foundations. Quantitative research is grounded in the positivist paradigm and focuses on the measurement and analysis of causal relationships between variables. It utilises organised instruments such as surveys, questionnaires, and statistical modelling to produce numerical data that may be generalised across populations. This methodology allows researchers to evaluate hypotheses, corroborate ideas, and provide reproducible outcomes. Conversely, qualitative research originates from the interpretivist paradigm, prioritising the investigation of intricate phenomena via comprehensive, contextual, and subjective data. Techniques such as comprehensive interviews, participant observations, and thematic analysis are employed to elucidate the lived experiences, viewpoints, and interpretations formed by individuals within certain social or cultural frameworks. In contrast to its quantitative cousin, qualitative research does not pursue generalisability; instead, it seeks a profound comprehension of specific cases or contexts. Each method possesses intrinsic benefits and weaknesses: quantitative approaches deliver precision and scalability but may neglect the complexities of human experience, whereas qualitative approaches offer depth and complexity but may be deficient in statistical power and objectivity.

Researchers like Creswell (2014) contend that the techniques are complementary rather than antagonistic, and the selection between them should be determined by the research objectives, the nature of the inquiry, and the required data type. Quantitative research functions as a methodology for assessing objective theories. Qualitative research is used to explore and understand the meanings that individuals or groups assign to a social or human phenomenon (Weyant, 2022). Current research increasingly prioritises mixed-methods techniques that combine both paradigms to capitalise on their strengths and offer a more thorough knowledge of intricate situations.

3.3 Survey as the Research Method

To achieve the above goals, this study uses the survey technique as its main research strategy, emphasising the value of methodically collecting quantifiable and generalisable data. The adoption of a survey methodology is warranted due to its capacity to gather a broad spectrum of data from a large and varied respondent pool, resulting in statistically credible results. The principal benefit of survey research is its systematic format, which guarantees consistency in data collection and enables objective measurement of variables via standardised tools like questionnaires. These instruments mitigate researcher bias and augment the credibility and reproducibility of the results. Moreover, the survey methodology allows the researcher to interact with a significant, representative sample, hence enhancing the validity and generalisability of the findings. This study's systematic methodology incorporated a meticulously devised sampling technique to guarantee that the surveyed population accurately represents the wider demographic and industrial context of the machinery and metal manufacturing industry in Klang Valley, Malaysia. Surveys have significant practical benefits, notably in efficiency, scalability, and cost-effectiveness, particularly when conducted via digital platforms. Surveys may face obstacles, including non-response bias or limitations in obtaining nuanced insights; nevertheless, these issues can be alleviated by meticulous questionnaire design and pilot testing. Qualitative approaches provide in-depth, contextual data but lack the scalability and generalisability essential for studies demanding extensive empirical validation. Qualitative insights can enrich understanding when combined with surveys in a mixed-methods approach. The survey approach offers a dependable and effective means for analysing trends and behavioural patterns associated with digital technology adoption, hence reinforcing the primary research objectives through solid, evidence-based results (Bryman, 2016).

3.4 Research Process

To assure the validity, reliability, and applicability of the findings, this study on the use of digital technology in the machinery and metal manufacturing sector in Klang Valley, Malaysia, used a methodical and rigorous research procedure. The process began with the establishment of explicit research objectives to examine the technological, organisational, and environmental aspects affecting digital adoption in the sector. A comprehensive literature analysis was subsequently performed to situate the study within current academic discourse, utilising pertinent theories such as the Technology-Organisation-Environment (TOE) framework, which facilitated the identification of independent and dependent variables. This foundational phase developed the theoretical and conceptual frameworks for the investigation.

Subsequent to the review, a quantitative study approach was chosen, as it facilitated the acquisition of standardised, generalisable data from a diverse group of stakeholders, encompassing plant owners, supervisors, and technical staff. A survey tool was created, featuring closed-ended questions consistent with the study's theoretical framework. Before distribution, the questionnaire underwent pre-testing to verify clarity and internal consistency. The sample strategy emphasised representativeness and incorporated both random and stratified sampling methods to reflect the sector's variety.

Data collection was executed via a combination of online questionnaires and in-person distribution, enhancing participation and assuring representation across diverse organisational tiers. Subsequently, the dataset underwent comprehensive quantitative analysis, incorporating multiple regression and reliability assessments utilising statistical software. The concluding portion of the process entailed synthesising information, interpreting statistical outcomes, and developing evidence-based recommendations to guide industry practices and policy measures. This structured procedure embodies the systematic model proposed by Saunders, Lewis and Thornhill (2023), highlighting the coherence across study design, data gathering, and analytical methodologies.

3.4.1 Literature Review

A literature review is a thorough and critical analysis of existing research pertaining to a particular subject. This study entails the systematic identification, retrieval, evaluation, and synthesis of academic sources pertinent to the factors affecting the use of digital technologies in the machinery and metal production industry in Klang Valley, Malaysia. This approach entails evaluating peer-reviewed journal articles, academic books, industry reports, and other pertinent resources that offer insights into the technological, organisational, and environmental aspects of technology adoption within the sector. The literature review seeks to elucidate established findings, techniques, theoretical models, and conceptual frameworks through the critical analysis of these sources. This comprehensive research enhances the comprehension of the existing knowledge regarding digital technology adoption in the Malaysian industrial sector. Furthermore, it uncovers research deficiencies, inconsistencies, and domains that are inadequately examined, thereby pinpointing prospects for additional investigation. The literature evaluation fundamentally establishes a crucial basis for the formulation of novel views, research enquiries, and theoretical contributions that can direct subsequent studies on the digital transformation of the machinery and metal manufacturing sector in Klang Valley.

3.4.1.1 Purposes of Literature Review

The use of a questionnaire as a study method serves several important functions when analysing the factors impacting the implementation of digital technologies in the machinery and metal production sector in Klang Valley, Malaysia. Electronic questionnaires provide an economical and efficient method for accessing a broad and varied respondent pool, allowing researchers to get data without substantial financial expenditure. Employing standardised questions guarantees uniformity and comparability of responses, therefore improving the dependability of the results. Furthermore, questionnaires can be swiftly disseminated to a wide demographic, facilitating the acquisition of significant data in a comparatively brief timeframe. The anonymity provided by online surveys encourages participants to share candid responses, particularly regarding sensitive issues related to the adoption of digital technology. Furthermore, the information gathered through surveys can be readily quantified and subjected to statistical analysis, providing valuable insights into the factors that facilitate or hinder the adoption process. Due to their effectiveness, adaptability, and capacity to yield statistically generalisable outcomes, questionnaires are esteemed as excellent tools in technology adoption research. Consequently, they are especially aligned with the aims and methodological needs of this study.

