

Article

Conceptualizing Smart Manufacturing Readiness-Maturity Model for Small and Medium Enterprise (SME) in Malaysia

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Abstract: Manufacturing enterprises today are forced to face radical challenges in the disruptive concepts of Smart Manufacturing (SM) and Industry 4.0 to stay competitive. Most Multinational Enterprise (MNEs) have initiated their journey towards adopting SM. As a mainspring of many manufacturing economies, Small and Medium-Enterprise (SMEs) are still struggling to understand the complexity offered in SM, and many of them are not ready to embrace the concept of SM. To overcome this, SMEs first need to assess their readiness and maturity before embarking on an SM journey. The existing available readiness assessment model seems to be suitable for MNEs, and there is still a lack of tailored models that suit SMEs. This paper sought to pinpoint the conceptual framework from the review of the existing readiness-maturity assessment and identify the gap of existing model as well as proposed a tailored model framework that are suitable for SMEs. Ultimately, this model will be used to pursue a comprehensive scholarly study across Malaysia. The proposed model is enhanced with 4M attributes as the dimension and embedded with the characteristic of Industry 4.0 build component to help the SME's overcome the possible uncertainties in adopting SM concept.

Keywords: Smart Manufacturing (SM); Industry 4.0; smart factory; readiness assessment; maturity model; technology readiness; Small-Medium Enterprise (SME)



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1. Introduction

Industry 4.0 is an advanced strategy introduced by the German government to promote the integration of diverse technologies that make manufacturing process smarter [1–6]. For instance, the technologies such as the Internet of Things (IoT), Internet of Service (IoS), social product development, Enterprise Resource Planning (ERP), and radio frequency identification (RFID) have been widely implemented to achieve smarter production system. The combination of this technology will foster mass customization, inexpensive product planning, accurate control of the manufacturing process, condition base maintenance, as well as the automated manufacturing process [7–9].

These technological trends are designed to facilitate machine to machine (M2M) communication using minimal to null dependence on human force. Industry 4.0 transform processes, operations, machinery, supply chain management, and the entire energy footprint of manufacturing enterprises. It also enhances and monitors the after-purchase performance such as maintenance and servicing. At the global front, manufacturing enterprises are already exploring the limitless possibilities of Industry 4.0 and are reimagining the future. The traditional manufacturing processes and machinery are undergoing digitization and technological transformation to accelerate efficiency, flexibility, and speed to survive the fierce market competition.

1.1. Digitalization Transformation towards the Industrial Revolution

Digital technology perceived as a mixed match of information, computing, communications, and connectivity technologies [10]. Digitalization will ensure that the manufacturing business runs efficiently, responsively, and cost-effectively [11]. In a holistic approach, digitalization is an enabler for a vertical (within the company) and horizontal (between companies) integration. Monostori et al. [12] and Nick et al. [13] reiterated that the vision of Industry 4.0 should have these four goals:

1. *Vertical integration*: In a smart factory system, a digital model communicates via the cyber-physical system, which comprises people, machines, and resources, is mapped.
2. *Horizontal integration*: The smart factory adapts itself to the surrounding system as it can optimize the entire production process in real-time.
3. *Smart product*: The ability to retrieve product lifecycle information that will add to the digital modelling of the smart factory and offer a better product-based service.
4. *Human Being*: The focal point and the driver of valued addition to the entire chain.

With the relationship between the service provider, supplier, and customer becoming integrated, a stand-alone automation manufacturing system is becoming an isolated choice [13]. Such a system has its limitation within the organization [1,11]. The disapproval of the stand-alone automation system is also due to the rising concern on interoperability between machines. The inability to communicate vertically and horizontally in Industry 4.0 offers the ideal answer for the misalignment between automation technologies. With the ability to interact with each other, the Cyber-Physical System (CPS) and the Internet of Things (IoT) are the missing puzzle pieces for the stand-alone automation solution [14]. Thus, integrating the philosophy of Industry 4.0 will help manufacturing businesses leap forward, and this involves strategic decisions due to the enormous investments that need to be made.

Many success stories have been attained from the significance of the digital transformation of an organization [10,15]. Digital technologies are viewed as a tool that profoundly eases the transformation of business strategies, processes, capabilities, the way their customers are served, and their product offerings. Digitalization is in line with Industry 4.0 [16,17]. Nevertheless, embracing digitalization is not an easy task and can become complicated at times. A survey done by the Harvard Business Review [18] encompasses that corporate and people's culture, process and technologies of the organization are directly influencing the transformation process. Henceforth, the manufacturing enterprises needs to emphasize further the assimilation of inclusive knowledge and technology transfer [19].

1.2. Industry 4.0 Pillars in Crafting Smart Manufacturing (SM)

In line with Industry 4.0, Smart Manufacturing (SM) employs computer-integrated manufacturing, high levels of adaptability and rapid design changes, digital information technology, and more flexible technical workforce training [17]. Throughout the first industrial revolution to this date, other industrial revolutions have been driven by automation and digital transformation. Following the revolutions' trends, a smarter manufacturing system that is integrated with robots and sensors is expected to play a pivotal role in next-generation manufacturing.

With the birth of 5G technology, machines can interact, visualize the production chain, and make a crucial decision accurately and timely. Industry 4.0 is being backed by the combination of several new technology enablers as well with some existing technological apparatuses. Visibly, SM is a repackage of the combination of capabilities and technologies that serve as the pillar in making SM happen. The IoT, robotics, cloud computing, big data analytics, virtual reality, system integration, additive manufacturing, cyber security, and cyber-physical system are the pillars of the Industrial Revolution 4.0 [20–25].

1.3. Smart Manufacturing

Today's manufacturing is getting more complicated [26,27]. The term SM and Industry 4.0 expound the same reference meaning. In the United States of America, "smart manufacturing" is referred to as "Industry 4.0", and the Germans have officiated it in the Hannover Fair in the year 2011. Similarly, the Koreans refer to the term "Industry 4.0" as a "Smart Factory". Regardless of the terminology, these three terms signify the key goal of improving businesses and their manufacturing environments in diverse countries to connect and embrace the narrative of technological advancement in the information and operation technologies. This noble aim is expected to facilitate steady income flows with the associated cost reduced and efficacy gains.

