Industry 4.0:

Adoption Challenges and Benefits for SMEs

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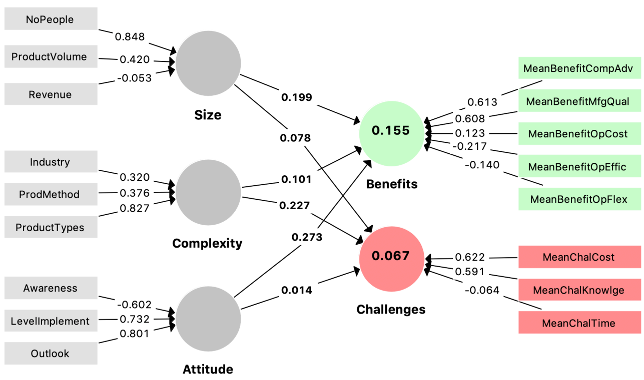

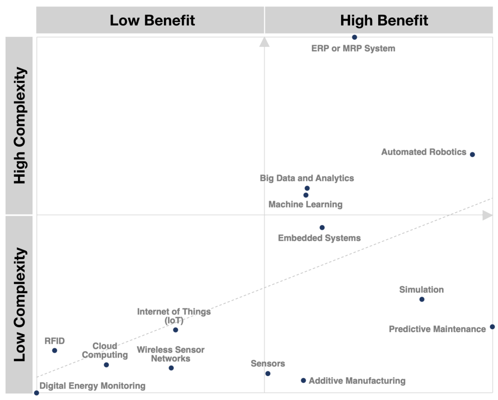

Highlights

- First survey of UK SMEs (n=271, KMO=0.701) on adoption of Industry 4.0 technologies (n=20)
- First application of Technology Acceptance Model on Industry 4.0 in SMEs
- Guidance on which aspects should be focussed on to ensure success of Industry 4.0 in SMEs
- Flexibility, cost, efficiency, quality and competitive advantage are key benefits
- Financial, awareness and knowledge constraints are found to be key adoption challenges

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Industry 4.0: Adoption challenges and benefits for SMEs

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Abstract
Future industrial systems have been popularised in recent years through buzzwords such as Industry 4.0, Internet of Things (IoT), and Cyber Physical Systems (CPS). Whilst the technologies of Industry 4.0 and likes have many conceivable benefits to manufacturing, the majority of these technologies are developed for, or by, large firms. Much of the contemporary work is therefore disconnected from the needs of small and medium-sized enterprises (SMEs), despite the fact they represent 99% of registered companies in Europe. This study approaches the disconnect through an industrial survey of UK SMEs (n=271, KMO=0.701), which is the first in the UK that used to collect opinions, reinforcing the current literature on the most reported Industry 4.0 technologies (n=20), benefits, and challenges to implementation. Flexibility, cost, efficiency, quality and competitive advantage are found to be the key benefits to Industry 4.0 adoption in SMEs. Whilst many SMEs show a desire to implement Industry 4.0 technologies for these reasons, financial and knowledge constraints are found to be key challenges.

Keywords
Industry 4.0; Internet of Things; IoT; Cyber Physical Systems; CPS; Future industrial systems; Technologies; Small and medium sized enterprise; SME; Characteristics; Adoption; Challenges; Benefits; Industrial Survey; Survey; Technology Acceptance Model; TAM, United Kingdom; UK

List of Acronyms

CPS	Cyber-Physical System/s
DOI	Diffusion of Innovation
ERP	Enterprise Resource Planning
I4.0	Industry 4.0
IoT	Internet of Things
KMO	Kaiser-Meyer-Olkin Test
MF	Matrix Factorisation
MNE	Multi-National Enterprise
MRP	Manufacturing Resource Planning
PLS	Partial Least Squares
RG	Research Gap X
RO	Research Objective X
RQ	Research Question
SEM	Structured Equation Modelling
SIC	Standard Industry Classification/s
SME	Small and Medium-sized Enterprise
TAM	Technology Acceptance Model
TOE	Technology, Organisation, Environment

1.0 Introduction

Over the last decade, future industrial systems have been frequently discussed within industry and academia while many initiatives have emerged to describe such systems. The successful development of such systems is considered vital to creating competitive advantage between manufacturing companies and national economies (Doh and Kim, 2014; Kusiak, 2018).Within Europe, the most established is “Industry 4.0” (I4.0) (Strozzi et al., 2017; Galati and Bigliardi, 2019; Frank et al., 2019; Sharp et al., 2019). Originating from Germany in 2011, I4.0 was intended to support national growth by promoting manufacturing development (Yin et al., 2018). There is a variety of other initiatives to promote this progression, such as “Smart Manufacturing” in the USA, “Made in China 2025”, and “Future of Manufacturing” in the UK (Liao et al., 2017; Kusiak, 2018). Since I4.0 is the most prominent term in Europe (Liao et al., 2017), it will be used to describe future industrial systems in this article.

While many authors have defined I4.0 in different contexts, the general idea behind I4.0 is that of a “fourth industrial revolution”, caused by the rapid technological advancements in recent times. Shafiq et al. (2015; 2016) have defined I4.0 as “I4.0 facilitates interconnection and computerisation in to the traditional industry. The goals of I4.0 are to provide IT-enabled mass customization of manufactured products; to make automatic and flexible adaptation of the production chain; to track parts and products; to facilitate communication among parts, products, and machines; to apply human-machine interaction (HMI) paradigms; to achieve IoT-enabled production optimisation in smart factories; and to provide new types of services and business models of interaction in the value chain”.

It is evident that the I4.0 is aimed at “creating intelligent factories where manufacturing technologies are upgraded and transformed by CPS, IoT, and cloud computing” (Zhong et al. 2017). I4.0 is also characterised by other technologies which include but not limited to augmented reality (Egger and Masood, 2019; Masood and Egger, 2019; Masood and Egger, 2020), virtual reality, digital twins, (collaborative) robotics and advanced simulations (Malik et al., 2019). Whilst the culminating effects on manufacturing are yet to be seen, the proposed future technologies are likely to have many challenges in implementation due to the significance of changes from the current state.

Whilst I4.0 is well anticipated, the majority of research addressing implementation techniques is created for, or by, larger organisations or multi-national enterprises (MNEs) (Mittal, Khan, et al., 2018). Although MNEs contribute significantly to the economy (Etemad, 2009), it cannot be ignored that SMEs make up 99% of companies operating within the EU (European Commission, 2015). The impact of SMEs is also substantial; they create jobs, economic growth and ensure social stability (Knight, 2000; Wallsten, 2000).

In comparison to MNEs, SMEs tend to face greater financial and knowledge resource constraints (Arend and Wisner, 2005; Brunswicker and Vanhaverbeke, 2015). This leads to many authors identifying a mismatch between current I4.0 theory and the specific requirements of SMEs (Müller and Voigt, 2016; Kaartinen et al., 2017; Moeuf et al., 2018; Mittal, Khan, et al., 2018; Vrchota et al., 2019). While production research is transforming in the wake of I4.0 developments across planning, execution and maintenance related research clusters (Rauch et al. 2019), however introduction of I4.0 technologies in SMEs is still challenging, particularly in production, logistics, organisational and managerial perspectives (Modrak et al. 2019).

