Adopting Industry 4.0 Technologies in the UK Manufacturing Supply Chains

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Abstract

Purpose/Aim

This study aims to investigate how the supply chain (SC) experts from the UK manufacturing organisations (MO) interpret the drivers and barriers to adopting Industry 4.0 technologies from a technological, organisational and environmental (TOE) point of view. Furthermore, this study evaluates how adoption drivers and barriers influence innovative practices that support Industry 4.0 adoption.

Methodology

A qualitative narrative inquiry strategy, involving 9 semi-structured interviews with leading SC experts, including group executives, global directors, and vice presidents was adopted.

Key Findings

The people factor across the SC is found critical for successful Industry 4.0 adoption. It was also found that the firm size is an insignificant factor, rather Industry 4.0 readiness in SMEs is driven by flexibility and agility while larger organisations are driven by resource availability and scalability. Evidently, the culture and attitude of the MO tend to facilitate or hinder the Industry 4.0 adoption, therefore innovative practices in building an expert team, establishing a systematic change management process, actively involving suppliers in the adoption process and continuously monitoring the adoption process were introduced.

Novelty

By addressing the relationships between the drivers, barriers and innovative practices from a business perspective, a detailed Industry 4.0 adoption framework for the UK MSC was developed as a unique theoretical and practical contribution. This study also highlights the lessons learnt from applying Industry 4.0 in the UK context. The findings can also be informed in applying Industry 4.0 technologies in emerging market contexts.

Keywords: Industry 4.0 Technologies; Supply chain management, Manufacturing, Digital Transformation, Emerging Market, SMEs, UK

INTRODUCTION

In the Industry 4.0 era, SC is a multifaceted ecosystem connecting product development, manufacturing systems, logistics networks, and the end customer into a fully transparent digitized system (Fawcett, 2018). To acknowledge the importance, the UK government, for instance, aims to increase 30% manufacturing productivity by 2030 to establish the UK as a global leader in digitalization (Innovate UK, 2018). This trend involves advanced manufacturing techniques to establish systems that are interconnected to communicate in real-time, analyse, and use the information to drive further intelligent actions (Deloitte, 2019).

In recent years, adopting Industry 4.0 technologies in the manufacturing sector has attracted many scholars' attention (Wu et al., 2016; Bienhaus & Haddud, 2018; Ben-Daya et al., 2017). While there is a great interest among practitioners in applying innovative digital technologies in the Manufacturing supply chain, however, the application of these technologies in the manufacturing supply chain is still in its early stages in developed nations such as the UK (Liao et al., 2017). In emerging markets, the application of these latest technologies is faced with numerous challenges in their manufacturing supply chains, spanning from infrastructure constraints to regulatory barriers.

Therefore, this research aims to identify the key drivers and investigate the barriers to Industry 4.0 adoption in MSC, to evaluate these findings on innovative practices and propose an Industry 4.0 adoption framework for manufacturing organisations in the UK to successfully adopt Industry 4.0 technologies within their SC. Aligned with this aim, this research addressed the following research questions:

1. What are the driving and resisting factors to adopting Industry 4.0 technologies in MSC?
2. How can manufacturing organisations in the UK overcome the barriers to Industry 4.0 technology adoption in their organisation and SC?
3. What are the innovative practices that organisations can focus on to support adopting Industry 4.0 technologies in MSC?
4. How do the drivers and barriers of industry 4.0 technologies influence innovative practices for industry 4.0 adoption in the UK MSC?

METHODOLOGY

Following qualitative research methodology, this research undertook 9 semi-structured interviews for data collection via non-probability, self-selected, large to SME MO in the UK (i.e. Aerospace industry, Consumer Electronics industry, etc). The purpose of this research

requires an exploratory element to conclude casual relationships between variables (i.e. Industry 4.0 adoption drivers, barriers and innovative practices) to develop the Industry 4.0 adoption framework. Each interview lasted around 30 mins to 1 hour. During the interviews, new ideas and significant discussions also led to the discovery of areas in Industry 4.0 adoption in MSC that has not previously been identified in order to address research questions.

Prior to interviewing the participants from MO, the purpose of the research and interview questions were provided to enhance the transparency as much as possible without compromising the research quality and validity. Moreover, cultural reflexivity was taken into consideration throughout the interview process to maintain the most appropriate level of relationship, formality and unbiasedness (Saunders et al., 2016). Prior to conducting the actual interview, a pilot interview was conducted with one of the participants to establish the understanding, quality and appropriateness of the interview questions. In addition, to ensure the quality and validity of data, all transcripts were emailed to the participants to confirm their validity.

For this research, an inductive data analysis approach was conducted to develop an Industry 4.0 adoption framework through the process of data collection, analysis and interpretation. First, to guide primary research a conceptual framework was developed during the literature review. Second, a Thematic analysis was conducted allowing flexibility to generate themes from qualitative interview data (Saunders et al., 2016). This means, the procedure to be familiar with the data, code data, search for themes and identify relationships between variables, refine themes and test the propositions. Therefore, all critical parts of the interviews were audio-recorded and transcribed and carefully analysed to grasp the relevance. These transcriptions were later analysed through comparisons, interpretations and thematic categorisations.