Lasi et al. [16] explained that to reduce operating costs, the prospect of future production is no longer dependent on batch order. This phenomenon has changed, and the manufacturer needs to think about smarter alternatives to meet customer-driven batch sizes while retaining mass production economies. As a driving force, intelligent sensors, intelligent solutions, innovative technologies, and the Internet and the Cloud are proven to promote digitalization and automation. Such disruptive developments of the technology enable product development time to be fostered and customization and versatility to be encouraged.

A smart factory consists of integrated systems from various components within a factory that makes the entire factory system more flexible and reconfigurable Wang et al. [28]. The smart factory system integrates and connects the industrial network via the cloud and supervisory control terminals with smart shop floor object that leads to autonomous decision making. This was primarily to develop a smarter and higher-efficiency factory systems. Without cloud services, big data analysis, and networks, an intelligent self-organized multi-agent system cannot be established. Kang et al. [17] stressed that cutting-edge ICT technologies are enablers and drivers of manufacturing's fourth revolution. Wan et al. [29] and Zhong et al. [30] agree that a myriad of useful data is needed in making a smart factory. Davis et al. [31] explained that SM will lead and respond to dramatic and fundamental business transformations to demand dynamic economies with IT-enabled smart factories. Ultimately, Smart Factory focuses on the shift on task-connected changes focusing not only profit but also flexibility and product output, together with further declining cost, reducing resource utilization, as well as a decrease in ecological impact.

Despite the hype towards Industry 4.0, smart manufacturing, and the Smart Factory concept, Canetta, Barni and Montini [32] have mentioned that numerous businesses have encountered challenges in implementing Industry 4.0. Rajnai and Kocsis [33] and Sony and Naik [1] indicated that some business owners are not clear on the current trend of industrial digitalization, and some leaders are clueless on how to implement it. Many manufacturing companies are still struggling to employ the SM concept [27,34–36]. With regards to the highlighted problems, readiness and maturity assessments have become an integral tool for the manufacturing enterprises, specifically for SMEs. A readiness model promotes the initialization of the development process. Since the business owner is uncertain about the consequence of Industry 4.0 technology [37], the readiness assessment is the right fit to diminish uncertainties on the invested technologies [38]. Readiness assessments typically conducted on a self-assessment basis that can be performed online or offline. In this self-assessment, the likely information gathered includes understanding, awareness, perception, current practice, as well as attitude of the organization.

To this date, many manufacturers are still exploring, working, and planning to boost their potentials so that they can stay relevant and face the market competition in time to come. In improving competitiveness, global manufacturing needs to empower themselves with technological breakthrough [17]. Rajnai and Kocsis [33] have commented that there is no rigid or standard model and commonly accepted methodology for measuring the adopters' Industry 4.0 readiness. Some readiness assessments are found to only focus on organizational Infrastructure Technology (IT) readiness [39–42]. Furthermore, the assessment outcome is often measured using various dimensions. Shifting to a smarter

way of manufacturing practice involves high investment and changes in the organization's vision mission at the strategic level, as well as the modification of infrastructure and a new normal for the worker to adapt to. It does impact the Management, Machine, Method, and Man dimension in an organization. Choi, Jung and Lee [43] have also reported that a maturity assessment could enhance manufacturing companies' competitiveness.

Since moving into Industry 4.0 is directly correlated to the amount of investment an organization must make, this is risky, as failure is costly for the SME's. Prior to the implementation of SM, it is crucial for SMEs to assess the readiness of their manufacturing company's practice [44,45]. For instance, most SMEs in Malaysia are still in the adopting stage of modern technology under Industry 3.0 [46]. The adoptions of the Industry 4.0 concept are still at the infancy level among the small and medium enterprise (SMEs) [47]. Herewith, this paper is constructed to propose a readiness assessment model to help SMEs stimulate their journey in their implementation of SM. Schumacher et al. [38], in their industry-wide interview, have spotted problems in implementing Industry 4.0 in a manufacturing business, as follows:

- Failure of assessing Industry 4.0 readiness and capability is costly.
- Failure to understand the uncertainty of the technology implementation will directly influence its benefits and cost.
- Lack of strategic assistance and prior knowledge of the Industry 4.0 concept will tarnish the organization's development.

To this purpose, this paper addresses the type of readiness assessment needed to assist the SME's in understanding the mechanism towards adopting technological advancement and preparing SMEs to embark on the journey of SM and Industry 4.0. A readiness assessment model is derived based on the review findings. The developed mental model is expected to be used as a guide in developing a tailored readiness assessment for SMEs based in Malaysia. This research article therefore directed to find answers for the following research questions (RQ) from the review:

1. RQ1: Are the current assessment models best fit for SMEs?
2. RQ2: What is the assessment element in the current existing model that can be adapted to support SMEs?
3. RQ3: What is the study gap obtained from an existing model that is missing from an SME perspective?

This paper is organized as follows: Section 2 exhibits the Method section. Section 3 presents the critical review, and in Section 4, the findings obtained from the critical review are discussed, and therefore the conceptual framework is deliberated. The readiness assessment model is presented and discussed later in Section 4. Correspondingly, Section 5 exhibits the overall conclusion of this paper.

2. Methodology

This paper intends to pinpoint the conceptual framework from the review of existing readiness-maturity assessments and identify the gaps of the existing model, as well as propose a tailored model framework that is suitable for SMEs through a desk study of the relevant literature. The search was conducted in the powerful database such as Web of Science, Scopus, and Google Scholar, and the data are being compared among the subject literature from the secondary data from. Throughout this research work, "readiness assessment; maturity model; technology readiness" was consistently used as the keyword search. Empirical studies that evolve on the readiness and maturity model in the area of smart manufacturing and articles published in referred journals are all included in this study. The literature search disclosed four main criteria of an assessment models:

- a Dimension;
- b Measurement Approach;
- c Analytic Method;
- d Thrust.

