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IR4.0 Readiness Model for Small and Medium Enterprises (SMEs)

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Abstract: The Industrial Revolution 4.0 (IR4.0) is transforming the global economy, necessitating mall and medium-sized enterprises (SMEs) to adopt new technologies like artificial intelligence (AI), the Internet of Things (IoT), blockchain, and cloud computing. Therefore, SMEs need to assess their readiness to identify capabilities and areas for improvement to remain competitive. However, existing IR4.0 readiness assessment such as the Industry4WRD Readiness Assessment and Industry 4.0-Readiness by IMPULS German are time-consuming and restrict the participation of various sectors. Using the understanding of theories such as Technology Acceptance Model (TAM), Unified Theory of Acceptance and Use of Technology (UTAUT), Technology Readiness Index (TRI), and Diffusion Of Innovation (DOI), this study developed an initial research model that identifies the dimensions of IR4.0 readiness; (i) organization, (ii) data, (iii) infrastructure, (iv) analytics, and (v) IT, development and operations. This study carried out qualitative methods through four different phases. The first phase is a systematic literature review, and data collection through participant observation (PO) in IR4.0 skills training programs, seminars, and workshops. The second phase is the development of an initial research model to identify the dimensions of IR4.0 readiness that will be used in the next phase. The third phase is a survey on SME's IR4.0 readiness via the IR4.0 e-Readiness Checker (IR4.0 eRC) readiness assessment system, which produces the final research model, IR4.0 SME Readiness Model. In the fourth phase, the IR4.0 Readiness Model is confirmed for use by SMEs in Malaysia through interviews with three industry experts in Malaysia. Based on the 50 responses in the IR4.0 eRC evaluation, the average IR4.0 readiness of SMEs is 66%, and only 10 SMEs with less than 50%, showing room and improvement opportunities for the continuous research and development of IR4.0 transformation. This study developed IR4.0 readiness model for SMEs to assess readiness for IR4.0 transformation, support investments in IoT projects and employee upskilling programs.

Keywords: digital transformation; IR4.0; self-readiness; diffusion of innovation; SMEs

Introduction

In the 4IR National Policy in Malaysia, Industrial Revolution 4.0 (IR4.0) is a disruptive transformation in industry through new technologies that affected many sectors, industry and economy. The technologies are Artificial Intelligence (AI), Internet of Things (IoT), Blockchain, Cloud Computing, Big Data Analytics, and Advanced Technology. Meanwhile, in a dynamic modern businesses, IR4.0 is essential for small and medium-sized enterprises (SMEs), such that from market structure to the production, use and management, IR4.0 can give changes (Sabo et al., 2024). For example, fast decision making, advanced shop floor monitoring, and demand forecasting (Hernandez et al., 2020). By automating routine tasks and using real-time data insights, SMEs can allocate their resources more effectively, ultimately leading to cost savings and increased profits (Bandari, 2019). Therefore, SMEs need to assess their readiness to identify capabilities and areas for improvement to remain competitive. This is because IR4.0 readiness assessment tool is expected to measure employees' readiness towards the IR4.0 challenges (Demong et al., 2021), such as high investments and expertise (Saleh et al., 2023). But, research gaps found the readiness assessment is applicable to big company (Brozzi et al., 2018), long assessment process (Zaidi et. al., 2021; Saleh et. al., 2022), bias (Mohd et. al., 2022; Leang et. al., 2023), and need for external consultation (Choi et. al., 2018; Saleh et. al., 2022), such as Industry4WRD Readiness Assessment (MITI, 2018) and IMPULS Industry 4.0 Readiness Online Self-Check for Businesses.

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The concept of IR4.0 has gained global recognition and adoption when Schwab (2017) highlighted its transformative potential. IR4.0 primarily aims to enhance the automation and integration of cyber-physical and biological systems. For instance, Malaysia has implemented AI and robotics to clean the market floor, transport chickens from trucks to hawker stalls, and manage waste intelligently (MOSTI, 2023). Cloud computing and analytic data empower business to make decision based on data for a better product quality and customer satisfaction (Ali et. al., 2021). Sabo et al. (2024) observed, businesses that use big data will get better understanding on market and customer needs. As a result, businesses of all sizes, including SMEs, face both challenges and opportunities to adopt these technologies (Telukdarie et al., 2023). SMEs plays important role in global economy but they often in difficulties to adopt digital transformation and IR4.0 such as limited financial resources, lack of expertise, and resistance to changes (Ganapathy, 2018; Jayashree et. al., 2019; Halili et. al., 2022; Lim et. al., 2023; Singaram et. al., 2023). This is opposite to the big company that have big budgets and information technology department, while SMEs struggle to occupy sources for the technology implementation (Vuong et. al., 2021; Balakrishnan et. al., 2021; Ali et. al., 2023). Readiness model is proven as a tool to measure readiness dan organization progress in adopting new technologies (Chen et al., 2023).

Ganapathy (2018) stated that industry sectors significantly SMEs in Malaysia are still not ready to adopt IR4.0 technologies. This is because IR4.0 use rate among Malaysia industries is low with only 15% to 20% only (Kaur, 2019). Meanwhile, there are industry players with low confidence to use the IR4.0 due to lack of strategy, leadership, resources, skills, understandings about IR4.0, unfit instrument, environment technologies and organization (Jayashree et. al., 2019; Pirola et. al., 2020; Ghobakhloo et al., 2022; Sabo et al., 2024). Sario (2019) asserted, even though Malaysia follow the IR4.0 policy (Industry4WRD), it will take 12 years to be in the same level with developed countries such as German and Japan. In addition, from the knowledge and understanding perspective, Sony et al. (2020) and Hizam et al. (2020) agreed that there are no generic understandings to measure IR4.0 readiness. Since achieving IR4.0 readiness is key for the industry today (Hizam et. al., 2020), a model of IR4.0 readiness is necessary to allow industry players identify precedents and antecedents in this digital transformation process.

This study aims to identify factors adopting IR4.0 among SMEs, develop IR4.0 readiness model and validate it with industry experts in Malaysia. SMEs can use the model to determine their improvement in implementing IR4.0 technologies in the process hence concluded the IR4.0 readiness. It also aids policymakers in developing new policies and programs to support IR4.0 transformation, prioritizing investments in infrastructure and training programs, fostering a thriving IR4.0 ecosystem in Malaysia.

This paper comprises a literature review, methodology, results, discussions, and conclusion of the study, providing valuable insights into IR4.0 readiness assessment for SMEs and its potential for enhancement.

Literature Review

IR4.0 Overview

IR4.0 is derived from the German term 'Industrie 4.0', refers to an intelligent network of interconnected machines and processes, powered by ICT (Economic Planning Unit, 2021). According to McKinsey (2022), Industry 4.0 and IR4.0 both refer to the current era of connectivity, advanced analytics, automation and advanced manufacturing technologies that have transformed global business over the years. In addition, based on Malaysian national policy such as Industry4WRD has used the term Industry 4.0 and the targeted sector is manufacturing only. Meanwhile, for the National 4IR policy, it uses the term Fourth Industrial Revolution and targets all sectors other than manufacturing such as agriculture, education, construction, and real estate.

IR4.0 is enabled by technologies such as the IoT, AI, Big Data Analytics, Cloud Computing, Cyber-Physical Systems, Additive Manufacturing (AM), Robotics, Simulation, System Integration, and Virtual Reality (VR) (Vuong et. al., 2021; Saleh et. al., 2023; Sima et al., 2020). The technology enables intelligent production systems to increase efficiency, flexibility and competitiveness by

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reducing downtime, minimizing resource waste, and fostering a more environmentally friendly approach in IR4.0 settings (Osterrieder et. al., 2020; Çınar et. al., 2020). For example, Cloud Computing enable SMEs to process and store large volumes of data generated by IoT devices and other sources and facilitate collaboration, data sharing and remote access to information (Oztemel et. al., 2020; Das, 2023). Big Data Analytics can predict future actions, optimize production processes, improve product quality and improve customer experience by identifying patterns and correlations (Ali, 2023). Meanwhile, Robotics helped the survival of SMEs during the COVID-19 pandemic, by increasing manufacturing automation due to the lack of foreign workers at that time (Bernama, 2022).

IR4.0 is introduced with the policies such as Germany: Industrie 4.0, Industry4WRD (MITI, 2018), National 4IR (MITI, 2021), Making Indonesia 4.0, Thailand 4.0, Indonesia Industry 4.0 Readiness Index (INDI 4.0), and Smart Industry Readiness Index (SIRI) (Musyarofah et. al., 2022). The similarities is to project the IR4.0 adoption and increase the Gross Domestic Product (GDP), but vary based on priorities and contexts of each country in objectives, strategies and implementation. For instance, according to the European Commission (2017), an IR4.0 policy has been published that targets manufacturers, producers, SMEs and policy makers to provide a consistent and reliable framework for developing Germany's competitive position in the manufacturing sector through recommendations and actions. Meanwhile, Industry4WRD aims to promote collaboration among manufacturing industry stakeholders to address challenges and capitalize on identified enablers (MITI, 2018). Making Indonesia 4.0 is purposed to increase the contribution of the industrial sector to more than 30% of the country's GDP (Pratiwi, 2021).

SMEs in IR4.0

Commonly defined as companies with fewer than 100 employees, SMEs are vital for economies, recognized as such since 1981 by Research Professor David Birch (Yuik et al., 2020). Factors such as nation's economic development, population size, and varying employee counts categorize companies as micro, small, or medium enterprises (Ismail et al., 2022). SMEs is a micro-enterprises with fewer than 10 employees, small enterprises with fewer than 50 employees, and medium-sized enterprises with fewer than 250 employees (OECD, 2023). In Malaysia, SMEs are characterized as firms with sales below RM50 million or 200 employees, with service SMEs having sales below RM20 million or 75 employees (SME Corp Malaysia, 2024).

