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## Article

# The situation of technology companies in industry 4.0 and the open innovation

Journal of Open Innovation: Technology, Market, and Complexity

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*Suggested Citation:* Mohd Hizam Hanafiah; Mansoor Ahmed Soomro (2021) : The situation of technology companies in industry 4.0 and the open innovation, Journal of Open Innovation: Technology, Market, and Complexity, ISSN 2199-8531, MDPI, Basel, Vol. 7, Iss. 1, pp. 1-20, <https://doi.org/10.3390/joitmc7010034>

This Version is available at:

<https://hdl.handle.net/10419/241619>

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Article

# The Situation of Technology Companies in Industry 4.0 and the Open Innovation

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**Abstract:** Digitalization has increased the adoption pace of Industry 4.0 technologies, particularly in connection with Open Innovation. However, companies are still finding it challenging to know the variety of Industry 4.0 technologies available, and their fit with the scope of the organization. To address this issue, a cross-sectional research design under quantitative approach was adopted. The data were collected first-hand through a survey questionnaire from a total of 238 technology companies in Malaysia. Technology companies were selected as they have higher agility in terms of technology which suits the digital revolution nature of Industry 4.0. The findings of this descriptive study revealed a range of insights in terms of Industry 4.0 technologies and open innovation. First, this study presents the standing of technology companies in terms of 12 Industry 4.0 technologies. Second, a comparison of these technologies is analyzed in terms of company size (small, medium, and large). Third, a contrast of these technologies is ascertained based on the type of company (manufacturing and services). In brief, this research contributes in providing valuable insights that can help companies in the awareness of open innovation and adoption of Industry 4.0 technologies.

**Keywords:** Industry 4.0; Industry 4.0 technologies; fourth industrial revolution; open innovation; technology companies; manufacturing companies; services companies



**Citation:** Hizam-Hanafiah, M.; Soomro, M.A. The Situation of Technology Companies in Industry 4.0 and the Open Innovation. *J. Open Innov. Technol. Mark. Complex.* **2021**, *7*, 34. <https://doi.org/10.3390/joitmc7010034>

Received: 12 December 2020

Accepted: 12 January 2021

Published: 14 January 2021

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## 1. Introduction

Industry 4.0 is a rapidly arriving future. Since its inception in 2011, it was considered as a phenomenon of the distant future, but in the last few years starting from 2016, it has gained increased prominence and application for manufacturing and service companies both [1,2]. Gartner forecast presumed that 26 billion things in the year 2020 will be internet-connected, and hence the dependence on Industry 4.0 technologies will be higher than ever (Gartner 2018). Likewise, the author Bahrin study suggested Industry 4.0 technologies will be intensely used in the new manufacturing age, to be called as Smart Manufacturing age [3]. Furthermore, it is the age of Open Innovation, as collaboration with people and organizations outside the company is increasing, resulting in more knowledge creating and knowledge sharing opportunities [4,5]. Moreover, the vision of Industry 4.0 by Neugebauer projects that the importance of Industry 4.0 technologies will increase with the improvement in real-time digitalization [6]. From the industry perspective, McKinsey in 2018 stated that 90% of firms visualize Industry 4.0 as an opportunity and not a threat.

By all means, digital technology is the driving force for Industry 4.0, and nearly all the innovations of Industry 4.0 come through digitalization [7]. However, Sharma and Gandhi observed risks in adopting these digital technologies, in the areas of data security and job loss [8]. In a similar vein, Fatorachian and Kazemi studied three challenges in adopting Industry 4.0 technologies [9]. One challenge is to draw sanity from machine-generated data. The second challenge is the Internet of Things (IOT) vulnerability to cyber-attack. The third challenge is technological and cultural cohesion to implement Industry 4.0 technologies. However, despite these challenges, Industry 4.0 technologies have gained reputation in both industry and academia.

Overall, the challenge companies are facing is to know the spectrum of Industry 4.0 technologies available, and the standing of their processes, procedures, and philosophy to tap with these technologies [10]. Moreover, despite the rising acceptance of Industry 4.0 technologies, there are barriers to implementing them. These barriers include coordination difficulty, resistance, lack of talent, cybersecurity, lack of benefits, technology uncertainty, data acquisition, and restricted technology diffusion [8]. Similarly, the question that Industry 4.0 theorists deal with continuously is ‘how can we get somewhere without knowing where we are now?’ [11]. In brief, the popularity of Industry 4.0 technologies has increased in recent times, but several firms are still struggling to make use of them [12]. In the context of Malaysia, the Malaysian government launched a nationwide policy ‘Industry4WRD’ in 2018 to take benefit from Industry 4.0 technologies. Ex-Prime Minister Tun Dr. Mahathir Mohamad at the beginning of 2019 stated that Malaysia risks losing out with untapped talent in Industry 4.0 (February 2019, The Star Newspaper). Later in the same year, his statement further escalated mentioning that Malaysia has no choice but to adapt and master Industry 4.0 disruptive technologies (July 2019, The Star Newspaper). Furthermore, Malaysia is an emerging economy and an important market for the implementation of Industry 4.0 technologies. In this respect, there are three important research questions that this descriptive study aims to address:

Research Question 1: *What is the status of implementation of Industry 4.0 technologies among the technology companies in Malaysia?*

Research Question 2: *What are the main insights of Industry 4.0 technologies in comparison with company size (small, medium and large)?*

Research Question 3: *What are the main insights of Industry 4.0 technologies in contrast with company type (manufacturing and services)?*

The remaining paper is organized in this sequence: Section 2 states the literature review and theoretical background. Section 3 presents the research methods, and Section 4 states the findings. Based on the results then, Section 5 expands the discussion on the research questions of this study. Lastly, Section 6 summarizes this paper with the study contributions.

## 2. Theoretical Background

The literature on Industry 4.0 technologies can be better understood through the intersection of Industry 4.0 technologies, the impact of Industry 4.0 technologies, and the Unified Theory of Acceptance and Use of Technology (UTAUT). These three theoretical aspects are discussed further in this section.

### 2.1. Industry 4.0 Technologies

Industry 4.0 is a phenomenon, whereby the physical world and the virtual world have merged into one as Cyber-Physical Systems (CPS) [13]. Combining the technologies and concepts revolving around Industry 4.0, the consulting firm Boston Consulting Group (BCG) first identified Nine Pillars of Industry 4.0 in 2016 [14]. These nine pillars of Industry 4.0 are Additive Manufacturing, Augmented Reality, Autonomous Robots, Simulation, Horizontal/Vertical Integration, Internet of Things, Cloud Computing, Cybersecurity, and Big Data Analytics. This paper extends these nine technologies by including three more technologies: Artificial Intelligence, Mobile Technologies, and Radio-Frequency Identification (RFID). The reason for the inclusion of these three additional technologies is their direct connection and relevance with Industry 4.0. In terms of Industry 4.0, Artificial Intelligence is important as it forms the basis for all computer learning [15]. Likewise, Mobile Technologies are important in technology communication in all sorts of ways [16], and Radio-Frequency Identification (RFID) is important as it can identify and locate objects leveraging the potential of other Industry 4.0 technologies [17]. Several authors have discussed these nine pillars of Industry 4.0 independently and in conjunction. First, the author Gilchrist illustrated the concept of Augmented Reality (AR) [18]. As technology is progressing, miniaturization is getting popular and challenging. Chips now are a grain of sand, and this is just the beginning of miniaturization and Augmented Reality (AR). The

concept of AR is in its infancy but technologies such as AR glasses are rapidly becoming common though [19].

Next, Hofmann and Rüsç worked on the two components of Industry 4.0: Cyber-Physical Systems (CPS) and Internet of Things (IOT) [20]. Furthermore, Hofmann and Rüsç defined Industry 4.0 as products and services that are digitally connected over the internet or other platform, and can operate without human interventions [20]. For example, Big Data has improved the data quality available, Simulations have leveraged real-time data and result, Additive manufacturing have made mass product customization possible. Subsequently, the author Kang gave a brief account overview of five Industry 4.0 Technologies: Cyber-Physical Systems, Cloud Manufacturing, Big Data Analytics, Internet-of-Things, and Additive Manufacturing [21]. Cyber-Physical Systems (CPS) are collaborating entities with the surrounding physical world and data-processing services available on the internet. It is the backbone for Smart Manufacturing. Following that, Roblek et al. explained the Cyber-Physical System as a mix of computation, networking, and physical processes [22]. For example, control of vital human functions through mobile applications, or sensors in clothing. Based on this study, Cloud Manufacturing is a mix of cloud computing and manufacturing. It's customer-centric and on-demand. Big Data Analytics involves working on a data set that goes beyond traditional data process methods [23]. Internet of Things (IOT) makes physical things streamlined through internet protocol or wired network. Additive Manufacturing (3D Printing) transforms a three-dimensional model into a physical object through an electronic beam. First, it was used for prototyping, but now for full product designing [24]. Overall, Additive Manufacturing has a major advantage of material efficiency and resource efficiency.

Moreover, for the successful implementation of Industry 4.0, two perspectives should be considered: Horizontal Integration and Vertical Integration [25]. Vertical Integration establishes the astute digitalization of specialty units at various levels inside the organization. In this manner, Vertical Integration empowers the change needed for a Smart Factory. Conversely, Horizontal Integration improves the holistic value for advancing the product life cycle utilizing technology architecture (Acatech 2015). Overall, the Horizontal and Vertical Integration empowers constant information sharing, profitability in asset allotment, sound working of organizational units which are pivotal for Industry 4.0 [26]. Furthermore, RFID technologies, Cyber Security, and Mobile Technologies are also considered important for Industry 4.0 technology infrastructure [17]. This includes geographic identification and location monitoring of things using various ID technologies. The information collected from different procedures assists in integration and promotes faster decision making. Thus, RFID produces value in logistics and other service operations [27]. It is also important to note that these Industry 4.0 technologies bring their own set of challenges which can be better overcome through the notion of Open Innovation [5]. In fact, the era of Industry 4.0 technologies values Open Innovation greatly, as the integration of external knowledge is more important than ever in driving innovation within the organization [4]. In summary, this section elaborated on the 12 Industry 4.0 technologies that can help companies in digitalization, and thereby Industry 4.0 transformation.