Both the conceptual framework and the mental model are derived from the fact findings. English language articles from renowned authors and reputable publishers located largely in Germany, the USA, Switzerland, South Korea, China, as well as other countries where the concept of SM correlates are analysed in this article. The methodology of this research work entails of a library search and an evaluation of the literature work on Industry 4.0, smart manufacturing, and readiness assessments. A thorough review of the current readiness assessment has enabled the author to address the drawback of current readiness assessment (Table A1 in Appendix A). Furthermore, a conceptual framework was derived to understand the mechanism of assessment logic. Different starting conditions for SMEs against the MNEs have blazed a new trail to enhance the existing framework tailored to SMEs. From the review, the assessment concept and dimension were identified that could be enhanced further to fit SMEs' requirements.

3. Critical Review

3.1. Industry 4.0 Adaption in Malaysia

In line with the global trend, the Industrial Revolution has spread to many countries, including Malaysia. In response to the Industry 4.0, or Fourth Industrial Revolution (4IR), the National Policy on Industry 4.0 was launched as Industry4WRD on 31 October 2018. Industry4WRD aims to boost the digital transformation of the manufacturing and related services sectors in Malaysia. The ultimate goal is for Malaysian manufacturers to be more robust through smart technologies. To this purpose, the Ministry of International Trade and Industry of Malaysia (MITI) has introduced various initiatives such as readiness assessments, intervention programmes, high-speed broadband connectivity to potential industrial parks, enhancing competence centres at public higher learning institutions, and reskilling programmes to address the technology and skills gaps among the industry players, especially for SMEs [48].

Nonetheless, the common challenges faced by Malaysia in the Industry 4.0 journey include the lack of understanding of the industry's best practices and failure in analyzing relevant information using case studies. In addition, there are also cases with the awareness deficiency to the need and impact of Industry 4.0 technologies, especially among SMEs, that reduces the chances of exploring opportunities and further disrupting their business models [49]. Other than that, it is reported that there is a shortage of the essential skills, knowledge, and talents for adopting Industry 4.0, especially in areas such as AI, IoT, robotics, and cybersecurity. Most importantly, the main drawback of Industry 4.0 implementation in Malaysia is the high adoption costs and a lengthier payback period [50].

Table 1 measures the different dimensions of the readiness in adopting digital technologies. Based on the GII index, Malaysia is still far from the best compared to its neighboring countries. Singapore seems to be the champion of the digitalization readiness in the ASEAN region. The lag behind the strong technology adopters is clearly seen when it comes to the digital adoption index for Malaysia. This supports the argument that Malaysia are still lacking behind and need progressive improvement to be the best among the best in the ASEAN region.

Table 1. Rankings of the ASEAN countries by their innovation and digitalisation readiness.

Country	Global Innovation Index (GII) (Out of 127 Countries)	Readiness for the Future of Production Assessment (Out of 100 Countries)		Networked Readiness Index (NRI) (Out of 139 Countries)	Digital Adoption Index (Out of 180 Countries)
		Structure of Production	Drivers of Production		
Singapore	8	11	2	1	1
Malaysia	35	20	22	31	41
Vietnam	42	48	53	79	91
Thailand	43	12	35	62	61
Philippines	54	28	66	77	101
Indonesia	85	38	59	73	109
Cambodia	98	81	91	109	123

Source: [51].

3.2. Small and Medium Enterprises (SMEs)

A manufacturing-based SME in Malaysia is referred to the company in which their sales turnover is not exceeding RM 50 million or full-time employees are not exceeding 200 workers [50]. On the other hand, the sales turnover must not exceed RM 20 million or full-time employees not exceeding 75 workers for SMEs in the services and other sectors. In 2019, the Department of Statistic Malaysia (DOSM) [52] reported that the GDP for SMEs in Malaysia grew at 5.8% compared to 6.2%. Nevertheless, the performance remained above Malaysia's GDP and non-SMEs, which registered 4.3% and 3.4% growths, respectively. The contribution of SMEs to the GDP increased to 38.9% from 38.3% in the previous year. The value-added of SMEs at constant 2015 prices were RM 552.3 billion as compared to RM 522.1 billion in 2018. In nominal terms, SMEs' GDP was recorded RM 586.9 billion in 2019 (2018: RM551.8 billion). Despite being the backbone of Malaysia's business environment, SMEs are relatively poor in digitalization [52]. Therefore, to promote the digitalization among SMEs in Malaysia, this paper proposes a readiness assessment model with the aim to provide a better guideline towards Industry 4.0's implementation. To this purpose, the existing readiness assessment model is thoroughly reviewed in the next section. The advantages and drawbacks of the existing model are analysed accordingly.

3.3. Smart Manufacturing among SMEs and Readiness Assessment

Numerous literatures have highlighted how SMEs cope and battle with technological sophistication. Over the decades, the competition among SMEs is felt locally and internationally [53]. In most condition, SMEs often support multinational companies. SMEs have to cope with unrelenting pressure from buyers and competitors to lower prices and accept diminishing sales margins [54]. In addition, they must also maintain their short delivery times with constant supply to avoid businesses loss. SMEs who upkeep with the technological advancement will have a brighter chance to survive, and those who are lacking will have to enhance themselves with the technological progress [54–56]. In most cases, these companies are not the early adopters of technological advancement [27]. This scenario must change, and SMEs need to leap forward and quickly learn to appreciate the emerging technologies and digital practices if they plan to stay relevant.

Mittal et al. [27] have mentioned in his work that there is still a low level of study focusing on SME entities related to smart manufacturing, technological adoption, and Industry 4.0. Many SMEs are aware of the concept of SM and Industry 4.0, but they do not know how and where to start. According to Sommer [57], SMEs are easily self-satisfied with what they have and ignore trends associated with digitalization and automation. The reluctancy of SME's invites urgency in research disparity within the current scientific body of knowledge. In helping the SMEs in leaping forward in technological digitalization, first the SMEs need to measure their readiness.

