

AI Adoption among Manufacturing Smes in Malaysia: Interview Insights from A Toe Perspective

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ABSTRACT

Artificial Intelligence (AI) has emerged as a critical enabler of Industry 4.0 transformation, offering manufacturing firms opportunities to enhance productivity, operational efficiency, and data-driven decision-making. However, adoption among small and medium enterprises (SMEs), particularly in developing economies, remains uneven. This study examines the challenges influencing AI adoption among Malaysian manufacturing SMEs through the Technology, Organization, and Environment (TOE) framework. A qualitative research design was employed, drawing on in-depth semi-structured interviews with 10 manufacturing SME owners and managers. The findings reveal that technological challenges remain substantial, particularly high implementation costs, legacy machinery incompatibility, limited data infrastructure, and the absence of scalable AI solutions tailored to SME production environments. From an organizational perspective, although leadership awareness toward AI is generally positive, workforce capability gaps, limited digital training structures, vendor dependency, and resistance to constrain implementation readiness. Environmental factors exert both pressure and constraint, as supply chain digitalization requirements and competitive intensity drive adoption urgency, yet institutional support mechanisms remain procedurally complex and underutilized. Collectively, the study demonstrates that AI adoption is not determined by technological availability alone but by the alignment of technological readiness, organizational capability, and ecosystem facilitation. The study contributes empirically grounded insights to SME digital transformation discourse and offers practical implications for policymakers, technology providers, and manufacturing firms seeking to accelerate inclusive AI adoption.

Keywords: Adoption, AI, Small and Medium Enterprises, Manufacturing SMEs, Digital Transformation

INTRODUCTION

AI is a global agenda that leads to the Industrial Revolution 4.0. From automated manufacturing in Germany to AI-powered retail recommendations in the U.S., businesses leveraging AI are gaining a competitive edge in efficiency, cost savings, and customer engagement (Dwivedi et al., 2021). However, while multinational corporations and tech giants rapidly adopt AI, SMEs, especially in developing economies, are being left behind (OECD, 2021). The reasons could be (i) high costs, (ii) lack of expertise, and (iii) fears of disruption often outweigh the perceived benefits (Nguyen et al., 2022). This global AI divide threatens to widen economic inequality, making it crucial to understand how SMEs, which are the backbone of most economies. It can challenge the application of AI without being overwhelmed by its challenges.

In Malaysia, SMEs are more than just business entities, but they represent the backbone of the national economy. Data shows that from 97.4% from total enterprises, SMEs contribute 38.2% to the country's GDP, and creating

50% of the jobs (Department of Statistics Malaysia, 2023). This clearly shows their performance led to Malaysia's overall economic resilience. Within this landscape, manufacturing SMEs play a particularly strategic role, serving as key drivers of industrial production, export activities, and supply chain development. Recognizing their importance, the government has introduced national digitalization initiatives such as MyDIGITAL, aimed at positioning Malaysia as a high-tech, digitally driven economy by 2030 (Economic Planning Unit, 2021). However, despite these policy efforts, many manufacturing SME operators, especially small factory owners and family-run production firms and continue to perceive AI as a technology suited primarily for large corporations rather than for businesses of their scale.

The gap is not merely technological or financial, but it is deeply rooted in managerial mindset, workforce capabilities, and institutional trust toward emerging technologies. Within manufacturing SMEs, AI is often perceived as complex, costly, and relevant only to large-scale industrial players. For instance, small factory operators may view AI-driven production analytics or predictive maintenance systems as overly sophisticated for their operational scale. Similarly, local manufacturers in sectors such as furniture, metalworks, or food processing may underestimate AI's potential to optimize supply chain coordination, automate quality inspection, or enhance demand forecasting.

These perceptions reflect broader structural challenges, including financial constraints, limited digital skills, fear of workforce displacement, and the absence of clear implementation guidance. While such concerns are valid, they frequently overshadow the transformative capacity of AI to enhance productivity, reduce operational costs, and unlock new market opportunities (Chatterjee et al., 2023). If left unaddressed, these challenges risk slowing the digital progress of manufacturing SMEs and, by extension, constraining Malaysia's industrial competitiveness.