3.4.1.2 Literature Review Development

In order to comprehend the current understanding of the elements impacting the adoption of digital technologies in the machinery and metal production industry in Klang Valley, Malaysia, it is imperative that a literature review be developed. The first step in the process is defining the scope of the review, which includes formulating research questions or objectives and clear inclusion and exclusion standards for choosing relevant papers. After that, a comprehensive analysis of scholarly content is carried out using specialised databases and search engines, using particular keywords and filters relevant to the topic of industrial sector use of digital technology.

This is followed by a rigorous screening and selection process to ensure that only studies aligned with the research focus and offering valuable insights are included. The selected literature is critically analysed, with key findings, research methodologies, theoretical frameworks, and conclusions systematically extracted and summarised. This phase also involves identifying recurring themes, inconsistencies, and gaps in the literature, as well as assessing the credibility and relevance of the selected studies.

The literature is organised thematically to ensure a logical progression of ideas and to facilitate the synthesis of diverse findings. This structure supports the identification of broader implications and enables connections to be drawn between existing research and the current study. While careful editing improves coherence and clarity, proper citation to any material guarantees academic honesty. The literature review provides a solid foundation for the research by situating it within the broader scholarly context and underscoring its significance in advancing understanding of digital technology adoption in Malaysia's machinery and metal manufacturing sector.

3.4.2 Questionnaire

A questionnaire is a structured research instrument comprising a series of carefully formulated questions designed to collect data from a targeted group of respondents. Gathering pertinent data on the elements impacting the adoption of digital technologies in the Klang Valley, Malaysian machinery and metal production industry is the purpose of this study. The questionnaire incorporates a variety of question formats—such as multiple-choice items, Likert scales, and open-ended responses—each tailored to elicit specific insights into technological, organisational, and environmental factors. Distribution channels may include online platforms, email, or face-to-face delivery to facilitate broad participation from key stakeholders within the sector.

This method is particularly effective for collecting quantitative data from a large sample, offering measurable insights into the attitudes, behaviours, and perceptions of industry professionals regarding digital technology adoption. Designing an effective questionnaire for this research involves careful consideration of wording, structure, sequence, and clarity to minimise bias and enhance the accuracy, validity, and reliability of the data collected. Attention to these design principles ensures that the responses accurately reflect the realities of technology adoption and provide a robust basis for subsequent statistical analysis. As a vital instrument for gathering data, the questionnaire supports the quantitative technique of the study and adds to the overall validity and rigour of the investigation.

3.4.2.1 Purposes of Questionnaire

There are a number of benefits to using a questionnaire in this study, especially when looking at the variables affecting the uptake of digital technologies in the Klang Valley, Malaysia, machinery and metal manufacturing industry. When administered electronically, questionnaires offer a cost-effective and efficient means of collecting data from a wide and diverse pool of participants, enabling broad representation without incurring substantial expenses. The structured format of the questions promotes consistency across responses, thereby enhancing the reliability and comparability of the data. Additionally, this approach makes it possible to distribute surveys to big groups of people quickly, which speeds up the process of gathering a lot of data in a short amount of time.

Furthermore, the anonymity afforded by electronic questionnaires encourages greater openness and honesty, which is particularly valuable when investigating sensitive issues such as technological adoption. The data gathered through this approach can be easily quantified and subjected to statistical analysis, providing clear, evidence-based insights into the primary factors that drive or hinder digital technology adoption within the sector. Overall, the versatility, scalability, and methodological robustness of questionnaires make them an essential tool for capturing the complex dynamics of digital transformation in the machinery and metal manufacturing industry in Klang Valley.

3.4.2.2 Selection of Questionnaire Respondents

Practitioners working in the Klang Valley, Malaysia, machinery and metal manufacturing industry who are either or are in some way involved in manufacturing activities are the study's target respondents. These individuals represent a diverse range of professional backgrounds, encompassing various business affiliations, educational qualifications, age groups, and levels of industry experience. The sampling strategy is designed to capture a broad spectrum of perspectives, thereby enabling a more comprehensive understanding of the factors influencing the adoption of digital technologies within the sector.

3.4.2.3 Questionnaire Development

The questionnaire was created following a comprehensive analysis of current literature on Industry 4.0, digital transformation, and manufacturing performance, assuring conformity with recognised theoretical frameworks such as the Technology–Organisation–Environment (TOE) model. Items were modified and enhanced using validated instruments employed in previous studies to assess constructs like technology preparedness, organisational competence, environmental effects, and performance outcomes. The questionnaire utilised a five-point Likert scale to consistently capture respondents' perceptions. Efforts were made to guarantee clarity, relevancy, and logical coherence of the items. The tool was designed to enable precise data collection across various sizes of manufacturing firms.

3.4.2.4 Questionnaire Administration

The questionnaire administration for this study was carefully created to ensure the collection of accurate and reliable data regarding the use of digital technologies in the machinery and metal production business. A well-structured and user-friendly questionnaire was developed, addressing key factors influencing the digital adoption process within the sector.

Selected participants were given access to the completed questionnaire through a safe and user-friendly online survey platform. Google Forms, an automated survey tool, was employed to facilitate efficient distribution through a shareable link. Email and social media sites like Facebook, Instagram, and WhatsApp were among the many ways the survey link was shared in order to reach the intended respondents. To guarantee that participants understood the goals of the study, the confidentiality of their answers, and the correct methods for filling out the survey, clear instructions were given.

To improve response rates, follow-up reminders and incentives were incorporated into the distribution strategy. The date and context of the survey introduction were also carefully considered in order to reduce the possibility of bias and promote sincere, deliberate participation. This method ensured a robust and comprehensive data collection process, thereby enhancing the overall quality and validity of the study’s findings.