SMEs are easy to establish, require minimal resources, operate from small offices, family-owned, relying more on local clients and suppliers, and leading to higher presence in rural regions (Ismail et al., 2022). A key advantage of SMEs is their ability to quickly respond to local market trends and changes in customer preferences. For instance, during COVID-19 pandemic, SMEs effectively leveraged digital marketing platforms and cloud-based technologies to identify new customers and develop online ordering systems rapidly, ensuring their survival in an evolving market landscape (Klein et al., 2021). SMEs are more likely than large businesses to introduce new products and services (Caballero, 2021). This is because, they are more agile, can respond more quickly to changes in the market, and have the ability to support companies in improving their own sustainability performance (Nirmalarajah, 2023; Kraut, 2024). But, limited resources in SMEs make them vulnerable to skilled employee recruitment and research, limiting their adaptability to technological advancements and industry trends (Rao et al., 2023).

In addition, SMEs are the largest source of job creation in most economies (Chege et. al., 2020). In Malaysia, SMEs account for over 99% of businesses, employ 60% of the workforce, create two-thirds of new jobs each year, and contribute over 40% of GDP (SME Corp Malaysia, 2022). The World Bank (2023) emphasizes that SMEs, which comprise 90% of businesses and more than 50% of jobs worldwide, are important for job creation and economic development. This is because, SMEs contribute to more than 55% of GDP and 65% of jobs in high-income countries, 60% in low-income countries and 70% in middle-income countries (Mahidin, 2019; Ratanova et. al., 2021; Ismail et al., 2022; Sari et al., 2023). Following that, SMEs promote exports and help increase the country's foreign exchange reserves, and in 2021, SMEs contribute more than 20% of Malaysia's total exports (SME

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Corp Malaysia, 2022). Significantly, rural firms such as SMEs have increased their export capabilities and developed goods or services suitable for export (Phillipson et. al., 2019).

IR4.0 Readiness

IR4.0 readiness is influenced by factors such as having the necessary technology infrastructure, a skilled workforce, innovation capabilities, effective data management, robust cyber security measures, a supportive regulatory framework, an organizational culture that promotes continuous learning and adaptability, and a strategic vision which is in line with the IR4.0 Principle (Geissbauer et al., 2016; Dalenogare et al., 2018). Evaluating IR4.0 readiness involves evaluating those factors to determine the extent to which an organization or entity is prepared to take advantage of the opportunities presented by the fourth industrial revolution (Liao et al., 2017; Deschamps et al., 2017; Müller et al., 2018).

Optimizing financial allocation and human resources ensure investment is aligned with strategic business objectives and technology deployment plans (Hindarto, 2023). This is because effective resource management increases the return on investment for IR4.0 initiatives, supporting long-term viability and success (Lok et. al., 2022). However, limited budgets can prevent SMEs from investing in advanced technology and infrastructure, especially those related to IR4.0 (Tay et. al., 2021; Muhamad et al., 2023) due to large initial investment (Alam et al., 2020; Khor et al., 2020; Gomes et al., 2023). Such investments not only include the technology itself but also infrastructure, training, and potential process modifications (Mulu et al., 2021; Hang, 2021; Dixon et al., 2023; Qatawneh et al., 2024). The uncertainty of the return on this investment, especially in the initial phase, adds to the reluctance of SMEs to allocate their limited budgets (Tay et. al., 2021).

In order to achieve successful IR4.0 integration, SMEs need to prioritize improving their technology infrastructure (Silva et. al. 2021). This involves development of new hardware, software and network capabilities for interconnected and data-driven technologies such as cloud computing, big data analysis, AI, IoT, AM and robotics (Haseeb et al., 2019). Akbari et. al. (2019) emphasized, SMEs face challenges in accepting IR4.0 due to their lack of infrastructure, such as high-speed Internet and cloud computing. This is because, replacing old IT infrastructure is expensive, which is a concern for all companies (Teichmann et al., 2023). One of the main obstacles of blockchain technology is the computing infrastructure, extensive data storage, and intensive energy use (Alazab et al., 2024). The development of IR4.0 technology is also complex and risky (Rafikov et al., 2020; Balakrishnan et al., 2021; Kaur et al., 2023) due to the required flat structures, short paths, and free space to realize ideas, while highly controlled structures prevent digitization (Wolf et al., 2018). This can be caused by a lack of skills, even by SMEs in the developed country of China (Zhong et. al., 2019; Othman et al., 2022).

SMEs are often unfamiliar with the potential benefits of IR4.0 technology, such as improved productivity and quality, cost reduction, customer service, increased efficiency, enhanced flexibility and innovation capabilities (Boschmann et. al., 2019; Ritter et al., 2019; Wang et al., 2019). This is because, SMEs lack insight into the broad potential of IR4.0, including its capacity to enable product customization, refine supply chain management and reduce operational costs (Kshetri, 2019). Such knowledge is important to avoid the potential failure of IR4.0 adoption (Ismail et al., 2023) in terms of cyber security vulnerabilities, data quality and integrity, Return of Investment (ROI), new workforce, and skill gaps (Kim et al., 2012; Ariffin et al., 2021; Amer et al., 2023; Bahri et al., 2023). Therefore, the common reluctance among SMEs to adopt IR4.0 often stems from a lack of awareness of the results it can provide (Thakur et. al., 2019). Adamik's study (2020) shows that, although Polish SMEs are aware of the benefits of modern solutions, there is still a lack of knowledge about IR4.0 requirements and an average use of tools. Although SMEs are aware of its benefits, they are still reluctant to upgrade and take advantage of IR4.0 technology due to financial budget constraints (Yong, 2023).

With the influx of data from interconnected devices, SMEs need to strengthen their data management and analytics capabilities. Effective data management involves the collection, storage and analysis of data to obtain valuable insights that inform strategic decision-making (Yin et. al., 2019). By enhancing data capabilities, SMEs can optimize operational efficiency, anticipate market

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trends and deliver personalized customer experiences (Chan et. al., 2020). Improving those skills requires continuous training (Cheng et al., 2024). Arthur et al. al. (1995) found that training has a positive effect on employee performance, with an average effect size of 0.35 which is a 14% improvement. Training for digital competence is positively associated with SME innovation in terms of developing new products, processes and markets (Haseeb et al., 2019). However, according to Yong (2023), SMEs admit that releasing employees from duty due to reskilling and skill improvement training will leave a much-needed void in operations.

Cultural factors play an important role in organizational readiness for IR4.0 (Maskun et. al., 2020; Zaidi et. al., 2021; Saleh et. al., 2023). A culture that emphasizes innovation, collaboration, adaptability and flexibility is essential for companies to successfully transition to IR4.0 (Ahmad et. al., 2020; Vasudevan et. al., 2021; Latif et. al., 2023). For example, a culture that fosters open communication since IR4.0-related systems require cross-functional collaboration (Galipeau, 2023). Besides, SMEs that accept change and quickly adapt to new processes and technologies are better prepared for IR4.0 (Sánchez-Báez et al., 2020; Abd Shukor et al., 2023). Lok et al. (2022) emphasized data-driven leadership in both the manufacturing and non-manufacturing sectors in the era of IR4.0. SMEs that are now increasingly placing their business platforms on Shopee and TikTok (Hasim et al., 2022) can take actions such as increasing the frequency of direct sales (livestream selling) when the percentage of customer engagement data (customer engagement data) is low.

Theories of IR4.0 Adoption

Understanding theory is important for this initial research model while Logan et al. (2014) stated, theory is a fundamental to knowledge for advanced learning in academic discipline. Various theories support technology readiness assessment including IR4.0 used in previous studies, such as the Acceptance Theory, the Unified Theory of Acceptance and Use of Technology (UTAUT), the Technology Readiness Index (TRI), and the Diffusion of Innovation Theory (DOI). These theories will help in the development of the initial research model in which the dimensions of IR4.0 readiness will be determined.

TAM is developed by Davis in 1989, focuses on users' adoption of new technology or information systems. TAM emphasizes the significance of perceived usefulness and ease of use in influencing users' attitudes and acceptance of a system. Various studies have used TAM to understand user acceptance across different domains, such as language learning, internet banking, and the digitization of the accounting profession (Awang et al., 2022). Meanwhile, TRI helps researchers and businesses understand consumer attitudes toward technology. It comprises five dimensions; Optimism, Innovativeness, Discomfort, Insecurity, and Resistance. Researchers have applied TRI to assess the IR4.0 readiness such as solar adoption among Malaysian SMEs (Hassan et al., 2023).

UTAUT is a comprehensive framework that integrates eight models related to technology acceptance. It focuses on four key factors influencing technology acceptance; performance expectancy, effort expectancy, social influence, and facilitating conditions. This theory has been applied in assessing residents' willingness to use e-money and understanding factors affecting the intention to use electric vehicles and wearable devices (Chen et al., 2023). Additionally, DOI theory categorizes users into five groups: Innovators, Early Adopters, Early Majority, Late Majority, and Laggards through factors of perceived advantage, complexity, and compatibility. DOI is pivotal in understanding how innovations are adopted and diffused in societies (Shaikh et al., 2023). Early adoption of IR4.0 can be facilitated by addressing concerns about complexity, discomfort, user-friendly interfaces, ease of learning, and new technologies through effective communication such as IR4.0-RA and active participation. These theories will help in the development of the initial research model in which the dimensions of IR4.0 readiness will be determined.

IR4.0 Readiness Model

The concept of readiness models dates back to NASA's Technology Readiness Model, which emerged in 1974 but was publicly published in 1989 (Sadin et al., 1989). The model places the readiness of any component on a scale of 1 to 9 (Eljasik et. al., 2019). Then, several studies have been

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presented to extend other readiness assessment models such as the IR4.0 maturity model (Schumacher et al., 2016), AI readiness model (Tinholt et. al., 2019), technology readiness model for SMEs (Saad et. al., 2021), a blockchain readiness model for the banking industry (Ozturan et. al., 2019), and a smart hospital readiness model (Ronaghi, 2024).