If manufacturing SMEs are to prosper in the future, there is a strong suggestion that they should adopt I4.0 in order to compete nationally and internationally. The magnitude of SMEs means that the effect of increased adoption would likely be greater than that in large MNEs only. This article therefore aims to address these gaps by exploring challenges and benefits of adopting key I4.0 technologies in SMEs, and thus motivating I4.0 adoption.

The rest of this article is organised as following. Related literature is presented in section 2. The survey methodology is presented in section 3. Section 4 presents results and analysis, which are then discussed in section 5, and ultimately concluded with further work suggestions in section 6.

2.0 Background

The section involves a review of current literature, concluding with a synthesis, gap identification, and progression into a developed research question.

2.1. Industry 4.0 in SMEs

The intersecting research domain is somewhat more nascent than the separate fields of I4.0 and SMEs. Although this intersection has been a topic of discussion for several years, it has only recently gained momentum, as seen from the annual publications in Figure 1.
The earliest work on the matter was by Würtz and Kölmel (2012), being the first to highlight the potential issues of smart factory implementation in smaller businesses. Despite the realisation, issues were not studied in any significant detail until the emergence of later works in 2016.

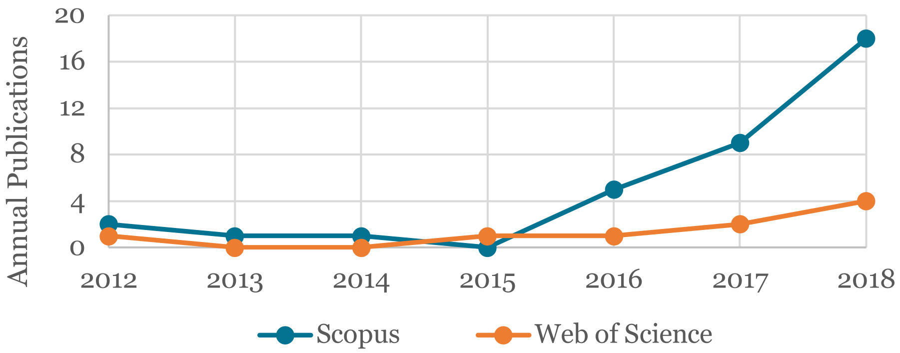

Figure 1 - Annual Publications of Intersecting Fields (Scopus and WoS Databases, 2019)

Much of the research after 2016 continues to highlight mismatches of current research on I4.0 and the needs of SMEs (Rauch et al., 2018; Sevinç et al., 2018; Moeuf et al., 2018; Mittal, Khan, et al., 2018; Bär et al., 2018; Orzes et al., 2019; Türkeş et al., 2019). Many papers also propose frameworks, models, toolkits and strategies of varying focuses (Y. Wang et al., 2016; Wank et al., 2016; Jordan et al., 2017; Mittal, Romero, et al., 2018).

One of the seminal works on the topic was by Wang et al. (2016), whereby a procedure to implement I4.0 within SMEs was proposed. The model proposed a five-step framework to implementation. This early work is, however, rather conceptual, with limited links to SME requirements for technology investment. A model very similar to Wang et al. was proposed by Wank et al. (2016). This model follows similar steps of analysis, idea definition and concept creation, however there are limited links to SME needs and no empirical support.

Several other studies cover similar ground, proposing a mix of frameworks and models that follow a logical sequence of SME implementation, however, the link to SME requirements remains relatively indistinct, with issues, barriers and challenges stated, but few proposed solutions. One notable paper by Jung and Jin (2018) involved technology implementation case studies at three South Korean SMEs. Although some success was highlighted, they concluded that all three SMEs in the case study were *"reluctant to build the smart factory due to financial problems",* however, they did have *"great interests in building low-level implementations"*.

There is further research focusing on the technical aspects of I4.0 implementation, with most case studies showing issues with SME acceptance for a variety of technical reasons (Contreras et al., 2018; Jung and Jin, 2018).

A topic of recent interest is raising awareness of I4.0 technologies to SMEs, through means of hands-on workshops (Wank et al., 2016; Scheidel et al., 2018; McFarlane, 2018). Research in this area has shown promising results, demonstrating that awareness of the latest technologies is an issue for SMEs, since they are not often exposed to the developments of academia and MNEs.

Orzes et al. (2019) make an attempt to empirically determine the latest barriers to implementation through a focus group study of 37 SMEs in Italy, Thailand, Austria and the USA. Six major barriers of I4.0 implementation in SMEs were identified: economic and financial; cultural; competence and resources; legal; technical; and implementation process. This is one of the first papers to empirically determine these barriers and is the current status of this research field which is *"expected to rise significantly in the next few years"* (Orzes et al., 2019).

While I4.0 technologies have not been adopted widely in SMEs, these are already being used and adopted in MNEs (Mittal et. al. 2018 ; Horvath and Szabo 2019). Some key benefits of I4.0 reported in literature include: cost reduction, improvements in quality, efficiency, flexibility and productivity, and competitive advantage (Doh and Kim, 2014; Kusiak, 2018).

2.2. Challenges around Industry 4.0 adoption in SMEs

The following three clear challenge themes faced by SMEs in adopting I4.0 have been reported in the literature (Orzes et al. 2019; Mittal et. al. 2018 ; Horvath and Szabo 2019):

- Financial resource limitation
- Knowledge resource limitation
- Technology awareness limitation

Considering I4.0 adoption, not only are SMEs different to MNEs, they are also different to each other. This makes developing a universal model difficult and explains why much of the research in the intersecting field is fragmented. Further challenges include:

- Abundance of technologies for SMEs to be aware of
- Varying SMEs are difficult to assess

Furthermore, Modrak et al. (2019) conducted a structured literature review, and identified following I4.0 challenges for SMEs:

(i) Production: using RFID technologies for data processing, use of mobile user interfaces, use of machines with internet connection, using ICT to identify production statuses, and introducing IoT into the production.
(ii) Logistics: implementation of automatic control into delivery processes, and introducing autonomous inventory management.
(iii) Organisational and managerial: applying organisational models of production for mass customised products.

2.3. Research Gaps

Based on the systematic review and synthesis, benefits of I4.0 are well identified, with many existing frameworks and tools. There is, however, only a small amount of work focusing on the implementation of I4.0 within SMEs. In 2019, the barriers are well identified but the field is still developing. This leads to the identification of the first research gap (RG):

Research Gap 1 (RG1) – *There is a disconnect between current I4.0 technologies and the characteristic needs of SME organisations:*

- The most established I4.0 models, frameworks and toolkits are developed for, or by, larger MNEs (Mittal et. al. 2018 ; Horvath and Szabo 2019),
- SME priorities are largely different to that of MNEs, they are more focused on costs and short-term benefits, and
- Some SMEs have no prior experience or knowledge of I4.0, so adoption is difficult.

In addition to this first gap, many SMEs struggle with the awareness of an overwhelming number of technologies which are constantly developing. Although workshops can be used to effectively demonstrate the benefits first-hand, these methods are naturally limited in impact and scope. Consulting from external experts is also a common solution, however this requires funding that SMEs tend to struggle with. This leads to the identification of the second research gap:

Research Gap 2 (RG2) – *There is no clear method to evaluate I4.0 technologies against the needs and requirements of specific SME organisations:*

- SME oriented tools, frameworks and models do not extend beyond giving a current "I4.0 readiness" state of an organisation (Mittal et. al. 2018 ; Horvath and Szabo 2019), and
- There is a knowledge gap in SMEs due to the overwhelming number of implementation technologies and options.