## 2.2. Impact of Industry 4.0 Technologies

Industry 4.0 technologies have helped organizations in taking the technological shift [28]. This applies to both technology-forward and technology-lagging organizations, as Industry 4.0 can give a leap to new entrants as well [29]. As Industry 4.0 technologies revolve around digitalization and digital transformation, the impact that Industry 4.0 technologies can have on organizations can be immense. In the case of the manufacturing sector, Additive Manufacturing and Autonomous Robots have improved efficiency as machines in the Smart Factory (factory with Industry 4.0 technologies) can complete variable tasks without reprogramming [30]. These factories then are not only resilient but sustainable, due to their digitalization advantage. In the case of the service sector, Artificial Intelligence

can improve customer service by multiple knots or levels, at a reduced cost and faster time [31].

All in all, Industry 4.0 technologies are a key enabler [32]. The impact of Industry 4.0 technologies on organizations can also be understood by the need for novel business models and new ways of value creation in the organization [33]. Digital transformation has improved organization's productivity and industry competitiveness to an unprecedented level. For example, organizations are already shifting from 'if' to 'how' in the adoption of digital technologies [34]. The easiest to understand is the usage of IOT (Internet of Things) to improve business outcome [35]. In terms of Cyber Security technologies, organizations are already shifting from caution to action. However, in order to adopt Industry 4.0 technologies, organizations have to make certain adjustments in terms of people, process, and structure to take full advantage of Industry 4.0. Overall, organizations are learning faster than ever and making extensive use of different sorts of Industry 4.0 technologies leading to significant service and product innovation [36].

### 2.3. Unified Theory of Acceptance and Use of Technology (UTAUT)

The Unified Theory of Acceptance and Use of Technology (UTAUT) is about user intentions to use an information system and their subsequent usage behavior [37]. This theory is a combination of five important models: Theory of Reasoned Action (TRA), Technology Acceptance Model (TAM), Theory of Planned Behavior (TPB), Diffusion of Innovations Theory (DOI), and Social Cognitive Theory. This theory is well-positioned to explain the derivations of Industry 4.0 technologies. UTAUT was conceptualized by Venkatesh and Zhang, taking inference from Technology Acceptance Model (TAM) as it combines various constructs into a single psychometric construct [38]. To empirically test UTAUT, Venkatesh and Zhang also compared the U.S. with China [38]. The study then confirmed that social influence is important for all, without any inference to gender, age, and voluntariness. By all means, there is high motivation for technology adoption research, as mentioned by Gartner in 2007. For the same reason, research on psychological and sociological factors has already taken center stage with reference to behavioral intention towards using technology.

This theory has four main components: (i) performance expectancy, (ii) effort expectancy, (iii) social influence, and (iv) facilitating conditions. The first three are focused on usage intention and the last one is based on user behavior [39]. Performance Expectancy is the extent to which people believe that technology will improve their performance and hence rewards. Effort Expectancy is the extent to which technology is easy to use. Social Influence then is defined as the extent to which people perceive that others will use or adopt the technology [40]. The last component Facilitating Conditions is the extent to which support infrastructure is available. Overall, this paper underpins UTAUT as the underlying concept to provide the base for the implementation of the various Industry 4.0 technologies [41]. This theory also helps to explain the behavioral, social, and psychological perspective in connection with the adoption of these Industry 4.0 technologies [42].

## 3. Methods

### 3.1. Data Collection and Sampling

This study captured the opinions of the management team from technology companies in Malaysia, in terms of implementation of Industry 4.0 technologies. Purposive sampling as part of non-probability sampling was used [43]. This sampling technique was used as the complete population of technology companies in Malaysia is not known. Instead, a sampling frame was drawn from the different databases in Malaysia, including Persatuan Industri Komputer dan Multimedia Malaysia (PIKOM) which is the national tech association of Malaysia, Malaysian Green Technology Corporation, Malaysian Bioeconomy Development Corporation, and Technology Park Malaysia Corporation. A technology company is one that uses technology as an advantage in its internal and external operations [44,45]. Precisely, technology companies in the scope of this study included: (i)



manufacturing technology companies, (ii) services technology companies, (iii) local technology companies, and (iv) foreign technology companies operating in Malaysia. This paper focused on technology companies alone, as they are at the forefront of adoption and implementation of advanced technologies, including Industry 4.0 technologies. Furthermore, Industry 4.0 technologies are more relevant and much more needed by technology companies, and hence the impact of technological shift can be better understood first by studying technology companies. In the context of the Malaysian economy, technology companies are particularly important as they directly contribute to the digital economy of Malaysia [46]. Furthermore, Malaysia has a vision of becoming a high-tech-based manufacturing hub, for which more technology companies and technology solutions are needed (June 2020, The Star Newspaper). Overall, this establishes the role and importance of technology companies in the context of the Malaysian economy.

There were two criteria in selecting members of the management team for this study: (i) he or she should be at least a manager working in that company, and (ii) he or she should have worked with that company for at least 1 year. These two conditions are important as this will filter professionals that are senior and have greater decision making [47,48]. The data were collected with the help of enumerators. A total of 32 enumerators played a key role in data collection. As a result, 276 technology companies were surveyed. Data editing and deletion due to outliers and missing values resulted in the removal of 38 responses. Thereon, 238 companies were finally analyzed in this study. Enumerators were given two filter questions for the initial screening of companies in line with the purpose of this study: (i) company should be a technology company, (ii) company should have implemented at least one of the Industry 4.0 technologies. The responses received in this study were targeted with these filter criteria. The dimensions criteria of sales turnover and employees were used to establish the taxonomy on small, medium, and large size organizations in comparison with manufacturing and services companies. This taxonomy was adopted from Small and Medium Enterprises Corporation (SME Corp.) and is presented in Table 1.

**Table 1.** Taxonomy for classification of companies.

	Manufacturing	Services
Large	Sales turnover: Above 50 mil Or Employees: More than 200	Sales turnover: Above 20 mil Or Employees: More than 75
Medium	Sales turnover: RM15 mil $\leq$ RM50 mil Or Employees: From 75 to $\leq$ 200	Sales turnover: RM3 mil $\leq$ RM20 mil Or Employees: From 30 to $\leq$ 75
Small	Sales turnover: RM300,000 < RM15 mil Or Employees: From 5 to < 75	Sales turnover: RM300,000 < RM3 mil Or Employees: From 5 to < 30

Source: Small and Medium Enterprises Corporation (SME Corp.) Official Website (last accessed on 27 December 2020).

### 3.2. Measurement and Scale

In terms of instrument measurement, the questions were adopted from two studies Yagiz [33] and Stentoft [49]. All the measures used in this study had reliability and validity tested. Additionally, all the measures selected in this study were used by various previous studies. Yagiz focused on the readiness of Industry 4.0 in terms of technologies, whereas Stentoft gave an overview of Industry 4.0 readiness with its barriers and drivers [33,49]. In terms of instrument scale, data was collected through a cross-sectional survey using the 5-point Likert scale. The scale ranged from 1 (Do not use) to 5 (Use to a very high degree). A Likert scale is recommended in the assessment of the opinions of the respondents [43]. Moreover, a 5-point Likert scale is better as it is adequate, and it includes a middle option which does not force the respondent to take a leading side [50]. The survey used in this study is presented in Table 2. The findings and results obtained by using these research methods follow in the next section.

**Table 2.** Survey items and scale.

To Which Degree on a 1–5 Scale, Do You Apply the Following Industry 4.0 Technologies in Your Organization? (1 Do Not Use, 5 Use to a Very High Degree)	
No.	Industry 4.0 Technologies
1	Big Data and Analytics
2	Autonomous Robots
3	Simulation
4	Horizontal and Vertical System Integration
5	Internet of Things (IoT)
6	Cybersecurity
7	Additive Manufacturing
8	Augmented Reality
9	Cloud Computing
10	Mobile Technologies
11	Artificial Intelligence
12	Radio-Frequency Identification (RFID)

#### 4. Results

The profile of the organizations in this study can be understood from Table 3. In terms of company type, 62.6% are services companies and 37.4% are manufacturing companies. In terms of company size, 49.6% of companies are large, 29.8% of companies are medium, and 20.5% of companies are small. It is not surprising to see that majority of the companies in this study are large size, as large size companies often have a higher probability of implementing Industry 4.0 initiatives.

**Table 3.** Organization profiling.

Items	Frequency	Percentage (%)
Manufacturing Large	45	18.9
Manufacturing Medium	22	9.2
Manufacturing Small	22	9.2
Services Large	73	30.7
Services Medium	49	20.6
Services Small	27	11.3
Total	238	100

Following the research questions of this paper, this section is divided into three sub-sections. These three sets of findings are presented with their visuals and illustrations, followed by their respective interpretation.

##### 4.1. Status of Implementation of Industry 4.0 Technologies

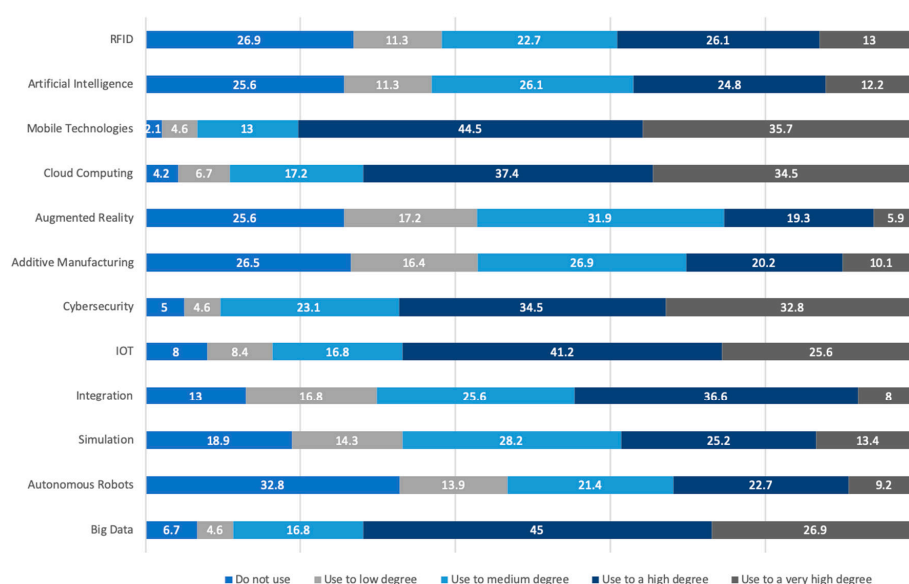
The first set of results focused on the current implementation status of Industry 4.0 technologies, among the 238 technology companies in Malaysia. This analysis has been presented from seven different perspectives, as elaborated in this section. First, the Mean, Standard Deviation, and adoption percentage were calculated on the 238 responses received. The study followed the scale range from 1 (Do not use) to 5 (Use to a very high degree). As shown in Table 4, the Mean of six Industry 4.0 technologies (Big Data, Horizontal and Vertical System Integration, Internet of Things, Cybersecurity, Cloud Computing, and Mobile Technologies) is above 3, which means that the organizations are using it to some degree. The highest Mean is 4.07 for Mobile Technologies, which implies that the implementation of this technology is the most common. On the contrary, the least used technologies are Autonomous Robots (Mean 2.62) and Augmented Reality (Mean 2.63). Likewise, Standard Deviation is a measure that shows the distance to the Mean. The lower the Standard Deviation, the more condensed the data are towards the center. In this study, the Standard Deviation of all Industry 4.0 technologies (except Mobile Technologies) is

