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Industry 4.0: Current practice and challenges in Malaysian manufacturing firms

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ABSTRACT

This research employed a qualitative approach to discuss the current practice and challenges of Malaysian manufacturing firms in the implementation of Industry 4.0. The study examined data from seven manufacturing companies pursuing Industry 4.0 initiatives to identify various options for their strategies. The study found that the implementation of Industry 4.0 in the manufacturing firms is still in the exploratory stage. The companies involved in this study were discovered to conduct exploration using an adaptive-like framework. That is, throughout the process, the majority of the subjects are 'trying and adding' Industry 4.0 to their operations. Their trial-and-error approach is based on what is feasible and effective in their manufacturing environment. Overall, the investigation determined that data management and integration, as well as personnel re-education, were the respondents' primary operational challenges.

1. Study background

1.1. The concept of manufacturing in industry 4.0

Industry 4.0, smart manufacturing, and industrial internet-of-things (IIoT) are all terms that refer to the intersection of operational technology and information in order to monitor physical processes within manufacturing and use data to make predictive, corrective, and adaptive decisions in order to reduce operational costs [1,2]. Industry 4.0 is a catch-all term that refers to the fourth industrial revolution, or more precisely, the transition to smart and intelligent manufacturing [3]. Smart manufacturing, as defined by the National Institute of Standards and Technology (NIST), is a fully integrated collaborative manufacturing system that adapts in real time to changing demands and conditions in the factory and supply chain [4], as well as changes in customer needs [2].

Industry 4.0 adoption necessitates both horizontal and vertical data integration across the enterprise [5]. Manufacturing, procurement, supply chain management, design, product life cycle management, logistics, operations, and quality are all examples of vertical digitalisation. All are integrated to ensure a continuous flow of data. Horizontal digitalisation may entail integrating data from suppliers, customers, and strategic partners. Integrating a business requires upgrading or replacing equipment, networks, and processes until a seamless digital ecosystem is achieved. In the smart and intelligent manufacturing model, digitally integrating a business system is insufficient. The integrated system requires end-to-end engineering transformation, strong data services, and analytics to convert the data generated by systems, sensors, and machinery into actionable insights that can result in a return on investment [6].

Smart manufacturing also increases cyber security risk as a result of the adoption of connected systems [5,7,8]. This is why adopting Industry 4.0 requires close collaboration with the organisation's IT experts. IT professionals must collaborate with top management to ensure that cyber security best practices are implemented throughout the business's digital ecosystem. One of the most critical components of Industry 4.0 adoption in manufacturing is an organisation's internal cultural transformation [4,9]. This requires strong leadership committed to change management and to investing in the technology and education necessary to successfully implement smart manufacturing practices [10–12].

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1.2. The Malaysian initiatives for industry 4.0 and its progression in manufacturing firms

Malaysia's government has taken positive steps by launching various initiatives to assist manufacturing players in adopting Industry 4.0 [13–15]. Malaysia's manufacturing enterprises are facing rapid change as a result of the digital revolution. In the initiatives, the government has launched an RM50 million initiative to advance the Technical and Vocational Education and Training Plan (TVET). This is intended to support the future growth of Industry 4.0 by increasing the technical workforce agility in the business's digital ecosystem. The budget for this initiative is made up of 30% of the funds raised by the Human Resources Development Fund (HRDF) [16].

Malaysia's government also allocated more than RM 5 billion in the 2019 budget to assist businesses in adopting Industry 4.0 [15]. Meanwhile, the Business Loan Guarantee Scheme (SJPP) has set aside RM 2 billion to assist SMEs in investing in modernisation and automation. Additionally, the RM 3 billion Industry Digitalisation Transformation Fund, managed by Bank Pembangunan Malaysia Berhad and offering a 2% subsidised interest rate, accelerates the adoption of Smart Technology, which includes automation, artificial intelligence, and robotics. In the initiative, Industry4WRD's Readiness Assessment Online Registration was launched in 2019. This Readiness Assessment Program is one of the tools used to assist SMEs in advancing toward Industry 4.0 adoption. A total of 500 SMEs were selected, screened, and assessed on-site in order to determine their readiness to participate in industry 4.0.

The government also offered additional incentives in the form of a fund for the commissioning of Industry 4.0 projects. In the 2020 budget [14], the government offered tax incentives for the electric & electronics sector to switch to the 5G digital economy and to support Industry 4.0. Fourteen Digital Enhancement Centres will be established to facilitate access building for businesses that participate in Industry 4.0, particularly SMEs. Furthermore, the Malaysia Digital Economy Corporation (MDEC) has been allocated RM 70 million for this purpose [14]. In short, the government's aforementioned plans have demonstrated that advanced technology is heavily emphasised in each field, with industry 4.0 having numerous beneficial effects on the country. In this scenario, the workforce and digital worlds will begin to merge. Thanks to advanced technologies and phases, citizens will be able to communicate with governments, express themselves, and even avoid government oversight.

However, Malaysia has taken a more relaxed approach to developing workable policies for the implementation of Industry 4.0 in its manufacturing enterprises than neighbouring countries such as Thailand and Vietnam, which have already implemented Industry 4.0 governance structures [17,18]. Malaysian manufacturing technology is likely to remain largely at the mass production and automation levels of Industry 2.0 and 3.0 [19]. In efforts to encourage the transition of conventional manufacturing practices into IR4.0, the government has developed a primary performance index to assist the targeted local manufacturing companies [13–15]. However, only 90 companies have taken part [20]. Meanwhile, the HRDF reports that private sector employees in Malaysia require increased multi-skilling to meet the current job requirements, particularly as workplace digitisation and automation increase [11,16]. This scenario demonstrates that there is still a knowledge gap [21], as well as a lack of training and skills, among Malaysia's Industry 4.0 professional workers and manufacturing enterprises [20].

In Malaysia, small and medium-sized enterprises (SMEs) account for 98.5% of all businesses, spanning all sizes and industries [22]. Alas, there were scarce reports that focus on the trend nor initiatives of Industry 4.0 taken by SMEs in Malaysia [21]. Recently, Malaysian Investment Development Authority (MIDA) reports that most SMEs cannot afford today's smart factory solutions, which are extremely expensive, preventing them from integrating the concept into their existing manufacturing systems. The only thing that needs to be done during this pandemic is to digitally transform the company's documents using cloud computing, which is both necessary and affordable. Therefore, the Malaysian Digital Economy Corporation (MDEC) offered SMEs the Digital Transformation Acceleration Program, while MIDA offered the Industry4WRD Intervention Fund, the Domestic Investment Strategic Fund, and the Automation Capital Allowance. All of which are aided in their efforts to educate SMEs about IR 4.0 and grant applications by consulting firms [23].