2.4. Research Question and Objectives

Based on the two identified gaps, the following research question (RQ) is proposed:

> *RQ: "What are the benefits of I4.0 technologies against the characteristic challenges of SMEs?"*

The aim of this research is to answer this question empirically and with industrial context. A number of research objectives (ROs) are therefore defined:

RO1. Identify the characteristics and challenges posed to manufacturing SMEs regarding I4.0 technology adoption

RO2. Identify the key I4.0 technologies and the associated benefits to manufacturing SMEs

RO3. Develop an empirical method to;

(i) evaluate a specific SME for its characteristics and challenges, and;

(ii) evaluate I4.0 technology benefits against those characteristics and challenges

The remainder of this article builds on learnings from previous literature analysis to achieve these ROs.

3.0 Research Methodology

The research methodology is developed to answer the RQ and the associated ROs.

3.1. Research Approach

In order to evaluate SME challenges (RO1) against the benefits of technologies implemented (RO2), a survey was determined to be the most suitable approach. A survey provides a cross-sectional and deductive approach that can be used to generate quantitative and objective outputs; a methodology that is lacking within current literature (RG2).

For deducing the factors that influence technology adoption (ROs 1-3), the industrial survey and literature were used to provide primary and secondary data sources respectively. The unit of analysis for the survey is limited to UK-based SMEs, as the region was previously unstudied, and this audience was accessible to the authors.

In order to design a survey, the independent survey factors were determined following the combination of a framework and the outputs of the literature review (ROs 1-3).
The overall research approach is shown in Figure 2.

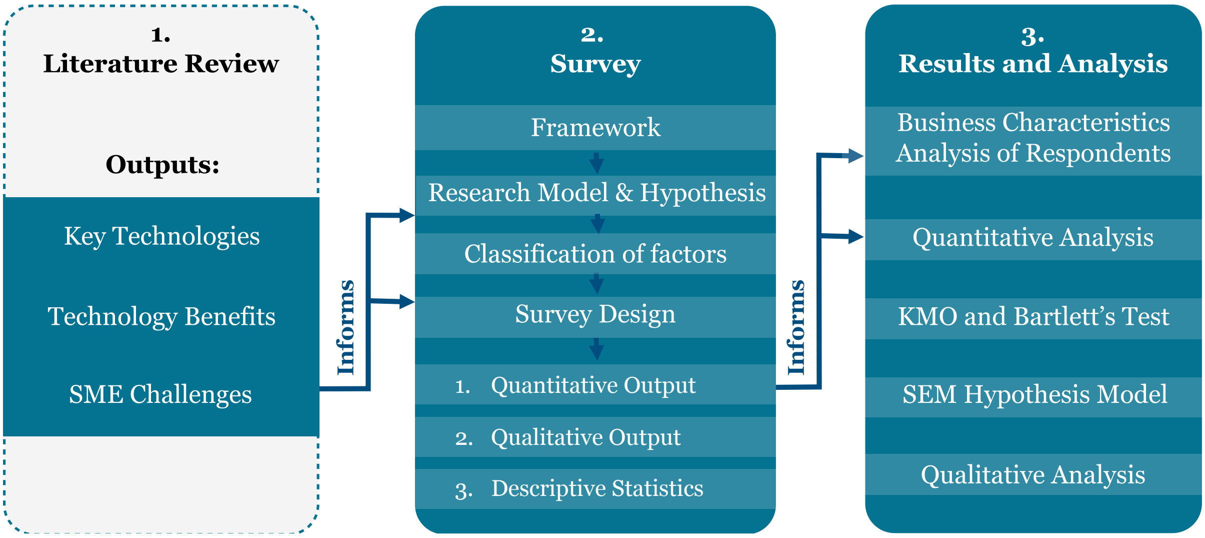

Figure 2 - Research Approach

3.2. Survey of SMEs

The primary purpose of the survey is to determine how SME characteristics affect the benefits and challenges of I4.0. The survey must therefore collect information on the technologies implemented by SMEs, the benefits seen from the technologies, and what challenges they have had during the implementation process.

3.2.1 Framework

There are many existing frameworks to explain technology adoption. The technology acceptance model (TAM) was initially defined by Davis (1989) to study the reasons for adoption and use of computer systems. The model is shown in Figure 3.

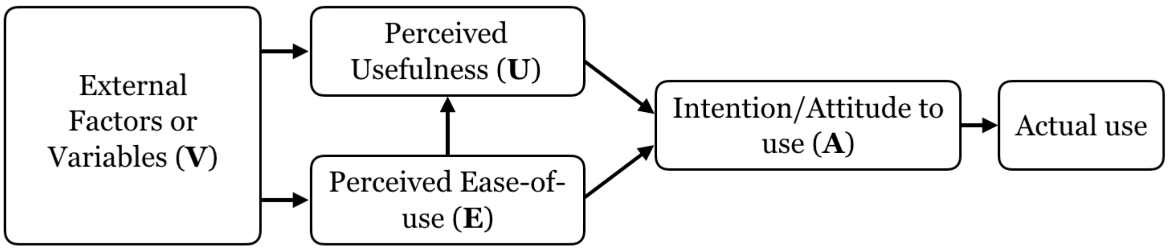

Figure 3 - Technology Acceptance Model (TAM) (From Davis et al., 1989)

The TAM model describes four key factors that determine adoption:

1) External factors, such as business size, social factors, cultural factors etc.
2) Perceived usefulness of a technology
3) Perceived ease of use of a technology
4) Intention or attitude towards use

The TAM framework has been cited by multiple authors as *"one of the most popular theories to explain information system use"*, being widely studied and verified with *"substantial* *empirical support"* (Surendram, 2012; Lai, 2017; Taherdoost, 2018). Other frameworks also exist, such as the Diffusion of Innovation (DOI) theory by Rogers (1995) and the Technology, Organisation and Environment (TOE) theory by DePietro et al. (1990) (Lai, 2017; Masood and Egger, 2019). DOI was considered too broad, whilst TOE too specific; focusing on additional factors that do not relate to the RQ. The TAM framework is sufficient to explain the major factors that determine Industry 4.0 technology adoption within SMEs and is thus suited to the nascent research field.

The framework is adapted to match the RQ, changing "ease of use" to "challenges", and "usefulness" to "benefits", as seen in Figure 4. Since I4.0 technologies are still in early stages, especially within SMEs, the connection to "actual use" is disregarded as it is too early to determine. Assessment of the benefits and challenges are the key objectives needed to answer the RQ.

