Industry 4.0 maturity of the composites manufacturing industry in the UK.

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Abstract

The purpose of this paper is to establish the relative maturity of industry 4.0 implementation by the composites manufacturing industry in the UK. The overall goal of this research is to establish Industry 4.0 implementation methodology for composites manufacturing SMEs, and the maturity measure is an important indicator of the current or “as is” status of the composites companies concerning Industry 4.0 adoption.

To achieve the stated aim, this paper employs a survey methodology based on a well-established VDMA tool (IMPULS, 2015) for assessing the maturity of Industry 4.0, adjusted for composite manufacturing. The questionnaire was largely based on quantitative questions, however, one question offered the respondents the opportunity to qualitatively describe Industry 4.0. Convenience sampling was used in this study as it targets a population that satisfies practical criteria, such as ease of access, knowledge or experience and that is keen to participate in the study. The professional network is utilised to distribute the questionnaire. The descriptive statistics data analysis approach was applied in this study when dealing with convenience sampling data. Although statistical analysis results from convenience sampling data are not necessarily generalisable beyond the sample inferential statistics tools were applied in determining dimensions significance and the effect of organisation size and maturity on the ability to quantify the benefit.

The mix of sectors and sizes of the respondent's companies is deemed indicative of the composite manufacturing industry. Analysis of qualitative questions from the pilot study revealed a level of consistency in understanding what Industry 4.0 is. Respondents focused solely on the technological benefits of Industry 4.0, the use of data and digital vertical and horizontal integration. However human, social, commercial or risk assessment aspects were not mentioned, and some had a narrow understanding of Industry 4.0, indicating that promoting awareness of Industry 4.0 to create a common understanding is necessary. Statistical analysis of data pointed out that composite organisations irrespective of their size are at similar emerging-developing maturity of Industry 4.0. Regarding the dimensions that define the Industry 4.0 maturity level, there was no significant statistical difference in contributing to the overall maturity level between “Strategy”, “Smart Factory”, “Smart Operations”, “Data-Driven Services”, and “Organisation, culture, values”. On the other hand, there is a difference in “Smart Products” significance in contributing to the overall maturity level indicating a lack of smart features in composite part production, as well as the relative immaturity of this dimension and the understanding of its impact on the overall maturity of Industry 4.0. Overall organisational maturity level had a statistically significant effect on benefit quantification, however, organisation size did not.

The results of this survey inform the follow-up stages of this research whilst providing a useful platform for other researchers to investigate this topic as well as the source of information for the UK composites industry.

1. Introduction

This paper aims to examine the current position of Industry 4.0 adoption by the composite industry in the UK. Findings of the literature survey [**1**] suggest that the composites industry could benefit from Industry 4.0 in combating standardisation and tacit knowledge. However, due to the reported absence of Industry 4.0 implementation methodologies related to composite manufacturing, composite companies are struggling to understand implementation or simply how to make the first step [**1**].

This paper aims to establish the current maturity of Industry 4.0 adoption by the composite industry in the UK, and consequently enable understanding of the necessary steps in implementing Industry 4.0 into composite firms. The found information will feed into further research, the final aim of which is to develop an Industry 4.0 technology implementation model for composite manufacturing SMEs.

In this paper firstly a brief overview of understanding Industry 4.0 is presented to enhance understanding of this trend, followed by a review of Industry 4.0 maturity models. This information is used to inform the Research Methodology section of this paper, in which the questionnaire structure, sampling technique, and data analysis process are presented. The data analysis chapter provides the analysis details of the gathered data offering rationalisation of the results, whilst the conclusion section reflects on the stages of the survey process and explains the following steps in the research.

1.1. Understanding Industry 4.0

The term “Industry 4.0”, originated in Germany in 2011 as a proposal to safeguard and allow competitiveness of the manufacturing industry [**2**]. This proposal is based on the interconnectivity principles of physical and digital (cyber) assets, information transparency, and decentralised decision-making, aimed at enabling competitiveness and technical developments in manufacturing. By integrating cyber-physical systems (CPS) in industrial manufacturing, Industry 4.0 intends to deliver intelligent, self-regulating, and interconnected industrial systems that enhance value creation [**3**], [**4**].

Various reports [**5**], [**6**], [**7**] define 9 Industry 4.0 enabling technologies as: industrial internet of things, simulation, horizontal and vertical system integration, autonomous robots, additive manufacturing, big data and analytics, the cloud, cyber security, and augmented reality. Although these technologies exist individually, the real benefit is gained when they are connected.

A paper by Stojkovic and Butt [**1**], provides a detailed survey of Industry 4.0 concerning the composites manufacturing industry, however, a very brief summary of the base technologies is presented here.

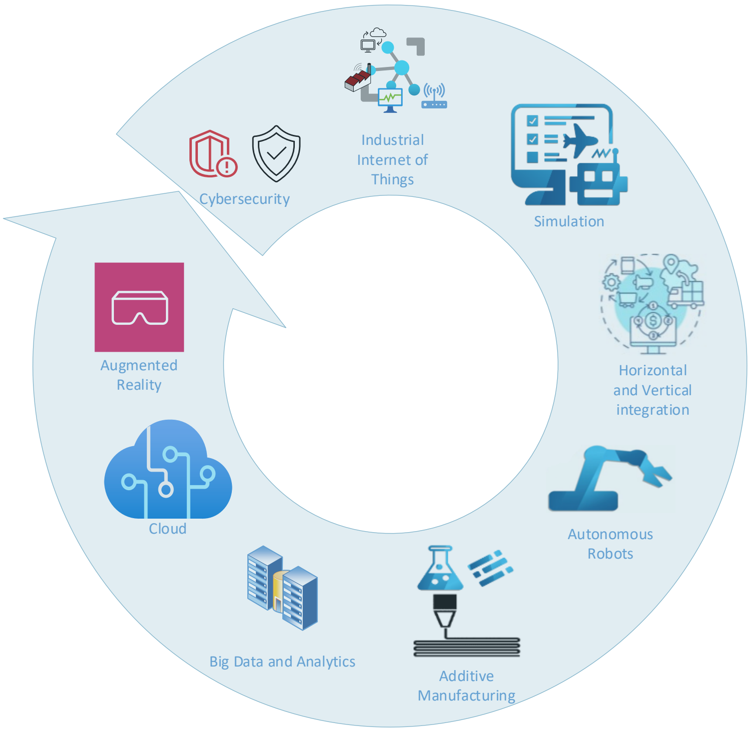

Figure 1: Nine Pillars of Industry4.0

Simulations are used more extensively in plant operations to leverage real-time data and mirror the physical world in a virtual model [**5**]. This includes machines, products, supply chains and humans, allowing operators to test and optimise machine settings in the virtual world before the physical actions take place.

The new simulation modelling paradigm is based on the concept of Digital Twin (DT) [**8**], which makes the “right-first-time” approach for composites more realistic [**9**], by enabling virtual verification and testing of products at any stage of development.