Readiness assessments or self-readiness assessments can be used as a guiding model to help the SMEs attain maturity in their explicit sphere and help them move in the right direction. According to Erol, Schumacher and Sihm [58], the existing maturity and readiness assessment model is established based on large companies' requirements rather than that of the SMEs'. Readiness assessment indices must not be too complex [59] and must be in favour to ensure that SMEs understand the detail of the assessment. A proper transformation plan and the measurement of their readiness index are in need to ensure a smooth transition towards successful transformation. Understanding user acceptance remains the first critical step in identifying readiness [60]. Readiness assessments typically occur before embarking on the transformation journey, while the maturity model used to assess that implies the progress in the process of adoption [38]. To date, there are many well-known readiness models for reference. Table A1 in the appendix describes the details of comprehensive SM and Industry 4.0 readiness assessment and maturity developed from 2014 to the latest one. Rockwell Automation was among the pioneer consultation companies who have proposed the Connected Enterprise Maturity Model. In other similar works, Lichtblau et al. [61] proposed IMPULS-Industrie 4.0 Readiness model.

The readiness and maturity model shows an inclining trend, and each model presents unique dimensions and measurement criteria. Since there is no standard and perfectly consented model in this area [1,37,40,58], the evidence of a research gap is distinctly observed [40].

3.4. Review on the Conceptual Framework of Readiness and Maturity Model

According to Basl [45], the readiness assessment and maturity model aids the organization in making fast decisions in addition to recommending the organization on the areas to improve. Maturity refers to the “state of being complete, perfect, or ready” [38,59], while readiness is commonly described as a state of being prepared of something. To date, several assessment models have been proposed by Academician, government organizations, private organizations, as well as consulting firms [62], and this assessment we constructed based on descriptive, prescriptive, or comparative purposes [32,63]. The readiness and maturity assessment consist of evaluating dimensions with scales to measure their readiness level. This model is commonly equipped with stages of maturity or readiness level. This readiness level depicts Level 1, which defines a dearth of the attribute, and level 5 represents an advanced level or required attribute [38].

In this work, 11 different mixed models from readiness to maturity model irrespective of any area and industries have been studied. All these models offer different dimensions, complexities, and depths with regards to their scope and methodology. This is again proof that no standard has been agreed upon in developing the maturity and readiness model. Table A1 reflects the comparative analysis of the published readiness and maturity model intended for SM and Industry 4.0. Several renowned model and tools are discussed in detail below.

Lichtblau et al. [61]: “IMPULS-Industrie 4.0 Readiness”. This model is regarded as one of the most comprehensive and well-grounded readiness models. It consists of six dimensions for assessment: Information Technology, Organization strategy, Data Management, Factory, Employee, and Product. This assessment consists of six readiness levels, starting with 0—outsider, 1—beginner, 2—intermediate, 3—experience, 4—expert, and 5—top performer. The application’s purpose is descriptive. The IMPULS readiness assessment is best fit to measure the readiness level of the manufacturing and engineering industries. This Industry 4.0 readiness model is an online self-assessed readiness model that suits medium to larger or large enterprises who intend to embark on the Industry 4.0 journey. With enabling the advance criteria of manufacturing technology in this assessment, SMEs would not score well and may often be left behind. SME readiness assessment outcomes will always be reflected as “outsiders”.

Leyh et al. [64]: “System Integration Maturity Model Industry 4.0-SIMMI”. This model focuses mostly in assessing the industrial internet maturity. Vertical integration (VI), Horizontal integration (HI), Digital product development, and Cross-sectional technology criteria are all included in the model dimension. This model evolves within five levels of maturity, starting from level 1 (basic digitalization level) to level 5 (optimized full digitalization). This model embraces the descriptive application purpose in developing the model. Most SMEs are not even near to the digitalization stage. Since SIMMI focuses more on VI and HI that reflects the real time integration, SMEs are more conventional in terms of their supply-chain rather than integrated due to financial constraints. Therefore, the VI and HI does not consider the SME’s sensitivity.

Schumacher, Erol and Sihni [38]: “Maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises”. The model includes nine dimensions, namely Products, Customer, Operation, Technology, Strategy, Leadership, Governance, Culture, and People. This model is based on the Maturity Model that employs descriptive purpose covering the manufacturing industries as their assessment scope. This model utilized five maturity levels (level 1–level 5), representing a lack of attributes to state-of-the-art attributes. Schumacher, Erol and Sihni [38], in their work, imply that a maturity index can calculate the readiness level of the industry.

Gökalp, Sener and Eren [40]: “Industrie 4.0 Maturity model”. This model consists of six maturity levels (incomplete, performed, managed, established, predictable, and optimizing) with a focus in five dimensions, namely, asset management, data governance, application management, process transformation, and organization alignment. This whole assessment is more focused on skill capability assessment. This model offers a comprehensive evaluation measure; nevertheless, this model did not mention fit for use by the small-medium enterprise. The authors of [40] also cited that no model would satisfy all criteria.

Malaysian International Trade and Industry [48]: “Industrial 4ward”. The first-ever Malaysian Industry 4.0 readiness assessment focuses on manufacturing industries that cover three major shift factors, such as the dimension (people, process, and technology). Five types of readiness levels are adopted in this model (none, learner, experience, performance, and leader). Not much data is published in related to this assessment, as this assessment are handled in a close loop within appointed government agencies.

Rockwell Automation (2014) [65]: “The Connected Enterprise Maturity Model.” With a greater focus on the information technology readiness, this model includes four dimensions (information infrastructure, controls devices, networks, and security policies). This model was reported to embrace five levels of maturity measure; nevertheless, not much detail was published on a related item. This model suggested that small-medium enterprises need to collaborate to archive the Industry 4.0 maturity level. This is an obvious point that all SMEs will be able to match up. The Rockwell model embedded the advance manufacturing technology in the measuring dimension that can lead to less participation by small-medium enterprises. This assessment tool offers less information about its development and detail process to the reader to judge further.