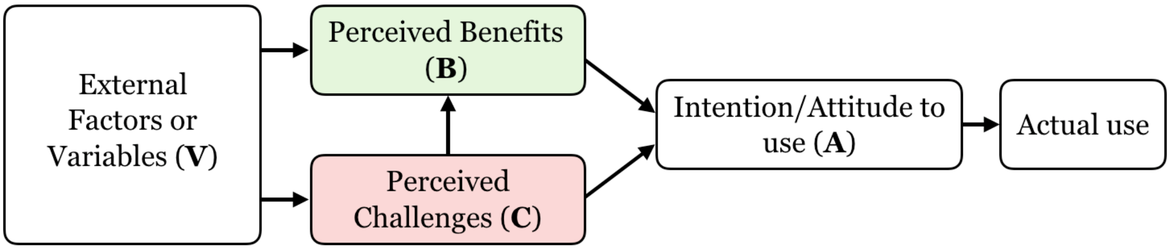

Figure 4 - Adapted TAM

3.2.2 Research Model and Hypothesis

Based on the adapted TAM (Figure 4), the research model is defined in Figure 5, with six major hypotheses. The external factors are the predictors, and their effect on benefits and challenges is to be determined by assessing six hypotheses (H1-H6). These are directly linked to the RQ and RO3.

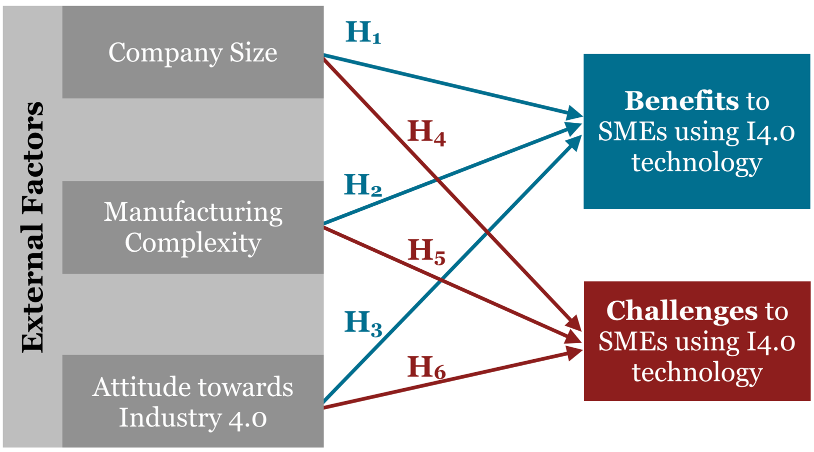

Figure 5 - Research model and six hypotheses

The six hypotheses are:

H1 – Company size affects the benefits seen by an SME implementing an I4.0 technology

H2 – Manufacturing complexity affects the benefits seen by an SME implementing an I4.0 technology
H3 – Attitude towards I4.0 affects the benefits seen by an SME implementing an I4.0 technology
H4 – Company size affects the challenges seen by an SME implementing an I4.0 technology
H5 – Manufacturing complexity affects the challenges seen by an SME implementing an I4.0 technology
H6 – Attitude to towards I4.0 affects the challenges seen by an SME implementing an I4.0 technology

3.2.3 Classification of Measurement Variables

The survey was designed to determine:

1) Several aspects about the business to suggest external factors,
2) The associated benefits to the technologies implemented (benefit measures taken from literature review on I4.0 benefits),
3) The associated challenges of technologies that have been implemented (challenge measures taken from literature review on key SME challenges), and
4) Intention or attitude to use, i.e. knowledge of I4.0 after being primed with a description.

To determine the measurement variables, the output of the literature review was used. The latent variables, measured variables and measure scales are shown in Table 2.

Table 2 - Survey variables and associated measurement methods

Latent Variable	Measured Variable	Measure Scale or Question				
External factors						
Company Size	Employee Count	1-10	11-49	50-250	>250	-
	Annual Revenue	0-2M	2-10M	10-50M	>50M	-
	Production Volume	1-100	100-10000	10k-100k	100k-1M	>1M
Manufacturing Complexity	Industry	Standard Industry Classifications (SIC)				
	Production Method	Project	Job Shop	Batch	Mass	Continuous
	Product Mix	<5	5-25	26-100	101-500	>500
Technology Benefits and Challenges						
		5 Point Likert - How much do you agree with this statement?				
		Strongly Agree	Somewhat Agree	Neither Agree nor Disagree	Somewhat Disagree	Strongly Disagree
Benefits offered by technology	Operational Cost	Operational costs have been improved by implementing this technology				
	Operational Efficiency	Operational efficiency has been improved by implementing this technology				
	Operational Flexibility	Operational flexibility has been improved by implementing this technology				
	Manufacturing Quality	Manufacturing quality has been improved by implementing this technology				
	Competitive Advantage	Competitive advantage has been improved by implementing this technology				
Challenges in implementing technology	Implementation Costs	Implementation cost of the technology has been a challenge				
	Implementation Time	The implementation time for the technology has been a challenge				
	Knowledge Needed	The knowledge/learning curve required to implement or sustain the technology has been a challenge				
Attitude or Intention to Use						
		5 Point Likert - Contextual				
Attitude towards Industry 4.0	Awareness	Are you aware of the "Industry 4.0" concept (after priming)				
		Extremely Aware	Very Aware	Moderately Aware	Slightly Aware	Not Aware at All
	Implementation Level	What is the implementation level of Industry 4.0 in your business?				
		Extremely Implemented	Very Implemented	Moderately Implemented	Slightly Implemented	Not Implemented at All
	Outlook	Within the next five years, will you invest in or develop the implementation of future manufacturing systems?				
		Definitely Yes	Probably Yes	Might or Might Not	Probably Not	Definitely Not

3.2.4 Classification of Technologies

Through the systematic literature review, several key technologies were defined. The respondents of industrial survey were asked to identify which technologies had been implemented, or were in the process of being implemented, such that their benefits and challenges could be assessed. The technology options are outlined in Table 3; several come from the literature review output; however, some are excluded for brevity.

Table 3 – Determination of technologies – Based on literature review

Source	Technology		Name Re-coding for Survey Understanding	Technology ID
From Literature Review **(Included)**	Additive Manufacturing			1
	Artificial Intelligence			2
	Augmented Reality			3
	Robotics	->	Automated Robotics	4
	Big Data	->	Big Data and Analytics	5
	Blockchain			6
	Cloud Computing			7
	Smart Grid	->	Digital Energy Monitoring	8
	Digital Twins			9
	Embedded Systems			10
	Machine Learning			11
	Multi-Agent Systems			12
	Predictive Maintenance			13
	RFID			14
	Sensors			15
	Simulation			16
	Virtual Reality			17
	Wireless Sensor Networks			18
	Technology		**Reasoning for include/exclude**	
Additional technologies **(Included)**	ERP or MRP Systems		Commonplace and baseline for further implementation	19
	Internet of Things (IoT)		Often viewed as a technology	20
From Literature Review **(Excluded)**	Virtualization		Too generic	N/A
	Distributed Computing		Weak literature support	
	Cyber-Physical Systems		Not a technology	
	Real-time Systems		Not descriptive	
	Data Mining		Paired with big data	

3.2.5 Quantitative Analysis

To validate the hypotheses, there are several common approaches to infer causality. The most common is multiple regression analysis (Massey and Miller, 2006; Jeon, 2015). The survey data was collected from ordinal Likert scales and in some cases is correlated to itself (e.g. production volume and employee count). This makes regression analysis unsuitable, since continuous scales are needed and co-variance is not considered (Jeon, 2015).

In contrast, another method, Structured Equation Modelling (SEM), uses multiple measured variables to predict latent variables and their causal relationships (Garson, 2016). SEM does not have the same issues as simple multiple correlation, with capability to consider *"multiple dependents, multiple independents, multicollinearity, and missing data"* (Garson, 2016).