Another example, a readiness model in a Hungarian industrial area was carried out by Nick et. al. (2019) is based on 99 questions which are divided into three sources of questions; 16% of the NTP Working Group introducing aspects of education, training, employment and access to financial resources, 18% of the VDMA framework consists of the company level, and 66% of the author's interviews about industry people. The readiness model developed by Lucato et. al. (2019) is based on the basic structure by the Society of Automotive Engineers (SAE) J4000. Alcácer et al. al. (2021) instead adapted the IMPULS maturity assessment model of which six dimensions were selected as their IR4.0 digital transformation research model. The IR4.0 readiness model empowers SMEs by providing a proactive and comprehensive approach to assessing their own capabilities. This can determine the areas they need to improve to adopt IR4.0 technology (Ritter et. al., 2019; Boschmann et al., 2019; Wang et al., 2019), and the challenges (Peña et. al., 2020). Therefore, SMEs can learn the best practices for adopting IR4.0 technology (Azevedo et. al., 2023).

Germany and Malaysia developed evaluation models for their IR4.0 policies. Germany's IMPULS (Figure 1) measures readiness in areas of strategy, operations, products, and workers, but is not for other sectors than manufacturing and mechanical engineering. Malaysia's Industri4WRD Readiness Assessment (Figure 2) assesses readiness in five dimensions through seven steps, targeting manufacturing sectors with valid business licenses. Both models are useful for SMEs in assessing their readiness for IR4.0, but provide recommendations for improvement such as expand scope, inclusivity, and flexibility.

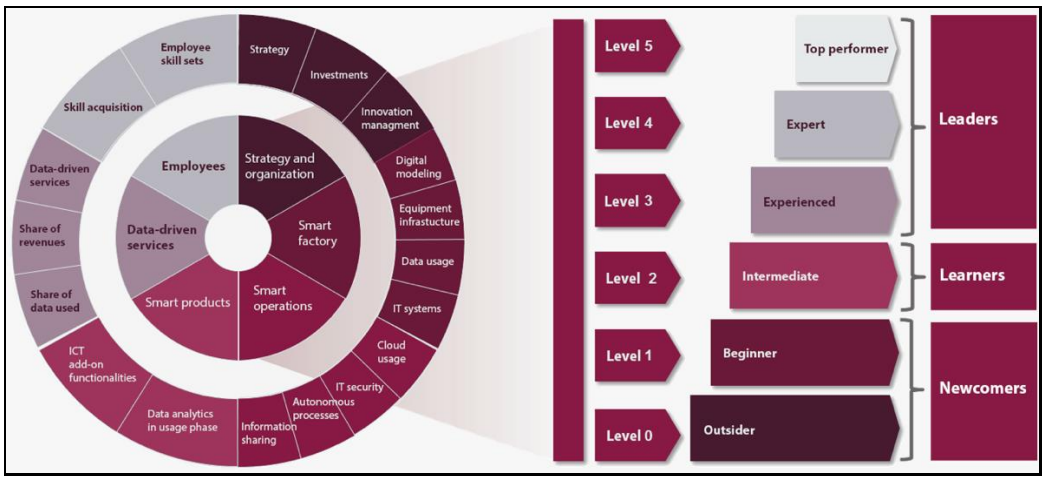

Figure 1. IR4.0 IMPULS self-assessment model (VDMA, 2021).

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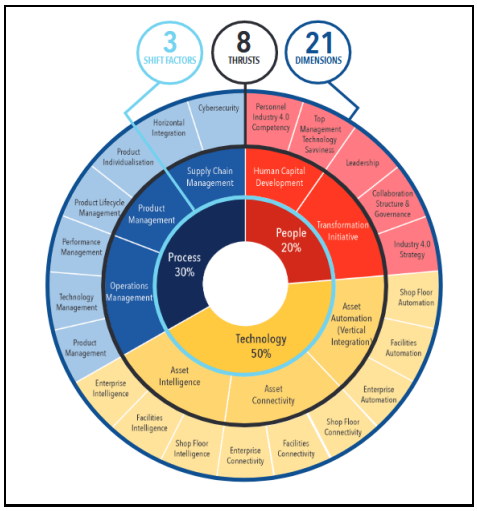

Figure 2. Industry4WRD evaluation model (MITI, 2018).

Both IMPULS and IR4.0 maturity model by Schumacher et al. (2016) have the same two dimensions of IR4.0 readiness; Strategy and Operations, showing that there is still no standard for IR4.0 readiness. Ashley (1990, p. 107) states, the term dimension is used to focus on the methodology of knowledge representation to represent factors, while the term factor is focused on what is to be represented, a stereotyped pattern of facts that tend to strengthen or weaken the party's legal claim. This means that, in the context of IR4.0 readiness, dimensions provide a framework for assessment, while factors are specific elements assessed within each dimension. Dimensions can also be considered as process areas (De Carolis et al., 2017) which are aspects in the company to be evaluated such as IT security, production processes and organization, and tems are detailed parts of each dimension to be evaluated individually with regard to digitalization (Brozzi et tal., 2018).

Saad et al. al. (2021) argue that the IMPULS model, which saves time and uses online tools, is not suitable for SMEs because of its difficulty in achieving high scores, placing them at Level 0. Rahamaddulla et. al. (2021) added, including advanced manufacturing technology criteria in the IR4.0 readiness assessment makes SMEs lag behind and considered "outsiders". In contrast to Harmoko (2020) who concluded that IMPULS is the most appropriate model to measure the readiness of SMEs in IR4.0. Apart from the IR4.0 policy in Germany, the policy in Singapore has resulted in an IR4.0 readiness index called SIRI. It was developed by the Singapore Economic Development Board in 2018, to assess the readiness of manufacturing companies in Singapore to incorporate IR4.0. The index can be used as a reference to develop an IR4.0 readiness assessment model based on 16 dimensions.

The Industry4WRD Readiness Assessment (Figure 2.10) by MITI Malaysia assesses the organization's readiness for IR4.0 through five dimensions namely Strategy, Infrastructure, Technology, Process and People. It is part of the Malaysian government's Industry4WRD policy, which targets the manufacturing sector with a valid business license and operating for more than three years. MITI offers a free assessment application on their website, followed by a visit to the applicant's premises, providing a report on readiness and recommendations for the implementation of IR4.0, and additional support for companies. The readiness and scoring profile has five levels: conventional (0%-20%), newcomers (21%-40%), students (41%-60%), experienced (61%-90%), and leaders (91 % -100%). Companies at the conventional level are considered ready to adopt IR4.0, while at the lower level they are only interested in continuing the application with plans and strategies. It should be noted that the process of this evaluation system does not have its own characteristics. So, Rahim et al. (2021) suggested that Malaysia provide skill development in 5G technology applications with specific skill sets and competencies that can accelerate the adoption of 5G system network applications and meet the important objectives of the Industry4WRD strategy, vision and mission. Because fast Internet networks such as those offered by 5G can help SMEs assess IR4.0 readiness autonomously and effectively.

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Methodology

Phase 1: Preliminary Study

a. Systematic Literature Review (SLR)

In the initial phase of the study, SLR was conducted using six well-respected online databases, Emerald Insight, IEEE, Science Direct, Scopus, Springer, and Web of Science. Then, the keywords are loaded in the search of each database using the Boolean operators AND and OR; Industrial Revolution 4.0, IR4.0, readiness model, driving factors, inhibiting factors, self-evaluation, and SMEs. The aim is to identify articles and research papers that addressed IR4.0 readiness. To streamline the search process, inclusion and exclusion criteria (Table 1) are used, ensuring the relevancy to align with the research objective of identifying the factors and models for industry IR4.0 readiness. This initial study has referring to the SLR methodology of Hizam et al. (2020) and Wippel et al. (2021) to identify and develop IR4.0 readiness models.

Table 1. Inclusion and Exclusion Criteria for the SLR Process.

Inclusion Criteria	- Directly or indirectly address any one or more research questions. - Focus on the development of IR4.0 readiness assessment models. - Published between 2017 and 2021.
Exclusion Criteria	Exclude books, articles unrelated to the research field, articles containing only abstracts with no full text available, and those not meeting the inclusion criteria.

b. Data Collection

Observation, especially participant observation, has been used in various disciplines as a tool to collect data about people, processes and culture in qualitative research (Kawulich, 2005). Participant observation (PO) is a field approach to collecting data where researchers enter a specific site for the purpose of engagement or observation (Hurst, 2023). Therefore, as a method of collecting research data, researcher have made observations by engaging in activities directly related to IR4.0 such as skills training, exhibitions, workshops, and seminars. This is to gain a deep understanding of the challenges and opportunities in the real reality of SMEs adopting IR4.0. For example, new sources of finance and manpower. In addition, researcher is able to have real experiences like other SMEs in Malaysia who intend to change their company's operations to the IR4.0 version, such as the use of machine communication with IoT, and real-time monitoring systems.

The results of the engagement produced the latest unbiased observations about the low adoption and use of IR4.0 technology among SMEs in Malaysia, and the importance of overcoming it through skills training programs and funds. Bias or inaccurate perception of individuals or groups, often shaped by our experiences, influencing behaviour towards others, and can lead to stigma and discrimination where individuals are misrepresented and treated unfairly (Kirk et al., 2020). This is because, the observation is in line with the latest findings such that in the year 2023 to 2024, out of 906,814.64 SMEs in Malaysia, only 21,591 have adopted digitization through the 100 Go Digital Malaysia Digital Economy Corp (MDEC) initiative (TMEF, 2024). To the best of this study's knowledge, there has no previous research on the topic of IR4.0 readiness model development that uses the PO method. Therefore, this study is expected to contribute to knowledge and research in this field about the reality of the role of training programs and funds in IR4.0 transformation by industry players, especially SMEs.