Against this backdrop, the present study moves beyond conceptual discourse by engaging directly with Malaysian manufacturing SME owners, industry practitioners, and policy stakeholders through qualitative interviews. The study is guided by two key objectives:

- i. To assess the level of awareness of AI technologies and their potential applications among manufacturing SMEs.
- ii. To examine the current state of technology utilization in manufacturing SMEs, particularly the extent of manual, automated, and AI-enabled operational practices.
- iii. To explore the primary technological, organizational, and environmental challenges hindering AI adoption among manufacturing SMEs based on TOE perspective

By uncovering these objectives, the study seeks to inform policymakers in designing targeted industrial digitalization support, assist manufacturing SME owners in making informed technological decisions, and contribute toward ensuring that Malaysia's digital transformation agenda progresses in an inclusive and industry-relevant manner.

LITERATURE REVIEW

The adoption of AI in business operations among manufacturing SMEs has gained significant scholarly and industrial attention due to its transformative potential. AI technologies, ranging from machine learning and natural language processing to intelligent automation, offer firms the ability to enhance operational efficiency, support data-driven decision-making, and foster innovation (Dwivedi et al., 2021). While large corporations have made substantial progress in implementing AI, SMEs often remain behind. This lag is typically attributed to limited resources, knowledge gaps, and a lack of organisational preparedness (Nguyen et al., 2022).

Underpinning Theory: Technology, Organization, and Environment (TOE) Framework

This study is based on the TOE framework (Tornatzky and Fleischer, 1990) that explains technology adoption by grouping determinants into three interrelated contexts: technological, organizational, and environmental.

Widely applied in studies of manufacturing SMEs, particularly within Industry 4.0, AI, and digitalization, the framework underscores that adoption is not merely a technical or economically rational decision (Marrucci et al., 2023). Rather, adoption outcomes emerge from the interaction between technological feasibility, internal organizational readiness, and external ecosystem pressures, which often develop unevenly across SMEs (Shukla et al., 2021).

From a technological standpoint, adoption is influenced less by perceived performance benefits and more by infrastructural compatibility, integration complexity, and investment affordability. Many manufacturing SMEs recognize AI's potential to enhance productivity and quality, yet legacy machinery, limited data infrastructure, and scalability constraints impede implementation (Shukla, & Shankar, 2021). Organizationally, while leadership awareness is generally positive, capability gaps, limited digital skills, financial constraints, and workforce resistance frequently restrict execution (Amin et al., 2024). Environmental factors further complicate adoption, such as competitive pressures, supply chain digitalization demands, and policy incentives may drive urgency but do not always translate into accessible or practical support (Marrucci et al., 2024). Consequently, the TOE framework highlights that successful AI adoption requires alignment across technological readiness, organizational capability, and environmental facilitation; without such convergence, adoption efforts are likely to remain fragmented and operational rather than strategically transformative.

The Challenges of AI Adoption among Manufacturing SMEs

The adoption of AI within manufacturing SMEs has attracted growing attention from both scholars and industry practitioners, particularly given its potential to reshape production and operational practices. AI applications, ranging from machine learning and natural language processing to intelligent automation, enable manufacturing firms to improve operational efficiency, support data-driven decision-making, streamline production workflows, and stimulate process innovation (Dwivedi et al., 2021).

Despite these advantages, the pace of AI implementation remains uneven. Large manufacturing corporations have been more proactive in embedding AI into areas such as predictive maintenance, quality monitoring, and smart factory systems. In contrast, many manufacturing SMEs continue to lag behind. This slower uptake is frequently linked to practical constraints, including limited financial capacity, gaps in technical knowledge, and insufficient organizational readiness to support digital transformation initiatives (Nguyen et al., 2022).

In Malaysia, conversations about AI are becoming more common and not just among researchers and policymakers, but also within the business owners. However, much of the existing research tends to focus on AI adoption at a broad, national or industry level. This often overlooks the real-life experiences of smaller businesses. Many studies do not break down the insights according to business size, and as a result, the challenges faced by SMEs are not always fully captured or understood, especially in manufacturing industry.