SmartPLS is a Partial Least Squares analysis (PLS) SEM software package that can perform SEM analysis on data, determining causal relationships, weights, and statistical significance. The research model (Figure 5) for each inference measure and latent variable was constructed in the format of an SEM diagram (Figure 6). There are five latent variables and 17 measured variables, as defined in Table 2. The causal analysis between latent variables will be used to validate the hypothesis tests.

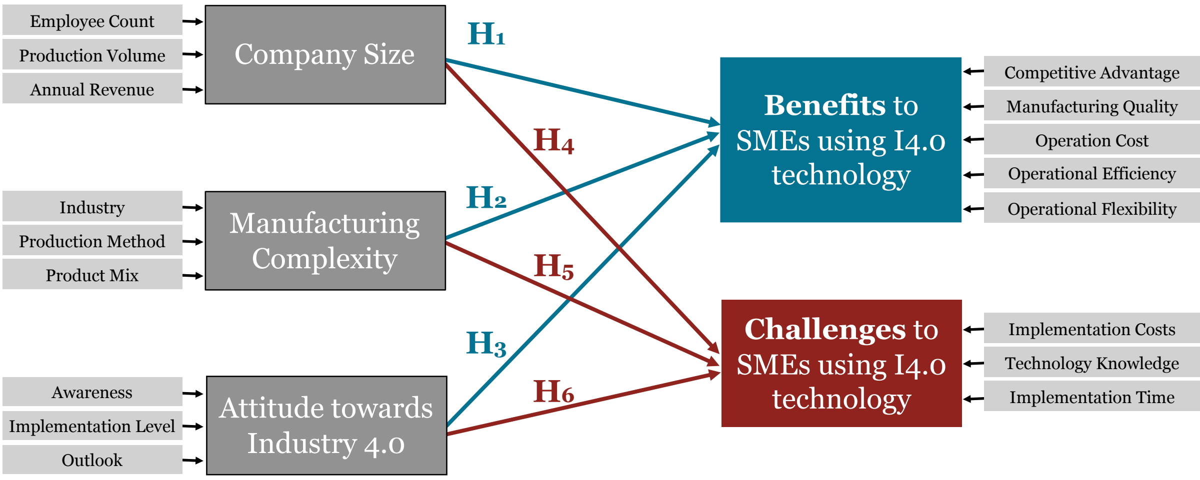

Figure 6 - SEM representation of research model

To ensure validity of the data for SEM, the Kaiser-Meyer-Olkin (KMO) test will determine suitability for Factor Analysis (Garson, 2016). The KMO test can be computed using the IMB SPSS software.

3.2.6 Qualitative Analysis

Optional text entry was provided in three locations to allow for additional qualitative data collection. This included "additional challenges" or "additional benefits" to technology implementation, as well as the question, "How do you think SMEs could better prepare for future manufacturing systems or technologies?". These are thematically assessed using text analysis in VOSviewer.

3.2.7 Audience, Design and Distribution

The audience for the survey is UK manufacturing SMEs. The contacts were obtained via the "FAME database" of companies registered in the UK (FAME, 2019). The database was filtered to; <£50m revenue; <250 employees; and in the manufacturing sector. These filters follow the definition of an SME in the EU.

The target recipients were high level employees such as directors, executives and operations managers. These people were targeted as they are likely to have influence on the technology implementation process. A random sample of a quarter of the dataset was taken, equating to 1,061 people.

The survey was designed using Qualtrics, with 29 questions in total. The survey was validated by three independent peers. The distribution process occurred via Email, with a digital link for the user to complete the survey.

4.0 Results and Analysis

This section outlines the results and analysis of the survey, which are then discussed in Section 5.0.

The survey was digitally distributed via Email to 1,061 influential members of the UK SMEs during June and July 2019. In total, 303 responses were collected (28.5% response rate). 59% of respondents were director or C-suite level (CEO etc.), with a further 34% from a management level or above. The respondents represented a diverse set of SMEs from varying locations in the UK.

Of the 303 responses, 271 were determined to be SMEs as per the EU definition, making an 89.4% validity rate. Whilst these 271 SME responses covered initial questions, only 238 finished the survey in entirety (78.5% completion rate). 196 of the completed responses said they had implemented a listed technology (82.4%). 658 technology implementations and their associated ratings were thus recorded.

Table 4 show the general business characteristics for each respondent.

Table 4 - Sample profile of the survey respondents

	Count	Percentage
Roles		
Managing Director		29.2%
Other: Manager		12.2%
Operations Manager		11.8%
CEO		11.4%
Operations Director		10.7%
Plant/Factory Manager		9.6%
Other: Director		8.1%
Other: Misc		7.0%
Total	271	100.0%
Sector / Standard Industry Classification		
Metal and fabricated metal products		15.5%
Machinery and equipment		8.1%
Electronics and Electrical Equipment		7.4%
Chemicals excluding Pharmaceuticals		7.0%
Rubber and Plastic products		6.3%
Food products, beverages and tobacco		5.2%
Textiles, textile products, leather and footwear		4.8%
Paper, paper products, printing and publishing		4.4%
Medical, Precision or Optical Instruments		4.1%
Automotive		4.1%
Furniture		3.3%
Stone, Clay, Glass, or Concrete		3.0%
Pharmaceuticals		2.6%
Energy		1.8%
Radio, TV and Communications equipment		1.1%
Office, Accounting and Computing equipment		1.1%
Aerospace		1.1%
Transport equipment		0.7%
Mining		0%
Other		18.5%
Total	271	100.0%
Number of employees		
1-10 people		1.5%
11-49 people		15.9%
50-250 people		82.7%%
More than 250 people		0%
Not sure		0%
Total	271	100.0%
Production Types		
Batch production		47.2%
Project based (one-off)		18.8%
Continuous Production		15.9%
Mass Production		9.2%
Job Shop		4.8%
Other:		4.1%
Total	271	100.0%

4.1. SEM Hypothesis Model

Prior to modelling the survey data using SEM methods, analysis on the validity of the data for factor analysis was completed in SPSS. The results of the KMO scores and Bartlett's Test of sphericity are shown in Table 5.

Table 5 - KMO and Bartlett's Test on Survey Data

Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		**.701**
Bartlett's Test of Sphericity	Approx. Chi-Square	1038.118
	df	153
	Sig.	**.000**

The KMO of 0.701 is described as "adequate" by the thresholds defined in Kaiser (1974). In addition, the significance from Bartlett's test of sphericity is also lower than 0.05, which suggests that the variables are related to each other on a statistically significant level and the survey data can thus be modelled with validity in an SEM.

Using the SmartPLS software, an SEM was created from the data of each user as per the methodology (Section 3). The mean scores for technology benefits and challenges were taken, along with the coinciding data for each SME on Size, Complexity and Attitude. The factor loadings can be seen in the model (Figure 7). The loadings represent the *"contribution of the indicator to the definition of its latent variable*" (Garson, 2016). In general, larger loadings show stronger causality.