3.5 Data Analysis Procedures

Data analysis procedures comprise a set of tools and techniques used to examine, interpret, and present data in a structured and meaningful manner. These methods aim to transform raw data into actionable insights that support evidence-based decision-making. By systematically analysing the collected data, these procedures enable the identification of underlying patterns, relationships, and trends. Following the distribution of the questionnaire and the collection of responses, the data will be subjected to a series of analytical processes.

Effective data analysis is essential to ensure the accurate interpretation of findings and to support the derivation of valid, reliable conclusions. To enable meaningful interpretation, this procedure entails organising, summarising, tabulating, and transforming data. The following are the main analytical methods to be used in this study:

1. Mean Ranking
2. Factor Analysis

These analyses will be conducted using the Statistical Package for the Social Sciences (SPSS), a robust statistical software developed by IBM. SPSS offers a comprehensive suite of tools for quantitative analysis, including both linear and non-linear modelling capabilities, as well as advanced data management and visualisation functions. The software is particularly well-suited for processing and analysing data collected from respondents in the machinery and metal manufacturing sector in Klang Valley. Its use in this study ensures methodological rigour and enhances the accuracy, reliability, and interpretability of the research findings.

3.5.1 Mean Ranking

An important analytical technique in this study, which aims to assess the relative significance of different drivers impacting the adoption of digital technologies within the machinery and metal manufacturing industry in Klang Valley, Malaysia, is the mean ranking of adoption factors. This method involves calculating the average (mean) score assigned to each factor based on participant responses. The resulting mean values allow for the factors to be ranked according to their perceived significance, where higher mean scores indicate more influential factors, and lower scores suggest less critical ones.

In this study, respondents were asked to rate a range of factors associated with digital technology adoption, including technological capability, market demand, organisational readiness, and external pressures. By averaging the responses for each item, the analysis offers insights into which factors are most impactful in shaping the decisions of industry practitioners.

The mean ranking technique is particularly effective for simplifying and synthesising multifaceted survey data into a format that is both accessible and analytically valuable. It enables the direct comparison of adoption factors, supporting a clearer understanding of their relative weight. This approach is especially useful for informing policymakers, industry leaders, and practitioners about priority areas for strategic intervention. Ultimately, the mean ranking method contributes to the practical utility of the study by highlighting which factors organisations should emphasise to facilitate the successful adoption and integration of digital.

3.5.2 Factor Analysis

This study used factor analysis, a statistical technique, to find underlying patterns or dimensions among the many factors impacting the adoption of digital technologies in the Klang Valley, Malaysia, machinery and metal manufacturing sector. The primary objective of factor analysis is to reduce data complexity by grouping interrelated variables into broader constructs, commonly referred to as factors or dimensions. This enables researchers to detect which variables are most strongly correlated and how they collectively influence the adoption process.

In this study, factor analysis is applied to responses gathered through the questionnaire, focusing on adoption-related elements such as technological readiness, organisational culture, government support, market demand, and competitive pressure. This method allows for the identification of variables that tend to co-occur and exert a similar influence on digital technology adoption.

By consolidating related variables into coherent groups, factor analysis offers a more structured understanding of the key drivers behind technology adoption and their interrelationships. It not only simplifies complex datasets but also reveals latent structures and associations that may not be immediately evident through basic descriptive analysis. This deeper insight helps stakeholders, such as industry leaders and policymakers, focus on the most influential dimensions affecting adoption. Factor analysis strengthens the analytical depth of the research and provides a nuanced understanding of how various elements interact to either facilitate or hinder the adoption of digital technologies in the sector.

3.6 Research Ethics

Research ethics emphasises the importance of conducting the study with integrity, transparency, and respect for all participants in the deployment of digital technologies in the machinery and metal production sectors. It is crucial to protect respondents' privacy and confidentiality, especially when dealing with sensitive data pertaining to proprietary technologies or commercial processes. All participants must provide informed consent, which includes a detailed description of the study's goals and procedures, as well as the opportunity to withdraw at any moment during the research process.

Moreover, the research must be conducted impartially, with any potential conflicts of interest disclosed to prevent bias and uphold the validity of the results. The collection and analysis of data must adhere to rigorous standards of accuracy, reliability, and objectivity to ensure the production of credible findings. It is also important to consider the broader ethical implications of digital technology adoption in the sector, including its potential to contribute to responsible innovation, data stewardship, and sustainable industrial practices.

Adherence to these ethical principles not only safeguards the rights and dignity of participants but also reinforces the credibility, transparency, and scholarly value of the research. By upholding high ethical standards, this study contributes meaningfully to the academic discourse on digital transformation in manufacturing while maintaining professional and social responsibility.

3.7 Conclusion

This study employed a quantitative research technique to examine the factors affecting the use of digital technologies in the machinery and metal production sector in Klang Valley, Malaysia. The research was carefully structured to achieve the goal of identifying and assessing the primary factors influencing technology adoption in this particular industrial setting. Data were gathered using a standardised questionnaire survey distributed to industry professionals.

To analyse the responses, mean ranking and factor analysis were employed as core analytical techniques, providing a systematic framework for uncovering patterns, trends, and critical variables related to digital technology adoption. These methods enabled a comprehensive and objective examination of the factors that either facilitate or impede the adoption process. The findings offer valuable insights into sector-specific challenges and opportunities, thereby contributing to a deeper understanding of digital transformation within Malaysia’s manufacturing landscape.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter utilises the Statistical Package for the Social Sciences (SPSS) to analyse survey data. It offers a succinct summary of the respondents' demographics and the results related to the use of digital technology in the machinery and metal production industry in the Klang Valley, Malaysia. A quantitative analysis will be undertaken to ascertain the primary factors affecting the sector's adoption of digital technologies. This will include mean ranking, factor analysis, the Kaiser-Meyer-Olkin test, Bartlett's test, total variance explained, and a rotated factor matrix.

4.2 Pretesting the Questionnaire

The questionnaire was pretested with nine participants, comprising three representatives from small, medium, and large manufacturing businesses, to ensure clarity, relevance, and applicability across different organisational scales. Participants assessed the survey items for linguistic precision, content validity, and suitable responses. Feedback indicated that the questionnaire was systematically structured and unambiguous, with no redundancies identified. Therefore, no alterations were necessary. The pretest confirmed the instrument's appropriateness for extensive data collection, validating its effectiveness in capturing essential characteristics across different company sizes within the manufacturing sector.