AI adoption among Malaysian manufacturing SMEs sits at the intersection of Industry 4.0 transformation and the country's broader digital economy agenda. Although Malaysia promotes technologies such as AI, IoT and advanced analytics through policies like Industry4WRD, adoption and readiness among SMEs remain uneven and generally at an early stage (Shahzad et al., 2023; Khin & Kee, 2022; Wong & Kee, 2022).

Research on Industry 4.0 and AI in Malaysian SMEs shows that organizational and managerial factors are often more decisive than technology availability. Studies using the Technology–Organization–Environment (TOE) and related frameworks identify top management support or commitment, organizational readiness such as skills, infrastructure, and financial capacity play a vital role. In addition, perceived relative advantage and compatibility of new technologies as core predictors of AI adoption (Wong & Kee, 2022; Lada et al. 2023; Lai et al; 2025; Kee et al., 2023). For AI specifically, survey evidence from Sabah SMEs finds that top management commitment and organizational readiness significantly predict AI adoption, while competitive pressure, employee adaptability and external support are not significant drivers (Lada et al. 2023).

In manufacturing, Industry 4.0 readiness studies highlight similar mechanisms. Organizational capabilities, SME institutional support and market factors all strengthen readiness for digital technologies, including AI (Wong & Kee, 2022; Kin & Kee, 2022). Financial capability and perceived benefits enhance managerial, operational and

technological readiness, underscoring the need for sufficient resources and a clear business case before firms move beyond pilot projects (Kee et al., 2023). A national assessment of over 500 Malaysian SMEs shows that leadership and strategic alignment are strongly correlated with overall Industry 4.0 readiness, whereas workforce competency scores are lowest, signaling a major skills gap for AI and related technologies (Techanamurthy et al. 2025).

At firm level, qualitative work on Malaysian manufacturers indicates that many companies are still in an exploratory, “trial and error” stage, experimenting with Industry 4.0 solutions based on what is feasible in their existing operations (Tay et al., 2021). Common challenges include data management and integration, re educating personnel, and aligning new technologies with legacy systems (Kalesamy, 2021). Broader reviews of smart manufacturing digital technology adoption, including AI, confirm that technological, organizational and environmental factors jointly shape decisions, and that SMEs must integrate AI with clear strategies and process changes to realize value (Peretz-Andersson et al., 2024; Ghobakhloo et al., 2022).

Despite these challenges, AI adoption can contribute to digital value creation, competitiveness and sustainability. Evidence from Malaysian SMEs shows that intention to adopt AI is positively associated with digital value creation, especially when supported by a strong technological orientation (Jalil et al., 2024). In manufacturing SMEs, effective Industry 4.0 implementation—driven by top management commitment and IT infrastructure—supports triple bottom line sustainability (economic, environmental and social outcomes) (Jayashree et al., 2021). Conceptual work on AI readiness in Malaysian SMEs argues that, if resource and capability gaps can be addressed, AI has the potential to enhance productivity, innovation and long term competitiveness in line with national technology policies.

Awareness of AI among Malaysian SMEs has been steadily increasing; however, adoption remains cautious and uneven. As highlighted by Hassan et al. (2022), many SMEs continue to hesitate due to concerns surrounding high implementation costs, uncertain return on investment, and perceptions that AI technologies are overly complex and technically demanding. Similarly, Noor and Mohamed (2021) observed that a significant proportion of local SMEs still rely on manual processes or only basic automation, indicating that their digital transformation journey remains at an early stage and is not yet fully aligned with Industry 4.0 aspirations. In response, government agencies such as the Malaysia Digital Economy Corporation (MDEC) and SME Corp Malaysia have introduced various digitalization initiatives, including grants, training programs, advisory services, and pilot AI projects (MDEC, 2022). While these initiatives reflect strong institutional commitment, accessibility challenges persist, as some SMEs remain unaware of available support, find application procedures complex, or feel unprepared to utilize such resources effectively.