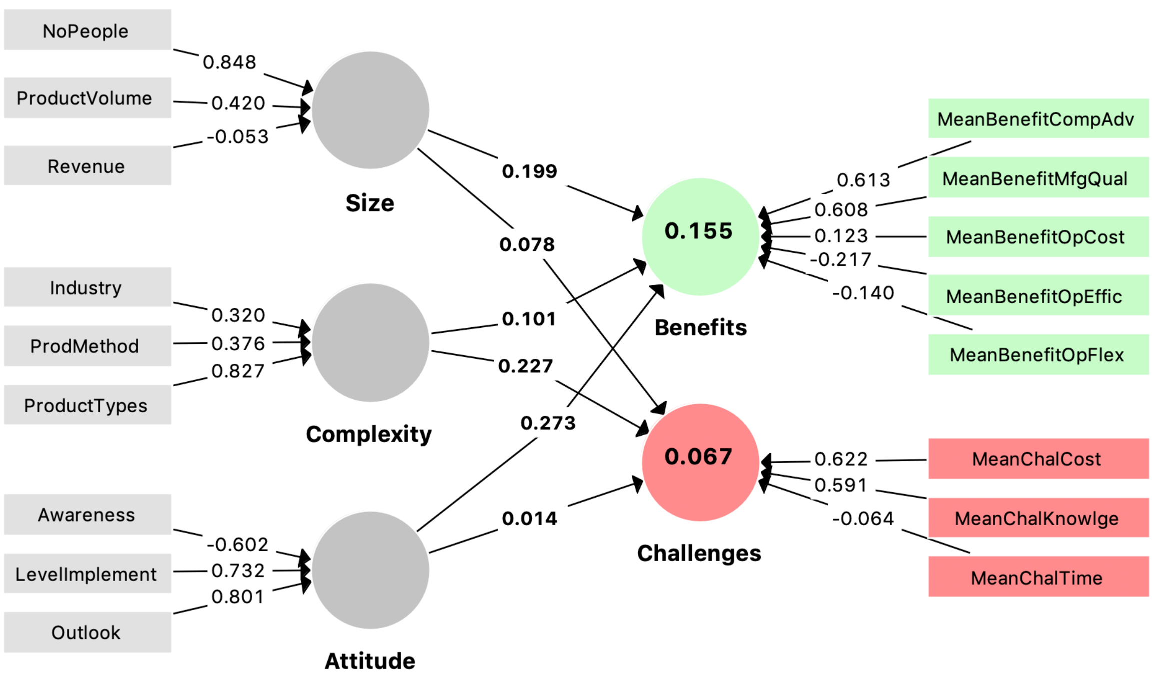

Figure 7 - Measured and Latent Variable Factor Loadings from PLS-SEM (Made with SmartPLS)

The loadings in the model can also be assessed for statistical significance by generating a p-value. These can be used to test the hypotheses outlined in the methodology. The results for these tests and the accept/reject decision are shown in Table 6. A 90% statistical significance level was used as the data is sparse.

Table 6 - Hypothesis test results from PLS-SEM

No	Hypotheses	Path Coefficient	P-value	Significance	Result	Sign
H1	Company size affects the benefits seen by an SME implementing an I4.0 technology	0.199	0.028	p<0.1	**Accept**	+
H2	Manufacturing complexity affects the benefits seen by an SME implementing an I4.0 technology	0.101	0.248	p<0.1	**Reject**	
H3	Attitude towards I4.0 affects the benefits seen by an SME implementing an I4.0 technology	0.273	0.075	p<0.1	**Accept**	+
H4	Company size affects the challenges seen by an SME implementing an I4.0 technology	0.078	0.257	p<0.1	**Reject**	
H5	Manufacturing complexity affects the challenges seen by an SME implementing an I4.0 technology	0.227	0.023	p<0.1	**Accept**	+
H6	Attitude towards I4.0 affects the challenges seen by an SME implementing an I4.0 technology	0.014	0.463	p<0.1	**Reject**	

From these tests, H1, H3 and H5 are accepted as valid hypotheses, whilst H2, H4 and H6 are rejected. The results can be interpreted as following:

- Larger size SMEs show higher observable benefits,
- A more positive attitude towards I4.0 shows higher observable benefits, and
- Higher company complexity shows higher observable challenges.

4.2. Qualitative Responses

The survey also collected qualitative responses. 14 text responses were collected regarding "further benefits of I4.0 to SMEs". Whilst there were no key themes, time-to-market, reduced stockholding and tighter supply chains were among some new benefits that emerged.
When asked about further challenges, 17 additional text responses were collected. Five answers discussed additional cost and finance issues; the largest theme. Complexity challenges occurred twice, as did security concerns. Two comments noted the "inertia" associated with change, and the likely issues in the respondents' traditional industries with future technology.

When asked how the respondent believed SMEs could prepare for future manufacturing systems or technologies, 102 text responses were entered. Key themes were identified, with the major key words shown in Figure 8.

Figure 8 - Word Cloud of most frequent terms in question "How do you think SMEs could better prepare for future manufacturing systems or technologies?"

The most common theme was that of **training**, with 9 responses identifying this as "required". Most suggested that SMEs should train their workforce, whilst others suggested government training was required. **Support** was another similar theme to training, with 9 responses. Most discussed how government support through "grants and funding" would be useful. "Support from experts" was also reoccurring.

Another theme was **time**, with 8 responses indicating it was difficult to dedicate to new technology development. Two suggested "employing a responsible individual" to keep abreast of new developments. One CEO states it is "often hard to find the time to lift one's head up to do these things". **Awareness** was also stated by 8 respondents, closely linked to training, support and time. Awareness of a wide amount of technologies is clearly an issue, and over half stated lack of awareness was due to time constraints.

Investment was the final theme identified; with many statements suggesting that it is "needed to make technology implementation work". Suggestions of investing in "training" and the "right people" were made, closely linking to other themes. Other ideas were identified, such as the methods of implementing new systems alongside old systems, and how to make the business cases for new or uncertain technologies.

5.0 Discussion

The results of the survey are discussed in this section.

5.1. Survey Data

The survey was used to collect data from a sample set of 303 SMEs within the UK. The data from the survey was used to test six hypotheses in the research model (Table 6) in an attempt to determine how SME characteristics affect the challenges and benefits of I4.0 technology implementation; fulfilling RO3.

The results suggested that company size and attitude have a positive effect on the benefits of implementation, whilst manufacturing complexity has a positive effect on the challenges of implementation. The finding that complexity positively effects challenges reinforces much of the literature (Weiß et al., 2018; Orzes et al., 2019). Initial complexity remains a critical challenge for SMEs, as more complex existing operating procedures are likely to require more complex upgrade procedures. In the literature, a key benefit of I4.0 was dealing with complexity and increasing flexibility. This construct was not statistically significant enough to confirm in this study, however, possibly requiring more data to prove an effect.

Whilst company size was shown to have an effect on the benefits seen, it should be noted that almost 80% of survey data was collected from “medium-sized” SMEs (Table 7). This shows a trend that larger SMEs are forming the majority of I4.0 adoption, possibly because the benefits are more apparent to larger producers, as confirmed by H1 in the study. There is potentially less reason to optimise technology upgrades for a micro-size company that produces at very low volumes.

The strongest statistical relationship was the effect of I4.0 attitude towards the benefits observed. Although it is suggested that positive attitude has allowed for more benefits to be realised, this is an opinion survey, so it is a possibility that people with positive attitudes towards I4.0 would be more likely to see the benefits of it. The future outlook section shows promise, with 61% of respondents saying they would, at a minimum, probably invest in I4.0 technologies within the next five years.