above 1, which implies that the data are spread out, and there is a high deviation in the responses received from the different technology companies in Malaysia. However, for Mobile Technologies, the data are relatively less spread. In terms of adoption percentage, the companies rating on Scale 1 (Do not use) were excluded, and the results were then collated as presented in Table 4. The results show that the lowest adoption percentage is for Autonomous Robots (67%), implying that 160 out of 238 companies have adopted this technology. Conversely, the highest adoption percentage is for Mobile Technologies (98%) implying that 233 out of 238 companies have adopted this technology, Cloud Computing (96%) implying that 228 out of 238 companies have adopted this technology, and Cyber Security (95%) implying that 226 out of 238 companies have adopted this technology.

**Table 4.** Industry 4.0 technologies (mean, standard deviation and adoption percentage).

No.	Industry 4.0 Technologies	Mean	Standard Deviation	Adoption Percentage
1	Big Data and Analytics	3.81	1.093	93%
2	Autonomous Robots	2.62	1.381	67%
3	Simulation	3	1.302	81%
4	Horizontal and Vertical System Integration	3.1	1.171	87%
5	Internet of Things (IoT)	3.68	1.176	92%
6	Cybersecurity	3.85	1.087	95%
7	Additive Manufacturing	2.71	1.323	74%
8	Augmented Reality	2.63	1.222	74%
9	Cloud Computing	3.91	1.077	96%
10	Mobile Technologies	4.07	0.927	98%
11	Artificial Intelligence	2.87	1.365	74%
12	Radio-Frequency Identification (RFID)	2.87	1.401	73%

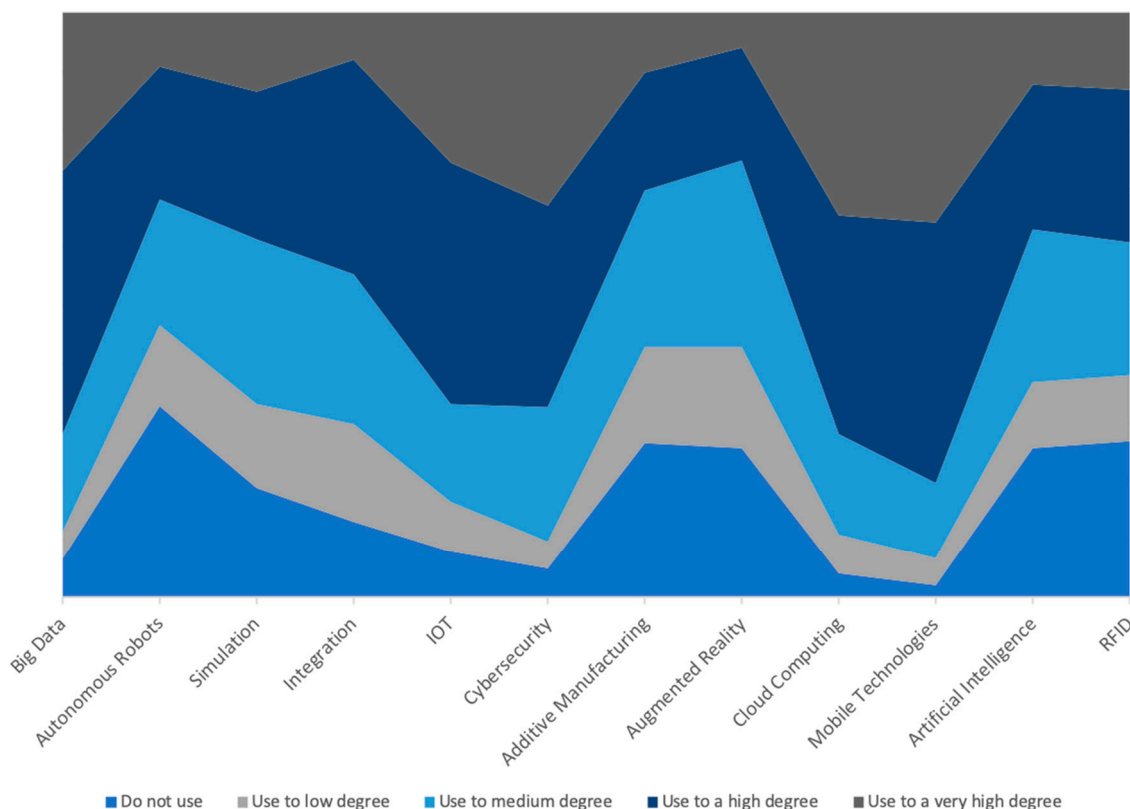
Second, Industry 4.0 technologies were analyzed through a stacked chart as shown in Figure 1. This figure shows that the top three Industry 4.0 technologies used are Mobile Technologies (35.7% use to a very high degree), Cloud Computing (34.5% use to a very high degree), and Cybersecurity (32.8% use to a very high degree). Conversely, among the Industry 4.0 technologies that are not used, amongst the 238 companies surveyed, the highest percentage corresponds to Autonomous Robots technology (32.8% do not use it at all).



**Figure 1.** Industry 4.0 technologies (stacked chart).



Third, Industry 4.0 technologies were analyzed through a surface chart as shown in Figure 2. This figure shows that the relative pattern of all 12 technologies for 238 technology companies in terms of usage scales (do not use to high degree use) is the same. In other words, the lower bound (bottom most) and upper bound points (topmost) of all 12 technologies show a similar trend. In terms of visual surface area, scale option 3 (use to a high degree) and scale option 4 (use to a very high degree) are the most common choice amongst the responses received. The least scale option selected by respondents is scale option 2 (use to a low degree). In summary, a majority of 238 technology companies in Malaysia range from high to very high degree in terms of the application of all Industry 4.0 technologies combined.



**Figure 2.** Industry 4.0 technologies (surface chart).

Fourth, Industry 4.0 technologies were analyzed through a line chart as shown in Figure 3. Here the 12 technologies are numbered in line with Table 4. On the horizontal axis at the bottom of Figure 3, 1 represents Big Data and Analytics, 2 represents Autonomous Robots, 3 represents Simulation, 4 represents Horizontal and Vertical System Integration, 5 represents Internet of Things, 6 represents Cybersecurity, 7 represents Additive Manufacturing, 8 represents Augmented Reality, 9 represents Cloud Computing, 10 represents Mobile Technologies, 11 represents Artificial Intelligence, and 12 represents Radio-Frequency Identification. The figure shows that scale option 4 (use to a high degree) is the most selected option and that too for technology 1 (Big Data) and technology 10 (Mobile Technologies). Likewise, scale option 1 (do not use) is the least preferred choice for technology 9 (Cloud Computing) and technology 10 (Mobile Technologies). Overall, the five lines (representing the five scales of the survey) have irregular patterns amongst the 12 technologies, which implies that the implementation patterns of all 12 technologies are unique from one another.