From an organizational standpoint, internal structural and human capital limitations further constrain AI adoption. Financial constraints, absence of clear digital transformation roadmaps, leadership risk aversion, and resistance to change continue to characterise many SMEs operating within traditional business models (Agrawal et al., 2018; Mikalef et al., 2022; SME Corp Malaysia, 2021). Human resource challenges are particularly pronounced, with shortages in AI-related skills and digital literacy significantly impeding implementation efforts (El-Haddadeh et al., 2021; Raut et al., 2023). The high cost of hiring AI talent and limited access to affordable upskilling programs exacerbate this challenge, reinforcing workforce readiness gaps identified by the OECD (2021) as critical for Southeast Asian SME digitalization. Externally, regulatory uncertainty, data privacy concerns, and uneven institutional facilitation further complicate adoption pathways (Dwivedi et al., 2021; Economic Planning Unit, 2021). Collectively, these technological, organizational, and environmental constraints highlight the need for more practical, accessible, and context-sensitive support mechanisms to accelerate AI integration among Malaysian SMEs.

Overall, AI adoption among Malaysian manufacturing SMEs is still emerging, constrained primarily by leadership, skills, financial and organizational readiness rather than by the absence of AI technologies themselves. Strengthening top management commitment, workforce competencies, digital infrastructure and institutional support appear central to accelerating AI enabled Industry 4.0 transformation in this sector.

METHOD

Both primary and secondary data were used in this study. Secondary data were gathered through a review of relevant literature on AI adoption and SME digital transformation. For primary data, the study adopted a qualitative research design to explore the perceptions and experiences of entrepreneurs regarding challenges to AI adoption. In-depth, semi-structured interviews were conducted with SME owners and managers in Malaysia. Using purposive sampling, a total of 10 manufacturing SMEs were selected, as they are directly involved in technology adoption and operational decision-making. The questions were adapted (Alsheibani et al., 2018; Jöhnk et al., 2021) are formulated as follows:

- i. How aware are you of AI technologies and their potential applications in your company's operations?
- ii. Are your company's operations currently performed using manual processes, automated systems, or AI-enabled technologies?
- iii. If AI is not currently implemented, what are the main challenges preventing adoption?

RESULTS AND DISCUSSION

Lever of AI Awareness and Current Status

AI among manufacturing SME leaders was assessed based on their ability to recognise potential AI applications within their operational environments. Overall, respondents demonstrated moderate to high conceptual awareness of AI technologies, particularly in relation to production efficiency and automation. Most CEOs were able to identify application areas such as process optimization, quality control, predictive maintenance, supply chain coordination, and customer demand analytics. However, awareness remained largely operational rather than strategic. While firms recognized AI's role in defect detection, machine monitoring, and production planning, fewer respondents associated AI with broader applications such as financial analytics, workforce management, or energy optimization. This indicates that AI awareness within manufacturing SMEs is still functionally concentrated and shaped by immediate production needs rather than enterprise-wide digital transformation perspectives.

The Challenges of AI Adoption

Technology Context

Respondents generally indicated that technological constraints remain one of the most significant challenges affecting AI adoption among manufacturing SMEs. Although most firms acknowledged the potential of AI technologies in enhancing production efficiency, defect detection, and machine performance, actual implementation remains limited and largely experimental in nature. Several respondents explained that their production processes continue to rely heavily on manual monitoring and inspection methods. This reliance was not due to a lack of awareness, but rather the absence of affordable and scalable AI solutions suitable for SME manufacturing environments. For instance, one production manager noted that defect detection processes are still performed visually by operators, which exposes the firm to inconsistencies arising from human fatigue and subjective judgement. As explained:

"For now, our defect checking is still done manually by operators. Sometimes when they are tired, small defects can be missed. We know AI visual inspection can help improve consistency, but the system cost and setup are still too high for us." (SME 1)

Similarly, predictive maintenance was frequently discussed as a desirable yet unattainable technological advancement. Respondents explained that unexpected machine breakdowns often disrupt production schedules and lead to delivery delays. While AI-based predictive analytics could potentially mitigate such risks, the financial investment required, coupled with uncertain returns, discourages adoption. As one firm shared:

“Machine breakdown is one of our biggest concerns. Once a machine stops, the whole production line is affected. We understand AI can predict failures earlier, but the investment required is still beyond our budget.” (SME 3)

This reflects broader observations that manufacturing SMEs tend to recognize AI’s operational value but remain hesitant due to cost–benefit uncertainties (Wong & Yap, 2024). In addition, some firms reported having automated machinery but without intelligent integration. These systems operate independently and lack real-time data analytics capabilities to support decision-making or performance optimization. One respondent explained:

“We do have automated machines in certain processes, but they operate on their own. There is no AI system analysing the data or giving performance insights. To move from automation to AI integration requires another level of investment.” (SME 5)

This suggests that automation maturity does not necessarily translate into AI readiness, a finding consistent with Ahmad et al. (2022), who argue that digital infrastructure depth is a prerequisite for advanced technology adoption. Another recurring issue relates to legacy infrastructure. Many SMEs continue to depend on long-serving machinery that remain operationally reliable but technologically outdated. Respondents explained that retrofitting such equipment with AI-compatible sensors or digital connectivity requires significant financial outlay and technical modification risks. As highlighted:

“Most of our machines have been running for more than 10 to 15 years. They are still usable, but not designed for AI connectivity. To retrofit them with smart systems is costly and technically risky.” (SME 6)

Prior studies similarly note that infrastructural rigidity constrains Industry 4.0 transitions among traditional manufacturers (Oldemeyer et al., 2024). Furthermore, respondents highlighted that most AI solutions offered by technology vendors are designed for large-scale manufacturing plants rather than SME production settings. As such, system architecture, implementation scale, and investment requirements are often misaligned with SME operational capacity. One respondent remarked:

“Many AI solutions proposed by vendors are more suitable for big factories. For SMEs like us, the system scale and cost are not very practical.” (SME 9)

This technology–scale mismatch reinforces adoption hesitation and reflects structural ecosystem gaps rather than firm-level resistance alone (Abubakar et al., 2024). Collectively, these findings indicate that technological challenges to AI adoption among manufacturing SMEs extend beyond technical awareness. Instead, they are embedded within issues of infrastructural compatibility, financial feasibility, and solution scalability. This aligns with prior empirical evidence suggesting that SMEs in developing economies face disproportionate technological constraints due to limited digital readiness and resource capacity (Oldemeyer et al., 2024; Wong & Yap, 2024).

Organizational Context

Respondents indicated that organizational readiness represents a critical internal barrier influencing AI adoption among manufacturing SMEs. While most firms demonstrated awareness of AI’s strategic importance, the transition from awareness to implementation remains constrained by structural, capability, and cultural limitations within the organisations.

A recurring theme across the interviews relates to workforce capability gaps. Several respondents explained that their organisations lack employees with the technical expertise required to manage AI systems, data analytics platforms, or automation integration processes. As one operations manager shared, although the firm is interested in implementing AI-driven monitoring systems, they remain dependent on external vendors due to the absence of in-house specialists. As expressed:

“We are interested in implementing AI, especially for production monitoring. But internally, we don’t have people who can manage the system. Even for data analytics, we still depend on vendors. That makes implementation more costly and difficult to sustain long term.” (SME 3)

This over-reliance on third-party expertise not only increases operational costs but also limits long-term technological sustainability (SME 3). Similar observations have been documented in prior studies, which highlight talent shortages as a primary organisational constraint in SME digital transformation efforts (Oldemeyer et al., 2024).