Another important aspect of the study is time. It was unknown for how long every technology had been implemented by each SME. This factor was excluded to maintain brevity of the survey, as this data collection may increase respondent effort. The time dimension may have some effect on how strong the benefits may be scored, since challenges often emerge early, but benefits often later.

5.2. Response Bias

When analysing the survey in further detail, it is seen that respondents rating technologies would tend to agree rather than disagree that there were benefits to using a specific technology. This can be seen from the response chart in Figure 9 (a). Response means and distributions are shifted high across all technology benefit ratings (e.g. artificial intelligence, automated robotics, predictive maintenance and multi agent systems are on more higher end), suggesting all technologies surveyed are in fact beneficial. No respondents ‘strongly disagreed’ that there were any benefits, and only two ‘disagreed’.

It must be considered that these technologies are being scored by respondents who have implemented them; thus, they are potentially more likely to perceive higher benefits from their investment compared to the true benefit. This is difficult to predict as each respondent is different; an inherent problem with opinion based surveys. The bias could also come from the survey context as a whole, as the study is about the benefits of future technologies.

Interestingly, as seen in Figure 9 (b), the technology challenges were asked in the same way as benefits, yet did not exhibit as prominent biases. Although the means are slightly above the centre (with e.g. multi agent systems and artificial intelligence on higher end), the spread of data is much greater.

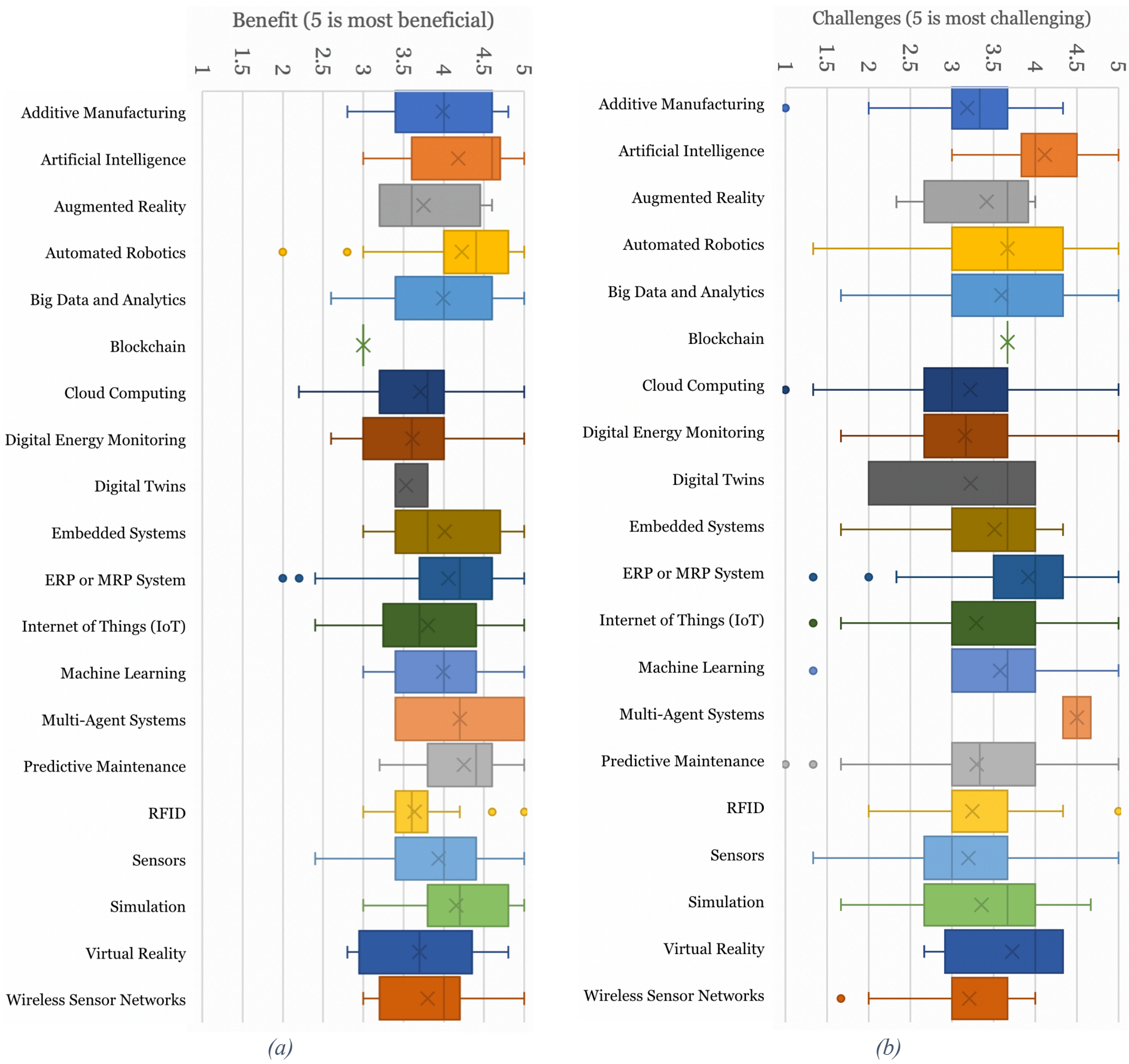

Figure 9 (a) – Mean Benefit Scales of Responses - Indicating Bias to Rate Highly, (b) Mean Challenge Scales of Responses - Indicating Less Bias than Benefits

5.3. Discussion of the SEM model

The loadings on the measured variables are shown in the SEM analysis in Figure 7. The KMO test performed on the survey data suggested that it is suitable for factor analysis, and the Bartlett's Sphericity test shows that each variable is significantly related to another. The statistical significance of each measured variable was also determined in order to identify which are the most indicative of the latent variables. These results are presented in Table 7.

All benefit measures and all challenge measures were concluded as significant contributors to the latent variables of "benefits" and "challenges". This shows validity in the initial survey factors and the factors identified in literature.

There are three measured variables that are not statistically significant predictors of latent variables, according to a significance level of $p<0.1$. These include; awareness as a predictor of attitude; industry as a predictor of complexity, and production methods as a predictor of complexity. This may be due to the way these variables were measured (Likert scales), or perhaps insufficient data.

The insignificance of industry type on complexity contradicts literature (Rosenbusch et al., 2011). It is more likely that, since 20 standard industry codes were studied, it is difficult for the SEM to determine a high significance on only 303 results.

Table 7 - Statistical Significance of Measured Variables on Latent Variables

Latent Variable	Measured Variable	P Value	Significance
Attitude	Awareness	0.274	No
	LevelImplement	0.025	Yes
	Outlook	0.024	Yes
Benefits	MeanBenefitCompAdv	0.001	Yes
	MeanBenefitMfgQual	0	Yes
	MeanBenefitOpCost	0.002	Yes
	MeanBenefitOpEffic	0.016	Yes
	MeanBenefitOpFlex	0.089	Yes
Challenges	MeanChalCost	0.003	Yes
	MeanChalKnowlge	0.002	Yes
	MeanChalTime	0.02	Yes
Complexity	Industry	0.168	No
	ProdMethod	0.124	No
	ProductTypes	0.001	Yes
Size	NoPeople	0	Yes
	ProductVolume	0.014	Yes
	Revenue	0.096	Yes

5.4. Qualitative responses

104 written responses were recorded on the opinions of the respondents for how SMEs could better prepare for I4.0. In the analysis, these themes were presented as a word cloud (Figure 8). The responses were highly varied in topic, however some themes emerged that both reinforced the literature and supplemented it.