On the other hand technologies such as **Virtual Reality (VR)** that immerses users in a computer-generated world, and **Augmented Reality (AR)**, overlaying digital information onto the physical world are spreading in the manufacturing sector [**10**], [**11**]. Augmented Reality in manufacturing provides aid in visualising simulation [**12**], and AR technology increases operative awareness by introducing additional data and feedback from the environment [**13**]. As composites manufacturing is a dominantly manual process, these devices can be used to train operators as well as in production to inspect for defects.

Industrial automation ensures the reliability of composite manufacturing [**14**], however, Industry 4.0 offers more, by bringing together automated machinery, including robots, with intelligence and connectivity which allow smart production decisions to be made in reaction to changing requirements. As the manufacturing paradigm rapidly shifts production from mass to customized, and on-demand production, reconfigurable intelligent automation and robotics technology become a necessity [**15**]. To allow for this, production systems need to be adaptable and enable product variation, and the production of a lot of size one. However, the inability to capture and automatically enact the expert skill [**16**] and understand material behaviour during automated production led to serious issues with process reliability and productivity [**17**] and resulted in limiting the composite production capability.

Substitution of the conventional manufacturing processes by Additive Manufacturing ones provides the ability to deliver bespoke products without waste [**18**]. The provision of feasible applications into the industry via the automated Additive Manufacturing route is increasingly becoming an attractive proposition [**19**]. Whilst some literature stipulates that advanced composites are effectively additive manufacturing processes [**10**] there are also claims that a fully integrated automated deposition of fibre or tape used to make composite parts can be considered a large-scale automated 3-D printer [**20**]. Composites can further benefit from conventional AM technologies, with the development of rapid tooling or moulds, for example, 3D printed tools for building aircraft [**21**], low-cost AM composite tooling, for marine or infrastructure composite applications [**22**], and 3D printing of composite tooling to reduce costs and lead times in wind turbines [**23**].

The Industrial Internet of Things (IIoT) connects industrial assets, products and machines to the internet [**24**]. The IIoT is a vital part of Industry 4.0 representing the connectivity between equipment or product with digital resources [**5**].

This connectivity allows the large amounts of different data types, otherwise known as **Big Data**, to come from interconnected heterogeneous objects, enabling **Advanced analytics** methods and tools such as machine learning and forecasting models to examine off-line and real-time data and allow for the formation of knowledge that helps manufacturers to understand the various stages of the product lifecycle [**25**].

The data analysis could also be facilitated through **cloud computing**, which also enables outsourcing of the IT resources [**26**]. Cloud computing for Small and Medium Enterprises (SMEs) could be a useful resource as it offers scalability of services and rapid change of network access [**27**]. The main advantage related to adopting this technology is cost reduction, achieved by the virtue of outsourcing the IT infrastructure and reduction of the related direct and indirect costs.

The data, information and knowledge created by the application of Industry 4.0 principles have critical value for the industry's success and require protection. **Cybersecurity** caters for information security [**28**], and the word ‘‘cyber” generalises its application to industrial environments, and generally means protecting, detecting and responding to attacks [**29**]. Recent reports claim that cybersecurity is rapidly becoming a major concern for manufacturers and consumers [**30**].

Horizontal integration assumes integration of the whole value and supply chain. This integration enables both detailed as well as top-level interaction of companies, by connecting the information systems of those entities, leading to the efficient and interconnected lifecycle of product development and value chain [**31**], [**32**], [**33**]. On the other hand, **vertical integration** is formed by interconnecting manufacturing systems [**34**], and enabling integration within the company [**33**], which forms the basis for better information flow and synchronised activities across all levels of a company. The new concept of digital twin technology enables both the vertical and horizontal integration of the value chains, naming them the key value-add elements of product lifecycle management [**35**].

Industry 4.0 in the manufacturing context considers the integration of the entire product lifecycle within a factory as well as the supply chain activities [**36**], [**37**]. The aim of gathering useful data in real-time that feeds back to the manufacturing system relies on the adoption of digital technologies [**38**], [**39**], which in turn change the way people work [**40**]. It is considered that the arrival of the Internet of Things (IoT), cloud services, big data and analytics, enabled the emergence of cyber-physical systems and Industry 4.0 [**41**], [**42**].

The manufacturing context of Industry 4.0 requires the implementation of complex interconnectivity of mentioned enabling technologies [**38**]. This is considered a primary concern related to the implementation of Industry 4.0 technologies, and is still a subject of research, as there is a lack of standardised implementation approaches for the industry to follow [**1**], [**38**], [**43**], [**37**] [**30**].

2. Industry 4.0 maturity models

The paper “Maturity Models for Digitalization in Manufacturing - Applicability for SMEs” [**44**] states that digitalisation in SMEs is challenging due to a lack of resources and knowledge to select appropriate technologies. The literature review [**1**] concurs with these views [**44**], and further states that composites manufacturers are particularly affected, as for many companies investment of time into Industry 4.0 understanding is seen as being costly and a distraction from commercial activities. This in turn negatively affects their agility and flexibility, promoted by the appropriate implementation of Industry 4.0, and the main challenge remains the risk of inappropriate investment. To reduce the risks of inappropriate investment it is proposed that companies need to understand their maturity in terms of Industry 4.0 to decide on the most appropriate implementation strategy [**44**], [**45**]. This is particularly critical in the case of composites manufacturing firms most of which are SMEs [**1**], as the challenges of technology and market uncertainty add pressure on the companies to focus on more tactical targets even more, as time spans in which technology and market uncertainties are resolved is often too long [**46**].

As no studies were identified on Industry 4.0 maturity neither within composite manufacturing nor fully covering the SMEs, general Industry 4.0 literature was examined. To understand the maturity of Industry 4.0 adoption within manufacturing businesses, one suggestion based on the survey of the companies proposes the following dimensions that characterise Industry 4.0: Smart Supply Chain, Smart Working, Smart Manufacturing, Smart Product, and Base Technologies consisting of IoT, Cloud, Big Data and Analytics [**47**]. Findings of this review suggest a staged approach to implementing Industry 4.0 principles, which should start with the adoption of front-end technologies with a focus on smart manufacturing.