4.3 Background of Respondents

A total of 55 completed questionnaires were gathered through a strategic blend of convenience and snowball sampling methods. Participants were contacted via email invitations and social media channels, such as WhatsApp. Out of 70 distributed questionnaires, this represents a response rate of 78.6%. The sample comprised participants from organisations of varying sizes—large, medium, and small—within the machinery and metal manufacturing sector. The demographic profile of the respondents was captured in Section A of the questionnaire, detailing aspects such as company size, job position, years of experience, and experience using digital technologies in the machinery and metal manufacturing sector, as illustrated in Table 4.3.

Table 4.3: Total of Demographic of 55 Respondents.

Demographic of Respondents				
Items	Frequency	Percent (%)	Valid Percent (%)	Cumulative Percent (%)
Organization size				
Small	21	38.2	38.2	38.2
Medium	17	30.9	30.9	69.1
Large	17	30.9	30.9	100
	55	100	100	
Position in organization				
Upper management	17	30.9	30.9	30.9
Middle management	20	36.4	36.4	67.3
Lower management	18	32.7	32.7	100
	55	100	100	
Years of work experience				
Less than 5 years	25	45.5	45.5	45.5
5 years and above	30	54.5	54.5	100
	55	100	100	
Experience using digital technologies in the machinery and metal manufacturing sector				
Yes	29	52.7	52.7	52.7
No	26	47.3	47.3	100
	55	100	100	

Table 4.3 shows that 38.2% of respondents were from small organisations, while 30.9% were associated with medium and large organisations, respectively. Of the participants, 30.9% held upper management positions, 36.4% were in middle management, and 32.7% occupied lower management roles. Of the respondents, 45.5% reported having less than 5 years of industry experience, whereas 54.5% indicated 5 years or more. In conclusion, 52.7% of respondents reported having experience with digital technologies, whereas 47.3% indicated a lack of such experience. The data reveals a comprehensive distribution of insights across different organisational levels and experience categories.

4.4 Mean Ranking of the Factors for the Adoption of Digital Technologies in the Machinery and Metal Manufacturing Sector

Respondents were asked to evaluate the significance of different factors affecting the adoption of digital technologies in the machinery and metal manufacturing sector to gain deeper insights. Descriptive statistical analysis was utilised to rank these factors according to their mean scores, as shown in Table 4.4. A mean value under 3.0 is deemed insignificant, as it is below the neutral threshold on the Likert scale. Standard deviation values below 1.0 were interpreted as indicative of a strong consensus among respondents. When multiple factors exhibited the same mean values, the factor with the lower standard deviation received a higher rank, thereby facilitating a more rigorous and equitable assessment of significance (Asante, Kissi and Badu, 2018).

Table 4.4: Mean Ranking for Factors in the Machinery and Metal Manufacturing.

Descriptive Statistics				
Factors	N	Mean	Std. Deviation	Ranking
F01 Perceived Usefulness	55	4.2909	0.71162	1
F12 Top Management Support	55	4.2545	0.75076	2
F05 Compatibility	55	4.2182	0.68559	3
F15 Market Demand	55	4.2000	0.75523	4
F16 Competitive Pressure	55	4.2000	0.91084	5
F06 Relative Advantage	55	4.1818	0.81856	6
F04 Technological Capability	55	4.1636	0.76409	7
F14 Managerial Support	55	4.1091	0.73718	8
F10 Organisational Readiness	55	4.0727	0.71633	9
F03 Technology Optimism	55	4.0182	0.68017	10
F08 Observability	55	4.0182	0.73260	11
F07 Trialability	55	3.9818	0.75745	12
F02 Perceived Ease Of Use	55	3.9091	0.86651	13
F13 Human Resources	55	3.8909	0.85359	14
F11 Absorptive Capacity	55	3.8727	0.72148	15

Table 4.4 (Continued)

F18 Trading Partner Readiness	55	3.8727	0.86184	16
F09 Organisational Scale	55	3.8545	0.84805	17
F17 Government Support	55	3.6727	1.01934	18
Valid N (listwise)	55			

The five major factors affecting the use of digital technology in the machinery and metal production industry are: F01) Perceived Usefulness, F12) Top Management Support, F05) Compatibility, F15) Market Demand, and F16) Competitive Pressure. The mean score for Perceived Usefulness was 4.2909, with a standard deviation of 0.71162, indicating its significant importance and strong consensus among respondents. F12) Top Management Support demonstrated a mean of 4.2545, with a standard deviation of 0.75076, ranking as the second highest. F05) Compatibility ranked 3rd with mean 4.2182 and the lowest standard deviation among top five at 0.68559, suggesting a consistent agreement regarding its importance. Market Demand was ranked 4th, exhibiting a mean of 4.2000 and a standard deviation of 0.75523. Although F16) Competitive Pressure shares a mean score of 4.2000 with F15), its higher standard deviation of 0.91084 resulted in a 5th place ranking based on the prioritisation criterion.

4.5 Factor Analysis of the Factors for the Adoption of Digital Technologies in the Machinery and Metal Manufacturing Sector

This section delineates the outcomes of the factor analysis performed to ascertain the fundamental structure of the factors affecting the adoption of digital technologies in the machinery and metal production industry. Factor analysis is utilised to condense several variables into a more manageable set of significant components, enhancing comprehension of the interactions among observable variables. This analysis incorporates the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity to evaluate the dataset's appropriateness for factor analysis. Thereafter, the overall variance elucidated by the extracted components and the rotated component matrix is analysed to evaluate the factor structure.

4.5.1 Kaiser-Meyer-Olkin and Bartlett's Test of the Adoption Factors

Table 4.5.1 displays the findings of the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity. The KMO value evaluates the extent to which variance among variables can be attributed to underlying factors. A KMO value exceeding 0.5 suggests that the variables possess adequate common variance, making them appropriate for factor analysis. The KMO value in this study is 0.874, significantly exceeding the acceptable threshold, thereby indicating excellent sampling adequacy. Bartlett's Test of Sphericity produces a Chi-Square value of 603.112, with 153 degrees of freedom and a significance level of 0.000, indicating that the correlation matrix is not an identity matrix. The results confirm the suitability of the dataset for factor analysis.

