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Productivity Enhancements through Fourth Industrial Revolution Technologies: Comparison of Small- and Medium-Sized Enterprises with Large Enterprises

Simon Karl Hubert Backhaus[1] and Devika Nadarajah[2]
[1,2] Putra Business School
University Putra Malaysia, Serdang, Malaysia
simon.mba16@grad.putrabs.edu.my[1], devika@putrabs.com.my[2]

Abstract

The purpose of this paper is to compare small- and medium-sized enterprises (SMEs) against large enterprises (LEs) in terms of their productivity enhancements through Fourth Industrial Revolution (IR4) technologies, specifically in the context of developing countries.
This study adopted a quantitative approach. Questionnaires were distributed to Malaysian manufacturers registered under Malaysia External Trade Development Corporation MATRADE via email and in-person at the Smart Manufacturing Uprising conference in Kuala Lumpur. A total of 76 valid responses were obtained and analyzed using multiple regression.
SMEs' productivity was found to have significantly increased due to the Internet of Things and digital automation without sensors, while LEs' productivity revealed a significant improvement from integrated engineering systems.
The small sample size of 76 raises generalizability issues. Thus, large-scale quantitative research is recommended to validate the relationships identified in this study.
The study is among the first to identify and compare the significant relationships between IR4 technologies and productivity enhancements among SMEs and LEs. The findings are of interest to academics as well as to public and private sector practitioners in directing resources to technologies that enhance productivity.
Keywords: Fourth Industrial Revolution, Industry 4.0, Productivity, Quantitative Study, Internet of Things

1 Introduction

The current era has brought forth the Fourth Industrial Revolution (hereafter IR4), which is also known as Smart Manufacturing or Industry 4.0 [20]. Most research linked to IR4 thus far has been conceptual in nature [21]. In particular, scarce field research has been conducted to distinguish the IR4 technologies that are suitable for small- and medium sized enterprises (SMEs) as opposed to large enterprises (LEs). This is concerning as a small-scale survey conducted in Denmark and Germany observed that the degree of IR4 technology implementation is remarkably low in SMEs [49]. This finding was supported by a large-scale study in Denmark in 2017, which pointed out that LEs are willing to work with IR4 technologies to a larger extent than SMEs [40]. Another survey conducted in Norway concluded that the implementation level of shop floor digitalization and organizational IT competence increases in tandem with company size [6]. Therefore, IR4 technologies' impact on SMEs and LEs is suspected to differ due to their varied level of adoption [15, 50].

Taking the example of a developing nation, the Malaysian government provides specific incentives for SMEs to increase their competitiveness and expand capital investment instead of investment in additional foreign labor. However, the adaption of enhanced manufacturing technologies in Malaysia is still low [28-29, 31] due to high implementation costs and a lack of skilled workers [10]. Moreover, despite the strong economic impact of IR4 technologies in other countries [18, 42], few quantitative studies have been performed on this topic in developing countries. Therefore, this quantitative study aimed to narrow the gap between the theoretical knowledge of IR4 technologies and their practical implications for SMEs and LEs in the developing country of Malaysia. The objective of this research paper was to examine how IR4 technologies impact the productivity of manufacturing organizations, as well as to compare these impacts between manufacturing SMEs and LEs.

The research questions of this study were:

1) Which IR4 technologies impact the productivity of SMEs?
2) Which IR4 technologies impact the productivity of LEs?
3) Which IR4 technologies have varying impacts across SMEs and LEs?

By addressing these questions, this research contributes to bridging the literature gap on the relatively understudied area of IR4 technologies and their practical impacts on firms' productivity. Additionally, this paper identifies and classifies the distinct impacts of each technology on manufacturing organizations based on their size, i.e., small and medium vs. large.

The remaining sections of this paper are structured as follows. The literature review focuses on the implementation of IR4 and its relationship with productivity in emerging and developed countries. In the third section, an elaboration of the study's methodology and data collection is presented. Fourth, the results and discussion section reveals the analyzed relationships and compares the results with recent empirical evidence. The final section concludes the paper with the study's implications, limitations, and suggestions for future research.

2 Literature Review

In this section an introduction to IR4 technologies and their impact on productivity is provided.

2.1 IR4 Technologies in LEs and SMEs

The focal point of the current research was on the technologies of IR4 and its goals of increasing the firms' sustainability and productivity [36]. Table 1 explains the technologies related to IR4 that were examined in this study.