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The researcher participated in a two-days data analytics workshop to utilize IBM-SPSS in handling complex and big data in an operation. After that, the researcher involved in a two-month training program focused on IR4.0 skills at the Selangor Human Resource Development Centre (SHRDC). The program is for university graduates and job seekers with backgrounds in electrical or mechanical engineering. The training covered essential modules such as introduction to IR4.0 fundamentals, electric motor control, sensors and transducers, data generation, IoT gateway, lean manufacturing, manufacturing process optimization, Overall Equipment Effectiveness (OEE), and essential Programmable Logic Controller (PLC).

In addition to the training, the researcher participated in Kuala Lumpur City Centre (KLCC) exhibitions themed 'SMEs 4.0: Moving Up in the Manufacturing Value Chain'. The exhibition aims to promote automation and digitalization in traditional manufacturing processes, including among SMEs, to enhance the Malaysian manufacturing industry's competitiveness and facilitate discussion and information exchange. Lastly, the researcher became a part of the LaunchX Accelerator Program, organized by Sunway University, which served as a valuable platform for guiding and fostering the entrepreneurial journeys of student entrepreneurs in new technologies and innovations.

Phase 2: Development Of IR4.0 Readiness Model for SMEs

The second phase of this research methodology has developed an initial study model as shown in Figure 3, which combines the factors and theory of technology IR4.0 acceptance by SMEs. This method has also been implemented in the study by Venkatesh et al. (2003). Therefore, the dimensions of IR4.0 readiness can be identified in addition to referring to IoT readiness by TWDI Research (Halper, 2016). This is because, the IR4.0 readiness dimension assessment is an assessment of an organization's IR4.0 readiness level that can help identify their strengths and weaknesses, and develop plans to improve their IR4.0 readiness (Hermann et. al., 2016). The assessment can also help SMEs meet production deadlines, expand into new markets and attract investors by identifying opportunities for digital technology upgrades, workforce skills and innovation readiness for the future of manufacturing (Oztemel et. al., 2020). The use of those dimensions is used in the IR4.0 eRC as a survey tool in the next phase.

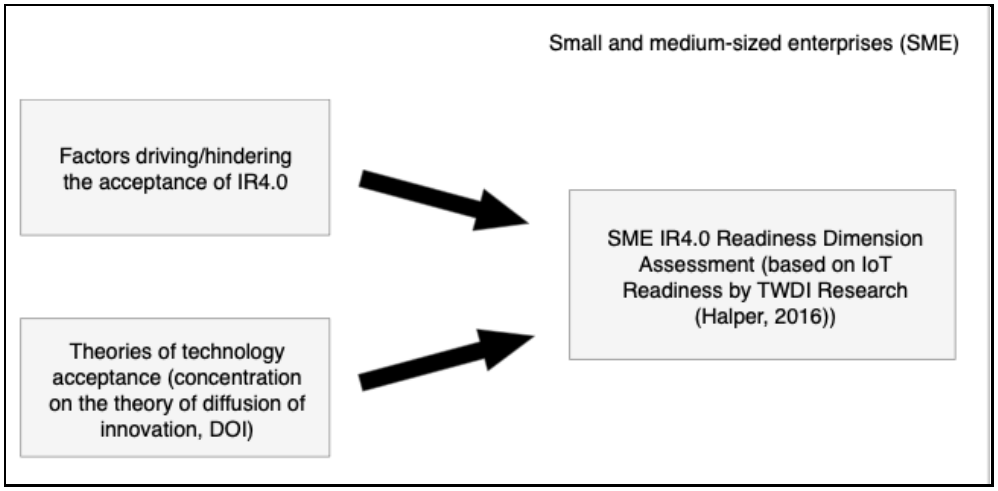

Figure 3. The initial model of the study.

Phase 3: Development of System for the IR4.0 Readiness Model

The development of IR4.0 eRC readiness assessment system through a web in this phase is a survey tool to test the use of IR4.0 readiness dimensions among SMEs. This is because, the survey web allows users to explore the collected survey information in more depth, as well as update or add entries for the survey (Crnovrsanin et al., 2023). The system is an assessment to measure the readiness of IR4.0 among SMEs based on the identified dimensions of IR4.0 readiness (refer Figure 3). Through the Xojo platform and SQL database, the system was developed online. The results of the 50 responses

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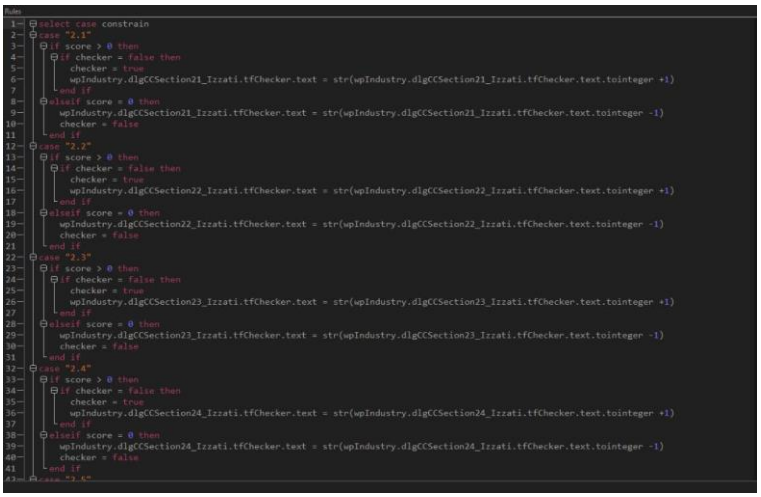
participated in the assessment will be discussed, such as their demographic situation, and their dimensions of IR4.0 readiness. The results hence produced the final model, IR4.0 SME Readiness Model which refined the initial model of the study.

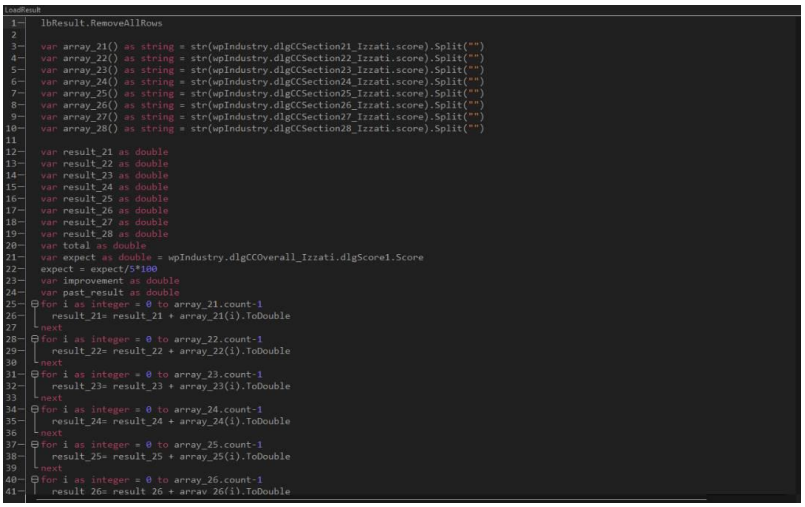
Figure 4 (a) depicts the Xojo programming for assigning scores to response choices in assessment questions (Figure 5). The choices range from 'Strongly Disagree' (score is 1) to 'Strongly Agree' (score is 5). The program stored all of the response choice values so that it could calculate the assessment results, as shown in Figure 4 (b) and (c). Equation (1) shows the formula used to assess the evaluation results. Figure 4 (d) shows the programming used to provide training and recommend funding to respondents at the end of the assessment interface. This required a .csv file from the data collection of the SME company in Malaysia, stored in SQL database so that the program could access it. Meanwhile, a SQL database is required to store user data for analysis purposes, including suggestion of training programs and funds in Malaysia during end of assessment. SQL database enables structured data management, allowing for smooth storage, retrieval and manipulation of relevant user data. Through the integration of Xojo platform and SQL database, IR4.0 eRC can collect, organize and analyze user data, and calculate the percentage of IR4.0 readiness rating.

$$(x/y/5)*100 \quad (1)$$

x = input score value based on response choice
y = number of questions in the section



(a)



(b)

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```
LoadResult
48  elseif wpIndustry.dlgCCSection27_Izzati.RadioGroup1.SelectedIndex = 0 then
49    result_27=1.0*100
50  end if
51  for i as integer = 0 to array_28.count-1
52    result_28= result_28 + array_28(i).ToDouble
53  next
54  result_21 = result_21/5/5*100
55  result_22 = result_22/5/5*100
56  result_23 = result_23/5/5*100
57  result_24 = result_24/5/5*100
58  result_25 = result_25/3/5*100
59  result_26 = result_26/8/5*100
60  result_28 = result_28/8/5*100
61
62  lbResult.AddRow("Section 2.1", format(result_21,"##.00") + " %")
63  lbResult.AddRow("Section 2.2", format(result_22,"##.00") + " %")
64  lbResult.AddRow("Section 2.3", format(result_23,"##.00") + " %")
65  lbResult.AddRow("Section 2.4", format(result_24,"##.00") + " %")
66  lbResult.AddRow("Section 2.5", format(result_25,"##.00") + " %")
67  lbResult.AddRow("Section 2.6", format(result_26,"##.00") + " %")
68  lbResult.AddRow("Section 2.7", format(result_27,"##.00") + " %")
69  lbResult.AddRow("Section 2.8", format(result_28,"##.00") + " %")
70
71  total=(result_21+result_22+result_23+result_24+result_25)/5
72
73  'lblReadiness.Text="IR4.0 Readiness"+endofline+"%"+format(total,"##.00") + " %"
74  lblReadiness_Expectation.Text="IR4.0 Readiness Rated Expectation"+endofline+"*****"+format(expect,"##.00") + " %"
75  lblReadiness_Challenges.Text="IR4.0 Challenges"+endofline+"****"+format(result_26,"##.00") + " %"
76  pbReadiness.Value=Floor(total).ToString.ToInteger
77  pbReadiness_expectation.value = floor(expect).ToString.ToInteger
78  pbReadiness_Challenges.value = floor(result_26).tostring.ToInteger
79  if total >= 90.0 then
80    lblReadiness.text = "IR4.0 Readiness"+endofline+"*"+format(total,"##.00") + " %" + endofline +"**"+ "Very Ready / Sangat Bersedia"
81  elseif total <= 89.0 and total >= 50.0 then
82    lblReadiness.text = "IR4.0 Readiness"+endofline+"*"+format(total,"##.00") + " %" + endofline +"**"+ "Ready / Bersedia"
83  elseif total <= 49.0 and total >= 25.0 then
84    lblReadiness.text = "IR4.0 Readiness"+endofline+"*"+format(total,"##.00") + " %" + endofline +"**"+ "Not Ready / Tidak Bersedia"
85  elseif total <= 24.0 and total >= 0.0 then
86    lblReadiness.text = "IR4.0 Readiness"+endofline+"*"+format(total,"##.00") + " %" + endofline +"**"+ "Extremely Unprepared / Sangat Tid
```

(c)