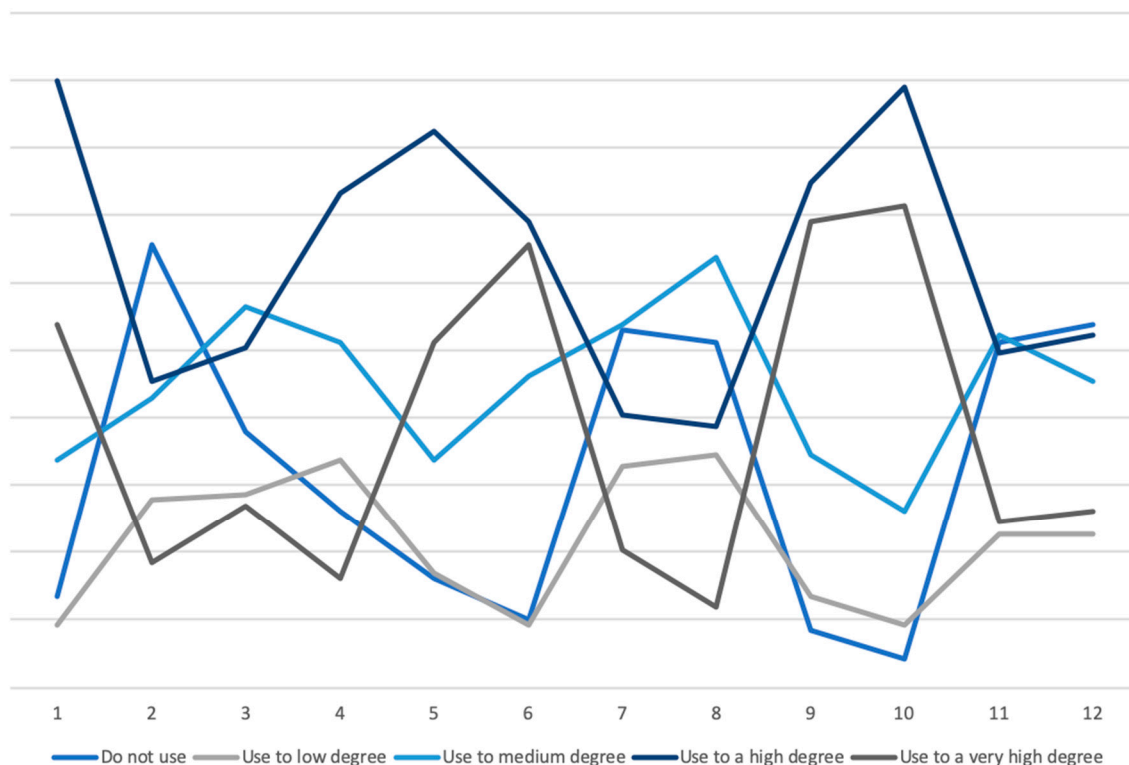
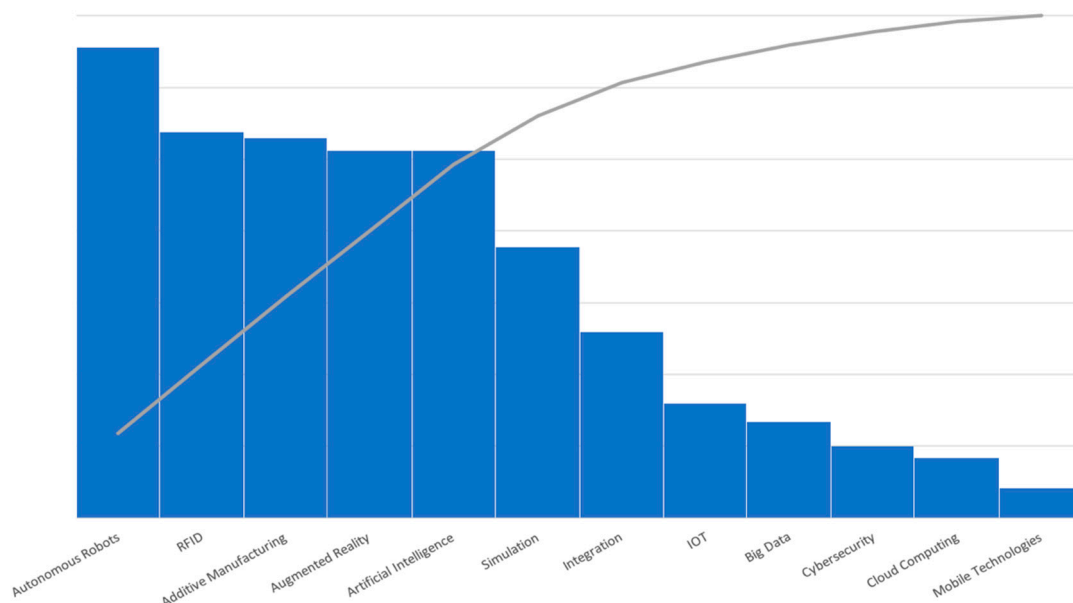


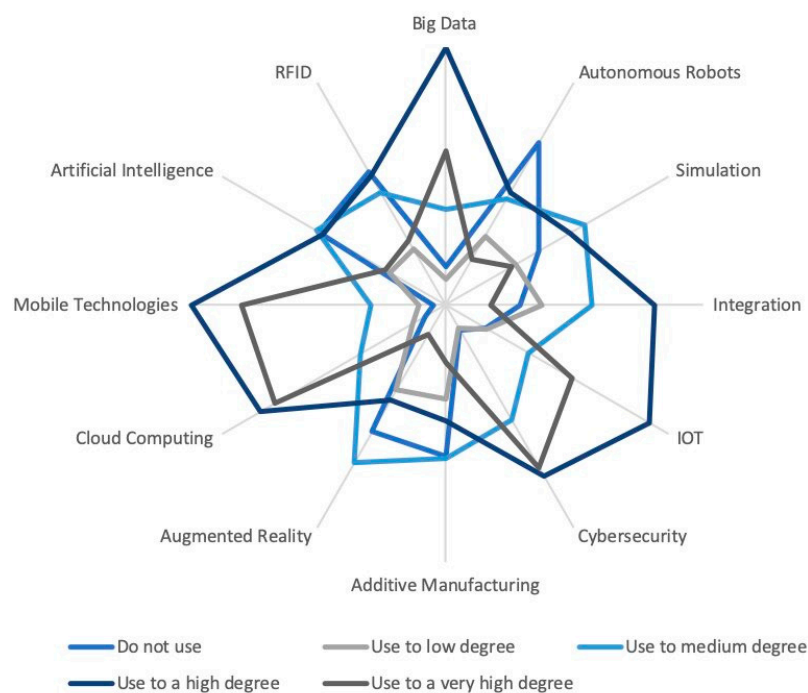
Figure 3. Industry 4.0 technologies (line chart).

Fifth, in terms of inverse impact, non-usage of Industry 4.0 technologies was analyzed through the Pareto chart as shown in Figure 4. This Pareto chart was prepared considering the first scale option of non-usage only (Scale 1: Do not use). This chart hence further confirms that the top three technologies used are Mobile Technologies, Cloud Computing, and Cybersecurity as their non-usage bar is the shortest, and the least three technologies used are Autonomous Robots, RFID, and Additive Manufacturing (3D Printing) as their non-usage bar is the highest. Furthermore, it is interesting to observe through this illustration that there is a clear divide of two parts between all 12 technologies. In total, five technologies (Autonomous Robots, RFID, Additive Manufacturing, Augmented Reality, and Artificial Intelligence) are almost on a similar footing of non-usage except for Autonomous Robots which is slightly higher, and then the remaining seven technologies are on another similar footing of the high degree except for Simulation and Integration which is also slightly higher. The grey curve shows the opposite effect which is the relative usage of Industry 4.0 technologies, based on the non-usage scale. The lower bound of the curve represents Autonomous Robots which is the least used and the higher bound of the curve represents Mobile Technologies which is the most used.

Sixth, Industry 4.0 technologies were analyzed through a Radar chart in terms of 12 technologies as shown in Figure 5. Here, option 4 (use to a high degree) is the outermost radar in dark blue color, applying to a maximum number of Industry 4.0 technologies. Big Data and Mobile Technologies are mostly implemented among 238 surveyed technology companies in Malaysia. The innermost radar in light grey color is option 2 (use to a low degree), which is the least opted choice, which primarily includes Artificial Intelligence. Overall, the five-color lines representing the five scales have different and unique standing for each of the 12 Industry 4.0 technologies.

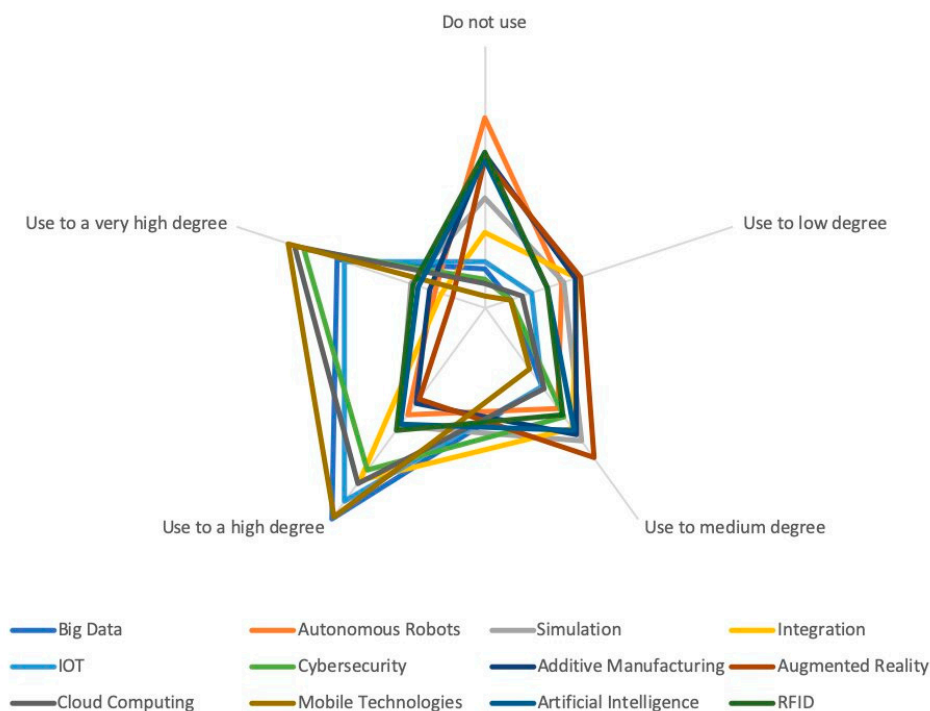


**Figure 4.** Non-usage of Industry 4.0 technologies (pareto chart).



**Figure 5.** Industry 4.0 technologies (radar chart in terms of technologies).

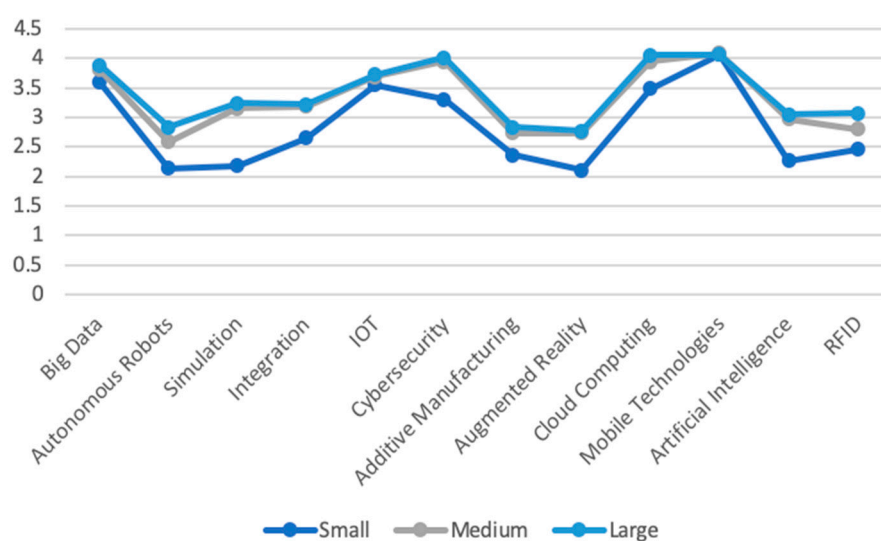
Seventh, Industry 4.0 technologies were analyzed through a Radar chart in terms of five scales as shown in Figure 6. Here, it can be clearly seen that option 4 (use to a high degree) and option 5 (use to a very high degree) are the two most selected options by 238 respondents. On the contrary, option 2 (use to a low degree) is the least selected option by 238 respondents. Overall, this figure shows that for most of the companies, the majority of the Industry 4.0 technologies have already been implemented, which is a positive sign implying that technology companies in Malaysia have good standing.