Table 4.5.1: Kaiser-Meyer-Olkin and Bartlett's Test for Factors in the Machinery and Metal Manufacturing.

KMO and Bartlett's Test	
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.	.874
Bartlett's Test of Sphericity	
Approx. Chi-Square	603.112
df	153
Sig.	.000

To verify the validity of the obtained data, it is important to evaluate the quality and appropriateness of the dataset. The Kaiser-Meyer-Olkin (KMO) measure of sample adequacy and Bartlett's test of sphericity were performed for this aim. The KMO test assesses the fraction of variance among variables that may represent common variance, with values approaching 1.0 signifying more cohesive correlation patterns and enhanced reliability for component analysis. A KMO value exceeding 0.5 is deemed acceptable. The KMO score in this study was 0.874, signifying exceptional sample adequacy. Furthermore, Bartlett's test of sphericity yielded a chi-square value of 603.112 with 153 degrees of freedom and a significance level of 0.000, affirming that the correlation matrix is not an identity matrix. This outcome indicates that the dataset possesses adequate intercorrelations for factor analysis, hence confirming its suitability.

4.5.2 Total Variance Explained of the Adoption Factors

This study examined the eigenvalues of each component to determine the optimal number of components to retain in Principal Component Analysis (PCA). Per the latent root criterion, components with eigenvalues exceeding 1.0 are deemed significant and retained for interpretation. Table 4.5.2 indicates that three components satisfied this criterion. Component 1 exhibits an eigenvalue of 8.904, representing 49.464% of the total variance. Component 2 accounts for 7.616% of the variance, with an eigenvalue of 1.371. In contrast, Component 3 has an eigenvalue of 1.062, contributing 5.898% to the variance. The cumulative variance explained by these three components is 62.978% more than 60%, demonstrating that they collectively account for a significant portion of the variability in the data, making them appropriate for further analysis.

Table 4.5.2: Total Variance for Factors in the Machinery and Metal Manufacturing.

Total Variance Explained			
Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	8.904	49.464	49.464
2	1.371	7.616	57.080
3	1.062	5.898	62.978

4.5.3 Rotated Component Matrix of the Adoption Factors

The factors impacting the adoption of digital technology in the machinery and metal production industry are shown in the rotating component matrix in Table 4.5.3. Component 1 primarily includes technological factors, including compatibility, relative advantage, and perceived usefulness, as well as two critical organisational factors: absorptive capacity and organisational readiness. This grouping underscores a significant focus on the perceived technological value and the internal readiness of firms. Component 2 illustrates the interplay between organisational and environmental factors, suggesting that internal support mechanisms and external pressures collectively impact adoption decisions. Component 3, which includes F16) competitive pressure and F09) organisational scale, illustrates the structural and market-driven forces that influence digital transformation. The component groupings highlight the interconnected influence of technological capabilities, organisational readiness, and environmental dynamics on the adoption of Industry 4.0 technologies.

Table 4.5.3: Rotated Component Matrix for Factors in the Machinery and Metal Manufacturing.

Component Matrix[a]			
	Component		
	1	2	3
F05 Compatibility	0.808		
F06 Relative Advantage	0.755		0.374
F04 Technological Capability	0.714		0.451
F07 Trialability	0.692		
F01 Perceived Usefulness	0.648	0.311	0.443
F11 Absorptive Capacity	0.618	0.564	
F10 Organisational Readiness	0.614	0.344	0.492
F08 Observability	0.514	0.372	0.338
F02 Perceived Ease Of Use	0.451	0.403	0.363
F03 Technology Optimism	0.429		0.397
F17 Government Support		0.799	
F14 Managerial Support	0.337	0.724	
F13 Human Resources Support	0.361	0.651	
F18 Trading Partner Readiness		0.647	0.48
F12 Top Management Support	0.531	0.637	
F15 Market Demand	0.368	0.389	0.355
F16 Competitive Pressure			0.789
F09 Organisational Scale		0.341	0.633

The rotated component matrix analysis confirms the presence of three distinct underlying dimensions that influence the adoption of digital technologies in the machinery and metal manufacturing sector. These 3 components represent the core thematic areas derived from the factor loadings. The clustering of variables within these components indicates that adoption decisions are not solely based on the perceived advantages of technology but are also significantly influenced by organisational support systems and external competitive forces. This classification provides a clear structure for understanding the multidimensional nature of digital adoption and forms a strong basis for developing targeted strategic interventions to facilitate successful implementation.

An Oblimin rotation method was employed, as this technique is appropriate for situations where the extracted components are anticipated to be correlated, a premise supported by previous statistical testing. The components were designated according to the predominant factor loadings identified within each group. Component 1 encompasses factors including compatibility, relative advantage, technological capability, and perceived usefulness, which collectively indicate the alignment of digital technologies with existing systems and their operational benefits. This component is designated as "Strategic Innovation Readiness". Component 2 includes government support, managerial support, human resources support, and trading partner readiness, emphasising the importance of institutional and organisational support mechanisms; thus, it is referred to as "Strategic Institutional Support". Component 3 encompasses competitive pressure and organisational scale, indicating external and structural factors that influence adoption. This component is designated as "Business Environment". The rotated component structure demonstrates the complex nature of digital adoption, indicating that a blend of technological compatibility, internal capacity, and external factors affects implementation success.