In Malaysia, Industry 4.0 practice and adoption are still in their infancy [24]. The lack of visibility and awareness of Malaysia's Industry 4.0 initiative, which aims to transform the manufacturing sector through the use of cutting-edge technology, is limiting the country's progress. Therefore, this study examined existing practices and barriers to Industry 4.0 implementation in Malaysia's manufacturing industry in order to address these concerns. The goal of this paper is to look at current practices and identify the obstacles that each company faces when trying to implement Industry 4.0 principles in the manufacturing firms. Mindset, culture, and competitors are three new key issues that have arisen as a result of implementing Industry 4.0 in the studied companies. These key issues can be used to assist policymakers in developing a National Policy on Industry 4.0 in Malaysia or another similar country, which subsequently allows manufacturing companies to overcome obstacles encountered during Industry 4.0 implementation in order to remain competitive locally and globally.

2. Research method

This research essentially provides a framework for manufacturing counterparts to use in responding to the Industry 4.0 current practice and challenges. As previously stated in the study background, the Industry 4.0 initiative in Malaysia began with digital transformation as a way to improve manufacturing industries before becoming a massive global revolution. So, the practice and challenges of Malaysia's manufacturing digital initiatives are the subjects that are being investigated in this study. In Malaysia's manufacturing firms, research on Industry 4.0 is still in its early stages. Thus, this study investigates the subject using the qualitative Grounded Theory Method (GTM) [12]. Rather than using variables from pre-existing theories, GTM develops theories that emerge from or are "grounded" in data [25]. The use of GTM does not always imply a lack of knowledge of the literature or a methodical approach [26]. Therefore, the methodology used in this study is designed thoroughly as detailed below.

2.1. Approach

According to Table 1, those from engineering firms who worked in positions where the top five subject areas in the enterprises, namely Computer Science, Business (Management), Decision Science, Mathematics, and Material Science, were used, should be interviewed. Thus, through a semi-structured interview, the study elicited insights from personnel in 7 engineering manufacturing firms from various positions, as listed in Table 2. The study uses content analysis to form relationships between Industry 4.0 initiatives in their respective businesses, as well as their driving factors and challenges, current practices, and expected benefits. The interview was conducted using an inductive qualitative analysis. The study starts with concrete observations and progresses through the induction process to produce abstract hypotheses and judgments. The inductive approach is justified by the context in which the research effort is being conducted, and it is also appropriate for small samples that produce qualitative results [27]. This method is based on the use of Industry 4.0 in single case studies involving multiple units of analysis (respondents). Participants were chosen to represent a variety of manufacturing companies that have adopted Industry 4.0.

Table 1
Documents by Subject Area that address the keywords for all challenges (data, knowledge, technology, security, capital, workforce, educations). In average, the highest of all is Engineering 30.9%, followed by Computer Science 24.6%, Business, Management and Accounting 8.6%, Decision Science 7.2%, Mathematics 5.3, Material Science 4.1%, and cumulatively from others (not the top 5 subject area) is 19.3%.

Keywords	Documents [a]	Subject Area (%)						
		Engineering	Computer Science	Business, Management and Accounting	Decision Sciences	Mathematics	Materials Science	Others [b]
All Challenges	**1504**	**31**	**25.1**	**8.7**	**7.6**	**5.5**	**4.1**	**18**
Data	690	31	26.2	8.8	7.3	5.4	4.6	16.7
Knowledge	859	30.9	25.6	9.8	7.9	5.5	4.1	16.2
Technology	948	30.4	23.7	9.8	7.3	5	4.3	19.5
Security	382	30.6	24.6	6.7	5.9	5.8	4.7	21.7
Capital	376	29.4	21.6	10.9	7.6	5.2	3.5	21.8
Workforce	521	30.8	24.2	9.8	8.1	5.7	3.3	18.1
Education	187	32.8	26	4.4	5.6	4.4	4.1	22.7
Avg. Percentage (%)		**30.9**	**24.6**	**8.6**	**7.2**	**5.3**	**4.1**	**19.3**

[a] All types of documents that were listed in the Scopus database.
[b] Apart from the top 5 subject areas listed in the Scopus database.

Table 2
List of respondents.

Company (Respondent)	Type of Industry	Position	Working Period
A (R1)	Bottle Water Manufacture	Assistant Manager	2 years and 5 months
B (R2)	Electronic	Director of Industry 4.0	6 years and 9 months
C (R3)	Electronic	Process Engineer	1 year and 3 months
D (R4)	Machining Tools Manufacturer	Product Engineer	6 months
E (R5)	Electronic	Supply Chain Engineer	2 years
F (R6)	Automotive	Embedded System Design Engineer	1 year and 3 months
G (R7)	Automotive	R&D Engineer	3 years

2.2. Interviews

A face-to-face interview session was used to gather data from targeted respondents in the manufacturing industry who use Industry 4.0. The GTM data collection process should ideally end when a researcher reaches theoretical saturation [28]. Saturation is a technique used to ensure that an adequate amount of high-quality data is collected to support the objective of the study. Thus, the interviewee's data is analysed until data saturation is reached and maintained in order to demonstrate that there is sufficient information to replicate this study once the ability to obtain additional new data is obtained. The interview questions were developed in response to seven thematic issues raised in recent literature [1,17,29–35], as summarised in Fig. 1. The interview content was expanded based on the interviewee's perspective and response to the thematic challenges, which were then developed into new conceptual frameworks and synthesised to form the study's current issues.

2.3. Sampling

Purposive sampling was used in this study [36–38]. Participants were pre-selected into groups based on their characteristics in relation to a particular research question. Sample sizes, which may or may not be fixed prior to data collection, are determined by the available resources and time, as well as the study's objectives. Purposive sample sizes are frequently determined in terms of theoretical saturation (the point at which new data no longer adds new insight to the research questions) [37–39]. From the selected manufacturing firms, this study used

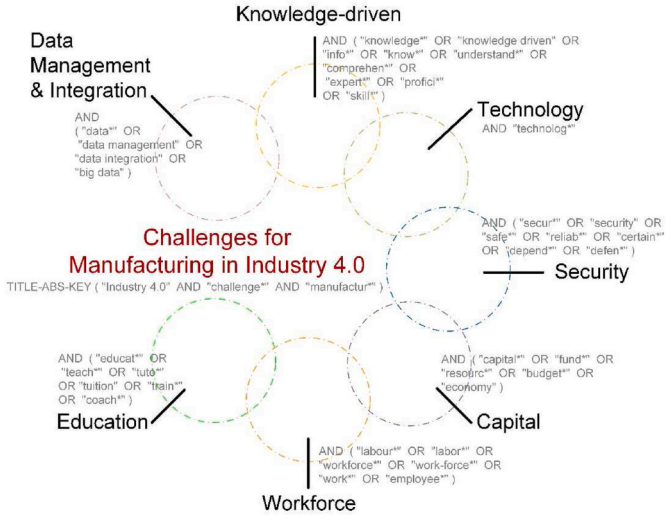

Fig. 1. The existing challenges for manufacturing Industry 4.0, extracted from the Scopus database (using the keywords as listed above will sort 1504 documents: 768 Conference Paper, 555 Article, 85 Review, 58 Book Chapter, 19 Conference Review, 8 Book, 7 Editorial, and 4 Short Survey). Recent articles as in Refs. [1,17,29–35] became the primary references for each of the keywords listed above.

snowball sampling (a type of purposeful sampling) for identifying and recruiting groups of respondents who are difficult to ascertain and are not readily accessible to researchers via other sampling strategies [38]. As a result, this study used snowball sampling to ascertain the challenges faced by manufacturing firms in Malaysia as they implemented Industry 4.0.