Table 1: IR4 Technologies

Technology	Explanation
Computer-Aided Design (CAD) Integrated with Computer-Aided Manufacturing (CAM)	CAD/CAM utilized in the production of complex shapes, and recently, 3D printing [26]
Integrated engineering systems	Exchange of information in product development & manufacturing by integrating IT support systems [16]
Digital automation with sensors	Digital automation systems detecting or measuring physical properties for monitoring through data [34]
Flexible manufacturing lines	Digital automation with sensors for product and operating conditions identification, flexible lines [8]
MES and SCADA systems	Remote monitoring and control of production through Manufacturing Execution System (MES) and Supervisory Control and Data Acquisition (SCADA) [8]
Simulation/Virtual models	Simulation/analysis of virtual models (Finite Element Analysis, Computational Fluid Dynamics, etc.) for design and commissioning [8]
Big data and analytics	Huge amounts of heterogenous data generated, collected and stored in manufacturing systems. Analyzed by data analytics tools to discover patterns and improve performance [20]
Internet of Things (IoT)	Things such as objects with sensors or actuators connected through a network [43]
Additive manufacturing	Truly digitally based process- and production-capable technology that enables design freedom [46]
Cloud services	Shared computing resources via networks [1]

Various implementation patterns of the IR4 technologies have been identified among SMEs and LEs. [44] proposed that for small enterprises to implement IR4, a logical decision-making model should be applied for a manager to choose the most feasible IR4 investment choice. First, the manager has to know the current state of the production process, wherein the plan to invest has to be presented as a decision-making problem. Second, the manager must choose the most favorable IR4 measure according to the selected methodology. Third, the manager must estimate the receivable tax credit by describing the application. Finally, the set of IR4 technologies to be implemented is selected [44]. However, this decision model is oversimplified and does not take into account the implementation patterns observed by [13].

[13] subdivided IR4 technologies into front-end technologies and base technologies. Beyond that, they ranked them in three stages of increasing complexity. Stage one includes MES and SCADA as front-end technologies and cloud computing as the base technology. In stage two, the base technology is IoT, while industrial robots, artificial intelligence, and automatic nonconformities identification are the front-end technologies. In stage three, flexible lines, additive manufacturing and augmented/virtual reality are mentioned as front-end technologies supported by the base technologies of big data and analytics. Hence, the implementation of IR4 in manufacturing organizations is proposed to be executed in stages [13].

Complementary to this model, the German Mechanical Engineering Industry Association's (VDMA's) Guideline Industrie 4.0 and the Frauenhofer IFF Industrie 4.0 CheckUp function as IR4 capability maturity models [2, 39] that can be used to assess the IR4 readiness of a specific SME or LE. For example, for LEs, the Frauenhofer CheckUp holds a workshop, conducts expert interviews, ranks the company's IR4 maturity index, identifies actions, and then recommends prioritized actions in a roadmap. It also prescribes an approach tailored for SMEs, which consists of five stages covering all business sections: standards, big data, smart data, dark factory, and industrial ecosystem. Similarly, the Guideline Industrie 4.0 targets predominantly SMEs by structuring the process into preparation, analysis, creativity, evaluation, and finally, implementation. Overall, it is highly recommended to perform extensive studies prior to implementing IR4 in any organization to avoid redundancies and compatibility issues [17].

It should be noted that the models mentioned above do not take employees into account throughout the implementation process. Employees are critical in the implementation of IR4 as it inevitably faces low employee acceptance and the lack of know-how and competencies at the employee level. Thus, [34] addressed this issue by suggesting a more holistic approach to complement technological and economical dimensions with the social dimension. Specifically, employees should be trained in areas such as sensors and data analytics to implement and sustain IR4 tools in SMEs [23].

Apart from models and implementation strategies, IR4 has also been examined in the empirical literature. A quantitative survey conducted in 2017 in Norway compared the implementation of IR4 between the oil and gas industry and the manufacturing industry. Significant differences were observed between the two groups, especially concerning the implementation of a digitalization strategy [32]. This implies that the clear differentiation between SMEs and LEs might be not adequate to provide size-specific recommendations, as sector-specific discrepancies also exist. Nonetheless, a qualitative study involving 26 participants confirmed the assumption that LEs have lower barriers and higher driving forces to implement IR4 than SMEs, evidencing that SMEs do not have equal opportunities as LEs in this regard. Moreover, due to less organizational complexity, the implementation of IR4 in SMEs is found to be less sophisticated [19]. Additionally, a survey conducted among SMEs in New Zealand in 2017 revealed that 33% of SMEs have a very poor or poor awareness of IR4, though almost half (49%) see IR4's potential contribution to all sectors. Interestingly, a large majority of 86% reported that they are planning to implement IR4 in the next 24 months. This is especially of interest as all organizations in the study were members of the New Zealand Manufacturers and Exporters Association (NZMEA). This manifests the diversity of manufacturing organizations in terms of awareness, willingness, and readiness to implement IR4 [18].