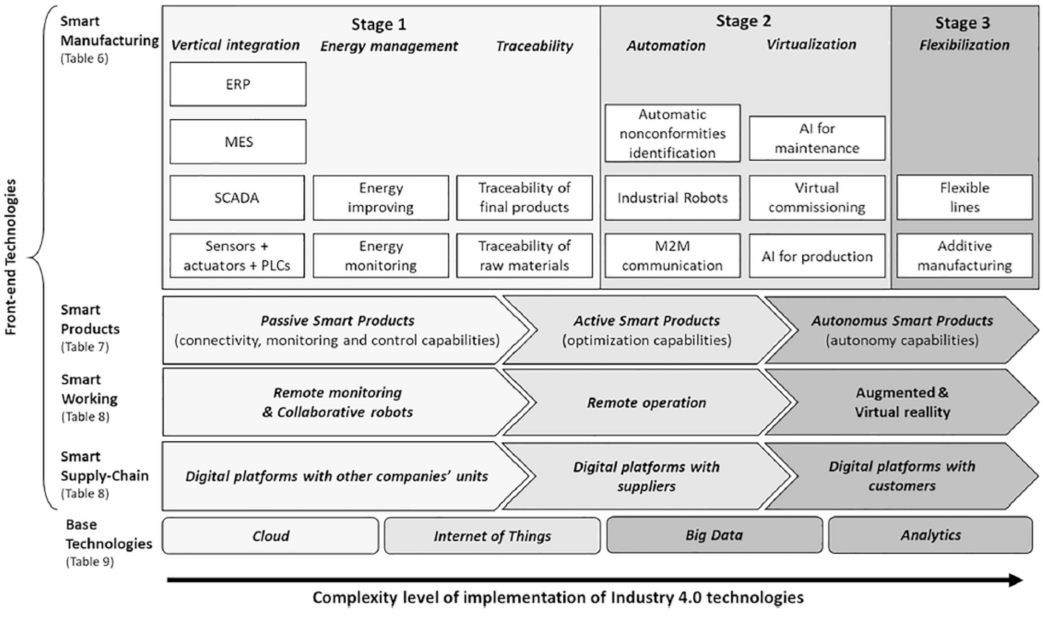

Figure 2: Theoretical framework of Industry 4.0 technologies [**47**]

Lichtblau [**48**], Figure 3, used the six dimensions to identify the maturity level of organisations: Strategy and organisation, Smart Factory, Smart Operations, Smart Product, Data-Driven Services, and Employees.

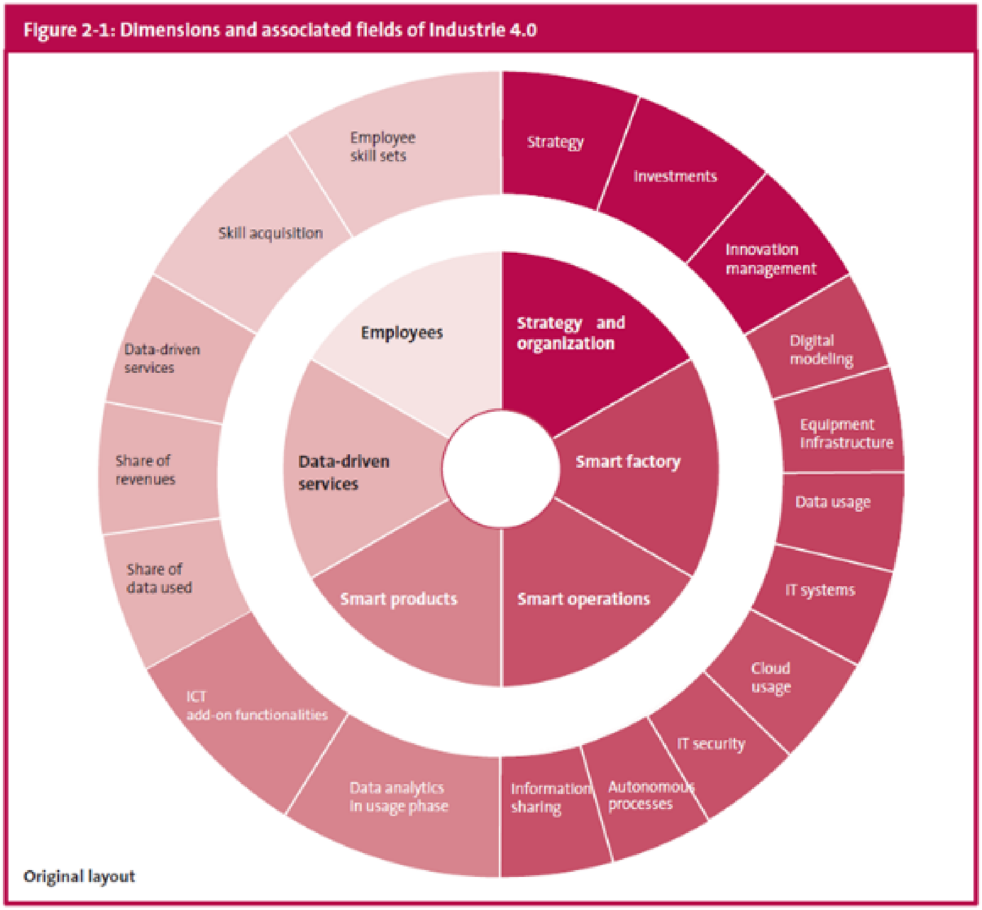

Figure 3: Industry 4.0 dimensions [**48**]

These dimensions have 6 levels measured from 0 to 5, where each number corresponds to the readiness level: 0 – Outsider, 1 – Beginner, 2 – Intermediate level, 3 – Experienced level, 4 – Expert, and 5 – Top performer. This is the basis of the Industry 4.0 readiness assessment by VDMA [**48**], [**49**], which was identified as a well-grounded tool that has been used and suggested by researchers to perform Industry 4.0 readiness assessments [**50**], [**51**], [**52**]. This maturity model is reported to not require significant time and resources and needs a medium Industry 4.0 skill level [**44**].

Another maturity model by Schuh [**45**] also uses 6 levels to measure identified dimensions of Resources, Information systems, Culture and Organisational Structure. The model is robust and offers guidance related to the company objectives, however, requires a significant investment of time and resources.

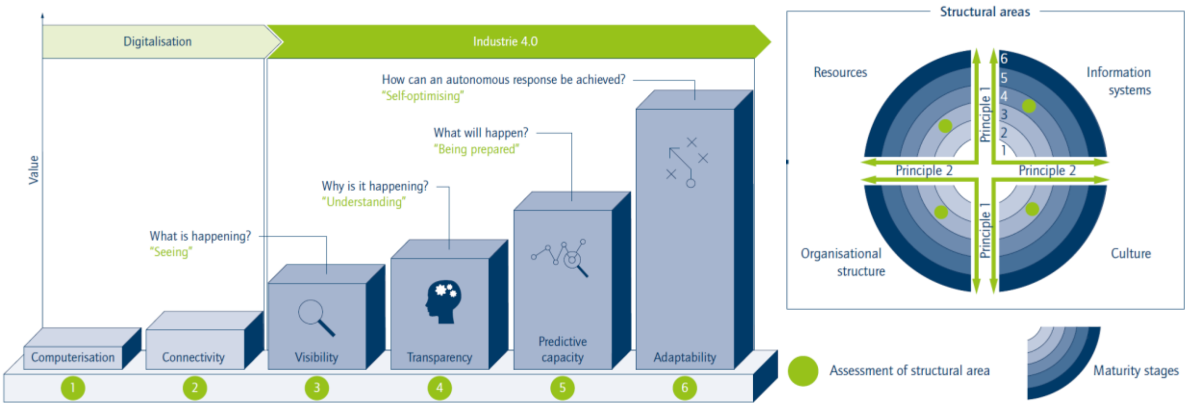

Figure 4: Industry 4.0 dimensions [**45**]

An assessment of existing maturity models in the context of Industry 4.0 examined many potential tools and methodologies [**53**]. They concluded that none of the examined approaches is fully suitable for manufacturing firms and that the most obvious deficiency of the examined models is that they don't support manufacturing enterprise architecture holistically. Similarly, [**44**] analysed existing maturity models' suitability for SMEs. They concluded that the currently available maturity models would be challenging for SMEs. To make a maturity model SME appropriate it would need to satisfy the conditions of simplicity, requiring little knowledge to fill out a questionnaire, suitability of the model for SME organization and providing guidance for the follow-up steps.