2.4. Informants

Personnel from manufacturing firms classified as SMEs that are implementing Industry 4.0 in Malaysia are willing to share their experiences and knowledge as part of the study. The companies in the study are all based in western Malaysia, in the states of Johor, Selangor, and Penang. Engineers (design, process, IT officers), director and assistant manager are among the seven respondents who are currently employed by their company in various working period capacities. The informants are Industry 4.0 experts as a result of their experience and knowledge in their field of expertise. They shared information and perspectives on their respective companies' Industry 4.0 initiatives. As shown in Table 2,

seven respondents from various companies were chosen and interviewed.

3. Results and discussion

Apart from the thematic issues depicted in Fig. 1, three additional challenges emerged as a result of the interview sessions, namely mindset, culture, and competitor were added to the framework as depicted in Fig. 2. The grouping of challenges in Table 3 was determined by the frequency with which the issue was brought up during the interview. Above all, all informants encountered difficulties with data management and integration during Industry 4.0 implementation. Only companies A (bottle water manufacturer), C (electronics manufacturer), and D (machining tool manufacturer) have raised concerns respectively about security, culture, and competitors.

3.1. Challenges of data management & integration

According to the information gathered from the interviews, all of the respondents identified data management and integration as their company's biggest challenges. According to their experience, the respondents also explained the categories of data, which include process data, products data, logistics data, and quality data.

Respondent R1 stated that:

> "Process Data will affect the results of analysing data due to the system. The book keeping system in the company is huge and unorganized, therefore it is very difficult to find an accurate data from old system to transfer to the new system. Then for the products data, there are too much product data in the system with different version and different understanding from different people. People come and go in the company, some of the product data was not communicated with other departments e.g. naming convention in the system hence creating confusion" –R1

Respondent R1 also stated that the company collects far too much data both internally and externally. Because the data volume is so large, judging the data quality in a reasonable amount of time is difficult because different situations necessitate different data. Some of the data, for example, is appropriate for production but not for the Finance Department. If companies are unable to collect required data in real time or deal with data requirements over a long period of time, the data collected may be outdated and the information may be inaccurate. As a result, the data's quality is critical for gathering information. Due to the involvement of various parties in the process, logistic data is frequently inconsistent and recorded in an unorganized manner. Different parties record their data in different systems, and sometimes even in different units of measurement, such as weight, dimensions, metric/imperial, and so on, making it difficult to reconcile and analyse the data to derive actionable insights. The logistic takes place outside of the company, and the company is unable to track the data's progress. Therefore, the accuracy of the data is influenced by a variety of external factors.

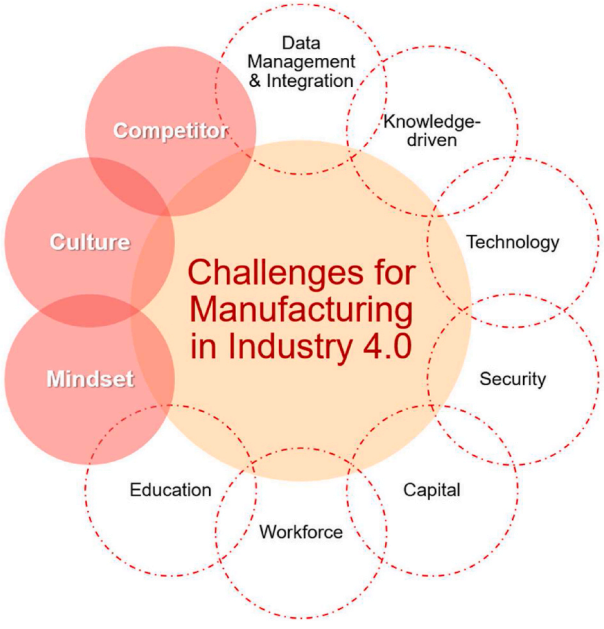

Fig. 2. New conceptual framework of challenges for manufacturing Industry 4.0 in Malaysia.

Meanwhile, Respondent R2 also agreed with R1 that data management is one of the critical challenges.

> *"Since we are doing vision inspection, quality is our main concern. Back in the days, we save the data in a hard disk. But when the hard disk is full, we replace it with another hard disk. It is inefficient and time consuming. Nowadays, we save all the required data on cloud computing. We are not just storing the data but we are analysing and interpreting it. Although we solve the problems of insufficient storage of data but there is still a barrier in processing the data. In the perspective of data management, Industry 4.0 is a comprehensive framework yet to prove the superiority over restricted approaches. Too much of date are gathered from internal and external of the* company. *In terms of logistics, we have an internal communication system with the distributor. We may update from time to time for the shipment status."* –R2

In addition, Respondent R3 also had the same opinion with R1 and R2.

Respondent R3 explained that:

> *"Data management might be a little bit tough for certain department. Celestica is using a third-party software developed by the vendor for data management. Since this software still is in its primary version, therefore, there is some restriction in data management for data sharing and processing."* –R3

And Respondent R4 stated that:

> *"From my own view, I think the process data and product data act important in data management and integration. Process Data –it belongs to the handling of big data, which is very complex. It is also a big barrier to process a big amount of data at an acceptable speed and validation of the data combination is also fulfilled by transferring data to consumers as well from one source to another. Gathering thr needed product data is one of the biggest challenges in manufacturing today because most companies record incredible amounts of data at every stage of a product's lifecycle."* –R4

According to Respondent 5:

> *"For the process data, it is really a difficult task to interpret the data obtained. Great amount flow of data happened between cloud systems and production sources in Industry 4.0 manufacturing phenomena. The sensor data from the resources of production need to be evaluated and analysed in an efficient and right manner. Thus, the use of competence snippets that are available through process data instead of comprehensive material and this will bring challenges to engineers who require knowledge and experience to analyse what's wrong with the process. But most engineers are still not equipped enough with knowledge of Industry 4.0 and experience to handle operation Industry 4.0 is still low."* –R5

Respondent 6 agreed with Respondent R5, who stated that processing the data is difficult. Because the data is large and complex, a large amount of encryption data was required to optimize the process. Then there's product data, which includes a wide range of products. Every product has its own set of specifications and features. As a result, the information gathered will be unique. It's difficult to make sense of so

Table 3
Grouping of challenges in Industry 4.0 faced by manufacturers in Malaysia.

	Data Management & Integration	Knowledge-driven	Technology	Security	Capital	Workforce	Education	Mindset	Culture	Competitor
Company A	X	X	X	X		X	X	X		
Company B	X	X	X			X	X	X		
Company C	X		X						X	
Company D	X		X		X	X	X			X
Company E	X		X		X	X	X	X		
Company F	X				X		X	X		
Company G	X							X		
Frequency	**7**	**2**	**5**	**1**	**3**	**4**	**5**	**5**	**1**	**1**

much information. As a result, quality is always the respondents top priority. As a result, optimizing without sacrificing quality necessitates extensive design and research. Therefore, data analysis is a significant challenge.