Ultimately, the implementation of IR4 in SMEs and LEs is a multi-year process. As such, focusing solely on technologies without achievable goals of digitalization leads to challenges during the implementation [25].

2.2 The Impact of IR4 on Productivity

Productivity improvements from IR4 have been quantitatively researched in numerous papers. For instance, productivity was another dependent variable measured by the aforementioned CNI survey in 2016, where the IR4 technologies CAD/CAM, digital automation with sensors, and big data analytics were found to have expected benefits for productivity. A recent global study with 705 responses also concluded that IR4 technologies have a positive impact on cost performance, quality performance, delivery performance, and flexibility performance [43]. Moreover, from the perspective of IR4 and competitiveness, simulation is believed to increase the productivity of the manufacturing process [4]. However, contrary to recent findings linking additive manufacturing positively with productivity enhancements [7, 41], [10] have revealed that additive manufacturing is perceived to have a negative impact on productivity at the operational level.

A qualitative study on the driving forces and barriers of IR4 distinguished between SMEs and Multinational Corporations (MNCs), concluding that IR4 driving forces' effect on productivity and efficiency is medium in SMEs and medium to high in MNCs [19].

Overall, several IR4 technologies have been established to have a positive impact on productivity, both in SMEs and LEs. This paper aims to add to the body of knowledge by identifying the specific technologies that are distinctly promising for SMEs and LEs.

3 Methods

A quantitative approach was adopted in this study. A close-ended survey questionnaire was designed with validated scales. It was distributed by sending more than 8000 emails using the MATRADE database between January and March 2019 and personally at the Smart Manufacturing Uprising conference in April 2019 in Kuala Lumpur, Malaysia, requesting more than 200 conference participants to respond to the questionnaire. A total of 40 valid responses were obtained through email while 36 valid responses were obtained in-person. The measures for the independent variables (IR4 technologies) were derived from [8] survey, which were used by [10]. The items for the dependent variable 'productivity' were adopted from [38] and were rated on a five-point Likert scale ranging from decreasing productivity to major and significant productivity gains. The pilot test revealed that the Cronbach's alpha of productivity was 0.733. Hence, the questionnaire was assumed to be reliable.

Using IBM's Statistical Package for the Social Sciences (SPSS) version 25.0, the collected data was analyzed in the form of descriptive and inferential statistics. Only questionnaires that were at least 80% complete and had indicated firm size were considered for analysis. One questionnaire that did not mention the company size was excluded, resulting in a final balanced data set of 39 SME responses and 37 LE responses. The dependent variables had skewness and kurtosis values below 2.0. Therefore, the data's normal distribution was assumed during the analysis. The independent and dependent variables are listed in Table 2. The independent variables comprised 10 IR4 technologies whereas the dependent variable is the expected benefit of the technologies (productivity gains).

Table 2: Independent and dependent variables

Independent Variables (Technologies)	Dependent Variables (Expected benefits)
IV01: Computer-Aided Design integrated with Computer-Aided Manufacturing (CAD/CAM)	DV01: Productivity
IV02: Integrated engineering systems (ENG_SYS)	
IV03: Digital automation with sensors (SENSORING)	
IV04: Flexible manufacturing lines (FLEXIBLE)	
IV05: MES and SCADA systems (MES/SCADA)	
IV06: Simulation/Virtual models (SIMaVM)	
IV07: Big data and analytics (BIG_DATA)	
IV08: Digital Product-Services, Internet of Things (IoT)	
IV09: Additive manufacturing (ADDITIVE)	
IV10: Cloud services (CLOUD)	

The following section discusses the results of the descriptive analysis and multiple regression analysis to explain the relationships between the variables.

4 Results and Discussion

4.1 Descriptive Analysis

Table 3 presents the profile of the SME and LE respondents who participated in this study. Overall, a majority of the respondents were males between 36 and 45 years old. Most of the SME respondents held founder or CEO positions, while most of the LE respondents held managerial or executive positions. Indicating a stark contrast between both sample groups, nearly all the SMEs in this study were small enterprises with less than 100 employees whereas most of the LEs had over 2000 employees.