The initial component elucidates the clustering of variables, including compatibility (0.808), relative advantage (0.755), technological capability (0.714), trialability (0.692), perceived usefulness (0.648), absorptive capacity (0.618), and organisational readiness (0.614). Collectively, these variables represented the predominant portion of variance in the factor structure, indicating that Strategic Innovation Readiness is a crucial determinant in the adoption of digital technologies within the machinery and metal manufacturing industry. This component was designated as Strategic Innovation Readiness, as each variable reflects the degree to which new technologies are regarded as pertinent, beneficial, and feasible for integration into current processes. The alignment of digital tools with existing workflows, coupled with organisations' internal preparedness and ability to adopt and leverage innovations, bolsters trust in technological investments. Specifically, trialability and perceived utility mitigate perceived risk and facilitate iterative testing, which is essential in conservative industrial settings. Prior research indicates that when technologies are congruent with operational requirements and current systems, adoption rates markedly rise, particularly among SMEs, which typically exhibit minimal tolerance for integration failures or extensive training demands. The existence of robust absorptive capacity and organisational preparedness indicates that organisations with advanced internal capabilities are more likely to thrive in digital transformation endeavours. Consequently, improving perceived technical fit—via infrastructural support, user-centred design, and pilot testing—can markedly enhance adoption outcomes, particularly in technology-intensive industries such as manufacturing. The congruence between digital technologies and current operational procedures profoundly affects adoption, as compatibility and perceived utility directly improve task–technology alignment in industrial environments (Mahatma et al., 2025).

The second component consists of a combination of organisational and environmental variables, including government support (0.799), managerial support (0.724), human resources support (0.651), trade partner readiness (0.647), top management support (0.637), and market demand (0.389). This set of characteristics jointly represented a substantial share of the explained variance and was designated as Strategic Institutional Support, since they embody the internal and external facilitators essential for the successful adoption of digital technology. The significant burden on governmental and managerial support underscores the crucial importance of policy frameworks, financial incentives, and leadership dedication in advancing digitalisation. Factors of organisational preparation, including human capital development and partner ecosystem alignment, highlight the significance of skills, collaboration, and preparedness for technological transformation. In numerous instances, particularly among SMEs, insufficient institutional support and a deficiency in organisational maturity have impeded innovation. Moreover, when trading partners lack digital readiness, integration challenges may emerge, hindering transformation throughout supply chains. The incorporation of market demand in this element emphasises that digital adoption is not solely internally motivated, but also responsive to competitive forces and consumer expectations.

This component demonstrates that a properly aligned organisational structure, along with conducive institutional and market conditions, is crucial for the successful and sustainable use of digital technologies in the machinery and metal manufacturing industry. In the absence of such preparedness, even altruistic digital projects may fail because of operational resistance, insufficient investment, or a lack of strategic guidance. Organisational preparedness, influenced by executive support, digital competencies, and absorptive ability, is a significant predictor of effective technology adoption in manufacturing settings (Machado et al., 2021).

The third component comprises two principal variables: competitive pressure (0.789) and organisational scale (0.633). These components collectively constitute the residual portion of the explained variance and have been categorised under the topic Business Environment. This component illustrates how external competition and internal organisational capacities influence the urgency and ability to adopt digital technology. Competitive pressure, whether originating from digitally adept competitors or global enterprises, compels organisations, particularly smaller manufacturers, to innovate swiftly to sustain market relevance. Organisational scale affects resource availability, decision-making agility, and investment capacity, which can either promote or hinder digital transformation. Large businesses may possess an edge in scaling digital adoption due to superior infrastructure and strategic positioning, but smaller firms frequently have challenges related to constrained funding and expertise. These two pillars encapsulate the market-driven necessity for digitalisation, compelling enterprises to consistently adapt to changing client demands, global supply chain dynamics, and technological progress. Neglecting to do so may lead to diminished competitiveness and forfeited growth prospects. This component highlights the influence of external market pressures and internal structural preparedness on a firm's digital progression in the machinery and metal manufacturing industry. External competitive pressure, particularly from digitally adept competitors, necessitates that enterprises implement Industry 4.0 technologies to sustain market relevance and performance (Zhou and Zheng, 2023).

This factor study revealed three principal components: Strategic Innovation Readiness, Strategic Institutional Support, and Business

Environment, which embody the essential attributes of the TOE framework thoroughly substantiated in industrial transformation literature. A study published in Business Strategy and Development utilised the TOE model to investigate the adoption of Industry 4.0 in Bangladesh, demonstrating that technological readiness (e.g., relative advantage, availability of IT resources), organisational capabilities (e.g., strategy, leadership, IT infrastructure), and environmental factors (e.g., market pressure, government support) substantially influenced manufacturing performance metrics (Amin et al., 2024). This connection enhances our component framework, confirming that digital transformation initiatives are shaped by enduring latent traits that embody both global best practices and local empirical evidence.

4.6 Mean Ranking of Improved Manufacturing Performance

The average ranking of perceived improvements in manufacturing performance ascribed to the use of digital technology in the machinery and metal production industry is shown in Table 4.6. Among the three key dimensions evaluated, time performance achieved the highest ranking, with a mean score of 4.45 and a standard deviation of 0.74, indicating a strong consensus among respondents about the time-saving benefits of digital adoption. The quality performance was subsequently measured at a mean of 4.33 and a standard deviation of 0.79, indicating improvements in defect reduction and consistency. Cost performance was ranked third, with a mean of 4.16 and a standard deviation of 0.76, indicating perceived enhancements in operational expense efficiency. The findings indicate that respondents perceive digital technologies primarily as enhancements to productivity and quality, with cost efficiency considered a secondary benefit.

Table 4.6: Mean Ranking of the Perceived Performance Effects.

Descriptive Statistics				
Factors	N	Mean	Std. Deviation	Ranking
IMP01 Adoption Of Digital Technologies In The Machinery And Metal Manufacturing Sector Improves Time Performance	55	4.4545	0.74082	1

Table 4.6 (Continued)

IMP03 Adoption Of Digital Technologies In The Machinery And Metal Manufacturing Sector Improves Quality Performance	55	4.3273	0.79476	2
IMP02 Adoption Of Digital Technologies In The Machinery And Metal Manufacturing Sector Improves Cost Performance	55	4.1636	0.76409	3
Valid N (listwise)	55			

4.7 Factor Analysis of Improved Manufacturing Performance

This section delineates the outcomes of the factor analysis performed to ascertain the fundamental characteristics of enhanced manufacturing performance resulting from the implementation of digital technologies in the machinery and metal production industry. This research aims to condense many performance indicators into a more concise set of latent components, therefore providing a greater insight into the fundamental areas affected by digital transformation. The analysis seeks to identify the underlying structure and loading of each performance element to ascertain their contribution to the overall dimensions of performance enhancement. The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity were utilised to assess the data's appropriateness for factor analysis. Upon confirmation of data adequacy, the analysis advances to assess the total variance explained and the component matrix, which elucidate the factor structure and the clustering of individual performance measures under shared components.