Respondent R7 stated that:

"All the data collected from different subsections; the integration of data is hard to achieve. One can only view and analyse the data separately but unable to see the whole picture at once." –R7

To recap, all respondents agreed that data management and integration are among the challenges they face as they implement Industry 4.0, which is consistent with a previous study that found that managing industrial big data analytics with multiple large-scale heterogeneous data streams has become a challenge [12,17,33,40–43]. Typically, traditional data management techniques are designed to process heterogeneous types of data from a single source, but they fall short of processing and managing heterogeneous types of data from multiple sources. A sophisticated data management methodology must be structured to accommodate multiple models of data streaming and integration, which appear to be impossible to manage in a single model. Numerous devices, for example, that are integrated into a variety of status streaming, textual, and geospatial sources, do not end up receiving the complete picture of information [11,33,42,43].

A limitation of current technologies is the lack of and redundancy of service feedback throughout the data lifecycle management process, particularly for Cyber-Physical Systems (CPS) that generate data at an unprecedented rate and trend over a small storage management system [11,29,42,44,45]. As a result, one of the problems is that the current storage system is incapable of handling the massive amounts of data migration in the integration that occurs on a regular basis during CPS operations. In industrial data management, the buried value is determined by processing time and storage management. Thus, data quality assurance is linked to the value of analysis over the time required to determine the usability, achievability, and retirement of data segments. Due to limited data storage capacity, streaming stability, and handling variability, manufacturing companies in Malaysia lack comprehensive and sophisticated programs or models for processing and analysing this big data. Data handling and migration are the primary burdens and tasks for all businesses involved in data management and integration. The most critical aspect of Industry 4.0 is how the business reacts to the feedback it receives from the data and how the machines react to the data collected, with the goal of resolving issues and extracting meaningful insights.

3.2. Challenges of knowledge-driven

Knowledge-driven challenges can be divided into two categories: intelligent equipment requirements and skill development. Most companies, according to data gathered from respondents, provide training to their employees to ensure that they are always up to date with the latest technology. Training can take place either internally or externally. This is to ensure that employees are capable of successfully completing their assigned tasks. Many businesses, on the other hand, may not face this issue.

Respondent R1 stated that:

"In the manufacturing environment, there are a few machines that are involved in order to produce the output. However, due to cost concern, not all equipment in the workflow is digitized and automated and information is being intelligently communicated through all workflow processes to eliminate manual processes that result in bottlenecks and human error. This enables seamless production. In addition, there is lack of expertise that advice on suitable equipment for the business as well as to fulfil the demand from the market." –R1

According to informant R1, one of the challenges is having relevant training and skill development knowledge. Since most knowledge-based technology in Southeast Asia is still in its infancy, there are few institutions that provide training and skill development. This could be due to additional challenges faced by institutions, such as difficulty recruiting experienced teachers, a lack of cutting-edge technology infrastructure, and ministry-mandated syllabuses.

Respondent R2 mentioned that:

"As it is mentioned in the education section, there are insufficient specialized personnel with the technical ability of data management in Malaysia. Some department may have more understanding for the inner mechanism of the machines but lack sufficient knowledge to derive what they get from the system." –R2

In addition, respondents R3, R4, R5, R6 and R7 had almost the same views on the challenges of knowledge-driven which infrequently occur in their companies. They stated as below:

"No. Training will be provided to all the staff by the firm that have partnership with Celestica for all the latest technology and information." –R3

"No. Staff will receive the training after recruitment" –R4

"No problem. Always a lot of in-house training will be given to learn about the equipment capability." – R5

Furthermore, respondents R6 and R7 also had the same feedback as respondents R3, R4 and R5 about the training provided by the company.

In a nutshell, five out of seven respondents agreed that knowledge-driven challenges occur infrequently in their organisation as a result of the training provided to staff to resolve these issues.

3.3. Challenges of technology

One of the primary concerns in this new industrial era is the highly complex technology architecture for manufacturing systems, which characterizes Industry 4.0. Therefore, effectively implementing Industry 4.0 technologies remains a challenge. The model maturity required to implement a diverse set of technologies and their impact on industrial performance is the primary interest in technology and its integration into the CPS. Thus, implementing a suitable technology into current manufacturing practices is a major challenge for the companies studied in this study. The study also discovered that respondents R6 and R7

believed that technology barriers occurred infrequently in each company, whereas respondents R1, R2, R3, R4, and R5 had nearly the same opinion on the challenges of technology with higher concern barriers in their companies. They stated the following:

Respondent R1 said that:

"Due to fast moving of technology, it is very difficult to catch up the technology available in the market as the manufacturer requires sufficient resources for its operation. The company may need to consider to send the key person for training or exposure on the technology every 6 months in order to gauge where we are now. Product variability is always related with cost of material planning. The manufacturer will consider to take on the new variation of products after considering the market demand with justifiable return of ROI as every customised requirement from customer involve investment not only money but also time and manpower." –R1

Respondent R2 said that:

"*We cannot directly compare with the big boys in the industry. But in other perspective, there is no any leading individual in the industry. We cannot compare directly because of the different category. In terms of Industry 3.0, many European firms are doing very well compared with Malaysia as Malaysia mainly relies on man power from Indonesia, Bangladesh etc. However, there is not necessary to transform step by step from Industry 3.0 into Industry 4.0. In Industry 4.0, it is not dependent on the hardware but more on the software and data management. In the end of the day, it is to be seen who is able to produce one lot size with minimum cost and time required. Vitrox is developing an own app which acts as a platform for other company to use for data management. There is a company policy that in Vitrox there must be a new product produced in every six months. Therefore, it is a drive for us to be innovative and creative."* –R2

Furthermore, Respondent R3 stated that because Celestica's software is still in an older version, a number of functions are not sophisticated or user-friendly. Therefore, data processing would be challenging. Respondents R4 and R5 concurred with respondents R1, R2, and R3 that one of the barriers to implementing Industry 4.0 in Malaysian manufacturing firms was technology.

"Technology. Yes. The current capability of the company in technology is still far from the optimum level of Industry 4.0. The equipment and software are also unable to handle data with high complexity. Investment to new technology also needs huge expenses" –R4

However, Respondent R6 had the same view as Respondent R7 that technology was not listed as a barrier for their company. Respondent R6 stated that:

"*No. Since we are an automation company. We are always equipped with the latest technology"* –R6

Finally, the majority of respondents agreed that technology is one of the challenges that should be addressed during the implementation of Industry 4.0. Furthermore, most businesses find it difficult to keep up with the latest technology, according to the respondents. Newer technologies are being introduced to aid in the development of Industry 4.0, as technology evolves on a daily basis. As mentioned by McKinsey [46], "*Even though we have all the enablers to make Industry 4.0 feasible such as connectivity technology, affordable IoT hardware, standardized communication protocol, collecting meaningful data and analysing for implications are still the biggest challenges to drive the impact from Industry 4.0.*" Hence, technology is one of the major barriers to implementing Industry 4.0, which consists of providing a new way of manufacturing that is closely associated with the end-to-end digitisation of all physical assets and the integration of all value chain partners into digital ecosystems. Additionally, respondents expressed their views on the investment in new technology, which requires significant expenditures and has created challenges. The respondents' perspective is also supported by previous research [47] where the issue of investment is a common one for most new technology-based manufacturing initiatives. Industry 4.0 requires a significant initial investment in a SME. Additionally, because technology is evolving at a breakneck pace, businesses must adapt and change as quickly as possible to maintain a competitive edge. Thus, the digitisation of the industry, from technology to management, will usher in a new era of industrial manufacturing. Businesses that do so will be able to realise their full potential for success in their respective sectors [48].