```
LoadTraining
1   lb_Training.RemoveAllRows
2   ProgramOutline.RemoveAll
3   var sql as string = "SELECT Recordid,ProgramName,programoutline FROM training_list"
4   var rs as rowset
5
6   Try
7     rs = session.dbConn.SelectSQL(sql)
8     if rs <> nil and rs.RowCount<> 0 then
9       for each row as DatabaseRow in rs
10
11        lb_Training.AddRow(row.Column("Recordid").stringvalue,row.Column("ProgramName").stringvalue)
12        programoutline.Add(row.column("programoutline").stringvalue.Left(60))
13
14      next
15    end if
16  Catch error As DatabaseException
17    MessageBox(error.Message)
18  End Try
```

(d)

Figure 4. Programming of (a) scoring, (b, c) calculation of evaluation results, and (d) proposed training and funding.

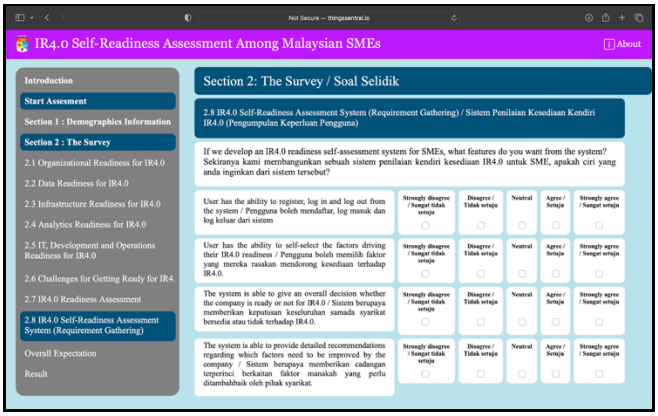

Figure 5. IR4.0 eRC front end.

Phase 4: IR4.0 Readiness Model and System Validation

Validating the IR4.0 readiness assessment model with experts is important (Bockstaller et. al., 2003) for several reasons. Among them is that experts have the necessary knowledge and experience (Balakrishnan et. al., 2021; García et. al., 2023) to assess the validity and accuracy of the model (O'Keefe et. al., 1993; Yezhebay et. al., 2021), based on their deep understanding of the IR4.0 needs (Halili et al., 2022). The interview method with experts has also been used in the IR4.0 readiness study by Schumacher et al. (2016) to support the initial assumption of the study on the problems when implementing IR4.0 in operation. Wippel et al. (2021) also confirmed the study model through interviews with experts.

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In the final phase, final model validation is carried out with industry experts, such as professionals from SHRDC and German Malaysian Institute (GMI). This validation step affirmed the robustness and applicability of the model and system among SMEs in Malaysia. Further, the findings from expert validation can be used to benchmark SMEs' readiness levels against industry standards and best practices. This enables SMEs to assess where they stand relative to their peers and competitors, facilitating informed decision-making and goal-setting.

Results and Discussion

IR4.0 Readiness Model For SMEs

The SLR process sifted through 10,428 articles, identifying 13 that met criteria. Of the 13 selected articles, only six developed IR4.0 readiness model, utilizing dimensions, sub-dimensions, scoring, and verification methods, despite different development phases sectors such as manufacturing, railway, and logistics (Table 4). The articles primarily focus on evaluating the readiness of IR4.0 among industry players, particularly SMEs, using survey tools, questionnaires, or models.

Table 4. IR4.0 readiness assessment model.

Model Name	Model Development Phase	Model Features
IR4.0 Readiness Degree Model (Lucato et al., 2019)	1. Literature review 2. Model development	Sector: Manufacturing Dimension: 6 Item: 52 Readiness level: Likert scale (0 – 3) Scoring: Readiness degree
Industry 4.0 Maturity Model (Schumacher et al., 2016)	1. SLR 2. Expert interview 3. Conceptual model 4. Model validation 5. Model testing 6. Case study	Sector: Manufacturing Dimension: 9 Item: 62 Readiness level: Likert scale (1 – 5) Scoring: Formula define
Industry 4.0 Technology Implementation Model (I4.0TIM) (Wippel et al., 2021)	1. SLR 2. Online survey 3. Model development 4. Model validation	Sector: Railway Dimension: 5 Item: 45 Readiness level: Likert scale (1 – 5) Scoring: Weightage
Logistics 4.0 Maturity Model (Oleśków et al., 2019)	1. Literature review 2. Model development 3. Model testing	Sector: Logistic Dimension: 3 Item: 21 Maturity level: 5 (Ignoring, Defining, Adopting, Managing, Integrated)

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acatech Industrie 4.0 Maturity Index (Zeller et al., 2018)	1. Literature review 2. Model development	Sector: Manufacturing Dimension: 4 Item: 24 Maturity level: 1-6
IR4.0 Self-Assessment Tool for Craftsmanship SMEs (Brozzi et al., 2018)	1. Literature review 2. Classification of existing IR4.0 readiness model characteristics 3. Model development	Sector: Carpentry Dimension: 3 Readiness level: Likert scale (1-5)

Lucato et al. (2019) developed a model to assess industrial companies' readiness for implementing IR4.0 technology, using the Society of Automotive Engineers J4000 standard on Lean Manufacturing. The model uses a four-level scale to measure the presence and effectiveness of various enabling technologies, including collaborative robots, additive manufacturing, augmented reality, simulation, system integration, IoT, cloud computing, cyber security, and data analytics. This shows that the model benefits from a well-established framework, providing a robust basis for the assessment and use a comprehensive approach ensures that all critical aspects of IR4.0 are involved. Meanwhile, a results vector and a radar chart are created for each technology to show its level of readiness. The visual tool makes it easier for SME managers to understand and communicate the company's level of readiness. The overall IR4.0 readiness level considers all these technologies through 12 algorithms. However, the model is not verified by experts or tool, which is acknowledged by Lucato et al. (2019) as his research challenge. This lack of validation may affect its credibility and the reliability of its assessments.

Schumacher et al. (2016) established an IR4.0 maturity model for the manufacturing sector, focusing on domain understanding, model architecture design, and field testing. The model includes nine dimensions: Product, Customer, Operations, Technology, Strategy, Leadership, Governance, and People. This provides a holistic view of IR4.0 readiness, but SMEs can find it difficult to carry out a detailed and multifaceted assessment, especially without substantial expertise and resources. The model has been tested in several companies to validate it for real-life applications and gather feedback for further improvements. Given the rapidly evolving nature of IR4.0 technology, the model requires regular updates to remain relevant. Keeping the model abreast of technological advances is important for its continued usability.

Wippel et al. (2021) evaluated the impact of IR4.0 implementation in maintenance, finding positive effects such as increased reliability, efficiency, and cost reduction. The Industry 4.0 Technology Implementation Model (I4.0TIM) guides railway operators to implement IR4.0 technology in rolling stock maintenance through five dimensions: Safety, Reliability, Availability, Ecology, and Economy. This can provide a significant assessment to SMEs in the maintenance sector, but there are challenges especially for operators who have limited resources or expertise in IR4.0 technology. Furthermore, the rapid evolution of IR4.0 technology necessitates regular model updates and continuous adaptability to ensure its long-term usability. The model involves four phases: maintenance strategy selection, technology maturity level selection, implementation decision-making, and future program planning, ensuring a structured process for IR4.0 implementation based on prerequisite factors and maturity levels. The model is verified by the subject of rolling stock maintenance experts. This can increase the credibility and reliability of the model. Expert feedback ensures the model is grounded in real-world practice and insights. However, such validation can also contain bias if experts have certain biases or experiences that do not fully represent the wider context of IR4.0 industry.

Oleśków et al. (2019) developed a Logistics Maturity Model 4.0 to determine alignment between a company's current processes, information systems, and management approaches with Logistics 4.0 solutions. The model is derived from extensive literature research and expert input and has not gone through a verification process by experts, reduce its credibility and use. Meanwhile, Industry 4.0

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Maturity Index by Zeller et al. (2018) offers a comprehensive approach for companies navigating their digital transformation journey. It assesses skills across four dimensions: resources, information systems, culture, and organizational structure, enabling companies to understand their capabilities and adapt to changing business environments, ensuring a balance between cost, capability, and benefits. This ensures a well-rounded assessment of a company's readiness for IR4.0. The model has validated by experts who are generally mentioned. Brozzi et al. (2018) developed a self-assessment model for small-scale handicraft companies involving three levels: literature review, metrics classification, and a self-assessment model adapted to the needs of carpentry. This focus ensures that the model is relevant and practical for SMEs. According to him, models with more dimensions have lower details, while models with more items are time-consuming. Brozzi et al. (2018) did not specify the use of his model validation process.

Models in Table 4 show lack of general coverage of non-manufacturing sectors and need more dynamic models to track progress and predict future readiness. The absent of standardization dimensions and scoring methods makes comparing different models difficult. Further research on unified frameworks and metrics for SMEs could facilitate cross-model comparisons and benchmarking. Significantly, most models use simple Likert scales, while others rely on weighted scores or maturity levels, hence, exploring advanced scoring mechanisms that account for nuances and interdependencies could improve accuracy such as fuzzy logic, multi-criteria decision analysis (MCDA), and machine learning.