In addition to technical skills shortages, training limitations further hinder adoption readiness. Respondents acknowledged that upskilling initiatives are necessary but difficult to execute due to financial constraints and operational pressures. Releasing employees for training disrupts production schedules, particularly for SMEs operating with lean manpower structures. One firm explained:

“We know training is important if we want to move into AI. But sending staff for courses takes time and cost. When workers go for training, production will be affected because our manpower is already limited.” (SME 4)

This reflects broader evidence suggesting that SMEs often struggle to institutionalize structured digital capability development programs (Omowole et al., 2024). While leadership orientation toward AI adoption, however, was generally positive. Several respondents emphasised that top management recognizes the long-term necessity of digital transformation in maintaining competitiveness. One managing director noted:

“From management perspective, we know automation and AI are the future. If we don’t start moving now, we may lose competitiveness in the coming years.” (SME 2)

This indicates that resistance at the leadership level is relatively low, aligning with findings by Lada et al. (2023) that SME leaders increasingly acknowledge the strategic value of digitalization. Despite this strategic awareness, many firms lack formal digital transformation roadmaps. AI adoption initiatives are often reactive, fragmented, and project-based rather than guided by long-term organizational planning. As one respondent explained:

“Management is interested in AI, but we don’t yet have a proper roadmap. Implementation is still discussion stage, no structured investment or timeline yet.” (SME 8)

This absence of strategic direction weakens execution capability and increases the likelihood of stalled or failed AI projects (Schwaeke et al., 2024).

Socio-cultural resistance within the workforce also emerged as a significant organisational barrier. Several respondents observed that employees, particularly those in production roles, perceive automation as a threat to job security. Such perceptions generate anxiety and slow technological acceptance. One production supervisor explained:

“Some workers are worried that once automation or AI comes in, their jobs may not be secure. Especially senior operators, they are more comfortable with manual processes.” (SME 10)

This reflects the broader phenomenon of technological change resistance documented in manufacturing environments (Wong & Yap, 2024).

Collectively, the findings suggest that organisational challenges to AI adoption are multidimensional. While leadership support is present, it is not sufficiently supported by workforce capability development, structured planning, or change management initiatives. This indicates that AI adoption readiness within manufacturing SMEs is shaped not only by technological feasibility but also by organisational maturity, human capital preparedness, and cultural adaptability.

Environmental Context

Respondents indicated that environmental factors play a dual role in influencing AI adoption among manufacturing SMEs, functioning both as external pressure mechanisms and as enabling support structures. Unlike technological and organizational challenges, which are largely internal, environmental constraints emerge from the broader industrial ecosystem within which SMEs operate.

One of the most prominent drivers identified relates to supply chain digitalisation pressures. Several manufacturing SMEs reported that their customers, particularly multinational corporations and large local manufacturers, are increasingly demanding digital production tracking, quality analytics, and traceability systems. As one respondent explained, compliance with these digital requirements is gradually becoming a prerequisite for maintaining supplier relationships. Failure to upgrade technological capabilities may therefore risk contract discontinuity. As shared by one firm:

“Our buyers, especially multinational companies, are now requesting digital production reports and traceability data. If we cannot provide this, it may affect our chances of continuing as their supplier.” (SME 1)

This finding reflects wider Industry 4.0 diffusion patterns where supply chain integration acts as a coercive force shaping SME digital transformation (Kamble et al., 2020).

In addition to customer-driven pressures, competitive intensity within the manufacturing sector was also cited as a key environmental influence. Respondents acknowledged that technologically advanced competitors, both locally and regionally, have begun leveraging automation and AI systems to enhance cost efficiency and production speed. One firm noted that benchmarking exercises revealed significant productivity gaps between traditional SMEs and digitally advanced manufacturers. As explained:

“When we compare with competitors who already use automation and AI, their production speed and cost efficiency are much better. That puts pressure on us to upgrade as well.” (SME 6)

Such competitive disparities create a sense of urgency but simultaneously heighten perceived investment risks. Similar dynamics have been reported in emerging economy manufacturing sectors, where competitive digitalization drives adoption awareness but not necessarily implementation (Pandey et al., 2024).