Akdil, Ustundag and Cevikcan [37]: “Maturity and readiness model for industry 4.0 strategy”. Uses a scale from 0–3 to measure the level of maturity; absence, existence, survive, and matured. This method deploys three central dimensions, in which smart products and services, smart business, and organization strategy are all included in the model. This model covers both the manufacturing as well as the retail part. This model employs a descriptive purpose to complete the survey. These authors have compared several models [38,61–65] in their study. In this work, the suitability of this model to the small-medium enterprise is not mentioned.

Schuh et al. [66]: “Industrie 4.0 Maturity Index”. This model deploys six levels of maturity level (computerize, connectivity, visibility, transparency, predictive capacity, and adaptability) with four dimensions (resources, information system, organization structure, and organizational culture). This model covers five functional areas in the business, which includes research and development, production, logistic, service, and marketing and sales. Digital transformation is the main motive of this maturity model. This model also includes advance manufacturing technology as part of the maturity index measurement. This model supports the concept of digitalization is the key enabler for Industry 4.0. The build-up of this model was based on consultation tools, and it is not a self-assessed tool. A company that plans to use this assessment is required to hire a consultant to assist them in the evaluation. Small industries that use this tool to measure maturity will find it costly, timely, and not suitable to cater to their business setup. This tool is more appropriate to be used by medium and large enterprises.

Gill et al. [39]: “Forrester digital maturity model 4.0”. It is a benchmark tool to measure the digital business maturity of a company. This model uses four major dimensions to assess the digitization maturity (culture, technology, organization, insight). This model is distributed into four maturity levels in which the beginner is known as sceptics, adopters, and collaborators, and the highest level provided in this model is differentiators. This model is based on a comparative application purpose in approaching the subject of their assessment. This model offers less information on the usage of an industrial-based organization but emphasis more on e-business and e-commerce digital marketing and digital

readiness capabilities. This model also provides an evaluation on how digital supports sales and service connections comprise touchpoint integration and technology complexity.

Botha [67]: “Future readiness for industry 4.0”. Since the future cannot be predicted, a future thinking model was developed that encounters possible future, plausible future probable future, and preferred future. This model is based on the future thinking model within the future, shaping factors that have been translated into the readiness dimension. Technology, the behaviour of people, and events that may change the world are all included in the measuring element. Technological readiness level and manufacturing readiness level developed by the United States Department of Defence we used as motivation in developing its own ten levels of Technology future-readiness level [68]. In this model, there are also five levels of Behavioural future-readiness level and Enterprise behaviour future-readiness level. Additionally, there is also an event future-readiness level and future thinking readiness level both with 10 levels of readiness level. There is evidence that this model is conducted as per audit procedure and requires a third party to assess the outcome. The complexity of this model may lead to hinder small-medium enterprises from using this tool.

Qin, Liu and Grosvenor [69]: “A framework of manufacturing for Industry 4.0 and beyond”. This model is a self-assessed tool that measures maturity in the five dimensions, namely, the single station automated cell, automated assembly system, flexible manufacturing system, computer integrated manufacturing, and reconfigurable manufacturing system. All these dimensions being tied up with 11 levels of a maturity gateway. This model offers the assessed the understanding of their current state and gap identification by employing a comparative purpose method. This model can be considered complicated to the most SMEs as small companies often hardly have more than two of these dimensions mentioned above. Hence, this model again belongs to the companies with a larger size group.

From the above-discussed model, it can be observed that vast majority of the model were produced in the last few years with diverse spectrum. The characteristic of the theoretical concepts of SM Industry 4.0 assessment model is the thrust, dimension, assessment analytic method, and the scale. The thrust in the assessment encompasses the organization’s wide scope attribute, while the dimension covers the sub-attribute of the organization. Elsewhere, the assessment is tied up with an analytic method that represents the type of assessment. The descriptive-analytical way is more likely to reflect the readiness model, whereas the prescriptive and comparative analytic assessment approach is best to fit the maturity assessment model. Scaling the dimension capacity is a vital mechanism to measure the degree of maturity and readiness [45]. Each model has its measuring approach to reflect the overall organization level.

4. Results and Discussion

Through the critical review analysis, a set of gaps between the models have been drawn. Firstly, the existing model is aimed for Multinational Enterprises (MNEs). Most of them presume that the MNEs are the information technology (IT) expert users with the advanced and interconnected machines, to mention a few. Hence, rest assured that a substantial number of MNEs have already embarked on their journey towards SM. Whereas SMEs are on the contrary, and they are still lacking on the resources such as dedicated automated machines, IT experts, or even IT departments that may lead to the difficulties of implementation of the SM concept. It is vital to acknowledge that this extensive view on SMEs is not applicable for all SMEs in general. There are some high-tech, technology-based SMEs that can be viewed as role-models in the SM perspective. Nevertheless, according to Quinton and Simkin [70], the extensive view is substantiated and it is appropriate basis for the work presented in the current research.

In this view, it epitomizes that when an assessment is conducted, the MNEs will start with a presumptive readiness level scale “Experience” or “learner” or “Level 1” phase where the status of starting to implement and executing the SM and Industry 4.0. In contrast, SMEs need to start with “Level 0”, or as “Newcomers”, which reflects extremely limited or

no adoption of technological or IT capability. Level 0 reflects the capabilities of SMEs on the know-how and ability to handle the technologies. From the aspect of upgrading the infrastructure and facilities, as well as people mindset, MNEs are more realistic to attain the shift in terms of IT facilities acquisition and human capital enhancement towards SM and Industry 4.0 compared to SMEs. The action plan execution is way too exponential to SMEs compared to MNE. This indicates that SMEs' and MNEs' starting conditions differ from each other. Finally, the measurement dimension assessed in the existing model (Table A1) are irrelevant to most SMEs.