**Figure 6.** Industry 4.0 technologies (radar chart in terms of scales).

#### 4.2. Industry 4.0 Technologies in Comparison with Company Size

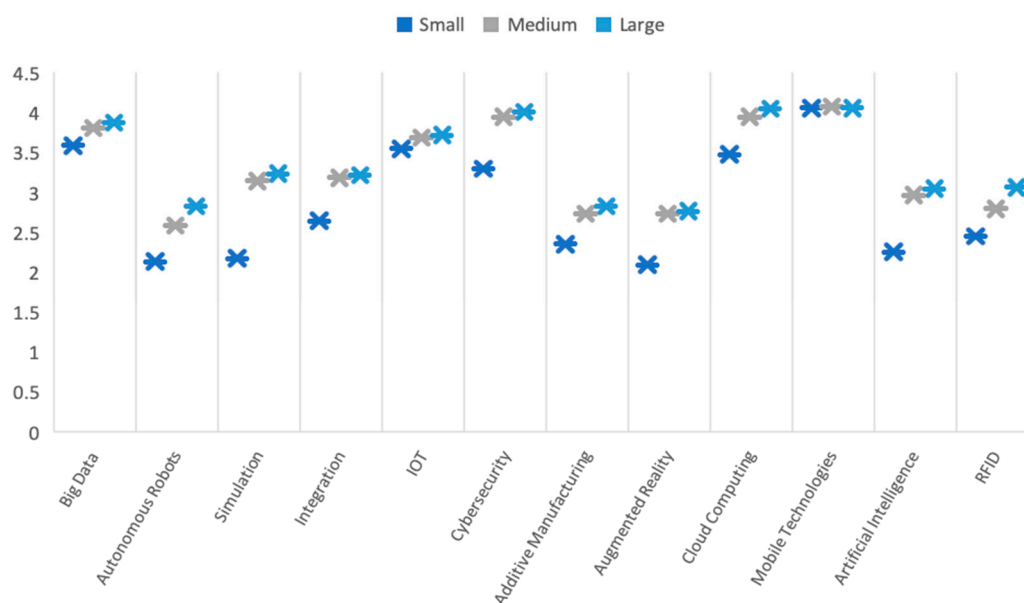
Next, in terms of comparing Industry 4.0 technologies with the company size, two perspectives are presented. Firstly, Figure 7 shows that large size companies and medium-size companies have shown equal potential in applying the Industry 4.0 technologies, with the exception of Autonomous Robots and RFID, where large size companies are better than medium size companies. This also shows in general, that small size companies score less in the implementation of Industry 4.0 technologies. Particularly, there are three areas where the gap between small and large size companies is highest. These areas are Simulations, Augmented Reality, and Artificial Intelligence in terms of which large size companies have a better score than small size companies.



**Figure 7.** Industry 4.0 technologies (line chart).

Secondly, the scatter chart in Figure 8 comparing these 12 technologies with small, medium, and large size companies shows that there are three technologies where all small,

medium, and large size organizations have equal standing. These three Industry 4.0 technologies are Big Data, IOT, and Mobile Technologies. This implies that small, medium, and large size organizations among technology companies in Malaysia have applied or implemented these three technologies to a high degree. The highest gap is in the area of Simulations, Augmented Reality, and Artificial Intelligence, as shown in the previous figure as well. In summary, Figure 8 also shows that for all size of companies, Autonomous Robots, Additive Manufacturing, Augmented Reality, Artificial Intelligence, and RFID are used to a medium degree, where Mobile Technologies is the only one Industry 4.0 technology that is used to a high degree by all three sizes of companies.



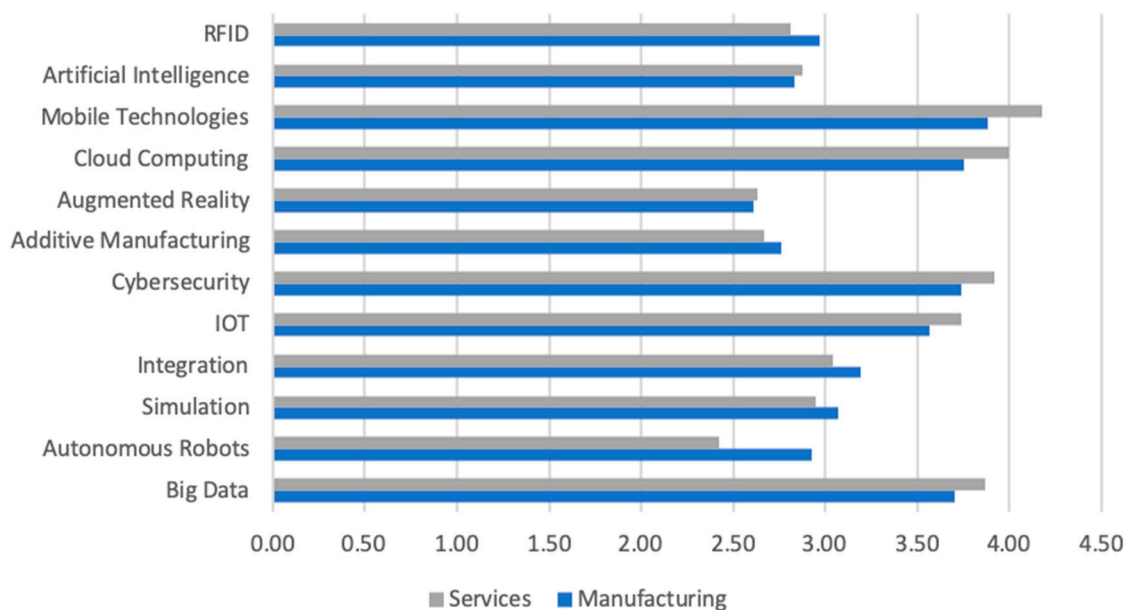
**Figure 8.** Industry 4.0 technologies (scatter chart).

#### 4.3. Industry 4.0 Technologies in Contrast with Company Type

Finally, the Industry 4.0 technologies were contrasted between the manufacturing and service concerns, in the survey of technology companies in Malaysia. As shown in Figure 9, there are three areas where the difference in implementation of Industry 4.0 technologies is large between manufacturing and service type of companies. These three areas are Autonomous Robots, Mobile Technologies, and Cloud Computing. In terms of manufacturing companies, the implementation of Autonomous Robots is to a high degree, in contrast to services companies which show its medium degree application. Interestingly, Mobile Technologies have a very high degree of application in service companies and have a medium to a high degree of application in manufacturing companies. Similarly, service companies among technology companies in Malaysia have a higher degree of implementation of Cloud Computing in contrast with manufacturing companies, though both company types use it extensively. In a similar vein, there are two Industry 4.0 technologies where manufacturing and service companies have almost equal degree of implementation in the category of medium degree of implementation. These two technologies are Artificial Intelligence and Augmented Reality, which is not common, but are equally relevant in application for manufacturing and service companies.

This paper was structured based on three research questions, drawing from the Introduction section. Based on these study results, this section further elaborates on those three questions in a similar order.





**Figure 9.** Industry 4.0 technologies (bar chart).

*Research Question 1: What is the status of implementation of Industry 4.0 technologies among the technology companies in Malaysia?*

This study surveyed 238 technology companies in Malaysia and results, in general, reveal that majority of these companies range from high to very high degree in terms of the application of Industry 4.0 technologies. From an implications perspective, the policy recommendation for government and government agencies in Malaysia would be to identify the best practices and build on these strengths. Policies should also include sustainability of these results, and possible upscaling particularly for small and medium-sized enterprises. In terms of descriptive statistics, the most common technology used is Mobile Technologies (Mean 4.07). Likewise, the least common technologies are Autonomous Robots (Mean 2.62) and Augmented Reality (Mean 2.63). In summary, the top three Industry 4.0 technologies used among technology companies in Malaysia are Mobile Technologies (35.7% use it to a very high degree), Cloud Computing (34.5% use it to a very high degree), and Cybersecurity (32.8% use it to a very high degree). Policy recommendations here would be to create Centers of Expertise in Malaysia in the areas of Mobile Technologies, Cloud Computing, and Cybersecurity, which should focus on regional markets in the Asia Pacific in terms of proximity. Here, the percentage is based on a total of 238 companies selected. The implementation of these technologies as the top three is mainly due to low cost and user convenience.

Likewise, the least Industry 4.0 technologies used among technology companies in Malaysia are Autonomous Robots and Additive Manufacturing. Thereon, the implementation of these technologies as the least used is mainly due to the specialized nature of these technologies and high upfront cost. In terms of implications, the relevant government agencies should provide funding and incentives to encourage investment in Autonomous Robots and Additive Manufacturing in Malaysia. Fatorachian and Kazemi reported that 60% of the companies see a huge Return on Investment (ROI) within 2 years on their Industry 4.0 projects [9]. This was also confirmed by PWC in 2016 through a global Industry 4.0 survey [51]. In general, Industry 4.0 technologies result in time-saving, as more free time is available for employees to be used elsewhere [52]. Furthermore, Industry 4.0 technologies generate accurate data at a lower cost, enabling more profitable decisions and projects [53,54]. The multitude of benefits conceded by Fatorachian and Kazemi include agile engineering, smart systems, and improved decision-making [9]. This will also broaden possibilities for improved integration, collaboration in terms of workflows, and energy-

saving due to optimized smart devices [55]. In short, the companies due to Industry 4.0 technologies will witness faster production, easy fault finding, unbiased decision making, and new service models [56].

In terms of differences, the largest difference, implying a greater gap between no use and extensive use, is for two technologies: Horizontal and Vertical System Integration and Simulations. Though these two technologies are common, their applicability and implementation for companies are varied. In other words, partial or sporadic implementation of Horizontal and Vertical System Integration and Simulations was not witnessed among technology companies in Malaysia. So, they either implemented fully, or they did not take any initiative on these two technologies. Likewise, the smallest difference between no use and extensive use is for another two Industry 4.0 technologies: Mobile Technologies and Cloud Computing. This reflects that most of the technology companies in Malaysia are well versed in the use and adoption of Mobile Technologies and Cloud Computing. Thereon, this discussion answers the first research question on the status of implementation of Industry 4.0 technologies among the technology companies in Malaysia, leading to the conclusion that the adoption patterns of various Industry 4.0 technologies are diverse and differentiated.