3.4. Challenges of security

Industry 4.0's increased connectivity and use of industry-standard communication protocols necessitate the protection of critical industrial systems and manufacturing lines, raising the issue of cyber security. Simultaneously, the amount of system data that is vulnerable to cyber security threats has increased significantly [4,9,49].

Based on the findings of this study, it is clear that all businesses have their own security system in place to ensure the safety of their data. As a result, security is not a major concern for Malaysian manufacturers. According to Respondent 3, they are a centralised IT centre based in Johor Bahru that focuses on IT-related problems worldwide, including the United States and Canada. This can make security work easier for various branches. Furthermore, the companies stated that the collected data is confidential and can only be accessed by those with authorised access. This reduces the possibility of being hacked and data leaks. Finally, only Respondent R1 agreed that security is a challenge for the company, whereas Respondents R2, R3, R4, R5, R6, and R7 claimed that security barriers are relatively uncommon in their company.

Respondent R1 said that:

"As for now there are specific authorised personnel that are able to access the data stored in the cloud system. Those required to access the data will need to seek higher management approval. At the moment, the cloud security system is strict and there are also limited access to external website to minimise the chances of being hack by others." –R1.

Respondent R1 also stated that there is a risk of attack from compromised devices when the devices are connected to networks. These types of attacks may not appear to be vulnerable or exploitable right now, but they could be in the future. The responsibility for protecting the security of connected devices should not be limited to the manufacturer who uses the connected device; rather, the responsibility should be shared by device manufacturers and users. Thus, the most effective security measures can be implemented.

Respondents R2, R3, R4, R5, R6 and R7 had the same view on security with the explanation below.

Respondent R2 stated that:

"Vitrox will provide two solutions for their customers. One is cloud and another one is server. In terms of cloud services, Vitrox will evaluate which cloud service provider is the most secure." –R2

Respondents R3 said that:

"Since there is a centralized IT department that will take care of all the IT related problems all over the world for Celestica." –R3

Respondent R7 explained that any data retrieved from machine required authentication. Thus, reduced the security concern since all electronic devices are connected via in-house closed networks.

Furthermore, respondents R4, R5, R6, and R7 gave the same answers about the challenges of data security. Hence, this barrier is unlikely to be a major source of concern among respondents. Security has become a major concern among individuals and organizations, including practitioners. However, cybersecurity is still an important topic to be discussed. Malaysia has implemented the National Cyber Security Policy to combat cyber-attacks [50]. The policy's goal is to strengthen the country's defences, while the policy's vision is to provide resilience and

secure the infrastructure. Therefore, management's full support is critical to the initiative and its goal of raising security awareness throughout the organisation. Besides that, according to the Norton Cyber Security Insights Report, Malaysia had a lower percentage of cybercrime than other Asian countries, such as Indonesia, China, the Philippines, and Thailand [50]. This demonstrates that Malaysia's cyber security was in good shape relative to its neighbouring countries as listed above.

3.5. Challenges of capital

The numerous opportunities, combined with the increased demand for investments in Industry 4.0, which requires advanced technologies, necessitate massive capital.

Respondent R2 stated that:

"*Vitrox is giving 80% discount to Malaysian SMEs that are driving into Industry 4.0. So, we do not have capital problem. In conversely, we encourage more firms to start the implementation of Industry 4.0 by purchasing machine from us and we will provide the instruction and knowledge based Industry 4.0.*" –R2

Meanwhile, respondents R4, R5, and R6 mentioned the following capital challenges during the implementation of Industry 4.0:

Respondent R4 stated that:

"My company spent more cost in preparing learning course related to Industry 4.0 for workers who are qualified, to make sure the operation can be more advanced." –R4

Respondent R5 stated that:

"Semiconductor industry is in downward spiral recently. All new technology investment that is not necessary will be cut short." –R5

According to the responses above, capital may be a barrier for some businesses to advancing Industry 4.0. It may alter the market trend, resulting in the economy not being in the same state of health as Company E. This could result in a budget reduction for Industry 4.0. Industry 4.0 is without a doubt consuming more budgets, particularly in automation manufacturing companies such as Company F. According to a previous study, innovation requires significant capital investments in advanced technology and process systems [34]. Budgeting for capital expenditures and financial strategies are critical components of the Industry 4.0 transformation. Therefore, such transformations are not inexpensive, alienating smaller businesses and potentially costing them market share in the long run.

In comparison to the others, companies A, B, and C do not face capital constraints. Respondents R1, R2, R3, and R7 stated that their businesses do not face significant capital constraints. This is due to the fact that the majority of these businesses are subsidiaries of larger companies and organizations that benefit from significant capital support from their partnerships. As a result, each company's capital budget allocation is determined by its size, which is determined by collaboration partnerships, international industry development, and strong enterprise sponsorship. Usually, SMEs require capital or funds to aid them in adopting new technologies to boost production capabilities as their capital is limited and low. They are unable to incur high costs and rely on economies of scale to invest capital in automating their processes and subsequently upskilling their workers.

3.6. Challenges of workforce

Based on the data gathered in this study, the majority of companies agreed that the workforce is an important component in implementing Industry 4.0. The workforce is a critical challenge for Malaysian businesses. Respondent 1 stated that as manufacturing becomes more automated and digitalised, companies will require more qualified employees to manage more complex activities, not only for machine management but also for data processing. Respondent 4 makes a similar point, stating that rapid technological advancements risk leaving workforces behind if some manufacturers lack the resources necessary to adapt to this new way of working. On the other hand, respondents 5 and 6 indicate that they mitigate the workforce impact of Industry 4.0 by recruiting employees with the appropriate qualifications and training their employees. Finally, respondents R1, R2, R4, and R5 agreed that one of the barriers to their companies implementing Industry 4.0 was the workforce, whereas respondents R3, R6, and R7 disagreed.

Respondent R1 stated:

"Yes. Due to the maximizing the digitization and automation of production, company needs more qualified employees to manage complex activities not only for the managing the machines but also processing the data. With the fast moving and changing of technology in the industry, the skill required keeps on changing. These new set of skills are not here to replace the existing skill sets but these new skills are to complement each other with existing skills in the current scenario. There are limited exposure and training centres to up-skill the employees. It is also need time for employees to accept the changes as they are uncertain of the changes and the implementation of newer technologies." –R1

Respondents R2, R4 and R5 also agreed with Respondent R1.