While external pressures encourage AI consideration, institutional facilitation remains uneven. Respondents recognised the availability of government grants, tax incentives, and Industry 4.0 support programmes aimed at accelerating SME digital transformation. However, many firms expressed difficulty navigating application procedures, eligibility criteria, and documentation requirements. One respondent highlighted:

“We know there are government grants for digitalisation, but the application process is quite complicated. SMEs like us don’t have dedicated staff to handle all the paperwork.” (SME 2)

This suggests that policy availability does not automatically translate into policy accessibility, a gap similarly identified in Malaysian SME digitalisation reports (SME Corp Malaysia, 2023). Another environmental constraint relates to technology vendor dependency. As most manufacturing SMEs lack internal AI expertise, they rely heavily on external solution providers for system installation, calibration, training, and maintenance. While vendor partnerships facilitate initial adoption, respondents expressed concern regarding long-term sustainability. One firm noted:

“When we adopt AI systems, everything depends on the vendor, installation, maintenance, even troubleshooting. If vendor support stops, we may not be able to manage the system ourselves.” (SME 9)

This reliance introduces operational vulnerability and limits technological autonomy. Prior digital ecosystem studies similarly highlight vendor lock-in risks as a structural adoption barrier among SMEs (Cenamor et al., 2019). Furthermore, respondents pointed to information asymmetry within the technology ecosystem. Many SMEs reported limited awareness of AI solution providers suitable for their operational scale. Technology showcases and industry briefings are often geared toward larger corporations, leaving SMEs uncertain about feasible entry points into AI adoption. As one respondent shared informally during the interview:

“Most technology exhibitions or briefings focus on big companies. For SMEs, we are still trying to understand where to start and which solutions are suitable for our scale.” (SME 5)

This environmental knowledge gap further delays decision-making and investment commitment. Therefore, these findings indicate that environmental challenges to AI adoption among manufacturing SMEs are shaped by

a complex interplay of competitive pressure, supply chain expectations, institutional support accessibility, and ecosystem knowledge structures. While external forces are increasingly pushing SMEs toward digital transformation, structural facilitation mechanisms remain insufficiently aligned with SME operational realities. Therefore, the interview inputs are presented in Table 1 based on a TOE-based categorization of factors influencing AI adoption among manufacturing SMEs. From the technological dimension, challenges relate to infrastructure readiness, legacy machinery compatibility, data capability, cybersecurity, and technical expertise. Organizationally, adoption is shaped by leadership support, financial readiness, workforce skills, training structures, and change management capacity. Environmental factors reflect external ecosystem influences, including supply chain digital pressures, competitive intensity, policy facilitation, vendor dependency, and technology awareness exposure. Collectively, the table illustrates that AI adoption is not driven by technology availability alone but depends on the alignment of internal organizational preparedness and external institutional support mechanisms within the broader industrial environment.

Table 1: Categorization of AI Adoption Challenges Using the TOE Framework

Factors	AI Characteristics	Organizational / Adoption Necessity
Technology		
Technological Infrastructure	AI systems require high processing power, system interoperability, and digital platforms	Investment in scalable IT systems is necessary to enable AI deployment
Legacy Machinery Compatibility	Existing production equipment lacks IoT sensors and AI connectivity capabilities	Retrofitting or upgrading machinery supports AI integration
Technical Expertise	AI deployment requires specialised analytics, programming, and automation skills	Building internal technical talent ensures system sustainability
Data Readiness	AI relies on structured, real-time, and high-volume operational data	Establishing data governance and storage infrastructure is critical
Cybersecurity & Data Protection	AI systems increase exposure to data privacy and security risks	Implementing robust cybersecurity frameworks safeguards operations
Organizational		
Leadership Support	AI initiatives require strategic direction and managerial commitment	Executive advocacy drives resource allocation and adoption momentum
Digital Strategy Alignment	AI adoption is more effective when embedded in long-term transformation planning	Formal digital roadmaps guide structured implementation
Workforce Capability	AI systems require employees skilled in analytics and automation operations	Continuous upskilling enables effective technology utilization
Training & Development	AI implementation demands structured employee training programs	Institutionalized training strengthens adoption readiness
Change Management	Automation alters job roles and operational workflows	Change management reduces resistance and fosters acceptance