For instance, Leyh et al. [64] included vertical and horizontal integration dimensions in their assessment tools. The assumption of digitally integrated SMEs may not be possible since the integration may need a huge investment of software that translates their business operation in real-time. SMEs are more open to a direct resource's management. The likely dimension that are more appropriate for SMEs are the Man, Machine, Method, and Management dimension. Thus, it validates the purpose of proposing a new assessment model for SMEs. If all these gaps are addressed appropriately, the proposed model can help SMEs to attain their journey to achieve Smart Manufacturing reputation.

4.1. Conceptual Framework for the Industry 4.0 SM Readiness and Maturity Assessment

From the analysis, a conceptual framework for the proposed Industry 4.0 SM readiness and maturity model is built and shown in Figure 1. It can be concluded that the common mainstays digested from the available readiness and maturity model are people, technology, process, product, infrastructure, organization, and customer.

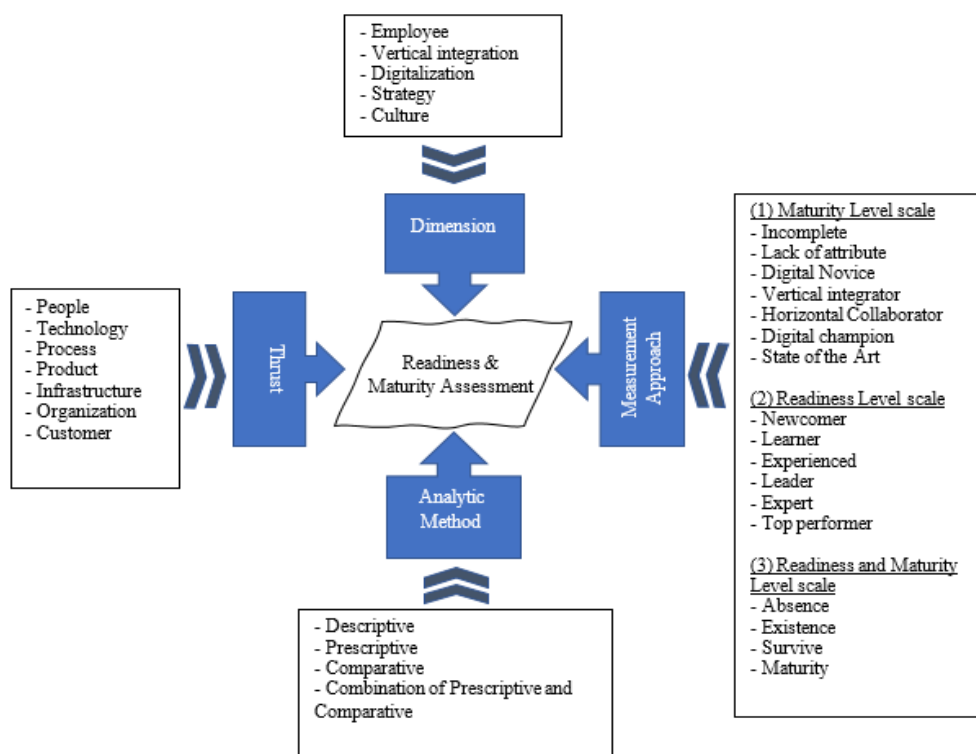


Figure 1. Conceptual framework of the industry 4.0 Smart Manufacturing readiness and maturity assessment.

Although most models encompass the above-said thrust, the conception varies among the models. For instance, one model may assess the people dimension; alongside people, a model tends to focus more on human resources capability while another assessment model may want to contain the training, culture, leadership, etc. In this context, all the attributes related to the mainstay are put into the sub-dimension section that will be translated to the primary needs of each assessment. Measuring the scale is to gauge the construct of the aim [71]. The scales determine the measurement approach used to quantify

variables in performing data analysis. The existing maturity and readiness model employ three primary different measurement approaches in their assessment tools. There is a visible contrast between the maturity model scales compare to the readiness model due to the nature of the assessment. Nevertheless, the combination measurement approach can be observed in the maturity and readiness model.

The principle basis scale are predominantly based on the traditional conception of the maturity model [45]. De Carolis, Macchi, Negri [72], in their work, have summarised the main purpose of the analytic assessment method in the following three classifications: (i) descriptive analytic: a model that assess the current state of an organization situation; (ii) prescriptive analytic: assessment model that outcome distillates the maturity improvement; finally, (iii) comparative analytic: the model evolves on benchmarking crosswise companies to check their readiness and maturity.

4.2. The Mental Model of Smart Manufacturing Readiness Assessment

An uncertainty needs to be address in earlier stage [73]. An assessment model should clarify uncertainties rather than forming new ones [74]. Technological complexity in implementing smart manufacturing is not precisely defined [75]. The complexity of future system will lead to uncertainties that may impact the SMEs in their journey to embrace smart manufacturing practices. SMEs with the ability to master the technology of Industry 4.0 will have the edge to occupy the right position in the market [76]. Wiesner at al. [74] suggested that SMEs need a step-by-step guide to help them embrace the concept of Industry 4.0 and smart manufacturing. Therefore, focusing on the Man, Machine, Management, and Method will be the easiest thrust for the SMEs to perceive the journey of smart manufacturing. Simplicity is proposed to avoid an entry barrier for the SME's. Accordingly, based on the conceptual framework presented in the previous section, a mental model of the Industry 4.0 Smart Manufacturing readiness assessment for SME's is proposed as shown in Figure 2.