Respondent R4 explained that rapid technological advancement exacerbates the issue of workforce lag if some manufacturers are unable to keep up with the new method of operation. Employers must also be astute in predicting current trends among potential candidates and constantly improve their interpersonal and technical skills required to implement Industry 4.0.

Respondent R5 also stated that:

"For knowledge, experienced and specialized technical engineer is hard to find while for skills probably no. The skills of certain process will pass down from experience engineer to new engineer. Machine vendor will also carry out training for new feature." –R5

Meanwhile, Respondents R3, R6 and R7 disagreed that workforce is perceived as a challenge.

Respondent R3 stated that:

"No. Celestica will hire the person with the right qualification when recruiting." –R3

Respondent sR6 and R7 had same view on the challenges of workforce due to recruitment based on qualification.

Since the start of the Industry 4.0 trend in Germany in 2011, Malaysian workers who are capable of handling further Industry 4.0 skills and knowledge are in short supply. Malaysia is still a developing country. That being said, the implementation of Industry 4.0 is still in its infancy. As a result, Malaysia's Industry 4.0 workforce will need more effort to practice everything about the technology from the ground up. The workforce is the most difficult aspect for organizations planning to implement Industry 4.0 when it comes to soft skills and qualifications. Failure analysis, problem-solving skills, and the ability to deal with constant change and entirely new tasks, for example, are all desirable. In addition, Pereira et al. [51] stated that Industry 4.0 has transformed jobs and required skills, including avoiding technological unemployment, redefining existing jobs, and adapting the workforce to the new jobs created.

3.7. Challenges of education

Following Industry 4.0's steps has altered the landscape of educational innovation, as Industry 4.0 is primarily controlled by a digital physical framework and artificial intelligence, allowing for a more universal human-machine interface.

Respondent R1 stated that:

"Industry 4.0 is a very new trend of manufacturing technology industry. It needs the adoption of few expertise not only in IT, and data management but also knowledge on equipment as well as the understanding of business in order to make it a success. It is not easy to hire a person that has all rounded knowledge with the implications. Moreover, manufacturing industry is always in a situation where shortage of skilled workers, high turnover rates, and rising costs of manpower, increases the struggle of manufacturers with having the manpower to stay operational." –R1

R2 concurred with R1. According to respondent R2, education is also critical. India, for example, has over 3000 data scientists. However, Malaysia produces an insufficient number of data scientists and data analysts in comparison to other countries. In Malaysia, recent graduates lack the technical skills necessary to work as a data scientist.

Respondents R5 and R6 also agreed with the statements of Respondents R1 and R2.

In addition, Respondent R3 stated:

"Not a major concern since it is not a "must" to possess the knowledge of Industry 4.0. Industry 4.0 still requires some time to be fully utilized in Malaysia. Therefore, it is not a concern if current batch of graduates are not fully aware of the importance and concept of Industry 4.0." –R3

Respondent R7 also had the same view with Respondent R3 that the barrier of education was not a big concern for their company.

Respondent R4 stated that:

"For my own opinion, I think education is a long-term study. There will be a good learning about Industry 4.0 for students nowadays before involved in the job. Hence, it can save the time to learn basically the knowledge of Industry 4.0 and at least there was study conducted prior. Additionally, the trends of Industry 4.0 will be getting more in manufacturing firm in Malaysia soon." –R4

Simply put, five out of seven respondents agreed that education is one of Industry 4.0's challenges. According to respondents R1, R2, R4, R5, and R6, the majority of businesses believe that the current batch of graduates lack knowledge of Industry 4.0. Graduates lack both the soft and technical skills necessary to implement Industry 4.0. Additionally, Respondent 2 asserts that Malaysia's current educational system is incapable of producing sufficient data scientists, a critical profession for implementing Industry 4.0. Industry 4.0, according to a previous study, has altered the landscape of educational technology. Rapid advancements in knowledge have necessitated the development of a future-oriented educational model. As a result, higher education in Industry 4.0 is an energising, perplexing, and rationalistic open door with the potential to transform society. Industry 4.0 is fuelled by counterfeit consciousness and will reorient the workplace away from task-based attributes and toward human-focused qualities. By integrating man and machine, the subject boundaries between humanities and sociology, as well as between science and innovation, will be reduced [52].

Umachandran et al. [53] agree that education is a challenge for Industry 4.0, stating that learning is facilitated by educational institutions that have integrated systems and infrastructure for knowledge and skill development through more practice-oriented methods than traditional methods. The new manufacturing age of Industry 4.0 aims to change the physical world with virtual facilitation by digital bond attenuating distances, eliminating differences, and guiding real-time worldwide transmission of information and material transactions. As a result, the Industry 4.0 educational concept should shift toward learning factories with specific needs to be learned, and then be processed by competent facilitators into a process of learning with necessary content following capacity building. In additional, previous researcher from Malaysia also stated that "*computerized interruptions are going on every day. Advancement among Malaysian colleges is a key aggressive factor of Digital Transformation in IR 4.0. Advanced education pioneers should abuse the potential open doors carried by the IR 4.0 with much obligation and astuteness, by giving computerized administration to their foundations*" [54].

According to the data gathered from the informants, the majority of them also believe that education is one of the areas that can be improved.

3.8. New barrier: mindset

In addition to the previously mentioned challenges, each company's informants have their own take on the challenges they face with Industry 4.0. R1, R2, R6, and R7 express concern about mindset issues. The following is how each of them expressed their views on mindset as a barrier to Industry 4.0.

Opinion from Respondents R1:

"Employee's mentality toward the changes that is going to happen. Employees are too used to the old way of working and hesitate for changes as they need to learn new way and new things. This is same as human natural feel very uncertain about the changes. This can be improved by proper way of communication and training provided to the employees to minimize the uncertainty and make them become more receptive about the changes" –R1

Respondents R2, R5, R6, and R7, on the other hand, shared respondent R1's perspective on the difficulties of changing one's mindset.

Luddites' viewpoint was explained by respondent R2. Firms' attitudes toward Industry 4.0 can also be said to indicate that most companies view the process of Industry 4.0 as a flow that must begin with Industry 1.0, move to Industry 2.0, then to Industry 3.0, and finally to Industry 4.0. This mindset is incorrect and deceiving. As a result, many companies in Industry 2.0 are finding it difficult to accept the rise of Industry 4.0. These businesses have yet to adopt Industry 3.0. Actually, there is no impact if Industry 2.0 becomes Industry 4.0 because Industry 4.0 is a trend and a requirement, not a process. As a result, most manufacturing companies in Malaysia lack the mindset and awareness of the importance of transforming to Industry 4.0.

Respondent R6 who also reputed mentality as a barrier also stated that:

"My opinion, mindset is the key differentiator to succeed in Industry 4.0. It related to the changes in each behaviour. For manufacturers, they must embrace the digital transformation and need to focus on digitalization trends in implementing Industry 4.0" –R6

Respondent R7 shared the opinion on employee's mindset. The fears of change make them unwilling to step out from comfort zone and try out new technology. Employees are not ready to adopt new technologies with their existing knowledge and mindset.