The strongest themes that emerged were the need for training and support, suggested by 18 people. There was also a suggestion that government should support this, however there is already government support for I4.0 in the UK by means of a £200m investment as part of the “Innovate UK” scheme (Innovate UK, 2017).

Not all SMEs are aware of the opportunities and this reinforces the awareness challenge identified in literature. Multiple comments also reinforced the literature challenges of financial constraints.

5.5. Summary of Benefits and Challenges

Since the measured values of benefits and challenges were all shown to be significant in Table 7, the 658 technology ratings can be deconstructed into their average benefits and average challenges across each measured dimension. If the scores are normalised, then the representation of the challenge-to-benefit ratios can be visualised on a 2x2 matrix, as shown in Figure 10. The line of best fit is shown, however, with an R^2 of 0.32, the points are too sparse to show any correlation. If a point falls below the line, then the survey data suggests that, on average, the technology has greater benefits for the challenges incurred, i.e. predictive maintenance, simulation, additive manufacturing, sensors, internet of things (IoT), wireless sensor networks, cloud computing and digital energy monitoring. This was not tested for statistical significance, however it serves as a good visualisation of the benefit and challenge data.

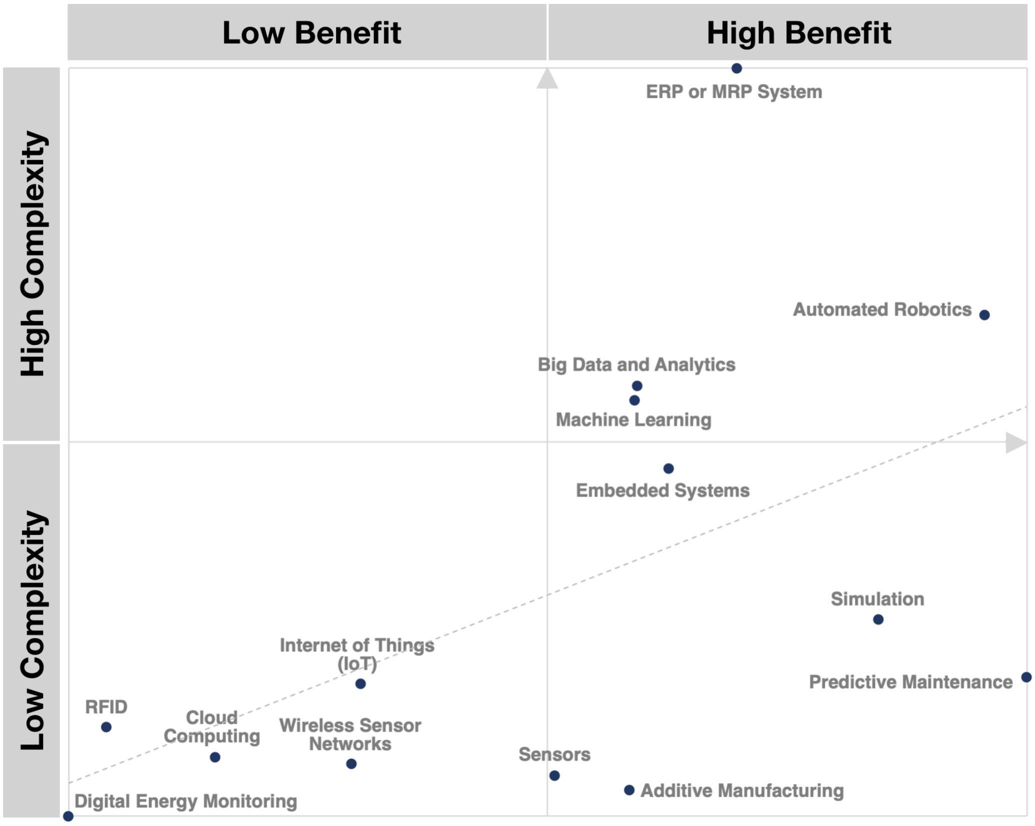

Figure 10 - Average Ratings for Technology Benefits and Challenges, Normalised

5.6. Evaluation of research objectives

The initial literature review of I4.0 identified key technologies within the industry (RO2). The SME literature was also used to identify key challenges to SMEs (RO2) and the intersecting field was used to identify benefits and challenges to SMES (RO1, RO2). RO3 was fulfilled mainly by the survey, collecting cross-sectional data and testing a number of hypothesis on the relationship between SME characteristics and the benefits and challenges of I4.0 implementation. Through this, contributions to research gaps, RG1 and RG2 were made; being one of the few studies to collect empirical data by survey, and the first in the UK to the best of the authors' knowledge.

5.7. Implications for industry

The SMEs wishing to adopt Industry 4.0 could benefit from the results of the industrial survey on the basis of similar SME characteristics and requirements. The results of the industrial survey can be used in its current form to inform such decisions.

6.0 Conclusions

The following main contributions of this article are based on the industrial survey, which has answered the research question, *"How can the benefits of Industry 4.0 technologies be evaluated against the characteristic challenges of SMEs?"*, within the context of Industry 4.0 for SMEs.

> *Contribution 1:* The industrial survey (n=271) provided new academic contributions within contemporary work. To the best of the authors' knowledge, this is the first opinion survey of SMEs in the UK in the context of I4.0. The findings represent some major learnings that both strengthen and challenge the literature.
>
> *Contribution 2:* This research has reported the first application of TAM model in Industry 4.0 for SMEs context.
>
> *Contribution 3:* The results of this research contribute to industrial knowledge, particularly SMEs. For example, it has been identified through survey that most SMEs struggle with the abundance of I4.0 technologies, the time to learn about them, and the funding to implement them.

The research question has been examined by determining the state of literature, conducting an industry survey in the UK, and synthesising the results into relevant analysis. The survey provides an empirical insight into UK manufacturing SMEs and their opinions on I4.0 technologies. The survey results are extended into a six-hypothesis model, testing how SME characteristics affect the benefits and challenges seen by technology adoption. It was determined from this study that company size and attitude affect these benefits with statistical significance. Company complexity was shown to have a significant effect on the challenges observed, which reinforces much of the literature and remains a prominent issue with technology implementation.

This study has reinforced the research gap that exists between I4.0 and SMEs. It is clear that SMEs wish to adopt I4.0, however, financial barriers persist as the greatest issue. With the advent of UK government funding schemes for SMEs and Industry 4.0 such as through "Innovate UK" or broadly through "UK Research and Innovation", the UK SMEs may get some motivation and support in the future. The development of SMEs with I4.0 technologies is clearly critical for companies to compete with each other inside the UK, but also in an international context. This will become increasingly important if the UK is to remain a competitive global manufacturer as an independent state.

In future, the research needs to focus on applying machine learning approaches on industrial (survey) data to develop recommender systems that recommends I4 technologies to SMEs based on their use in other SMEs with similar characteristics. The I4 technologies are clearly a step change from industrial systems of the past decades, however, with future technology selection solutions on the basis of direct industrial feedback and the necessary funding to SMEs, the magnitude of the step change has potential to be alleviated.

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