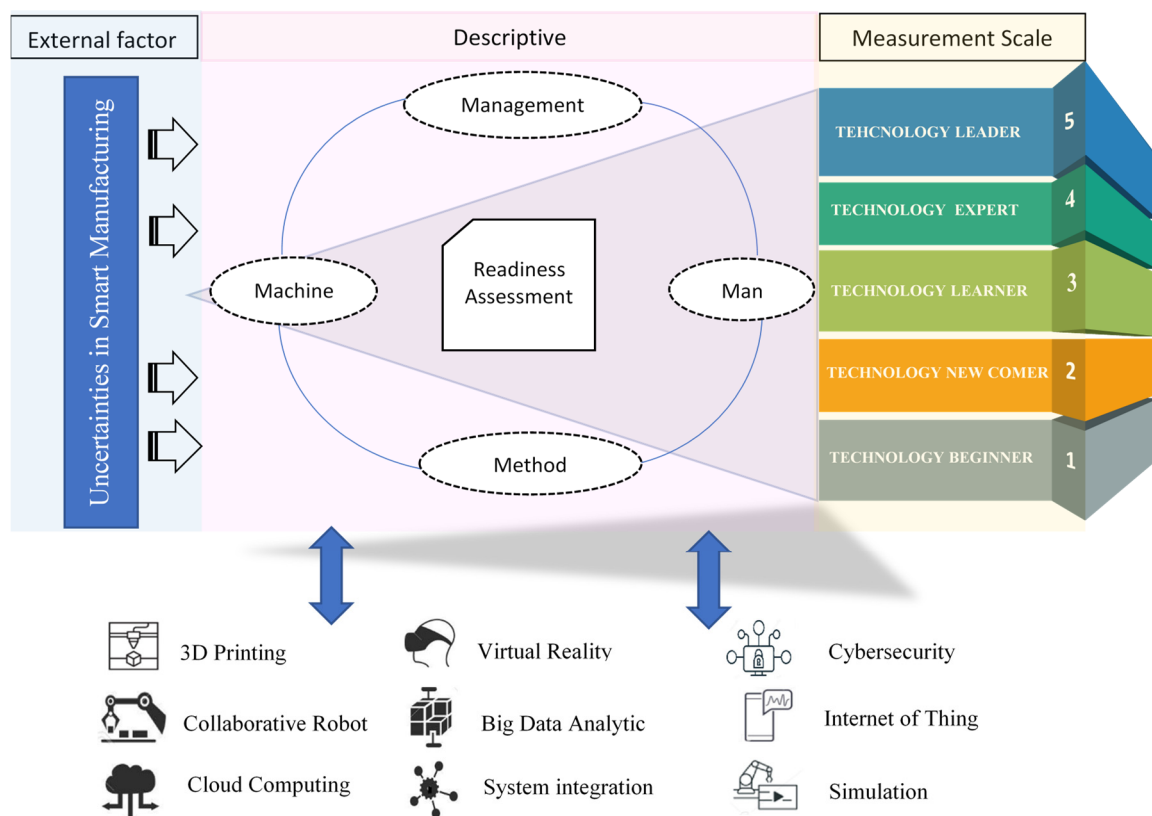


Figure 2. Proposed model framework of the industry 4.0 Smart Manufacturing readiness assessment for SME's.

As shown in Figure 2, the proposed model exhibits the build mechanism of a more inclusive model than others, while incorporating external factors that directly evolve among the pillars in smart manufacturing. This model considers the uncertainties in smart manufacturing as the external factors that could affect the assessment. Five measurement scales are listed in complying with the model. Small businesses that attempt to measure their readiness using the existing tools designed for big companies have encountered difficulties [9]. Commonly, scales were established from the engineering viewpoint. Moreover, the emphasis is more on technological issues. The proposed scale is mainly adapted from the literature, and it assists small companies to work on the action in improving their readiness.

The proposed framework model is expected to help evaluate the companies' present readiness level to embrace the smart manufacturing methodology and system and recognize solid measures to help them capitalize on the benefits of Industry 4.0 initiatives. This work has proven that the existing model that measures maturity and readiness could not satisfy all industry needs. Thus, this tailored readiness assessment is projected to fulfil the needs and wants of SMEs. This model is expected to help small scale manufacturing entities identify the required technologies according to the process related to their business nature. In addition, this model will also provide the uncertainties list that each technology offers, in which it will be beneficial to the business owner in making decision on the right technologies to invest in. Although this paper focuses on the implementation of SMEs in Malaysia, the proposed model is expected to be also viable in other countries.

5. Conclusions

Industry 4.0 conceivably signifies the beginning of the Fourth Industrial Revolution. Despite the hype behind the idea of Industry 4.0, the common ground on understanding the core concept of Industry 4.0 needs to be suggested among the SMEs. Interest in Industry 4.0 and smart manufacturing is increasing day by day. Nevertheless, the importance given to small-medium enterprises is still at a low level. From the model and readiness assessment evaluation done, the evaluation dimension and maturity or readiness level criteria should be carefully evaluated. All these models are unique from their author's perspective; nevertheless, this model is considered generic. The existing models are most suited to large businesses due to the complexity of the assessment. Most of the models cover the dimension of strategy, culture, leadership, and human resources. From the literature, the common traits found that the present maturity model and readiness assessment are unique and differ from each other despite some common dimensions being re-mentioned. Technology domains are the most popular dimension used among the existing assessment models. Despite the regularity of using the term technology, the view of each model is diverse. Some models use information technology, some use manufacturing technology, and few use digital technology. There are also models referring to technology as digitization. This is because the facet is dynamic corresponding to the nature of the industries and needs. Some authors of the models share the development detail of their tool, but most remain unrevealed. As not much detail on the development process of the tools is shared, it indicates that the area is still unsaturated. Few tools are made available online for self-assessment, whereas some models are used as a consultancy tool in which a third-party consultant is required if a company needs to assess their company's maturity or readiness level. It will be economical for the SMEs to perform a self-assessment check on their readiness level rather than hiring a consultant.