In addition to the mentioned dimensions of Industry 4.0, the literature survey identified the interest in investigating the maturity of risk assessment [**54**] and how to quantify benefit [**55**].

3. Research Methodology

From the reviewed literature the Industry 4.0 readiness assessment by VDMA is identified as a good basis for the intended survey due to its ease of use as well as being often referenced as an easy-to-use and reliable tool and used by the research community and industry [**50**], [**51**], [**52**]. Therefore to survey the Industry 4.0 maturity within the composites manufacturers in the UK this study employed a questionnaire based on the data and theoretical constructs derived from literature on generic Industry 4.0 trends, presented previously. For the proposed survey to be industrially relevant, and in addition to the quantitative element of the questionnaire, this research recognised the need for the qualitative assessment of the investigated topic. Within the survey, the technology managers, strategists, or senior experts have been offered the opportunity to provide their perception and interpretation of Industry 4.0. This can provide meaningful interpretation in establishing a relationship and enriching knowledge.

3.1. Questionnaire structure

A questionnaire instrument with quantitative criteria was used as the data collection method in this study. The questionnaire instrument from a study performed by VDMA [**48**], was modified to suit Composites Manufacturing. The instrument consisted of the original 6 dimensions contributing to the Industry 4.0 maturity level, and 2 more dimensions of interest ("Maturity of risk assessment" [**54**] and "Quantifying benefit" [**55**]. The investigated dimensions are presented below:

Category	Sub-category	Indicator
Organisational strategy	Industry 4.0 strategy implementation	Strategy implementation status Strategy compatibility with overall organisational strategy
	Organisational investment	Number of distinct areas with investments or plans to invest in Industry 4.0
	Systematic technology and innovation management	Number of distinct areas with systematic technology and innovation management
	Industry 4.0 technologies	Number of technologies in use
Smart Factory	Equipment functionalities	Level of use of IT to control machine systems Level of use of Machine to Machine communication Level of machines' interoperability
	Equipment functionalities adaptability	Level of use of M2M communication Level of machines' interoperability
	Digital modelling	Machine data collection and processing
	Systems, and interface to leading system	Number of systems in use Number of systems in use with leading interface
Smart Operations	Cross departmental information sharing	Number of departments with internal integrated cross-departmental information sharing Number of departments with external integrated cross-departmental information sharing
	Autonomous functionality	Availability of autonomous workpiece guides Availability of autonomous production process response in real time
	IT solutions	IT organisation Security solutions implementation level Use of cloud services
Smart Product	Product functionality based on ICT	Number of add-on functionalities
Data-driven services	Data usage and analysis	Use of data and process data to enable new services Use of data analytics
Organisation culture employees	Industry 4.0 skills	Level of existing skills
Maturity of risk assessment	Awareness of risks	Economic, ecological, social, technical, IT and legal and political risks
Quantifying benefit	benefit of introducing Industry 4.0 technologies	Investment appraisal techniques used in assessing technology benefits Rank value add of industry 4.0 in businesses

Table 1: Instrument dimensions

The questionnaire instrument consisted of two qualitative questions (respondents' role in the company and respondents' understanding of Industry 4.0), and 45 quantitative questions. The questions were grouped into the following sections:

Section 1: General questions, gathering respondents' sector served, organisational size, position, and a general understanding of the term 'Industry 4.0'.

Section 2: Strategy and governance questions assessed the strategy implementation status, organisational compatibility with Industry 4.0, level of investment in Industry 4.0 initiatives, and technologies used by the organisation at the time of the survey.

Section 3: Smart factory questions gathered data on the adaptability of equipment and infrastructure to Industry 4.0 functional requirements, enabling a link between the physical and virtual worlds.

Section 4: Smart operations questions assessed the concept of vertical and horizontal integration, which is the enterprise-wide and cross-enterprise integration of the physical and virtual worlds.

Section 5: Smart products questions measured the capability to gather data on products, navigate through production, and communicate with higher-level systems. Respondents were asked to identify product information and communication add-on functionalities offered by their organisations.

Section 6: Data-driven services questions measure organisations evaluated and analysed data collected on enterprise-wide integration. Respondents were asked whether they gathered data on production and in the usage phase, and analysed data for continual improvement.

Section 7: Questions on employees assessed the availability of employee skills for digital transformation. Respondents were asked to evaluate the skills available in their organisation for future requirements under Industry 4.0.

Section 8: Maturity of risk assessment questions assessed the awareness of the economic, ecological, social, technical, IT and legal and political risks imposed by the introduction of Industry 4.0 technologies. Respondents were asked to rank the relevance of the stated risk.

Section 8: Quantifying benefit questions sought to measure how organisations evaluated the potential benefit of introducing Industry 4.0 technologies. Respondents were asked to evaluate investment appraisal techniques used in assessing technology benefits, and to rank, the value-add of industry 4.0 in their businesses.

3.2. Sampling technique

Sampling techniques are grouped as probability and non-probability sampling methods, among others [**56**], [**57**]. The convenience sampling technique, which is a non-probability sampling method, applies to quantitative research [**56**] and was selected for this study. The type of non-probability sampling selected for a study depends on the type, nature, and purpose of the study [**56**]. Convenience sampling is acceptable in an area of study that is fundamentally new — in this case, Industry 4.0 within the composites manufacturing domain [**58**]. The survey instrument is designed in such a way that an organisational maturity assessment can be provided by any individual at the management level.

Convenience sampling targets a population that satisfies practical criteria, such as ease of access, knowledge or experience and that is keen to participate in the study [**56**].

In this study, the professional network is utilised to distribute the questionnaire. Additionally, the governing body of the composites industry in the UK – Composites UK has been approached for support in distributing the questionnaire to the composite industry, further justifying convenience sampling as an appropriate method.

The main disadvantage of convenience sampling is that it may be biased; the results would then not be representative of the population [**56**].

Skowronek [**59**] pointed out that bias in convenience sampling can be eliminated by making the sample significantly representative, increasing its diversity by how the survey instrument is distributed, and incorporating as much data as possible. In this study, convenience sampling bias was avoided by distributing the questionnaire to as many people as possible, using different platforms and approaches.

3.3. Data analysis process

The first three steps in the thematic analysis procedure outlined by Castleberry [**60**] were used to analyse qualitative question 7. Using the 25 first-cycle coding methods presented by Saldaña [**61**], descriptive codes were applied in performing this analysis. The amount of textual data collected in this question was notably small, justifying the use of manual analysis. The response to this question contributed zero points in the calculation of the maturity dimension score.