Table 3: Respondents' Profile

Characteristic		Frequency (N) SMEs	Percentage (%) SMEs	Frequency (N) LEs	Percentage (%) LEs
Gender	Male	22	56.4	33	89.2
	Female	17	43.6	4	10.8
Age	25 to 30 years	7	17.9	5	13.2
	30 to 35 years	5	12.8	6	16.2
	36 to 40 years	8	20.5	6	16.2
	41 to 45 years	5	12.8	10	27.0
	46 to 50 years	7	17.9	7	18.9
	51 to 55 years	3	7.7	1	2.7
	56 to 60 years	4	10.3	1	2.7
	61 to 65 years	0	0.0	1	2.7
Current position					
Director, Founder or CEO		15	38.5	4	10.8
Operations Manager or COO		3	7.7	5	13.5
Production Manager		1	2.6	8	21.6
Engineering Manager		1	2.6	3	8.1
Engineer		0	0.0	2	5.4
Marketing Manager		4	10.3	4	10.8
Project Manager		0	0.0	1	2.7
Senior Manager		0	0.0	2	5.4
Business Development Manager		2	5.1	0	0.0
Purchasing Manager		3	7.7	0	0.0
General Manager		3	7.7	0	0.0
Sales Manager		1	2.6	0	0.0
Information Technology Manager		0	0.0	1	2.7
Chief Technology Officer		0	0.0	1	2.7
Others		6	15.4	6	16.2
Firm size	1-100	34	87.2		
	101-250	5	12.8		
	251 to 500			6	16.2
	501 to 750			4	10.8
	751 to 1000			5	13.5
	1001 to 1500			2	5.4

1501 to 2000	1	2.7
Greater than 2000	19	51.4

4.2 Independent Samples t-Test

To detect the statistical difference between the means of each IR4 technology's user and non-user, an independent samples t-test was deployed separately for SMEs and LEs. Cut points 1 and 2 were determined for both groups. Cut point 1 included productivity dimensions but did not take into account the expected benefit of boosting Malaysia's productivity competitiveness. Cut point 2 takes both into consideration. The results of the t-test for group 0=0 and group 1=1. The responses indicating that a) the respective IR4 technology is used and b) will boost Malaysia's competitiveness in the next five years were excluded. It is the either a) or b).

Table 4: Independent Samples t-Test

Technology Test	Internet of Things	Integrated engineering systems
Levene's Test	Not significant	Not significant
t Test for equality of means equal variances assumed using group 0=0 and group 1=1 for SMEs	Significance 2-tailed 0.035	
t-test for equality of means unequal variances assumed using cut point 1 for LEs		Significance 2-tailed 0.036

Table 4 reveals that IoT demonstrated a significant relationship with SMEs' productivity. On top of that, integrated engineering systems revealed a significant relationship with productivity for LEs as well.

4.3 Discussion of Results

To recapitulate, IoT is significant for improving SMEs' productivity. On the other hand, integrated engineering systems are significant for enhancing LEs' productivity. These relationships are discussed in the following sections in relation to the extant literature.

The technologies that were found to affect productivity differed across SMEs and LEs in this study. Contrary to the results of the study, the productivity gains of SMEs and LEs are not differentiated in the literature. Thus, firm size will not be mentioned further in the discussion of the results.

4.3.1. Internet of Things (IoT) and Productivity

Digital product services, or the IoT, has a significant impact on SMEs' productivity. Industrial Internet of Things (IIoT) is projected to act beyond improving productivity [5]. This gap was narrowed by [22], who employed IoT solutions for people with disabilities (PWD) to enhance their productivity. The overwhelming majority of the PWDs strongly agreed that they were more productive when using IoT devices [22]. In the manufacturing sector, [14] concluded that the application of IoT improves productivity in the sector [14]. Meanwhile, looking particularly at Europe's labor productivity, it was found that IoT only accounts for a small positive impact on productivity due to its relatively early stage of development. Moving forward, the authors expect an increased share of labor productivity gains through the application of IoT [12].

[9] voiced out that productivity improvements through IoT application are accomplished through real-time feedback on configuration and optimization via the analyses of device performance and degradation [9]. Traditionally, data is stored locally in the company's server and is not shared with employees for educational purposes. Through IoT, this restriction changes and knowledge-based learning systems are enabled. Hence, the productivity and efficiency of a firm's operations improve [26]. Overall, a direct relationship between productivity gains and IoT has not been found in every research, though it has been conceptualized often. The results are ambiguous and should be verified by further quantitative and qualitative studies.