Thus far, the evidence shows that there is a lack of sector-wide assessment models formed in the automotive, food, and chemistry sectors. therefore, this can trigger future research to explore the lacking sectors to close the gap. Each SME is unique with specific needs. Small businesses, in the future needs an enhanced assessment model that fit their needs, and it should be straight forward and easy to comprehend. Given the analysis result from the literature, to be focus oriented, a disjunct assessment model emphasis exclusively to a small business environment is required. The conceptual model should encounter all the drawbacks highlighted in this paper. A specific yet straightforward

readiness model encompassing Man, Machine, Method, and Management is recommended to facilitate the small-medium enterprise to pave their ways in making their organization comply with smart manufacturing, and Industry 4.0 requirements are needed. Therefore, the proposed mental model is expected to help the SMEs in leaping forwards, achieving smart manufacturing status.

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Appendix A

Table A1. Comparison of Industry 4.0 readiness and maturity model.

Model Name	Year	Author/Source	Assessment Approach (Maturity Level)	Industry Covered	Assessment Mode	Dimension	Drawback
Industrial 4ward	2018	[48]	Assessment in 3 dimensions and indicated readiness in 5 levels (None, Newcomer, Learner, Experienced, and Leader); focus on efficiency and productivity	Manufacturing industry	IR4.0 capability assessment	People, Technology, Process	All 9 pillars in Smart Manufacturing are not being evaluated. Uncertainties are not highlighted. Not much detail published.
IMPULS–Industrie 4.0 Readiness	2015	[61]	Assessment in 6 dimensions and indicate readiness in 5 levels (Outsider, Beginner, Intermediate, Experienced, Expert, Top Performer) that divided into three main categories (Newcomers, Learners and Leaders)	Not Specified. However, based on the assessment model, it is more generic and suitable generally to Medium to Large manufacturing industries	Maturity assessment	IT, Organization Strategy, Data Management, Factory, Employee, Product	Assessments are not specified to Automotive industries. Suitable to a medium to large scale business as the complex terminology used are more advance and not ideal to SMEs. All 9 pillars in Smart Manufacturing are not being evaluated. Uncertainties are not highlighted; indicates minimal suggestion to improve.
Industry 4.0/Digital Operations Self-Assessment	2016	[77]	Online self-assessment in 6 dimensions; focus on digital maturity in 4 levels (Digital Novice, Vertical integrator, Horizontal collaborator, and Digital Champion)	Generic and suitable generally to manufacturing industries	Focus on Digital Maturity assessment	Business Model, Market and Customer Access, Value Chain and Processes, IT Architecture, Legal, Compliance and Tax, Organization, and Culture	It is a consultancy assessment tool. Fee for assessment is required. The choice of industry is available; nevertheless, the evaluation is more generic and not explicitly intended to specific industries. Suitable to a medium to large scale business as Complex terminology used are advance and not ideal to SME's. All 9 pillars in Smart Manufacturing are not being evaluated. Uncertainties are not highlighted.
Future Readiness for Industry 4.0	2018	[67]	Uses 5 to 10 readiness maturity levels. Each varies from one another.	Generic and suitable for the general manufacturing and service industry.	Based on a future-readiness level that measures future opportunities. Focuses more on the strategic level that stimulated the future thinking process. Evolving (technology, Behaviour and Event)	Technology Future Readiness, Market and Enterprise behaviour readiness, Event future-readiness levels, Future thinking readiness levels	Tools are too complicated to be used by the SMEs.

Table A1. Cont.

Model Name	Year	Author/Source	Assessment Approach (Maturity Level)	Industry Covered	Assessment Mode	Dimension	Drawback
SIMMI 4.0	2016	[64]	The model has five maturity stages (Basic, Cross-department, Horizontal and Vertical, Full Digitization, and Optimized Digitization) and four dimensions of integration	Not specified	System Integration Maturity Model in the context of IR 4.0	Vertical Integration, Horizontal Integration, Digital Product, Development, Cross-sectional Technology Criteria	They are focusing only on internet maturity and system integration, only without specifying a suitable industry. Tools are not available for public assessment.
Industrie 4.0 maturity model	2017	[40]	The model has six maturity levels (Incomplete, Performed, Managed, Established, Predictable, Optimizing) and five dimensions of capabilities	Not specified	Capability assessment of a company to achieve IR4.0	Asset Management, Data Governance, Application Management, Process Transformation, Organization Alignment	This maturity model focuses on the capability assessment of a company to achieve IR4.0. Tools are not available for public evaluation.
The Connected Enterprise Maturity Model	2014	[65]	Maturity model as part of a 5-stage approach to realize Industry 4.0; technology-focused assessment in 3 dimensions	Generic and suitable generally to manufacturing industries	Information Technology and Operation Technology readiness Assessment	People, Process, Technology	Not much detail about this assessment tool as it is more of a consulting tool. Tools are not available for public assessment.
Industry 4.0 Readiness and Maturity Model of manufacturing enterprise	2016	[38]	Five maturity levels (level 1 describes a complete lack of attributes supporting the concepts of Industry 4.0 and level 5 represents the state-of-the-art)	Manufacturing enterprise	Focuses on knowledge sharing and collaboration; ICT competences, openness, and autonomy of employee; effective use of mobile technologies	Strategy, Leadership, Customers, Product, Operation, Culture, People, Governance, Technology	Models are not made available. Validity and Reliability are not being addressed. Using a questionnaire and manual input in a software-assisted medium to obtain the output.
Maturity and Readiness Model for Industry 4.0 Strategy	2018	[37]	Employs 4 levels of maturity measures; (Absence, Existence, Survive and Maturity)	Retail business and can be used generally in all manufacturing industries.	It is a mix maturity model that covers the manufacturing and retail part of the readiness	Smart Product and services, Smart Business Process, Strategy and Organization	It is more service focused. Suitable for the retail and service industry. Nonetheless, it still can be used for the manufacturing industry. Not covering all nine pillars in IR 4.0.
Forrester digital maturity model 4.0	2016	[39]	Measures the digital business maturity in four levels (skeptics, adopters, collaborators, differentiators)	Not specified	Measures the digital business maturity	Culture, Technology, Organization, Insight	Focuses only on digital readiness and digital marketing or eCommerce.

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