*Research Question 2: What are the main insights of Industry 4.0 technologies in comparison with company size (small, medium, and large)?*

This study based on technology companies in Malaysia confirmed that small size companies find it challenging to implement the various Industry 4.0 technologies, as compared to medium and large size organizations. The immediate implication of which is that government institutions and regulators' role at grass root level in Malaysia needs to be focused and improved, to help small size organizations in achieving their small but related best possible contribution towards the adoption of Industry 4.0 technologies. Indirectly, this technological shift will also contribute in part to Malaysia's economic revival in testing times of pandemic (COVID-19), as the purely physical brick-and-mortar businesses are largely struggling, and digital businesses have instead survived and succeeded.

However, large size companies and medium-size companies have shown equal potential in applying the Industry 4.0 technologies, with the exception of Autonomous Robots and RFID, where large size companies are better than medium size companies. Here the policymaking should involve providing scale-up opportunities for medium and large-size companies in the area of trainings and exhibitions. In terms of economics, domestic firms should be strengthened to take the technology leap in Malaysia. Policy recommendations can be on improving Standard Operating Procedures (SOPs) to benchmark with the developed countries. Furthermore, there are three Industry 4.0 technologies, where large size companies take the lead: Simulations, Augmented Reality, and Artificial Intelligence. Large size companies excel in this primarily due to their human capital, technical expertise, and capability [57]. Simulations can improve the product or service planning [58]. As an example, Simulation can be used in product and design management. Virtualization technologies based on Augmented Reality can change human perception with augmented features [59]. Augmented Reality can also improve the integration of different technologies [60]. Similar integration is expected through Artificial Intelligence. So, in these areas, large size companies can easily outperform small size companies. Furthermore, as per Skordoulis, Open Innovation, taking leverage from external market insights, greatly helps in this case for medium and large size companies [5].

It is also important and interesting to note that there are three Industry 4.0 technologies where in general all small, medium, and large size organizations do relatively well. For these technologies, the scale and size of the organization is not the main strength or determinant. These three technologies are Big Data, IOT, and Mobile Technologies. As per a Kim and Laskowski study, Big Data infrastructure can coordinate positively with Industry 4.0 components, including Big Data acquisition, integration, processing, and storage [61]. The Big Data acquisition and integration phase then includes data collection from RFID sensors [62]. Big Data processing structures the data in real-time [63]. Then, Big

Data mining classifies the data [64]. Today, data are enormous and need fast processing on diversified formats for all sizes of companies [65]. IOT and Mobile Technologies also have similar applications for small, medium, and large size companies [17,63]. Hence, Big Data, IOT, and Mobile Technologies have implementation value for small, medium, and large size companies. In summary, this discussion provides interesting insights on Industry 4.0 technologies in comparison with company size (small, medium, and large), answering the second research question of this study.

*Research Question 3: What are the main insights of Industry 4.0 technologies in contrast with company type (manufacturing and services)?*

Finally, this study based on technology companies in Malaysia also confirmed that the implementation of Autonomous Robots is more in manufacturing companies than services companies. This is connected with the nature of manufacturing companies, as they have assembly parts and phases with industrial applications [10,66]. Contrary to that, Mobile Technologies have a very high degree of application in service companies and have a medium to a high degree of application in manufacturing companies. Similarly, service companies have a higher degree of implementation of Cloud Computing in contrast with manufacturing companies, though both companies typically use it extensively. Due to the intangible nature of services, both Mobile Technologies and Cloud Computing can be utilized optimally in services companies. Therefore, Mobile Technologies and Cloud Computing are two Industry 4.0 technologies that have important and similar scope for both manufacturing and services companies.

Industry 4.0 technologies increase the flexibility of individuals [67] and improve the integration of organizations [53]. Moreover, the study by Wang mentioned that conversion to Industry 4.0 is based on the groundwork of technology which includes Autonomous Robots and Artificial Intelligence [25]. However, these technologies should be reinforced with other fundamental technologies such as Cloud Computing, Cyber Security, and Mobile Technologies [68]. For manufacturing companies, Autonomous Robots decrease production costs, reduce working time, and reduce waiting time in operations. In services companies, Autonomous Robots assist in the design, planning, and delivery phases [69]. For example, dividing the tasks into modules. Overall, a detailed implementation roadmap for Industry 4.0 transformation cannot be perfected [70]. However, these insights can be used to determine the strength and improvement areas individually, as some Industry 4.0 technologies will be more applicable for manufacturing concerns, and others for service concerns.

Overall, the importance of digital transformation is for both manufacturing and services sectors. In the manufacturing sector, assembly lines with their production processes can be greatly optimized through the adoption of Industry 4.0 technologies. In the service sector, Industry 4.0 technologies can revamp business models and improve service standards. Thereon, policy recommendations on digital transformation are equally needed for the manufacturing and services sectors both. To arrive at the suitable policy recommendations for the manufacturing and services sector, opportunities, and threats on the format of SWOT Analysis were assessed separately for the manufacturing and services sector. SWOT is a strategic planning method used to evaluate strengths, weaknesses, opportunities, and threats (SWOT). For the manufacturing sector in Malaysia, the opportunity is automation, whereas the threat is a global competition. Automation, in this case resulting from Industry 4.0 technologies, can significantly improve the business performance of technology companies in Malaysia. However, the immediate threat is that technology is bringing the markets closer, and the global competition will hence increase. Likewise, for the services sector in Malaysia, the prime opportunity is cost advantage and the closest threat is the arising competitive advantage. Cost is an advantage as service companies due to their intangible products, in general, have lesser operational cost, whereas competitive advantage is a threat as services can be easily replaced and it is difficult to differentiate between service providers in comparison with product manufacturers.

Based on these opportunities and threats, in terms of policy recommendations for the manufacturing sector, government and development agencies in Malaysia can draft the Manufacturing Plan based on the adoption of Industry 4.0 technologies, starting with Autonomous Robots for high-end manufacturing. In terms of Public Policy, the 12th Malaysia Plan can be reviewed and restructured to create more funding and incentives for the adoption of Industry 4.0 technologies. Leverage can also be taken from Germany's High-Tech Strategy 2020 which builds on the concept of the Factory of Future [71]. In terms of policy recommendations for digital transformation in the services sector, service companies in Malaysia should expand their implementation of Industry 4.0 technologies beyond Mobile Technologies and Cloud Computing. In terms of economics, the tertiary sector based on services is the most lucrative opportunity that almost all the countries are eyeing on. Thereby, policy changes by the government agencies in Malaysia to better support investments in terms of human capital upskilling and customer service improvement through Industry 4.0 technologies will foster the service industry ecosystem in Malaysia, and will improve the digital transformation in the services sector. In brief, this discussion provides valuable insights on Industry 4.0 technologies in contrast with company type (manufacturing and services), answering the third and the last research question of this study.

## 5. Discussion: Industry 4.0 and the Open Innovation of Technology Firms

Innovation now is demanding a great pace of external changes [72], leading to the prominence of Open Innovation. As firms gain knowledge from different segments of society, the approach of open innovation seems to be a fit for Industry 4.0. Füller et al. (2006) defines open innovation as the utilization of external factors of influence to create internal innovation muscles [73]. This can increase the momentum of Industry 4.0 technologies' implementation, particularly for technology companies. Prause (2015) refers to virtual communities and living labs as tools in this regard [72]. The author also stresses that user data on virtual communities as comments, feedback, and recommendations are a good source of innovation, which can be well utilized for faster adoption of Industry 4.0 technologies. This path however needs to be carefully treaded, as privacy and intellectual property concerns can appear, particularly in connection with large-size technology companies.

Interestingly, Van de Vrande et al. (2009) drew the concept of open innovation for SMEs [74]. This was one of the initial attempts in a way, that all earlier studies instead discussed open innovation in the context of large, high-tech, and multinational companies. In this study, technology exploration and exploitation with respect to SMEs and in the context of 4IR has been discussed. The study findings show that there is no variation in manufacturing and service firms based on open innovation. However, firm size does matter for open innovation. Large and medium-sized organizations perform better at open innovation than SMEs. SMEs are more concerned about the exterior environment in terms of competition than the internal environment in terms of culture [75,76]. In the same vein, open innovation is considered as flow of information to propel internal and external innovation [77]. Hence, it includes both outside-in and inside-out technologies, which in other words are known as 'technology acquisition' and 'technology exploitation', which is significantly needed for Industry 4.0 technologies.

It is also important to note that large companies have big budgets and can rely on Research and Development (R&D) to develop new offerings of Industry 4.0 [78]. SMEs on the contrary lack these capabilities [79]. This process of large companies developing and commercializing a technology or initiative is known as the closed innovation model [77]. However, times have now changed, where open innovation is being sought by large companies, due to skills diversity and finance accessibility. To maximize value, companies now need both technology exploitation and technology exploration [80]. Technology exploitation discusses various ways to gain from a firm's internal knowledge. The three activities mainly related to this are venturing, outward licensing of Intellectual Property (IP), and the involvement of Research and Development (R&D) personnel. Technology exploration on the contrary discusses activities that enable companies to gain new outside

information. Here, four areas related to technology exploration are outside networking, customer engagement, outsourcing R&D, and inward licensing. As per von Hippel (2005), technology companies are not passive adopters of innovations, but they craft their innovations which other companies in other economies would want to imitate [81,82], which is consistently associated with open innovation [77]. Overall, open innovation theorists value the use of open innovation business models for the implementation of Industry 4.0 amongst technology companies.

## 6. Conclusions

The blend of Industry 4.0 technologies and open innovation is a game-changer, as it enables businesses in radically saving on both cost and time [67]. This research paper studied 238 technology companies in Malaysia and assessed their current standing in terms of the application of Industry 4.0 technologies. The study led to the understanding that the majority of technology companies in Malaysia have implemented or are implementing the Industry 4.0 technologies between high to a very high degree. In terms of company size, large and medium-sized organizations are in a better position than small-size companies to leverage the various Industry 4.0 technologies. In terms of company type, certain Industry 4.0 technologies are more pertinent fit for manufacturing concerns like Autonomous Robots, whereas other Industry 4.0 technologies are more relevant for service concerns like Mobile Technologies.