4.3.2. Integrated Engineering Systems and Productivity

[35] developed an Overall System Efficiency (OSE) decision support model aimed to observe and improve overall productivity and customer satisfaction. Through the system, the assessment of productivity improvement would be boosted. Nonetheless, a relationship between the use of integrated engineering systems and firm productivity was not established in the study [35]. Similarly, [33] developed an adaptive integrated production management system model to solve the difficulties of processing technologies and operative change, but found that the exchange of information does not increase firm productivity [33]. This was further supported by [16] case study of a Malaysian manufacturing firm over a five-year period, which revealed that IT support systems do not automatically increase a firm's productivity.

Based on the literature, the relationship between integrated engineering systems and firm productivity has not been supported. This might be rooted in the lack of differentiation of studies conducted between SME's and LE's productivity improvement through integrated engineering systems. This study indicates that integrated engineering systems is significant for LE's productivity enhancement only, not for SMEs.

4.3.3. Comparison with other Quantitative, Qualitative and Case Studies

Table 5 lists the results of 6 studies in the manufacturing environment of the identified impact on firm's productivity. The studies are sorted by year of publication. Process control sensors, smart sensors, sensors and actuators are grouped under sensors. This quantitative study is listed as Malaysia (2021). Quantitative, qualitative and case studies are included.

Table 5: Comparison of IR4 studies indicating countries

Country, authors (Year of publication)	IES	Simulation	AI	IoT/ IIoT	Cloud	Big data
Malaysia (2021)	+ LE			+ SME		
Australia, [27]		+				
India, [11]			+			+
Italy, [45]					+	
Japan, [3]				+		
Sweden, [47]		+			+	

Table 5 illustrates that various quantitative, qualitative and case studies have been performed in recent years. In a nutshell, all findings in our quantitative sutdy are supported by reviewing recent studies except the claim that IES enhances the productivity of LEs.

5 Conclusion

This study found that SMEs' productivity is improved by IoT, while LEs' productivity is enhanced by integrated engineering systems. This paper did not establish relationships between eight of the 10 IR4 technologies and productivity enhancements. Thus, large-scale surveys are recommended to test these relationships with a clear distinction between SMEs and LEs. However, despite its limited findings, the paper contributes to an initial understanding of the key differences between SMEs and LEs in the application and role of IR4 technologies.

5.1 Practical Implications

Despite the small scale of this study, significant differences were observed between SMEs and LEs in terms of their IR4 technologies, thereby offering valuable insights to these firms. In particular, the study names specific IR4 technologies that impacts productivity, especially highlighting that potential productivity achievements through IR4 technologies differ between SMEs and LEs. This is apparent by looking back at implementation models that call for IR4 technology implementation in stages. Thus, depending on the size and level of IR4 readiness of an organization, suitable technologies may vary tremendously. The ultimate contribution of IR4 to enhance productivity further depends on technological, economic, and social dimensions, as well as the company's culture and willingness to change. Therefore, this study reveals distinct relationships between IR4 and productivity enhancements, with an emphasis that these relationships are subject to the respective organization.

5.2 Managerial, Policy and Theoretical Implications

The paper supports the argument that not all technologies have a positive impact on productivity in a respective organisation. Thus, decision makers are recommended to carefully examine company size, industry, readiness, and facility stage before launching the implementation of IR4.

Based on this quantitative study, policy makers should enhance national IR4 policies by conducting large-scale, industry-specific surveys aimed to direct resources to the most promising technologies. The first step towards directing resources has been accomplished by the present study.

The theoretical contribution of this paper is its distinction between SMEs and LEs in examining the impacts of 10 IR4 technologies. The differing relationships between specific IR4 technologies and productivity were identified by company size. This implies that the recommendation of specific IR4 technologies' depends on firms' size and level of development.

5.3 Limitations and Future Research

This quantitative study consisted of only 76 responses, which does not imply generalizability to other sectors. The results obtained in this study should hence be confirmed by large-scale quantitative studies to provide more substantial evidence on the identified relationships. The next limitation is that the data was not obtained from a single group of respondents, raising issues of a heterogenous sample. Moreover, given that implementing and observing the results of IR4 technologies is a relatively long process, the cross-sectional nature of this study may not have captured the respondents' actual opinions over time. Lastly, the study was conducted in Malaysia, where culture-specific factors may have impacted the responses. Future research may consider a larger, more homogenous sample, a longitudinal design, or a more culturally diverse sample when studying IR4 technologies.

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