Factors For SMEs Adopting IR4.0

This section continues the SLR findings on seven articles for the IR4.0 adoption factors among SMEs (Table 5). Additionally, the researcher's active participation propels, training and funding plays the main factor.

Table 5. IR4.0 readiness factors among SMEs.

IR4.0 readiness factors	Author
Source	Wippel et al. (2021), Zeller et al. (2019)
Infrastructure & Technology	Alcácer et al. (2021), Ali et. al. (2021), Caiado et al. (2020), Horvat et al. (2018), Lucato et al. (2019), Schumacher et. al. (2016), Soomro et al. (2021), Wippel et al. (2021), Brozzi et al. (2018)
Awareness	Halse et al. (2017), Tortora et al. (2021), Caiado et al. (2020)
Skilled workforce	Caiado et al. (2020), Alcácer et al. (2021), Wippel et al. (2021)
Culture	Schumacher et. al. (2016), Zeller et al. (2019), Horvat et al. (2018)
Strategy	Alcácer et al. (2021), Ali et. al. (2021), Schumacher et. al. (2016), Soomro et al. (2021), Tortora et al. (2021), Wippel et al. (2021), Horvat et al. (2018)
Innovation	Halse et al. (2017), Soomro et al. (2021), Tortora et al. (2021)
Organization	Soomro et al. (2021), Zeller et al. (2019), Horvat et al. (2018)
Management	Caiado et al. (2020), Horvat et al. (2018), Oleśków et. al. (2019)
Product & Operation	Brozzi et al. (2018), Alcácer et al. (2021), Schumacher et. al. (2016), Zeller et al. (2019), Oleśków et. al. (2019)
Collaboration	Halse et al. (2017), Horvat et al. (2018)

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For the resource, infrastructure and technology factors, awareness, skilled workforce, and culture (Table 5), are the same as those identified in Literature Review. Therefore, the findings and discussion will continue on the following strategy factors. For Strategy factor, Alcácer et al. (2021) revealed, one aspect that can contribute to the low level of average readiness is the fact that almost half of the study respondents (46,7%) do not have an IR4.0 strategy implemented or in development, and lack a corporate strategy as acknowledged by Wippel et al. (2021). Therefore, Tortora et al. (2021) suggested, SMEs continue to use current strategies and techniques, or accept changes through new products and IR4.0 organizational paradigms that allow to fully develop and grow. Meanwhile, Ali et al. (2021) asserted, Pakistan's retail industry should introduce IR4.0 through a comprehensive strategy, covering five technologies of 3D printing, big data analysis, cloud computing, IoT and robotics. Horvath et al. (2018) pointed out, SMEs that are most prepared for IR4.0 are those that fully implement their automation and digitization strategies. For example, Schumacher et al. (2016) proposed a strategy to implement the IR4.0 roadmap and business model. However, Soomro et al. (2021) insisted, larger and older organizations (more than 10 years) have better IR4.0 strategies.

For the Innovation factor, Halse et al. (2017) argued, the first step to implement or orient IR4.0 is to create a culture of innovation in the organization with employee involvement, while creating collaboration with other companies. Soomro et al. (2021) added, older SMEs (10 years and above) have better innovation than younger SMEs (3 to 5 years) in receiving IR4.0. Therefore, Tortora et al. (2021) stated that innovation policy guidelines at European, national and regional level have shifted to tools aimed at increasing the capacity of relationships between different organizations (businesses, universities, research institutions), due to closer collaboration with universities, research bodies, consultants and innovation managers can be key elements for the adoption of IR4.0 by SMEs in Italy. As for Organizational factors, Soomro et al. (2021) asserted, organizations over 10 years old are more willing to adopt IR4.0 technology, innovate, and have better leadership. This is because, Zeller et al. (2019) recorded, the level of effectiveness of a complex logistics process is dependent on organizational performance. Horvath et al. (2018) gives an example of organizing the product and logistics, which is by using the Radio Frequency Identification Tag database and the Cloud.

For Management factor, Caiado et al. (2020) stated, industry experts mention that technology and knowledge management are important for IR4.0 readiness. This is because, Horvat et al. (2018) revealed, the conceptual approach contributes to understanding the evolution of IR4.0 in a holistic perspective, which does not focus exclusively on the development or adoption of technology, but includes management and organization. This has been supported by Oleśków et. al. (2019) that management is a determinant of IR4.0 readiness. As for Product and Operation factors, Schumacher et. al. (2016) and Brozzi et al. (2018) put products and operations as dimensions of IR4.0 readiness by SMEs. Alcácer et al. (2021) added, SMEs that manufacture electronics-based products and equipment will find it easier to use digital modelling compared to transport and storage SMEs. Therefore, Zeller et al. (2019) said, manufacturing companies around the world recognize the high potential of IR4.0 to improve production efficiency. Oleśków et. al. (2019) acknowledge, assessing the logistics readiness of SMEs will help assess the logistics industry in Poland and provide data to analyse the relationship between a company's logistics readiness and its competitive position, size, growth rate, range of services, financial structure and level of international operations. Finally, for the Collaboration factor, Halse et al. (2017) considered the implementation of the IR4.0 concept as an open process that requires innovation capabilities in SMEs, as well as openness to collaborate with other companies. This is because, as stated by Horvat et al. (2018), IR4.0 has a high collaborative element, due to the relatively complex innovation process involved.

Therefore, the factors of SMEs' acceptance and rejection of IR4.0 significantly have an impact on the SME readiness to adopt IR4.0 technology in their operations. This requires a tool that is a model to help SMEs measure that readiness over time. However, depending on the study and the industrial setting, there is some difference in the specific factor that are deemed most essential. For example, technology might be paramount for a software company, while skilled workforce might be more crucial for a manufacturing firm. Hence, SMEs need to prioritize factors that can be adapted to their operational needs over time, so that transformation can be implemented in a structured and

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continuous manner. In addition, investment in factors can happen gradually and not comprehensively. This also opens up a new research space to build an IR4.0 readiness model that allows SMEs to choose factors to be evaluated at a certain time. This can narrow the scope and focus on the challenges faced by SMEs.

Initiative Factor

Active participation in IR4.0 activities, such as training, exhibitions, and workshops, is crucial for SMEs to gain experience and confidence in using technology, making it an initiative factor. Initiative is defined as self-starting and proactive behaviour to have a mediating effect (Hetzner et al., 20212), such as comprehensive road traffic injury prevention initiatives (Keefe et al., 2024). When change initiatives fail to meet the expected outcomes and implementation failures cannot fully explain the absence of positive findings, resistance to change or lack of change readiness are often considered as likely explanations (Dobson, 2001; Drzensky et al., 2012; Weiner, 2009). This study explores the role of active participation in building awareness, developing skills, and understanding the potential of IR4.0, as an initiative factor leading to successful IR4.0 transformation. Table 6 presents a summary of the researcher's findings regarding the readiness of SMEs in Malaysia towards IR4.0.

Table 6. Research findings regarding the readiness of Malaysian SMEs towards IR4.0.

Learning Aspects	Content
Insights and skills on how IR4.0 works in a company's operations or the production process of goods or services	Derived from research at SHRDC, where 99% of program participants had never used IoT and simulation applications such as NodeRED, FactoryIO, SFCEDIT, and Jaamsim before. However, the learning process is easy because the participants are engineering graduates who are used to using development applications. These applications are important in developing automation in factories.
SME readiness towards IR4.0	Low, obtained from SHRDC instructor exposure. Other challenges include the small size of the sector and few training program participants attending individually, indicating challenges in employee awareness versus superiors.
Funding for IR4.0	SMEs have little capital to change old machines to new ones. They apply for grants or funds offered by government and private agencies such as Digital Transformation Acceleration Programme (DTAP), Applied Innovation Fund (AIF) Malaysia, and Venture Investment Programme (VIP) to access new technology. The application process is not easy because of the strict requirements.
IR4.0 training program at SHRDC	The training program is well organized and relevant to the current needs of the IR4.0 industry. The smart factory exhibition that the researchers participated in was easy to understand because 100% of the technology on display was that which had been learned at the training.