The descriptive statistics data analysis approach was applied in this study when dealing with convenience sampling data [**62**]. Although statistical analysis results from convenience sampling data are not necessarily generalisable beyond the sample [**56**], [**57**], inferential statistics tools were applied in determining dimensions significance and the effect of organisation size and maturity on the ability to quantify the benefit.

Questions 8 to 47 were quantitative and were coded to calculate the total score for each maturity assessment dimension.

Table 2 shows the criteria that were used to identify the maturity level for each dimension.

Category	*Readiness level*	*Description*	*Criteria*
Emerging	Level 0	Outsider	0
	Level 1	Beginner	0 < X ≤ 30
Developing	Level 2	Intermediate	30 < X ≤ 65
Established	Level 3	Experienced	65 < X ≤ 80
	Level 4	Expert	80 < X ≤ 90
Advanced	Level 5	Top performer	90 < X ≤ 100

Table 2: Maturity levels criteria by percentage *[**48**]*

The total score for each question was determined in two ways:

1. (a) adding up a value of 1 for all positive responses, as required by the question, (b) finding the maximum possible total scores by adding up all possible positive responses, (3) calculating the percentage score for each question and (4) converting it to the Likert scale using criteria in Table 2;
2. converting the verbal Likert rating scale to a numeric Likert rating scale.

The total score for each dimension was calculated by (a) adding up the scores from each question; (b) finding the maximum possible total scores for each dimension by adding up all possible maximum responses of each question; (c) calculating the percentage score for each maturity assessment dimension, and (d) converting it to the Likert scale using criteria in Table 2.

The overall maturity for each organisation was calculated by: (a) adding the scores of each dimension; (b) adding the maximum scores of each dimension; (c) calculating the percentage score for the maturity level, and converting it to the Likert scale using criteria in Table 1.

Organisations were categorised into six categories by size:

0. Up to 19 employees
1. 20 to 49 employees
2. 50 to 99 employees
3. 100 to 249 employees
4. 250 to 499 employees
5. 500 or more employees

4. Data analysis

The total number of respondents in this study was 30, which is equivalent to a pilot study assessing the state of Industry 4.0 across German companies undertaken by [**63**]. The respondents were in the following positions: CTO(6), Principal research engineers(6), Programme managers(6), Managing director(3), CEO(3), Business development manager(3), Chief Engineer(3), which deemed appropriate in terms of responsibility level and knowledge about company strategy and processes.

Figure 5 shows the respondents' organisation by the sector they provide services for.

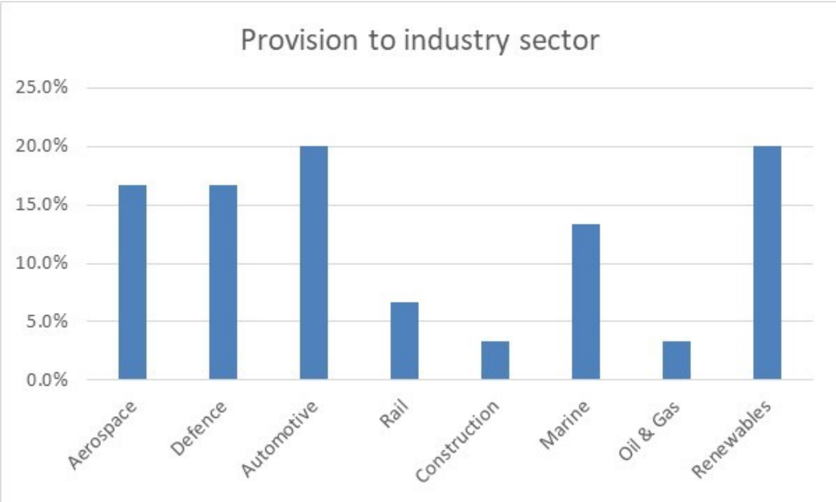

Figure 5: Companies by provision of services to the industry sector

Figure 6 represents the respondents' organisations according to their size, as defined in Section 3.3. Additionally, the respondents' organisations according to their revenue are provided in Figure 7. Considering the current definition of the SMEs (Small to Medium Enterprises) being up to 250 employees and with a yearly turnover of up to £50 million, 50% of the survey respondents were from the SME demographic.