Besides that, Respondent R5 gave out two challenges of implementation of Industry 4.0, which are mentality and environment with the explanation as below.

Respondents R5 stated that:

"First of all, most firms still not dare not change their revolution and still maintain at same Industry. They still depend heavily for foreign labour. Some firms still prefer to follow the old ways and process, and reject to learn new skills. But Industry 4.0 is belonging to the long run way learning. If cannot make any action to changed, finally will be eliminated." –R5

3.9. New barrier: culture

Respondent R3 proposed a new barrier, which he coined the term "culture." He discussed his work experience in a neighbouring country and made comparisons to Malaysia.

"I worked at Singapore before under electronic company too. The company also had implemented Industry 4.0. But due to personal reason, I

quit the job there and went to Johor. So, I can do a comparison on culture for both neighbourhood countries among Malaysia and Singapore. At Singapore, the government is controlling the ratio of foreign workers in a firm. So that, less dependence of low wages foreign labour had cultivated the good culture for always being innovative and creative to increase productivity. This is achieved by introducing all sorts of improvement plan where Industry 4.0 is one of them. Hence, the technologies used are newest and updated from time to time in many manufacturing firms. But in Malaysia, many firms are still heavily depending on low skill labour and want to save up the costs. This causes the firms to be unwilling to accept the Industry 4.0 revolution and the willingness depend on low skill labour." –R3

3.10. New barrier: competitor

Respondent R4 mentioned competitors as one of the barriers to Industry 4.0 implementation. Firms should always embrace new technology to gain a competitive advantage when competing with other firms in the same sector. Traditional businesses may face new competition if they do not embrace technological advancements in their industry. According to Felsberger et al. [55], in order to successfully implement Industry 4.0 projects, firms must have dynamic capabilities, core competencies, and changing business factors. This development is posing new challenges to companies' long-term competitiveness, such as rising costs, changing quality requirements, resource efficiency, dynamic customer requirements, and improving customer satisfaction, productivity, and flexibility. The performance of a company is determined by its capability and resources. As a result, it is critical to comprehend the role of dynamic capability in the impact of Industry 4.0 on achieving long-term competitive advantage. The integration of intelligent and smart systems, as well as the adoption of digital technology, has resulted in new management approaches and capabilities. Adopting these new potential opportunities via digitalised solutions in the context of Industry 4.0 has become increasingly important as customer demands for value chains have increased. To thrive in such a complex environment, businesses must become extremely agile and develop a high level of resilience, managerial capabilities, and structural flexibility to respond to these challenges quickly.

In a word, Industry 4.0 enhances digitisation and connection throughout the value chain, with the potential to drastically modify the industrial value chain and disclose multiple benefits. According to an empirical study conducted in Turkey [56], the most important benefit of Industry 4.0 was enhanced productivity. Significant cost savings, as well as greater speed and competitiveness, were highlighted as additional advantages. Increased revenue potential and the acquisition of new clientele were the least highlighted benefits. There are, however, several obstacles to overcome before Industry 4.0 can be adopted [1,17,29–35], especially in a developing country [56]. According to the qualitative evaluation in this study, respondents came from a number of different firms and faced a variety of various problems when implementing Industry 4.0 in their organisation. The findings of this qualitative study, along with the recent empirical findings of Yüksel [56] on the benefits of Industry 4.0, should serve as a starting point for future research on industry 4.0 practices and challenges in other developing countries, so that future studies can create a comprehensive framework for the impact of this revolution on the manufacturing ecosystem for developing countries.

3.11. The significance remarks of the new barriers: mindset, culture, and competitor

Fig. 2 illustrates a proposed conceptual framework for Malaysia's manufacturing sector in the context of Industry 4.0, in addition to the existing challenges reported in most of the literature, as depicted in Fig. 1. Table 3, on the other hand, summarises the frequency with which each informant raised challenges in this study. Among other new barriers, the mindset is one of the most significant new challenges confronting Malaysian manufacturing companies. Whether an employee or an employer has a positive or negative mindset, both perspectives on the stakeholders' mindset are critical. Employees are hesitant to learn new skills, and continuing to operate in the traditional manner will obstruct their transition to Industry 4.0. Employers' reluctance to adopt Industry 4.0 will make it more difficult to stay current with technology and even more difficult to transition to Industry 4.0 when necessary. Furthermore, respondent R3 pointed out competitors as a challenge for them. The transition to Industry 4.0 will be complicated by competitors' unwillingness to share expertise [55]. As a result, a concept for reconciling Malaysia's dynamic manufacturing industries appears difficult to formulate.

While other countries are working hard to build networks among manufacturing industries in order to support their dynamic capabilities and remain competitive [9,55], this study discovered that the implementation of Industry 4.0 in Malaysian manufacturing firms is still in its early stages. These companies were discovered to conduct exploration using an adaptive-like framework. Their current practices for implementing Industry 4.0 are based on a mix-and-match of traditional industry knowledge. This is where Malaysian manufacturers' mindset or mentality creates significant concern about how far they adapt to the concept of smart manufacturing as demanded by Industry 4.0. In education, for example, none of the respondents mentioned the need for upskilling or reskilling to meet the new Industry 4.0 concepts. Worse, they are unaware of Industry 4.0 norms and standard specifications [3–5,11,40], which are necessary compliance components for their current operating systems and professions [5,9,10]. Throughout the interview process, it was clear that the majority of the subjects were 'trying and adding' Industry 4.0 to their operations. Their iterative approach is based on what is feasible and effective in their manufacturing environment. This could be evidence that manufacturers' attitudes and mindset toward implementing Industry 4.0 in Malaysia are still in the exploratory stage.

Table 3 clearly shows that data management is the most significant barrier faced by respondents. Education, technology, and mindset were ranked second as the most difficult challenges for them, with five out of seven respondents quoting them as a barrier. Meanwhile, roughly half of respondents believe that one of the challenges is the workforce or capital. Knowledge-driven and security, on the other hand, are the least important concerns for the majority of respondents, with only a minority mentioning them. Furthermore, some respondents identified mindset, culture, and competitors as barriers. Enterprises or firms must leverage technological advancements to address current challenges in order to remain competitive in the market [2,6,49]. To improve quality and process competency, it is necessary to update outdated technology, such as an older version of business management software that appears to be still used by the manufacturers with whom respondents affiliate. To compete, new manufacturing methods and technologies that enable the rapid provision of new services must be introduced [56]. Furthermore, as end-users' self-efficacy gain a better understanding of Industry 4.0 [57], one way to keep up with ever-changing customer demands is to upgrade the technologies that support service quality [3,19,49]. Customers, as end users, have the power to influence demand and drive out incompetent manufacturers. Customers' expectations rise exponentially over time, and disruption of customer demands is a phase of social change that is thought to have advanced faster than the impact of the previous three Industrial Revolutions [49,55].