In terms of theoretical contribution, this study contributes to the Unified Theory of Acceptance and Use of Technology (UTAUT). UTAUT is about the intention to use technology, and the subsequent behavior or results expected [37]. In other words, UTAUT helps in understanding the concept of technology adoption and patterns [39]. This paper extends this theory by incorporating insights based on company size (small, medium, and large) and company type (manufacturing and services) for technology adoption of Industry 4.0 technologies, which is the original contribution of this research study.

In terms of practical contribution, this study can be used by the government and government agencies for policy-making and benchmarking. In the context of Malaysia, government agencies like the Ministry of International Trade and Industry (MITI), Malaysia Digital Economy Corporation (MDEC), and Ministry of Science, Technology, and Innovation (MOSTI) can utilize these study findings and insights to better allocate the funds for Industry 4.0 implementation and to reprioritize the incentives and trainings provided to technology companies in Malaysia. In terms of benchmarking, this study contributes in providing a baseline for the current standing of technology companies in Malaysia for Industry 4.0 technologies. This can be used for continuous benchmarking with other countries, especially in the Asia Pacific region.

In terms of study limitations, the survey in this research was based on a sampling frame as the full population of technology companies in Malaysia is not known. Hence, generalization of the study findings to the population cannot be made. However, important insights for Industry 4.0 technologies based on company size and company type have been drawn from this study. The future studies can empirically assess the application of these 12 Industry 4.0 technologies in countries other than Malaysia, to establish and compare regional and global benchmarks for readiness assessment on Industry 4.0 technologies.

**Author Contributions:** Conceptualization, M.H.-H. and M.A.S.; methodology, M.H.-H. and M.A.S.; writing—original draft preparation, M.A.S. and M.H.-H.; writing—review and editing, M.H.-H.; project administration, M.H.-H. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by Malaysian Technology Development Corporation (MTDC), grant number EP-2019-014, awarded to Universiti Kebangsaan Malaysia.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to restrictions by MTDC.

**Acknowledgments:** The authors are grateful to the editors and reviewers for their invaluable contribution.



**Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

## References

- Botha, A.P. Rapidly Arriving Futures: Future Readiness for Industry 4.0. *S. Afr. J. Ind. Eng.* **2018**, *29*, 148–160. [\[CrossRef\]](#)
- Saucedo-Martínez, J.A.; Pérez-Lara, M.; Marmolejo-Saucedo, J.A.; Salais-Fierro, T.E.; Vasant, P. Industry 4.0 framework for management and operations: A review. *J. Ambient Intell. Humaniz. Comput.* **2018**, *9*, 789–801. [\[CrossRef\]](#)
- Bahrin, M.A.K.; Othman, M.F.; Azli, N.H.N.; Talib, M.F. Industry 4.0: A review on industrial automation and robotic. *J. Teknol.* **2016**, *78*, 137–143.
- Fayyaz, A.; Chaudhry, B.N.; Fiaz, M. Upholding Knowledge Sharing for Organization Innovation Efficiency in Pakistan. *J. Open Innov. Technol. Mark. Complex.* **2021**, *7*, 4. [\[CrossRef\]](#)
- Skordoulis, M.; Ntanos, S.; Kyriakopoulos, G.L. Environmental Innovation, Open Innovation Dynamics and Competitive Advantage of Medium and Large-Sized Firms. *J. Open Innov. Technol. Mark. Complex.* **2020**, *6*, 195. [\[CrossRef\]](#)
- Neugebauer, R.; Hippmann, S.; Leis, M.; Landherr, M. Industrie 4.0—From the Perspective of Applied Research. *Procedia CIRP* **2016**, *57*, 2–7. [\[CrossRef\]](#)
- Schwab, K. *The Fourth Industrial Revolution*; Crown: New York, NY, USA, 2016; Volume 91.
- Sharma, S.; Gandhi, P.J. Journey Readiness of Industry 4.0 from Revolutionary Idea to Evolutionary Implementation: A Lean Management Perspective. *Int. J. Inf. Commun. Sci.* **2018**, *3*, 96–103. [\[CrossRef\]](#)
- Fatorachian, H.; Kazemi, H. A critical investigation of Industry 4.0 in manufacturing: Theoretical operationalisation framework. *Prod. Plan. Control* **2018**, *29*, 633–644. [\[CrossRef\]](#)
- Sony, M. Key ingredients for evaluating Industry 4.0 readiness for organizations: A literature review. *Benchmarking Int. J.* **2019**, *27*, 2213–2232. [\[CrossRef\]](#)
- Dillman, D.A. Moving Survey Methodology Forward in Our Rapidly Changing World: A Commentary. *J. Rural Soc. Sci.* **2016**, *31*, 8.
- Sanders, A.; Elangeswaran, C.; Wulfsberg, J. Industry 4.0 implies lean manufacturing: Research activities in Industry 4.0 function as enablers for lean manufacturing. *J. Ind. Eng. Manag.* **2016**, *9*, 811–833. [\[CrossRef\]](#)
- Imran, M.; Hameed, W.U.; Haque, A.U. Influence of Industry 4.0 on the Production and Service Sectors in Pakistan: Evidence from Textile and Logistics Industries. *Soc. Sci.* **2018**, *7*, 246. [\[CrossRef\]](#)
- Vaidya, S.; Ambad, P.; Bhosle, S. Industry 4.0—A Glimpse. *Procedia Manuf.* **2018**, *20*, 233–238. [\[CrossRef\]](#)
- Dirican, C. The Impacts of Robotics, Artificial Intelligence On Business and Economics. *Procedia Soc. Behav. Sci.* **2015**, *195*, 564–573. [\[CrossRef\]](#)
- Xiang, Z. *Information and Communication Technologies in Tourism 2014*; Springer: Berlin/Heidelberg, Germany, 2014; pp. 553–564.
- Majeed, M.A.A.; Rupasinghe, T.D. Internet of things (IoT) embedded future supply chains for Industry 4.0: An assessment from an ERP-based fashion apparel and footwear industry. *Int. J. Supply Chain Manag.* **2017**, *6*, 25–40.
- Gilchrist, A. *Industry 4.0, The Industrial Internet of Things (Getting from Here to There)*; Apress: New York, NY, USA, 2016; Volume 146.
- Ochs, T.; Riemann, U. Industry 4.0: How to Manage Transformation as the New Normal. In *The Palgrave Handbook of Managing Continuous Business Transformation*; Palgrave Macmillan: London, UK, 2016; pp. 1–610.
- Hofmann, E.; Rüscher, M. Industry 4.0 and the current status as well as future prospects on logistics. *Comput. Ind.* **2017**, *89*, 23–34. [\[CrossRef\]](#)
- Kang, H.S.; Lee, J.Y.; Choi, S.; Kim, H.; Park, J.H.; Son, J.Y.; Kim, B.H.; Do Noh, S. Smart manufacturing: Past research, present findings, and future directions. *Int. J. Precis. Eng. Manuf. Green Technol.* **2016**, *3*, 111–128. [\[CrossRef\]](#)
- Roblek, V.; Meško, M.; Krapež, A. A Complex View of Industry 4.0. *Sage Open* **2016**, *6*, 1–11. [\[CrossRef\]](#)
- Nagy, J.; Oláh, J.; Erdei, E.; Máté, D.; Popp, J. The role and impact of Industry 4.0 and the internet of things on the business strategy of the value chain—the case of Hungary. *Sustainability* **2018**, *10*, 3491. [\[CrossRef\]](#)
- Huang, Y.; Leu, M.C.; Mazumder, J.; Donmez, A. Additive Manufacturing: Current State, Future Potential, Gaps and Needs, and Recommendations. *J. Manuf. Sci. Eng.* **2015**, *137*, 014001. [\[CrossRef\]](#)
- Wang, Y.; Wang, G.; Anderl, R. Generic Procedure Model to Introduce Industrie 4.0 in Small and Medium-sized Enterprises. In *Proceedings of the world congress on engineering and computer science, London, UK, 29 June–1 July 2016*; pp. 971–976.
- Telukdarie, A.; Buhulaiga, E.; Bag, S.; Gupta, S.; Luo, Z. Industry 4.0 implementation for multinationals. *Process Saf. Environ. Prot.* **2018**, *118*, 316–329. [\[CrossRef\]](#)
- Uckelmann, D. A definition approach to smart logistics. In *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*; Springer: Berlin/Heidelberg, Germany, 2008.
- Fuchs, C. Industry 4.0: The digital German ideology. *TripleC* **2018**, *16*, 280–289. [\[CrossRef\]](#)
- Sood, A.; Tellis, G.J. Demystifying disruption: A new model for understanding and predicting disruptive technologies. *Mark. Sci.* **2011**, *30*, 339–354. [\[CrossRef\]](#)
- Bekar, E.T.; Skoogh, A.; Cetin, N. Prediction of Industry 4.0's Impact on Total Productive Maintenance Using a Real Manufacturing Case. In *The International Symposium for Production Research*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 136–149.
- Bayram, B.; Ince, G. Advances in Robotics in the Era of Industry 4.0. In *Industry 4.0: Managing The Digital Transformation*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 187–200.