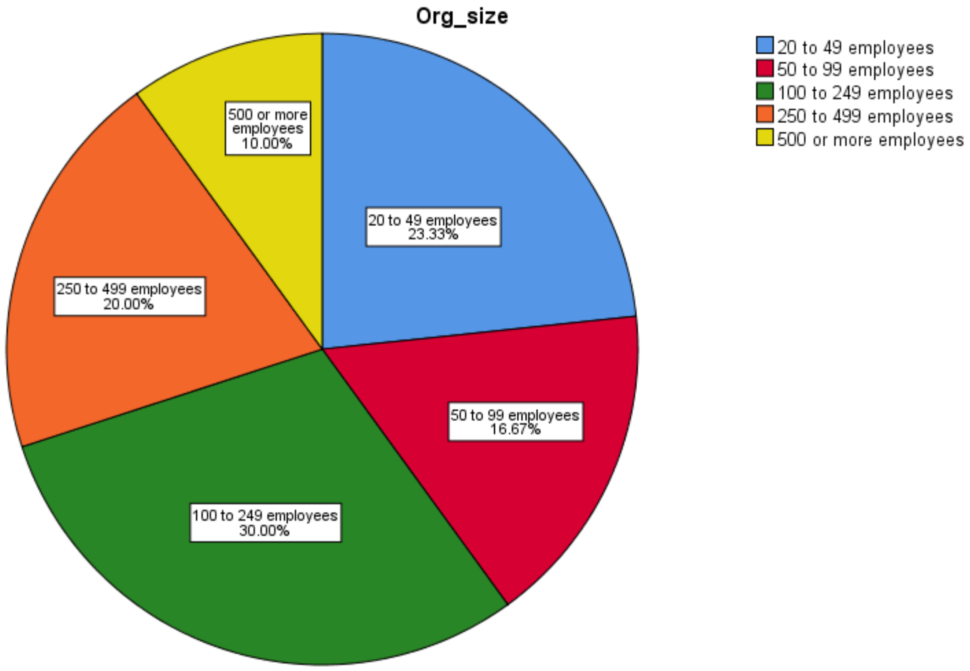

Figure 6: Companies' representation by the number of employees

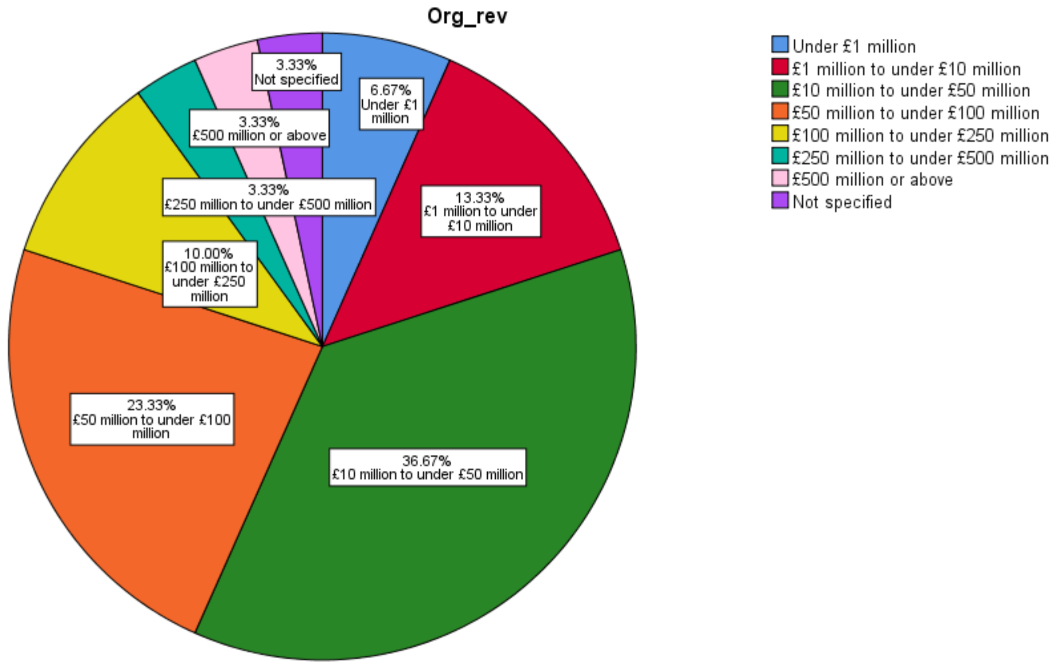

Figure 7: Companies' representation by revenue

4.1. Industry 4.0 definition analysis

All of the respondents answered qualitative question 7 “According to your understanding, how would describe Industry 4.0?”. The “what, who, when, where, why, how” concept [**60**] was used to identify codes describing respondents' understanding of Industry 4.0, and thematic analysis is summarised in Table 3.

Theme	Codes	Comments
What is involved?	Technology Data Automation Complete product life-cycle Manage ordering and material usage Managing factory movements Through life product support and maintenance	The respondents answers mainly focused on technological advancements and data were viewed as enablers of Industry 4.0. There was some variation in understanding Industry 4.0, with some respondents focusing on automation of operations and supply chain, others on building on Industry 3.0 (automation), or efficiency reasons. Small number of respondents displayed disbelief in in industry 4.0, commenting that Industry 4.0 is a collection of terms contrived to help industry get funding from the various government funding bodies and a rebadging of items and processes that have existed for years for the most part.
Who is involved?	All businesses and Industrial sectors Manufacturing Supply chain operations	Most of the respondents defined it as being only applicable to the manufacturing industry with typical input in terms of technologies, operations and supply chain. No respondents identified people involvement.
When should it take place?	Now Future	Some saw Industry 4.0 building on I3.0 (automation), and happening now and into the future.
Why should it happen?	Maximise efficiency Maximise output Enable manufacturing agility, flexibility, and adaptability Enable smart and autonomous manufacturing Enable environmentally friendly production	Most of the respondents commented that Industry 4.0 meant achieving efficiency, output, agility, flexibility and adaptability. Some mentioned smart and environmentally friendly production. No respondent mentioned increased competitiveness, ROI or change of the business model.
How can it be accomplished	Building on Industry 3.0 (automation) Integration and connectivity of business functions Automation of business operations Automation of supply chain operations	Respondents pointed out that Industry 4.0 will happen through use of data, integration of business operations, including manufacturing processes themselves from factory level to enterprise level, and through the integration and automation of supply chain operations.

Table 3: Analysis of respondents' answers to question 7.

The analysis of respondents' answers showed a degree of consistency in understanding what Industry 4.0 is, what was involved and why it should happen. The widespread thought involved digitally capturing and utilising data, integration from factory level to enterprise level, as well as integration and automation of supply chain operations.

4.2. Industry 4.0 maturity level of composites manufacturing in the UK

Figure 8 presents the results of the organisations' overall Industry 4.0 maturity level. The analysis revealed that the overall Industry 4.0 maturity level for all the organisations that were considered in this study ranged between level 1 and level 4. There were no "Outsiders" – Level 0, or "Top performers" – Level 5. The vast majority of the respondents were in the "Intermediate" group, with 60%, followed by the "Experienced" level of 16.67% and "Beginner" at 16.67%, and a small number of "Expert" accounting for 3.33% of the sample.

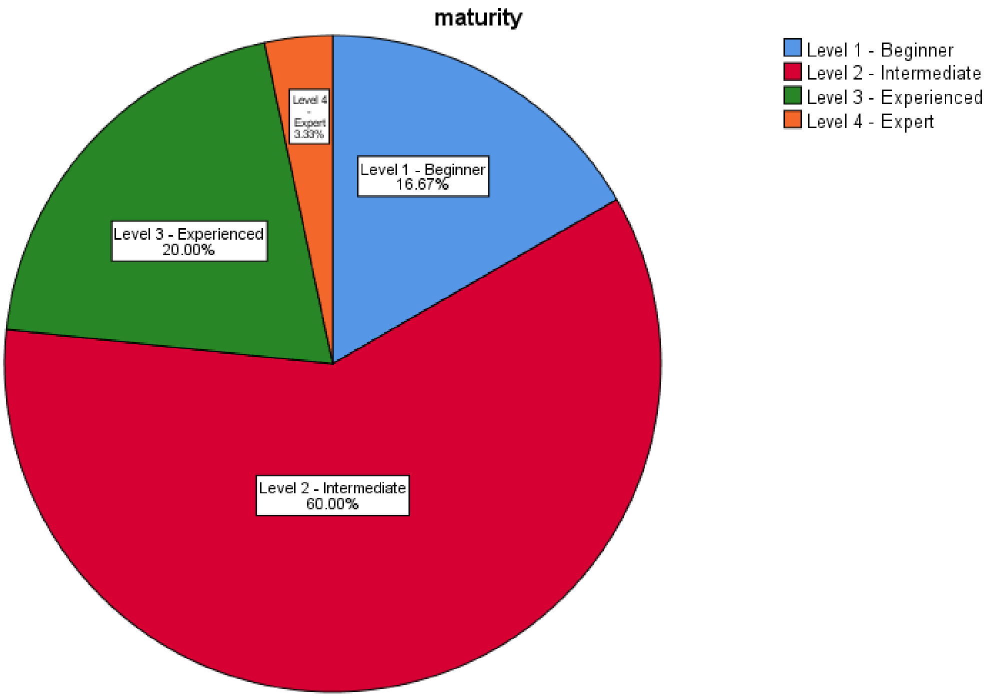

Figure 8: Respondents organisations overall maturity level

4.2.1. Overall maturity level by the size of the organisation

Before assessing the overall maturity level by the size of an organisation, the test of normality was carried out for the independent variable "Organisation size" and dependent variable "Maturity". The results of the Shapiro-Wilk test are presented in Table 4, demonstrating the normal distribution of maturity for organisations with 50-99 employees only. The rest of the organisations did not have a normal distribution of maturity.