4.7.1 Kaiser-Meyer-Olkin and Bartlett's Test of the Perceived Performance Effects

The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity were conducted to evaluate the dataset's appropriateness for factor analysis. Table 4.7.1 shows that the KMO value was 0.686, surpassing the minimum criterion of 0.5, showing that the sampling is sufficient for doing factor analysis. Additionally, Bartlett's Test of Sphericity produced a chi-square value of 53.408 with 3 degrees of freedom and a significance level of .000, indicating that the correlation matrix is not an identity matrix. This outcome indicates substantial correlations among the performance indicators, hence validating the suitability of employing factor analysis.

Table 4.7.1: Kaiser-Meyer-Olkin and Bartlett's Test of the Perceived Performance Effects.

KMO and Bartlett's Test	
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.	.686
Bartlett's Test of Sphericity	
Approx. Chi-Square	53.408
df	3
Sig.	.000

4.7.2 Total Variance Explained of the Perceived Performance Effects

The number of components to remain in the factor analysis was determined by examining the eigenvalues through the latent root criterion, which advises retaining components with eigenvalues exceeding 1. Table 4.7.2 indicates that just one component satisfied this condition, possessing an eigenvalue of 2.155, which represents 71.83% of the total variance. This elevated proportion signifies that a singular latent factor underpins the three performance-related variables—time, cost, and quality—implying their close interrelation. The last two components, possessing eigenvalues under 1.0, do not substantially contribute to variance explanation and were hence omitted from subsequent analysis.

Table 4.7.2: Total Variance of the Perceived Performance Effects.

Total Variance Explained			
Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	2.155	71.832	71.832
2	0.531	17.709	89.541
3	0.314	10.459	100.000

4.7.3 Component Matrix of the Perceived Performance Effects

Table 4.7.3 presents the component matrix, detailing the loading of each item on the extracted component. The three performance indicators—time performance (0.876), quality performance (0.875), and cost performance

(0.789)—exhibited strong loading on a single component, signifying a high degree of correlation among them. This indicates that these dimensions collectively form a cohesive construct of enhanced manufacturing performance as perceived by the respondents. The significant factor loadings indicate that digital technologies exert a simultaneous and reinforcing influence across these critical performance areas, supporting the conclusion that a singular latent factor underlies the observed performance enhancements.

Table 4.7.3: Rotated Component Matrix of the Perceived Performance Effects.

Component Matrix[a]	
	Component
	1
IMP01 Adoption Of Digital Technologies In The Machinery And Metal Manufacturing Sector Improves Time Performance	0.876
IMP03 Adoption Of Digital Technologies In The Machinery And Metal Manufacturing Sector Improves Quality Performance	0.875
IMP02 Adoption Of Digital Technologies In The Machinery And Metal Manufacturing Sector Improves Cost Performance	0.789

4.8 A Proposed Framework for Improved Manufacturing Performance

This study identifies three key performance factors—time performance, cost performance, and quality performance—and proposes a framework to demonstrate the foundational structure for enhancing manufacturing performance via the adoption of digital technology in the machinery and metal manufacturing sector. Figure 4.8 demonstrates that the framework is founded on a cohesive performance enhancement strategy, supported by real-time monitoring, data-driven decision-making, and digital process integration. The three performance domains align with the singular latent factor derived from the factor analysis, suggesting that enhancements in one domain typically bolster the others. Improvements in temporal efficiency via predictive maintenance and automation directly diminish expenses and boost product quality. This framework's fundamental enablers encompass technologies like the Internet of Things (IoT), Artificial Intelligence (AI), and Digital Twin systems, which together enhance operational efficiency, minimise waste, and augment output precision. The effective execution of this strategy necessitates synchronised involvement from essential organisational units, including production teams, quality control, and digital transformation leaders. Furthermore, strategic alignment with labour development, infrastructure preparedness, and executive endorsement is crucial for maintaining enhancements in manufacturing performance. The proposed framework acts as a guide for companies seeking to utilise digital technology to attain cohesive and sustainable performance results in an Industry 4.0 context.

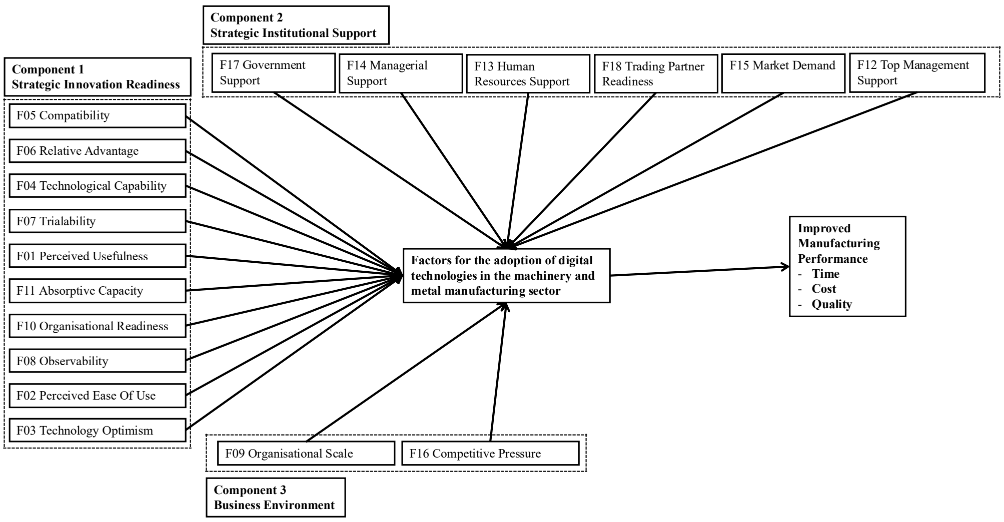

Figure 4.8: A Framework for the Improved Manufacturing Performances of Digital Technologies in the Machinery and Metal Manufacturing Sector in Klang Valley Malaysia.