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Data analytics skills	New skills to handle large volumes of data through data analytics workshops using IBM-SPSS applications. This reinforces the view that SMEs can also analyse data easily without having to know a programming language.
Funding and Guidance Program	This program provides financing opportunities and other resources to SMEs that want to develop technologies and projects relevant to IR4.0.

Researcher found that training, funding, and awareness building are initiative factor for SMEs to integrate IR4.0 technology into their operations. This is because comprehensive training programs focus on improving employees' understanding and skills in advanced technologies like IoT and simulation applications. Access to financial support from government and private agencies is essential for SMEs to invest in upgrading machinery and adopting new technologies. Awareness-building initiatives, such as workshops and information campaigns, can educate SMEs about the benefits of IR4.0 and help them make informed decisions.

IR4.0 Readiness Dimension for SMEs

In the Literature Review, the theories involved in the acceptance factors of SMEs towards IR4.0 have been stated. Then, in phase 1, the study has found the rejection and acceptance factors of IR4.0 among SMEs, presented in Table 5; 1) Resources, 2) Infrastructure and Technology, 3) Awareness, 4) Skilled workforce, 5) Culture, 6) Strategy, 7) Innovation, 8) Organization, 9) Management, 10) Product and Operations, and 11) Collaboration. The result of the combination of theoretical constructs and factors has defined the dimensions of IR4.0 readiness for SMEs; Organization, Data, Infrastructure, Analytics, and IT, Development and Operations. The dimensions have been used in the survey tool of the study, IR4.0 eRC system to assess the readiness of SMEs to use IR4.0 technology in operations.

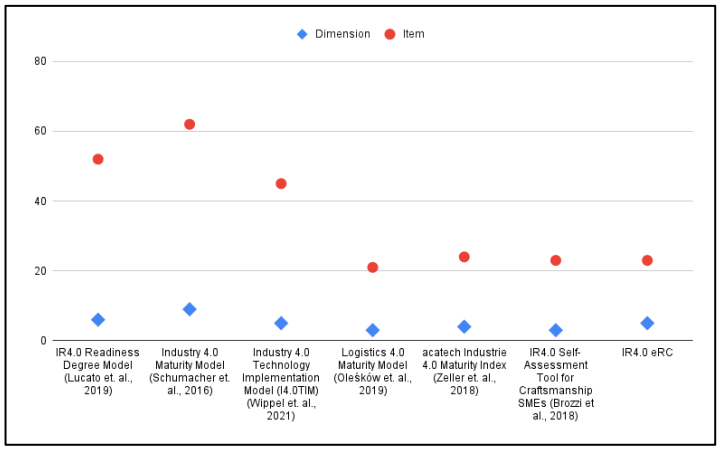

Figure 6. Comparison of six models with IR4.0 eRC.

Referring to Figure 6, IR4.0 eRC shows the use of dimensions (5) and items (23) which are very close to the last three models by Oleśków et. al. (2019) (3, 21), Zeller et. al. (2018) (4, 24), and Brozzi et. al. (2018) (3, 23). IR4.0 eRC is in the middle in the overall spectrum. This gives an insight that IR4.0 eRC is a balanced IR4.0 readiness assessment tool in assessing digital innovation readiness in SMEs. The suitability of IR4.0 eRC in achieving this balance is very important as a clear indication of the achievement of IR4.0 readiness among SMEs.

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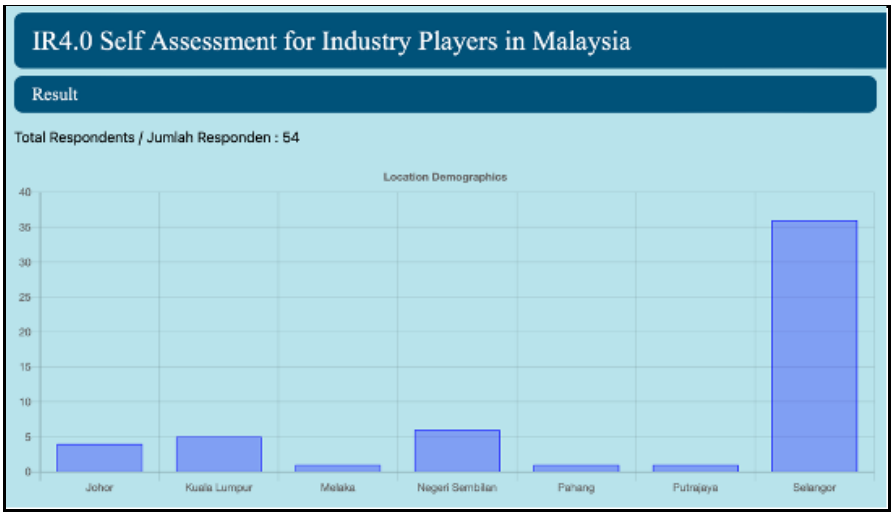
SMEs Readiness Towards IR4.0

In the phase 3, a survey is carried out on SMEs readiness towards IR4.0 using IR4.0 eRC system, and obtained 50 SME respondents in Malaysia. Their input statistics i.e. demographics, sectors and assessed dimensions will be presented in this section. The statistics are from the system dashboard which can also be accessed by respondents. Figure 7 (a) illustrates the location of respondents, showing that many respondents are from Selangor, a major industrial centre. This indicates that SMEs in Selangor are more active in adopting IR4.0 because SMEs in more developed regions may have easier access to information and resources about IR4.0, such as government grants, training programs, and consulting services. According to ECP (2021), Selangor is more willing to adopt IR4.0 as the Malaysian government has a policy supporting IR4.0 in Selangor. In contrast, Melaka, Pahang, and Putrajaya have fewer respondents, which suggests that there may be awareness gaps and outreach initiatives are needed. Meanwhile, figure 7 (b) shows that service sector being the most involved because it relies on technology, changes constantly, and is agile, making it easier to adopt new technologies (Guillet, 2020; Klein et al., 2021). Conversely, for the agricultural sector, the lower involvement is due to traditional industry practices and the perception that IR4.0 technology is less applicable, although there are now many farmers who use IoT in their operations (Jamilah, 2021). Automotive, mining and quarrying sectors have very high operating cost challenges due to handling complex processes.



(a)

(b)

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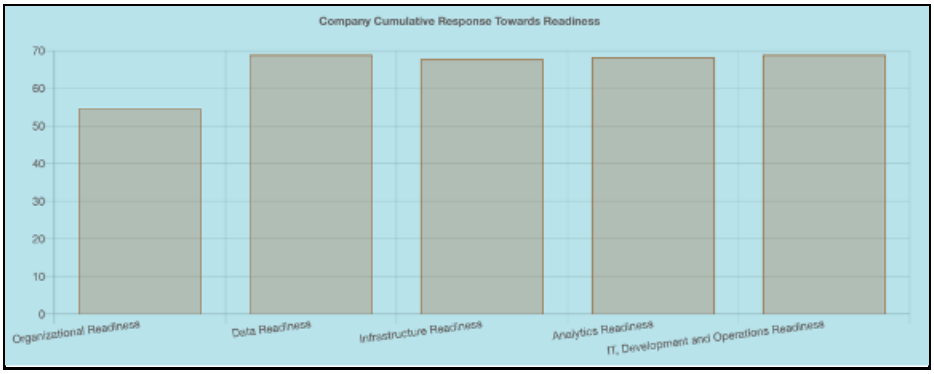
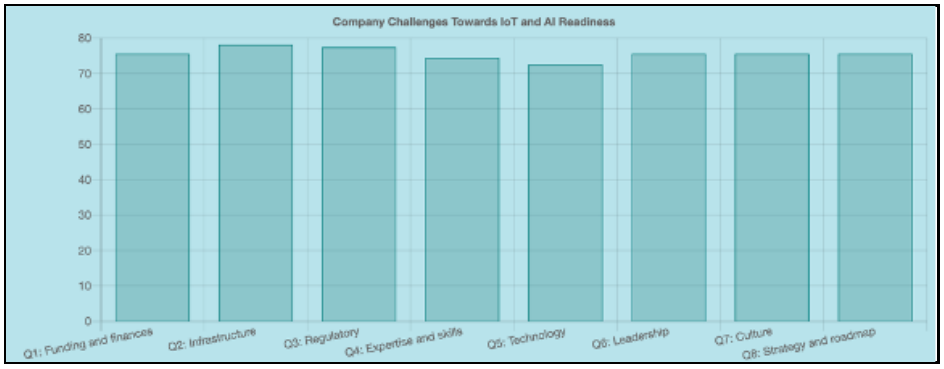


(c)



(d)

Figure 7. (a) Respondents' locations, (b), Respondents' sector, (c) Respondents' readiness in IR4.0 dimensions, d) Respondents' challenges towards IR4.0.

Based on the 50 responses, the average IR4.0 readiness of SMEs is 66%, and only 10 SMEs are less than 50% ready. This shows a room and opportunity for continuous improvement for the research and development on IR4.0 transformation of SMEs, even though it takes a long time. For all dimensions of IR4.0 readiness, respondents are the most ready for data, on the other hand, SMEs are the least ready for the organizational dimension (Figure 7 (c)). This indicates, SMEs invest in data-driven decision-making, recognizing its value and utilizing it in product development and marketing strategies, demonstrating a culture of data-driven operations. Ali et al. (2023) agreed, SMEs that exhibit high data availability have basically aligned their technology investments with the demands of IR4.0.

Organizational readiness, on the other hand, is a more complex and intangible dimension. SMEs that lag behind in organizational readiness can face various challenges. For example, resistance to change, lack of visionary leadership, and lack of skills in adapting to new technology are some potential challenges (Tortora et. al., 2021). They also face resource constraints that prevent investment in training and development programs geared towards achieving organizational readiness, supported by Wippel et. al. (2021). Organizational readiness, which includes culture, leadership and organizational processes, is a more complicated aspect compared to data readiness (Vaittinen et. al., 2019). This is because, it involves the development and transformation of cultural norms (Shahzad et al., 2023), leadership approaches, and operational processes, which is indeed a time-consuming endeavor (Cockburn, 2021). Unlike data availability, which has general guidelines that can be followed because it involves a technology that has a fixed program. Meanwhile, organizational readiness involves culture, people, strategy, and financial resources.

Respondents found difficulty to implement technologies associated with IR4.0, including automation, IoT devices, big data analytics, and AI. Implementing such technology often involves major changes to existing processes, skill sets and workflows, which is challenging. Instead, they consider providing or upgrading the infrastructure required for IR4.0 as a more manageable task, as

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suggested by Lucato et al. (2019). Infrastructure, in this context, refers to the physical and digital framework that supports the use of advanced technologies. This includes building or improving networks, data storage and communication systems that enable new technologies to work effectively. SMEs that are committed to modernizing and ensuring their IT infrastructure, are more receptive to new technologies and innovations (Amini et al., 2023). This study highlights that many SMEs lack email and business information online, hindering their progress in the IR4.0 transformation journey due to the high digitization required for IR4.0 technology, hence requires infrastructure change. Respondents acknowledge the challenge of implementing IR4.0 technology, but believe their organization has adequate resources and strategies to overcome difficulties during the implementation process.

Referring to Figure 7 (c), infrastructure, analytics and IT, development and operations readiness are almost identical. SMEs that have the skills and tools needed to analyze data effectively gain a competitive advantage (Schiffer et al., 2019). By extrapolating data, SMEs can optimize operations, respond efficiently to market trends and foster innovation. Increasing data analytics capabilities are directly aligned with greater readiness to effectively drive the IR4.0 landscape. SMEs with skilled IT teams capable of implementing fast technology are indeed more agile in adopting IR4.0 innovations (Alcácer et al., 2021). This can empower SMEs to align their technology capabilities with IR4.0 advancements, thereby improving their overall readiness.

Figure 7 (d) reveals the most common challenges faced by SMEs in adopting IR4.0 are lack of funding and finance (70%), lack of infrastructure (60%), regulatory challenges (60%), lack of expertise and knowledge (40%), technological challenges (30%), lack of leadership and support (20%), culture and resistance to change (10%), and a clear strategy and roadmap (10%). These findings show that SMEs in Malaysia face significant obstacles in adopting IR4.0, including the high cost of implementing and maintaining IR4.0 technology, lack of necessary IT infrastructure, complex regulations, lack of expertise and knowledge, continuous technological change, lack of leadership and support, and resistance to change. Therefore, the Malaysian government and other stakeholders need to provide more support to SMEs in adopting IR4.0, such as financial assistance to all SME sectors, free training programs, and simplifying regulations. This is to give more opportunities to SMEs who already know the transformative capabilities of IR4.0 in their operations, and want to change.