Tests of Normality

	Org_size	Kolmogorov-Smirnov[a] Statistic	df	Sig.	Shapiro-Wilk Statistic	df	Sig.
maturity	20 to 49 employees	.360	7	.007	.664	7	.001
	50 to 99 employees	.231	5	.200*	.881	5	.314
	100 to 249 employees	.414	9	.000	.617	9	.000
	250 to 499 employees	.407	6	.002	.640	6	.001
	500 or more employee	.385	3	.	.750	3	.000

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 4: Test of Normality

As the data were not normally distributed, the non-parametric Kruskal-Wallis H test was run to determine if there were differences in maturity scores between five groups of companies with a different number of employees: "20 to 49 employees" (N=7), "50 to 99 employees" (N=5), "100 to 249 employees" (N=9), "250 to 500 employees" (N=6) and "500 or more employees" (N=3). The result of the test is presented in Table 5, and the distributions of maturity scores given in Figure 9, were similar for all groups, as assessed by visual inspection of a boxplot. Median maturity scores were not statistically significantly different between groups, $\chi^2(4)=7.979$, $p=0.092$

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of maturity is the same across categories of Org_size.	Independent-Samples Kruskal-Wallis Test	.092	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.

Table 5: Kruskal-Wallis H test – hypothesis test summary

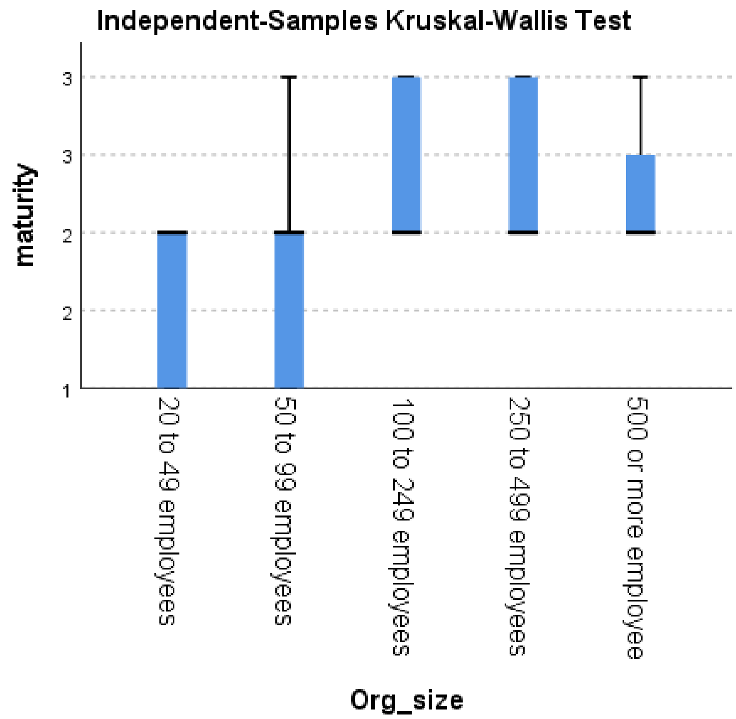

Figure 9: Distributions of maturity scores

Although the median maturities were not statistically significantly different amongst the groups, some companies with 20-49 and 50-99 employees had smaller maturity, compared to the larger organisations.

4.2.2. Industry 4.0 maturity by the dimension of composite manufacturers

To determine the Industry 4.0 maturity by dimension in composite manufacturing, the following two hypotheses were formulated:

H_{0_A}: There is no significant statistical difference in contribution to the Industry 4.0 overall maturity level between the six maturity dimensions.

H_A: There is a significant statistical difference in contribution to the Industry 4.0 overall maturity level between the six maturity dimensions.

A Kruskal-Wallis H test was run to determine if there were differences in maturity scores amongst six investigated dimensions of industry 4.0 (N=30 for all dimensions): "Strategy", "Smart Factory", "Smart Operations", "Smart Product", "Data-Driven Services", and "Organisation, culture and employees". The results are presented in Table 6 and Figure 10.

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of dim_maturity is the same across categories of dimension.	Independent-Samples Kruskal-Wallis Test	.045	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.

Table 6: Kruskal-Wallis H test – hypothesis test summary

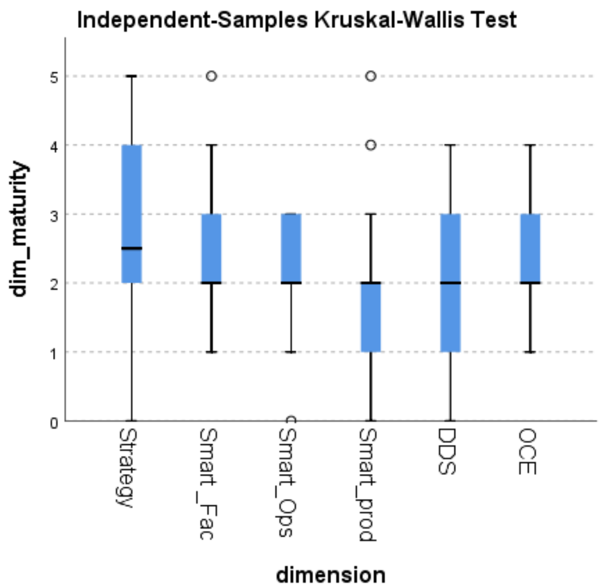

Figure 10: Distributions of maturity scores

Distributions of maturity scores provided in Figure 10, were similar for all groups, as assessed by visual inspection of a boxplot. Median dimension maturity scores were statistically significantly different between groups, $\chi^2(5) = 11.319$, $p = 0.045$

Subsequently, pairwise comparisons were performed using the Dunn procedure [**64**] with a Bonferroni correction for multiple comparisons. Adjusted p-values are presented. This post hoc analysis revealed statistically significant differences in median maturity scores between the “Smart product” (2.00) and Strategy” (2.50) (p = 0.057), dimension, but not between any other group combination.

This was further substantiated by performing Independent-Samples Mann-Whitney U Test between each pair of the dimensions.

Table 7 presents the summary of the Mann-Whitney U Test results. The number in each cell represents the p-value. The results show that there is no significant statistical difference in contributing to the overall maturity level between “Strategy”, “Smart Factory”, “Smart Operations”, “Data-Driven Services”, and “Organisation, culture, values”. On the other hand, there is a difference in “Smart Products” significance in contributing to the overall maturity level.

	Smart Factory	Smart Operations	Smart Product	Data Driven Services	Organisation, culture, values
Strategy	0.659	0.121	0.011	0.072	0.416
Smart Factory		0.272	0.018	0.151	0.754
Smart Operations			0.094	0.623	0.482
Smart Product				0.283	0.016
Data Driven Services					0.249

Table 7: Mann-Whitney U Test – Summary

4.3. Quantifying benefit of industry 4.0

To determine the impact of Industry 4.0 organisational maturity, and the size of composites organisation on the organisational ability to quantify benefits derived from Industry 4.0, the following pairs of hypotheses (B and C) were formulated:

H_{0_B}: There is no significant statistical contribution of Industry 4.0 overall maturity level on the organisational ability to quantify benefits derived from implementing this technology.