To accelerate the transformation of the manufacturing sector, the government has launched a number of initiatives aimed at digitising Industry 4.0. However, most businesses are still hesitant to adopt Industry 4.0, resulting in unsupported initiatives. Each industry's root cause begins with a shift in mindset. Manufacturers must be aware of the digital transformation trends that are propelling the Industry 4.0 framework forward. Manufacturers must use artificial intelligence,

machine learning, the IIoT, robotics, and other technologies to stay ahead of the competition [2,12,56]. Integrating Industry 4.0 technology requires a high level of quality, efficiency, and process optimisation. As part of the rapid digital transformation, Industry 4.0 in manufacturing aims to delight customers by delivering high-quality products while increasing productivity and profitability. Quality 4.0 is a subset of Industry 4.0 [58], which is all about using real-time data from industry 4.0 technologies, such as connected devices, to drive quality professional continuous improvement initiatives [57]. It is an appeal for the digitisation of quality assurance, compliance, and management systems. Quality 4.0 is about improving the quality of manufacturing, processes, and products, not about technology. Industry 4.0's central idea is to assist organizations in achieving operational excellence through the integration of quality management practices and emerging industry capabilities. On the other hand, unless an appropriate mindset is developed around Industry 4.0 concepts, Quality 4.0 will remain a pipe dream.

Thus, the appropriate mindset is one that is capable and willing to upskill and reskill technological knowledge in order to meet Quality 4.0 demands [11,18,58,59]. A positive mindset anticipates the implementation of updated technology and knowledge in the context of Industry 4.0 as a whole system, as well as the quality of the delivered systems. Physical systems operating within a quality network and management dictate the role of professions within system. A positive attitude will aid in the transition from quality assurance and control to the quality profession. It is a game-changer in terms of manufacturing quality management systems. By bridging the gap between people and machines, CPS adds value to the manufacturing process. This implies that current practices should place a higher premium on professional and managerial quality, as these factors have an effect on product profitability. Nowadays, consumers are more concerned with quality and are willing to pay a premium for a product with world-class features. Consumers expect a seamless purchase and delivery experience, which means that product manufacturers must reduce lead times in order to reduce product time to market, which is all dependent on Quality 4.0.

Another interesting point raised by one of the respondents is the possibility of Industry 4.0 having a negative impact on the environment. Which is an additional significant message that this study should address. According to Respondent R5, the environment may be vulnerable to the demands of running electronics supply on the machines during the implementation of Industry 4.0, and a negative impact on the environment may be inevitable. The CPS is expected to incorporate an increasing number of new electronic components and machines in order to completely transform Malaysia's current manufacturing operation into a smart and intelligent factory. All of these machines may require the manufacture of a variety of raw materials concurrently, resulting in increased electronic waste. If not managed properly, this condition could have a negative impact on the environment. It is possible that Industry 4.0 will exacerbate environmental pollution by increasing the production and use of electronic components, thereby increasing the amount of electronic waste generated during the transition or to maintain the operations required by the electronic systems in the CPS.

In terms of culture, these study findings reflect the associated effects of the country's policies. Policymakers and all stakeholders should take serious measures to transition Malaysia's current manufacturing industry to smart manufacturing operations based on Industry 4.0 principles. The policy must ensure a sustainable biosphere for the transition [1,35,49], not only by addressing the operation's environmental impact, but also by prioritising local professionals over low-cost and unskilled labour. As respondent 3 mentioned in relation to culture as a new challenge, a labour policy that imposes no limits on the workforce ratio of professionals and skilled workers to low-cost and unskilled labour, or foreign and local workers, would create an unhealthy working environment, impeding the development of a workable culture capable of meeting the Quality 4.0 requirements in the implementation of Industry 4.0 [3,5,11].

Furthermore, given the nature of socio-technical systems and the broad adoption of technologies such as the CPS/IoT in Industry 4.0, policy formulation on governance issues should include civil society – the silent majority [8]. By fostering interactions between everyday things and humans, this strives to ensure that technology governance is inclusive and of high quality. A more effective governance strategy for socio-technical systems during technological transition, commissioning, and maintenance is critical for meeting Quality 4.0 criteria [11,18,58,59], as the integrated CPS ecosystem's demand and supply are intrinsically linked to consumers' self-efficacy over time [57]. In developing countries [8,56], a dynamic and well-governed approach to industrial transition from traditional to 4.0 operations have the potential to have a positive impact on manufacturing, commercial demand and supply, as well as the environment, resulting in a greener ecosystem.

4. Conclusions

Malaysia's manufacturing industry is one of the most important sectors of the country's economy. As a result, keeping up with the latest industrial developments is critical for the industry in order to continue generating revenue for the country. The Malaysian manufacturing industry, according to the findings, is still in the early stages of transitioning from existing manufacturing (mostly Industry 3.0) to the Industry 4.0 ecosystem. The informants in this study faced a number of challenges as they transitioned to the current Industry 4.0 paradigm. According to the findings of this study, their current practice is based on an adaptive-like framework of practice, with the majority of subjects 'trying and adding' Industry 4.0 to their current operations throughout the process. Based on their responses, there was no clear paradigm shift in the respondents' practice of addressing or raising issues related to Industry 4.0's main operations, such as interoperability, decentralization, dynamic real-time analytics, virtualization, modularity and scalability, or service orientation. During the course of their adaptive-like framework practice, all respondents encountered challenges with "data management and integration." The majority of respondents cite knowledge-driven, technology, capital, education, and the workforce as major challenges. One of the three new barriers discovered in this study is "mindset" (along with the other two: "culture" and "competitor"), from the luddite mentality and misconceptions about industrial revolutions, which is the biggest challenge to the success of technological migration in implementing the Industry 4.0 ecosystem. The majority of respondents believe that the ability to change will be critical to the success of Industry 4.0 in Malaysian manufacturing firms. Traditional manufacturing industries are resistant to change, and overcoming this "mindset" would be a significant step forward in their adoption of Industry 4.0. Thus, the government's ability to raise awareness of the importance of implementing Industry 4.0 among Malaysian manufacturing firms will be a critical tipping point. According to this study, the majority of companies in Malaysia (and possibly other developing countries) are still in the early stages of Industry 4.0. To succeed in Industry 4.0, it is critical to find solutions to all of the challenges. This will only be possible with the cooperation of the government and the private sector. However, Malaysia's late adoption of Industry 4.0 may be due to a lack of public awareness, interaction, and practical policies between the government and the private sector. More incentives for SMEs to adopt Industry 4.0, such as funds for development and training in the Quality 4.0 paradigm, are proposed. These incentives will encourage more businesses to participate in the Industry 4.0 transformation. Since future manufacturing talents with manufacturing techniques and skills are in high demand for Industry 4.0, an updated syllabus for Industry 4.0 should be implemented in the educational system. The majority of respondents also believe that the current educational system needs to be revised in order to produce more talent to support the growth of Industry 4.0. Furthermore, the new challenges identified in this study are a call for the government and manufacturing sector to develop workable policies based on the norms and standard

specifications proposed in Quality 4.0 in order to achieve a sustainable transition from traditional industry to Industry 4.0. Both parties must overcome their fear of change and unwillingness to leave their comfort zone and current status quo.

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