Financial Readiness	AI adoption involves high capital and operational expenditure	Budget planning and financial allocation support adoption feasibility
Environmental		
Supply Chain Digital Pressure	Customers demand digital traceability and production analytics	Meeting digital supply chain requirements sustains partnerships
Competitive Intensity	Digitally advanced competitors create productivity and cost pressure	AI adoption supports competitive positioning
Government & Policy Support	Grants, tax incentives, and Industry 4.0 programs are available	Policy accessibility enhances SME adoption capability
Vendor Ecosystem Dependency	SMEs rely on external AI providers for system deployment	Developing internal capabilities reduces vendor lock-in risks
Technology Awareness Ecosystem	SMEs face limited exposure to SME-scaled AI solutions	Industry outreach and knowledge platforms improve awareness

CONCLUSION

This study examined the challenges influencing AI adoption among manufacturing SMEs through the TOE framework. Drawing on qualitative evidence from ten manufacturing firms, the findings reveal that although awareness of AI technologies is relatively high, the level of adoption remains limited and operationally confined. While the insights provide valuable exploratory understanding, the relatively small sample size suggests that the findings should be interpreted with caution in representing the broader population of Malaysian manufacturing SMEs.

From the technological dimension, AI is largely perceived as a tool for improving production efficiency, particularly in areas such as defect detection, predictive maintenance, and process monitoring. However, implementation remains constrained by high capital investment requirements, legacy machinery incompatibility, and the absence of scalable AI solutions tailored to SME manufacturing environments. Many firms continue to operate automated but non-intelligent systems, indicating that digital maturity has yet to progress toward integrated analytics or AI-enabled decision-making platforms. Future research incorporating quantitative measures could further validate the strength and significance of these technological constraints across a larger sample.

Organizational leadership across the firms demonstrates a positive orientation toward digital transformation, recognizing AI as a strategic necessity for long-term competitiveness. Nevertheless, this strategic intent is not sufficiently supported by internal execution capability. Skills shortages limit structured training initiatives, and heavy reliance on external vendors restrict firms' ability to institutionalize AI systems. Workforce resistance, particularly among production employees concerned about job displacement, further complicates organizational readiness and slows technology acceptance. A more structured comparative analysis across different SME categories (e.g., size, sub-sector, or digital maturity level) would provide deeper insights into these organizational differences.

Environmental factors simultaneously exert pressure and constraint. Supply chain digitalization requirements and competitive intensity are pushing manufacturing SMEs toward technological upgrading. At the same time, institutional support mechanisms such as government grants and Industry 4.0 incentives remain underutilized due to procedural complexity, documentation burdens, and limited accessibility. In addition, dependency on external technology vendors raises sustainability concerns, particularly in terms of long-term system

maintenance and knowledge ownership. These findings highlight the need for broader empirical investigation to examine how environmental factors vary across different manufacturing contexts.

Taken together, these findings suggest that AI adoption challenges among manufacturing SMEs are multidimensional and structurally embedded. Technological feasibility, organizational preparedness, and environmental facilitation must evolve in tandem to enable meaningful digital transformation. However, the largely qualitative and descriptive nature of this study indicates the need for more analytically rigorous approaches in future research to strengthen theoretical and empirical generalisation.

In light of these findings, several recommendations are proposed. First, technology providers should develop modular and cost-efficient AI solutions that are compatible with legacy manufacturing infrastructure, thereby lowering adoption entry challenges for SMEs. Second, manufacturing firms must prioritize workforce capability development through structured upskilling and reskilling initiatives, particularly in data analytics and automation management. Leadership commitment should also be translated into formal digital transformation roadmaps to guide systematic implementation.

From an ecosystem perspective, policymakers should focus on enhancing the accessibility of digitalization incentives by simplifying application procedures and providing advisory support for SMEs. Industry agencies and technology associations could further strengthen awareness by promoting SME-relevant AI adoption models and facilitating shared digital platforms to reduce investment burdens. Future studies are encouraged to adopt mixed-methods and longitudinal designs to enable validation, comparison, and tracking of AI adoption trends over time.

Overall, accelerating AI adoption within the manufacturing SME sector requires coordinated efforts across technological innovation, organizational capacity building, and institutional facilitation. Without such alignment, AI implementation is likely to remain fragmented and operationally limited rather than strategically transformative.

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