H_B: There is a significant statistical contribution of Industry 4.0 overall maturity level on the organisational ability to quantify benefits derived from implementing this technology.

H_{0_C}: There is no significant statistical contribution of organisation size on organisational ability to quantify benefits derived from implementing Industry 4.0 technology.

H_C: There is a significant statistical contribution of organisation size on organisational ability to quantify benefits derived from implementing Industry 4.0 technology.

A cumulative odds ordinal logistic regression with proportional odds was run to determine the effect of organisational Industry 4.0 maturity level, and organisational size, on the organisational ability to quantify benefits from Industry 4.0.

There were proportional odds, as assessed by a full likelihood ratio test comparing the fitted model to a model with varying location parameters, $\chi^2(18) = 15.165$, $p = 0.651$.

Both, Pearson and the Deviance goodness-of-fit test indicated that the model was a good fit for the observed data. Because the test statistics measure how poor the model is, these tests need to be not statistically significant to indicate a good model fit (i.e., $p > 0.05$ in the "Sig." column)

Goodness-of-Fit

	Chi-Square	df	Sig.
Pearson	48.206	34	.054
Deviance	25.984	34	.836

Link function: Logit.

Table 8: Goodness of fit test

The test of Model Effects, (see Table 9), produced the following conclusions:

1. The organisational Industry 4.0 maturity level had a statistically significant effect on the prediction of organisational ability to quantify benefits derived from implementing Industry 4.0 technology, $\chi^2(2) = 16.873$, $p < 0.001$, consequently rejecting the hypothesis H_{0_B}.
2. The organisation size did not have a statistically significant effect on the prediction of organisational ability to quantify benefits derived from implementing Industry 4.0 technology, $\chi^2(4) = 2.952$, $p = 0.566$, hence rejecting the hypothesis H_{C}.

Tests of Model Effects

Source	Type III		
	Likelihood Ratio Chi-Square	df	Sig.
maturity	16.873	2	.000
Org_size	2.952	4	.566

Dependent Variable: Qunt_ben
Model: (Threshold), maturity, Org_size

Table 9: Test of model effects

4.4. Discussion

The analysis of respondents revealed the mix of the higher management roles taking part in the survey. The mix of sectors, the respondent's companies provide services, and the size of the respondent's companies, are deemed indicative of the composite manufacturing industry and add to the trustworthiness and generalisability of the findings.

Results from the respondents revealed a level of consistency in understanding what Industry 4.0 is, although the respondents focused solely on the technological benefits of Industry 4.0, but did not mention human, social, commercial or risk assessment aspects. Some respondents still have a narrow understanding of Industry 4.0 — an indication that promoting awareness of Industry 4.0 to create a common understanding is necessary.

The Industry 4.0 overall maturity level results indicated that 60% of the organisations are at the developing level. Emerging-level organisations make up 16.67% of organisations. On average, it is evident that composite organisations irrespective of their size are at a similar range of maturity for Industry 4.0.

In terms of Industry 4.0 organisational strategy 7%of the respondents pointed out that their organisations were in the emerging category, and 76% in the developing category. This could be interpreted as a start of a commitment to drive Industry 4.0 initiatives in a significant number of organisations in the composites sector.

The results indicated that many organisations experience significant challenges in the dimension of “Smart Factory” representing the equipment infrastructure that supports Industry 4.0 requirements. All of the surveyed organisations are in the emerging category (38%) or developing category (62%). These results could be interpreted as a significant number of organisations in the composites sector not having equipment infrastructure that supports Industry 4.0 requirements. Further to this, their equipment functionalities might not be upgradable to Industry 4.0 requirements.

Regarding smart operations, 83% of organisations are either in the emerging category (31%) or developing category (52%). This could be an indication that a significant number of organisations are not prepared for vertical and horizontal integration of the physical world and virtual worlds. In addition, Industry 4.0 technical requirements for production and production planning might not be fulfilled. Regarding the “Smart Products” representing the products’ maturity for Industry 4.0, 97 per cent of organisations belong to the emerging category (69%) or developing category (28%). The result could be interpreted as organisations’ current products not having functionalities that meet Industry 4.0 requirements.

The dimension of “Organisation, culture and Skills” (OCE)s pointed out that 86% of organisations are in the category with limited maturity and 14% in the category of existing maturity. This could be interpreted as Industry 4.0 skills starting to form in the composites manufacturing sector however the respondents do not fully recognise the skills required for Industry 4.0, indicating that further study in this area is essential.

Regarding the dimension of “Data-Driven Services”, a total of 86% of the respondents indicated that their organisations were in the emerging category (17%) or developing category (69 per cent). This could be interpreted as a significant number of organisations not collecting digital data or analysing it for continuous improvement purposes, indicating that further study in this area is essential.

The Kruskal-Wallis H test and Mann-Whitney U Test results proved the point that the “Smart Product” dimension differs significantly from the other five dimensions in their contribution to overall maturity for Industry 4.0, although this could not be generalised beyond the sample used. The possible reason for this could be the relative immaturity of this dimension and the understanding of its impact on the overall maturity of Industry 4.0, as well as the lack of smart features in composite part production.

A cumulative odds ordinal logistic regression test indicated that the organisational Industry 4.0 maturity level had a statistically significant effect on the prediction of the organisational ability to quantify benefits derived from implementing Industry 4.0 technology. However, organisation size did not have a statistically significant effect on benefit quantification.

5. Conclusions

The survey of composites industry maturity concerning Industry 4.0 implementation was designed to collect mainly quantitative data using a questionnaire research instrument. Two questions requiring qualitative answers provided a useful tool for understanding respondents' profiles, and their understanding of Industry 4.0.

The questionnaire was well received and all the questions were answered. Although statistical analysis results from convenience sampling data are not necessarily generalisable beyond the sample, the mix of respondents' positions, size of organisations and spread of serviced sectors are deemed representative of the composite manufacturing sector.

The validity of the instrument was maintained by using a well-established process for assessing the maturity of Industry 4.0, which was adapted for composites manufacturing. Additionally, the questionnaire structure, sampling technique and data analysis process were detailed, all adding to the trustworthiness of the instrument.

Following the administration of the questionnaire, statistical methods were used to ensure objectivity, generalizability and reliability.

The results show a generally consistent level of maturity within the composites manufacturers, however, there is a need to raise awareness of the benefits of Industry 4.0 to further enable Industry 4.0 adoption by the composites manufacturing community. This is particularly important as one of the results demonstrated that the ability to understand the value proposition of Industry 4.0 is directly linked with the company's maturity concerning Industry 4.0.

The instrument and the findings are relevant and will inform both the composites industry in the UK as well as the following stages of this research. The results and the methodology are also providing a useful platform for other researchers to investigate this topic.

The results of this survey will inform the follow-up stage of this research and the development of the Industry 4.0 implementation methodologies related to composites manufacturing.

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