4.9 Conclusion

In conclusion, a comprehensive analysis and interpretation of the data collected to examine the factors impacting the adoption of digital technologies in the machinery and metal production sector was presented. The study found perceived usefulness, top management support, compatibility, market demand, and competitive pressure as the primary factors influencing digital adoption through descriptive analysis, mean ranking, and factor analysis. Factor analysis identified three fundamental dimensions: Strategic Innovation Readiness, Strategic Institutional Support, and Business Environment. Furthermore, the observed enhancements in manufacturing performance—specifically regarding time, quality, and cost—were validated by mean ranking and principal component analysis, with time performance receiving the highest rating. The data validated the suitability for factor analysis by the KMO and Bartlett's tests, with all performance metrics exhibiting high loading onto a singular factor. The findings confirm that effective digital transformation relies on a synergy of technological alignment, internal competencies, and external influences.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The study's main conclusions are summarised in the last part in light of the goals and purpose of the investigation. In addition to acknowledging the constraints found throughout the research, this document summarizes the accomplishment of each goal and describes the study's contributions to the understanding of the application of digital technologies in the machinery and metal production industry. This chapter presents suggestions for future research that could improve comprehension of the digital technology adoption process within the sector. This chapter emphasises the significance and relevance of the study within the broader framework of digital transformation in manufacturing by analysing these critical components.

5.2 Achievements of Research Objectives

The following significant findings demonstrate that the goals and objectives of the research were met. These findings provide a solid, fact-based foundation for the recommendations in the following chapter and provide important new information for academic research as well as business operations.

5.2.1 Research Objective One

The study on the determinants of digital technology adoption in the machinery and metal manufacturing industry was successfully conducted through quantitative data collection and analysis, including 55 respondents from small, medium, and large enterprises. Descriptive statistics and mean ranking indicated that the primary factors influencing digital technology adoption were perceived utility, top management support, compatibility, market demand, and competitive pressure. These findings underscore the importance of internal organisational preparation and external environmental factors in influencing adoption behaviour. The findings offer a fundamental comprehension of the incentives and facilitators for digital change within the sector.

5.2.2 Research Objective Two

To evaluate the potential of digital technologies in the machinery and metal production industry for obtaining increased manufacturing performance, was performed through statistical analysis of performance-related metrics was performed. Descriptive data showed that time, quality, and cost performance were the top benefits perceived by respondents. Subsequent factor analysis indicated that these dimensions are highly interconnected and substantially augmented by the implementation of digital tools, including automation, data analytics, and real-time monitoring. These technologies enhance production efficiency, minimise operational waste, and refine decision-making, thus affirming their transformative capacity in elevating overall manufacturing performance.

5.3 Research Contributions

This study provides significant contributions to academic literature and industrial experience about digital transformation in the machinery and metal manufacturing sector. Initially, it enhances the theoretical comprehension of digital technology adoption by amalgamating the Technology-Organisation-Environment (TOE) paradigm with essential aspects, including perceived utility, top management backing, and market demand. The results confirm the significance of these parameters and furnish empirical data to substantiate their involvement in effective digital adoption.

Secondly, the research methodologically contributes by employing Principal Component Analysis (PCA) to reveal latent factors that affect adoption and performance. The identification of three fundamental components—Perceived Technological Fit, Institutional and Organisational Readiness, and Competitive Market Pressure—provides a systematic comprehension of the multifaceted dynamics influencing digital transformation.

This study enhances practical knowledge by elucidating the effects of digital technologies on manufacturing performance on time efficiency, cost reduction, and quality enhancement. The findings offer decision-makers practical guidance for selecting investments and aligning digital strategy with organisational competencies and market dynamics.

The study addresses a regional knowledge deficiency by concentrating on Malaysian machinery and metal manufacturing SMEs, a sector that has been inadequately examined in the current literature. This localised viewpoint aids in contextualising global digitisation trends and advises both policymakers and industry leaders on customised support strategies for efficient technology integration.

5.4 Study Limitations

Though various limitations must be acknowledged, this study offers important insights into the deployment of digital technologies in the machinery and metal manufacturing sector. The geographical scope of the data collection was confined to enterprises situated in the Klang Valley region of Malaysia. The findings may not comprehensively reflect the viewpoints of enterprises in other regions with varying infrastructure, resources, or market dynamics. Secondly, the employment of convenience and snowball sampling methods may have engendered selection bias, thus constraining the sample's representativeness. Thirdly, the study depended on self-reported data, which is susceptible to personal views, social desirability bias, and differing levels of technical comprehension. The quantitative design limited the exploration of underlying organisational and contextual elements that may affect digital adoption. The study's cross-sectional design fails to consider temporal variations in adoption behaviours or performance outcomes.

5.5 Recommendations for Future Research

Based on the findings and limitations of this study, numerous recommendations for future research can be articulated. Future research should broaden its geographical scope beyond the Klang Valley to encompass more regions of Malaysia or other countries for comparative examination. This would improve the generalisability of the findings across other industrial contexts. Secondly, integrating qualitative approaches like interviews or case studies may yield profound insights into organisational behaviours, leadership positions, and cultural aspects affecting digital adoption. Thirdly, longitudinal study designs are advocated to investigate the temporal evolution of digital technology adoption and its long-term effects on manufacturing performance. Moreover, subsequent research may investigate sector-specific obstacles and facilitators, including cybersecurity issues, digital skill competencies of the workforce, and legislative frameworks pertinent to specific industries. The use of environmental and sustainability measures in performance assessment could provide a more comprehensive perspective on the effects of digital transformation in the manufacturing industry.

5.6 Conclusion

This chapter has delineated the principal results, accomplishments, and contributions of the research regarding the deployment of digital technologies in the machinery and metal manufacturing industry. The research objectives were accomplished by identifying essential adoption factors and assessing the influence of digital technologies on manufacturing performance regarding time, cost, and quality. The research enhances current literature by providing a systematic framework based on the Technology–Organisation–Environment (TOE) paradigm, substantiated by empirical evidence. It underscores institutional preparedness and market competitiveness as crucial factors in digital transformation. The research offers valuable insights; however, its scope was limited to enterprises in the Klang Valley region, which may affect generalisability. Recommendations were provided to guide future research directions, emphasising the need for broader geographical coverage, improved qualitative analysis, and longitudinal studies to enhance understanding of the digital transition in industrial manufacturing.

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