There is a positive relationship between the factors of acceptance and use of IR4.0 technology among SMEs with their readiness for IR4.0. This shows that the more SMEs accept and use IR4.0 technology, the higher their readiness to follow this transformation. In addition, despite various initiatives, seminars, and programs offered at the global and national levels to introduce the concept of IR4.0 to the industry, there is still uncertainty at the organizational level in using IR4.0 technology.

Final Research Model

The results of readiness assessment of 50 Malaysian SMEs through IR4.0 eRC, have developed a final research model which is the SME IR4.0 Readiness Model (Figure 8) to help SMEs assess their readiness for IR4.0, and formulate a plan to implement IR4.0 technology. The model is a comprehensive set of guidelines designed to help SMEs assess and improve their readiness for IR4.0. The model outlines a systematic four-stage process for SMEs to follow. In the Initial IR4.0 Project stage, SMEs identify key areas that require transformation and assess the potential impact of these changes. This involves understanding the strategic importance of IR4.0 and establishing the scope of the project. During the IR4.0 Requirement or Business Analysis stage, SMEs conduct a comprehensive assessment of their current situation, including existing processes, technologies and capabilities. Based on the analysis, SMEs develop a detailed IR4.0 plan that outlines the necessary steps to achieve readiness including the factors that have been discussed. The IR4.0 Design stage involves determining business-specific operational requirements, assessing readiness across multiple dimensions, and preparing a comprehensive test plan. It includes designing the technology infrastructure and processes required for successful IR4.0 implementation. In the final stage, SMEs conduct extensive testing to ensure IR4.0 readiness. This includes staff training, fine-tuning systems,

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and using new technologies and processes in the operational environment. Then, the test results are adjusted for continuous improvement.

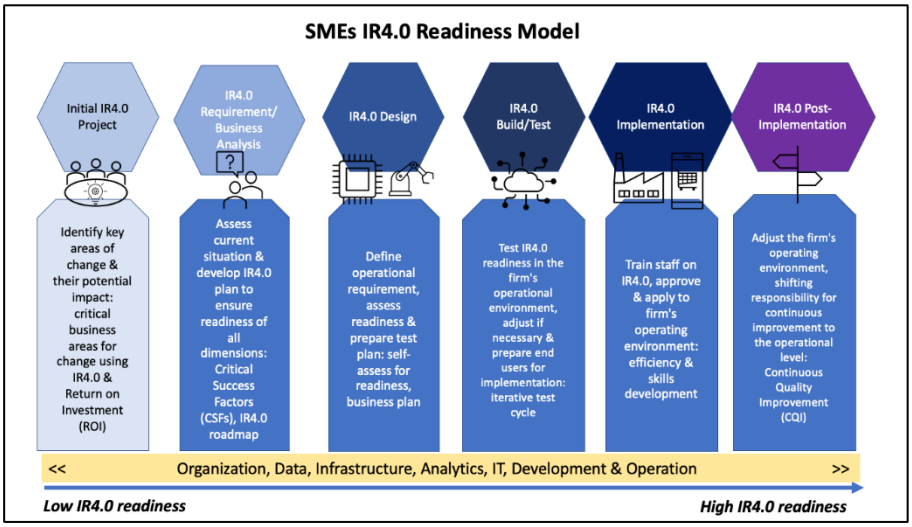

Figure 8. SME IR4.0 Readiness Model.

The SME IR4.0 Readiness Model provides a structured approach for SMEs to transition towards IR4.0, focusing on critical success factors such as a well-structured organization, robust data management, reliable infrastructure, advanced analytics capabilities, and an effective IT system. This is to ensure a smooth operation of IR4.0 technology, increase productivity, and reduce losses. The model equips SMEs with a roadmap to assess their current IR4.0 state, develop a strategic plan, and implement changes needed to thrive in the digital era of manufacturing. However, different SMEs may require different levels of effort to achieve IR4.0 readiness. Additionally, interviews are conducted with three industry experts in Malaysia regarding the suitability of the SME IR4.0 Readiness Model in Malaysia. The three experts agreed that the model should be used as a roadmap for IR4.0 transformation among SMEs.

Conclusion

This study developed a SME IR4.0 Readiness Model, aimed at helping SMEs assess and improve their readiness for IR4.0. The model addresses challenges faced by SMEs using theories like TAM, UTAUT, TRI, and DOI to understand readiness and barriers to IR4.0 adoption. Malaysian government has shown commitment to IR4.0 through the Industry4WRD Readiness Assessment, but there is still a gap in understanding among organizations, particularly SMEs. The model is developed to continue previous studies, which, to the best of study's knowledge, are limited to only a few sectors such as the manufacturing or carpentry sectors. This is in reference to the requirements of the sector stated in the focus of Malaysia's National 4IR Policy other than manufacturing in the country.

The findings confirm and conclude that SMEs face difficulties related to factors of resources, infrastructure and technology, awareness, skilled workforce, culture, strategy, innovation, organization, management, products and operations, and collaboration. These pressures are normative and coercive forces imposed by various external entities such as government, investors, IT experts, vendors and partners, as well as technology consultants. This is in line with the institutional theory of isomorphism mentioned by DiMaggio et al. (1983). The theory proposes that organizations become similar over time due to coercive, mimetic and normative pressures, with coercion originating from powerful actors and mimetic from organizations imitating successful organizations. In the context of this study, SMEs were forced to adopt IR4.0 technology since the outbreak of the COVID-19 pandemic that hit the country and the whole world. For example, Chatterjee et al. (2022) found, AI integrated customer relationship management (CRM) technology, cloud computing and IoT can improve SME performance in the COVID-19 pandemic scenario. In

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fact, use cases such as self-checkout systems, scanner heat, service robots have been widely used by SMEs in different geographies during the pandemic with their potential to enable business continuity (Pandey, 2022). E-commerce has increased buyers in developed countries including in developing countries, such as Malaysia, Singapore, Thailand, and Pakistan (Bhatti et al., 2020). The use of e-commerce such as Shopee by SMEs, can be seen from Shopee's analytics tools to understand customer behaviour, preferences and purchasing patterns enabling targeted marketing campaigns, personalized product recommendations and dynamic pricing strategies.

There are also internal factors such as top management leadership, business needs (ie, strategy, resources, systems and technology, policies and practices, and personnel), and the culture of working with new technologies. The role of the Malaysian government can be seen in promoting the adoption of IR4.0 by SMEs when the Indystry4WRD policy and the National 4IR Policy were launched. In addition, in the national budget, the government specializes in digitalization, IR4.0, and development and research. Programs such as the IR4.0 technology exhibition is also implemented as participated by the researchers of this study. Therefore, with these efforts, the Malaysian community, especially SMEs, will better understand over time the need for IR4.0 in operations. This can also be seen from the actions of the Federation of Malaysian Manufacturers (FMM) which urged the government to create a new system for applying for funds, grants and incentives offered to industry players related to the IR4.0 initiative (BH Online , 2023).

The limitation of this research starts with a small study sample due to the difficulty of getting feedback from SMEs in a limited period of time. This makes use of statistical power lower and increases the risk of not being able to detect patterns and trends of differences or real effects in the readiness of Malaysian SMEs towards IR4.0. For example, the sample of this study only has SMEs from the states of Selangor, Melaka, Putrajaya, Johor, Pahang, Negeri Sembilan and Kuala Lumpur. So, based on the research findings in the IR4.0 eRC readiness assessment, the percentage of SMEs that are ready to adopt IR4.0 is not representative of the entire state in Malaysia. Therefore, future studies are expected to further increase the study sample such as 20 SMEs for each state. Apart from the small sample size, the diversity of the respondents is required to further improve the analysis of the findings. This refers specifically to the respondent's role in the SME i.e. company owner, company manager, or supervisor. This study did not get responses from all types of roles, hence makes an incomplete or biased conclusion on the readiness of IR4.0 among SMEs in Malaysia. Therefore, this study does not accurately reflect the actual level of readiness and acceptance of IR4.0 among SMEs. This emphasizes the need for future research to bridge the gap and provide a more accurate understanding of the awareness and adoption of IR4.0 by SMEs.

Overall, this study strongly supports the use of the SME IR4.0 Readiness Model as an instrument that can assist SMEs in overcoming obstacles related to the assimilation of IR4.0 technology. This study outlines the characteristics of the SME IR4.0 Readiness Model, such as thoroughness, user-friendly accessibility and strategic alignment with Malaysia's comprehensive national IR4.0 strategy. Those qualities collectively make it an important reference, in empowering SMEs to efficiently leverage the transformative capabilities inherent in IR4.0. Therefore, although the level of IR4.0 readiness among SMEs in Malaysia is low, the SME IR4.0 Readiness Model is expected to be improved in future studies by taking into account IR5.0 elements. This is because, it has become a current research topic such as identifying employee competencies aligned with IR5.0, and proposing a framework for deep multi-level collaboration to improve human integration in intelligence systems (Nair et al., 2024).

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Conflicts of Interest:

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