32. Rojko, A. Industry 4.0 Concept: Background and Overview. *ECPE Eur. Cent. Power Electron.* **2017**, *11*, 3–38. [\[CrossRef\]](#)
33. Akdil, K.Y.; Ustundag, A.; Cevikcan, E. *Maturity and Readiness Model for Industry 4.0 Strategy Implementation of Industry 4.0 Strategies Require Wide Applications in Companies*; Springer International Publisher: Berlin/Heidelberg, Germany, 2018.
34. Leyh, C.; Martin, S.; Sch, T. Analyzing Industry 4.0 Models with Focus on Lean Production Aspects. In *Information Technology for Management. Ongoing Research and Development*; Springer: Berlin/Heidelberg, Germany, 2018; Volume 311, pp. 114–130.
35. Haddara, M.; Elragal, A. The Readiness of ERP Systems for the Factory of the Future. *Procedia Comput. Sci.* **2015**, *64*, 721–728. [\[CrossRef\]](#)
36. Wichmann, R.L.; Eisenbart, B.; Gericke, K. The Direction of Industry: A Literature Review on Industry 4.0. In *Proceedings of the Design Society: International Conference on Engineering Design*; Cambridge University Press: Cambridge, UK, 2019; Volume 1, pp. 2129–2138.
37. Awa, H.O.; Ukoha, O.; Igwe, S.R. Revisiting technology-organization-environment (T-O-E) theory for enriched applicability. *Bottom Line* **2017**, *30*, 2–22. [\[CrossRef\]](#)
38. Venkatesh, V.; Zhang, X. Unified theory of acceptance and use of technology: U.S. vs. China. *J. Glob. Inf. Technol. Manag.* **2010**, *13*, 5–27. [\[CrossRef\]](#)
39. Venkatesh, V.; Bala, H. Adoption and impacts of interorganizational business process standards: Role of partnering synergy. *Inf. Syst. Res.* **2012**, *23*, 1131–1157. [\[CrossRef\]](#)
40. Hizam-Hanafiah, M.; Soomro, M.A.; Abdullah, N.L. Industry 4.0 Readiness Models: A Systematic Literature Review of Model Dimensions. *Information* **2020**, *11*, 364. [\[CrossRef\]](#)
41. Hofstede, G. Dimensionalizing Cultures: The Hofstede Model in Context. *Online Read. Psychol. Cult.* **2011**, *2*, 8. [\[CrossRef\]](#)
42. Soomro, M.A.; Hizam-Hanafiah, M.; Abdullah, N.L. Digital readiness models: A systematic literature review. *Compusoft* **2020**, *9*, 3596–3605.
43. Sekaran, U.; Bougie, R. *Research Methods for Business: A Skill-Building Approach*/Uma Sekaran and Roger Bougie; John Wiley & Sons: Hoboken, NY, USA, 2016.
44. Rachinger, M.; Rauter, R.; Müller, C.; Vorraber, W.; Schirgi, E. Digitalization and its influence on business model innovation. *J. Manuf. Technol. Manag.* **2019**, *30*, 1143–1160. [\[CrossRef\]](#)
45. Steenhuis, H.J.; de Bruijn, E.J. High technology revisited: Definition and position. In *Proceedings of the 2006 IEEE International Conference on Management of Innovation and Technology*, Singapore, 21–23 June 2006; Volume 2, pp. 1080–1084.
46. Anuar, A.; Yusuff, R.M. Manufacturing best practices in Malaysian small and medium enterprises (SMEs). *Benchmarking Int. J.* **2011**, *18*, 324–341. [\[CrossRef\]](#)
47. Adil, M.S. Impact of Leader's Change-Promoting Behavior on Readiness for Change: A Mediating Role of Organizational Culture. *J. Manag. Sci.* **2014**, *1*, 113–150.
48. Hanna, N.K.; Knight, P.T. *Why National e-Transformation Strategies?* Springer: Berlin/Heidelberg, Germany, 2012.
49. Stentoft, J.; Wickstrøm, K.A.; Philipsen, K.; Haug, A. Drivers and barriers for Industry 4.0 readiness and practice: Empirical evidence from small and medium-sized manufacturers. *Prod. Plan. Control* **2020**. [\[CrossRef\]](#)
50. Kim, K. Likert Scale. *Korean J. Fam. Med.* **2011**, *32*, 1–2. [\[CrossRef\]](#)
51. Basl, J. Companies on the Way to Industry 4.0 and their Readiness. *J. Syst. Integr.* **2018**, *3*, 3.
52. Stăncioiu, A. The Fourth Industrial Revolution 'Industry 4.0'. *Fiabilitate Durabilitate* **2017**, *1*, 74–78.
53. Sibel, Y. Industry 4.0 and Turkey: A Financial Perspective. In *Strategic Design and Innovative Thinking in Business Operations*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 273–291.
54. Visconti, R.M.; Morea, D. Healthcare digitalization and pay-for-performance incentives in smart hospital project financing. *Int. J. Environ. Res. Public Health* **2020**, *17*, 2318. [\[CrossRef\]](#)
55. Visconti, R.M.; Martiniello, L.; Morea, D.; Gebennini, E. Can public-private partnerships foster investment sustainability in smart hospitals? *Sustainability* **2019**, *11*, 1–19.
56. Oztemel, E.; Gursev, S. Literature review of Industry 4.0 and related technologies. *J. Intelligent Manuf.* **2020**, *31*, 127–182. [\[CrossRef\]](#)
57. Uygun, Y. Human Resources Requirements for Industry 4.0. 2018, pp. 1–20. Available online: [http://iciee.untirta.ac.id/ICIEE-2018\\_Uygun.pdf](http://iciee.untirta.ac.id/ICIEE-2018_Uygun.pdf) (accessed on 10 January 2021).
58. Myrtveit, M.; Bean, M. Business Modelling and Simulation. *Wirtschaftsinformatik* **2000**, *42*, 156–160. [\[CrossRef\]](#)
59. Mourtzis, D.; Vlachou, E.; Dimitrakopoulos, G.; Zogopoulos, V. Cyber-Physical Systems and Education 4.0-The Teaching Factory 4.0 Concept. *Procedia Manuf.* **2018**, *23*, 129–134. [\[CrossRef\]](#)
60. Bibby, L.; Dehe, B. Defining and assessing Industry 4.0 maturity levels—case of the defence sector. *Prod. Plan. Control* **2018**, *29*, 1030–1043. [\[CrossRef\]](#)
61. Kim, H.M.; Laskowski, M. Toward an ontology-driven blockchain design for supply-chain provenance. *Intell. Syst. Accounting, Financ. Manag.* **2018**, *25*, 8–27. [\[CrossRef\]](#)
62. Zhou, K.; Liu, T.; Zhou, L. Industry 4.0: Towards future industrial opportunities and challenges. In *Proceedings of the 2015 12th International Conference on Fuzzy Systems and Knowledge Discovery, FSKD 2015*, Zhangjiajie, China, 15–17 August 2015.
63. Visconti, R.M.; Morea, D. Big data for the sustainability of healthcare project financing. *Sustainability* **2019**, *11*, 3748. [\[CrossRef\]](#)
64. Zheng, P.; Sang, Z.; Zhong, R.Y.; Liu, Y.; Liu, C.; Mubarak, K.; Yu, S.; Xu, X. Smart manufacturing systems for Industry 4.0: A conceptual framework, scenarios and future perspectives. *Front. Mech. Eng.* **2017**, *13*, 137–150. [\[CrossRef\]](#)

- 
65. Wan, J.; Xia, M. Cloud-Assisted Cyber-Physical Systems for the Implementation of Industry 4.0. *Mob. Netw. Appl.* **2017**, *22*, 1157–1158. [[CrossRef](#)]
  66. Silva, F.; Resende, D.; Amorim, M.; Borges, M. A field study on the impacts of implementing concepts and elements of Industry 4.0 in the biopharmaceutical sector. *J. Open Innov. Technol. Mark. Complex.* **2020**, *6*, 175. [[CrossRef](#)]
  67. Hermann, M.; Pentek, T.; Otto, B. Design principles for industrie 4.0 scenarios. In Proceedings of the 2016 49th Hawaii International Conference on System Sciences (HICSS), Koloa, HI, USA, 5–8 January 2016; pp. 3928–3937.
  68. Tvenge, N.; Martinsen, K. Integration of digital learning in Industry 4.0. *Procedia Manuf.* **2018**, *23*, 261–266. [[CrossRef](#)]
  69. Schlingensiepen, J.; Nemtanu, F.; Mehmood, R. *Autonomic Transport Management Systems—Enabler for Smart Cities, Personalized Medicine, Participation and Industry Grid/Industry 4.0*; Springer: Berlin/Heidelberg, Germany, 2016; Volume 32.
  70. Pessl, E. Roadmap Industry 4.0—Implementation Guideline for Enterprises. *Int. J. Sci. Technol. Soc.* **2017**, *5*, 193. [[CrossRef](#)]
  71. Kagermann, H.; Wahlster, W.; Helbig, J. *Recommendations for Implementing the Strategic Initiative Industrie 4.0*; acatech: Munich, Germany, 2013.
  72. Prause, G. Sustainable Business Models and Structures for Industry 4.0. *J. Secur. Sustain. Issues* **2015**, *5*, 159–169. [[CrossRef](#)]
  73. Füller, J.; Bartl, M.; Ernst, H.; Mühlbacher, H. Community based innovation: How to integrate members of virtual communities into new product development. *Electron. Commer. Res.* **2006**, *6*, 57–73. [[CrossRef](#)]
  74. Van de Vrande, V.; de Jong, J.P.J.; Vanhaverbeke, W.; de Rochemont, M. Open innovation in SMEs: Trends, motives and management challenges. *Technovation* **2009**, *29*, 423–437. [[CrossRef](#)]
  75. Prause, G.; Atari, S. On sustainable production networks for Industry 4.0. *Entrep. Sustain. Issues* **2017**, *4*, 421–431. [[CrossRef](#)]
  76. Yun, J.J. *Business Model Design Compass*; Springer: Singapore, 2017.
  77. Chesbrough, H. GE's ecomagination Challenge: An experiment in open innovation. *Calif. Manag. Rev.* **2012**, *54*, 140–154. [[CrossRef](#)]
  78. Zhu, X.; Xiao, Z.; Dong, M.C.; Gu, J. The fit between firms' open innovation and business model for new product development speed: A contingent perspective. *Technovation* **2019**, *86*, 75–85. [[CrossRef](#)]
  79. Yun, J.J.; Zhao, X.; Park, K.B.; Shi, L. Sustainability condition of open innovation: Dynamic growth of Alibaba from SME to large enterprise. *Sustainability* **2020**, *12*, 4379. [[CrossRef](#)]
  80. Weking, J.; Stöcker, M.; Kowalkiewicz, M.; Böhm, M.; Krcmar, H. Archetypes for Industry 4.0 Business Model Innovations. In Proceedings of the 24th Americas Conference on Information Systems, New Orleans, LA, USA, 16–18 August 2018.
  81. Von Hippel, E. Democratizing innovation: The evolving phenomenon of user innovation. *J. Betr.* **2005**, *55*, 63–78. [[CrossRef](#)]
  82. Yun, J.H.J.; Liu, Z. Micro- and macro-dynamics of Open Innovation with a Quadruple-Helix model. *Sustainability* **2019**, *11*, 3301. [[CrossRef](#)]