FINDINGS & DISCUSSION

Using a thematic analysis, this research has identified five key drivers that encourage Industry 4.0 adoption, nine key barriers that resist Industry 4.0 adoption and four innovative practices that support Industry 4.0 adoption as key themes.

Respondent Profile:

The profile of the 9 participants is shown in Table 6.1

Table 6.1: Respondent Profile in the study.

Company Source Code	Participant Source Code	Role	Overall years of experience in SCM	Industry	Company size (No: of employees	Location	Interview Time/mode	Duration
Company A	**Participant A**	Head of Supply Chain & Logistics UK	32	Aerospace & Defense	Large	Portsmouth, UK	07/08/2019 at 17.30 PM - Telephone	24:57 mins
Company B	**Participant B**	EMEA Supply Chain Manager	16	Consumer & Industry Electronics	Large	Reading, UK	09/08/2019 at 7.30 AM - Watsapp	1:01:11 mins
Company C	**Participant C**	Global Supply Chain Director	Over 25	Biotechnology	Medium	Oxford, UK	09/08/2019 at 10.30 AM -Telephone	29:36 mins
Company D	**Participant D**	Supply Chain Manager	13	Consumer Goods	Medium	Basildon, UK	09/08/2019 at 11.30 AM - Skype	29:23 mins
Company E	**Participant E**	VP Supply Chain Transformation	Over 15	Automotive & Aerospace	Large	Bristol, UK	14/08/2019 at 16.00 PM - Telephone	30:22 mins
Company F	**Participant F**	Supply Chain Director	7	Textile/Industrial workwear	Medium	Adlington, UK	14/08/2019 at 17.00 PM -Telephone	36:11 mins
Company G	**Participant G**	Executive VP Supply Chain Management & Operations	21	Marine Electronics	Large	London, UK	14/08/2019 at 18.00 PM - Skype	37:48 mins
Company H	**Participant H**	Operations Director	9	Telecommunication/Technology Enabled Care	Small	Lancashire, UK	16/08/2019 at 10.45 AM - Telephone	1:13:44 mins
Company I	**Participant I**	Group Executive and Director Purchasing & Supply chain	36	Machinery/Heavy equipment	Large	Staffordshire, UK	16/08/2019 at 15.00 PM Telephone	58:58 mins

1.1. Technological drivers that influence Industry 4.0 adoption in MSC

The research question and its variations were designed to explore the key drivers of Industry 4.0 adoption in MSC. Based on the answers given, these drivers were segmented into TOE perceptions.

1.1.1. Perceived Benefits

1.1.1.1. Operational improvements

During the discussion of understanding the benefits that drive Industry 4.0 adoption in MSC, Participant B suggested improvement in production processes due to automation as a key driver, which not only allows employees to monitor operational efficiencies remotely by capturing data but also to understand potential areas for improvement.

"…automated manufacturing, and understanding the yields without going into the factory, to understand the output, to understanding utilization, to understand the capacity. So, lot of technology being used to actually automate the production processes. Not only that and also, those tools giving the opportunities to analyse the areas for improvement… In the past we had these operational silos, but now it is all interconnected" (Participant B).

As Participant A emphasised: *"Clearly, I think efficiency, therefore cost-saving".* According to Participant G emerging technologies allow them to increase efficiency, reduce costs and work much better data from operations. These statements were also supported by Chen et al., (2015), who stated operational cost savings, or improvements in efficiencies that focus mostly on the internal efficiency of the organisation to be the direct benefits of Industry 4.0 adoption.

1.1.1.2. Customer service improvements

Indirect benefits associated with customers were highlighted by several participants. Utilising customer data through enhanced forecasting systems to improve product and service developments (Participant D), the ability to track order shipments through accurate predictions (Participant B), and improvements to customer service reliability (Participant H) are some of the key benefits that are perceived. Likewise, Ilin et al., (2017) highlight adopted advanced Industry 4.0 technologies to improve the quality of customer service and as Tao et al., (2018) state it will result in value-added products and services for the end-consumer. However, Participant B felt this achievement is possible if collaborated with supplier companies with connected technologies.

"every aspect of the business needs to be predictable…technologies need to help us be predictable, be more efficient and then help become more productive right… in the past there were no tracking technologies available. Now, in Company B we have kind of collaborated with the company that kind of tracks shipments within the ocean… we can give predictability to our customers" (Participant B).

As Participant I put it,

"we quite care a lot about the customers who are heavily impacted. But our vendors or suppliers will be increasingly impacted as we build the digital twin of the supply chain and start to use simulation and part of the scenario planning with our key suppliers we need as we move further down the road of digital collaboration with the supply chain, through the connected supply chain" (Partcipant I)

1.1.1.3. End-to-end SC visibility

One of the key drivers equally recognised by the participants is SC visibility. Participant G identified real-time visibility built by Industry 4.0 technologies as a primary driver to adopt Industry 4.0 technologies, because they increase SC efficiencies and reduce waste. As Barretoa et al., (2017) there is an increasing need for transparency to control human-machine interactions to overcome inaccuracies of information by sharing real-time data across the SCN effortlessly. Simultaneously, Participant C and E addressed visibility as a powerful factor to monitor the movement of the products across the end-end SC, by overcoming supplier boundaries and separate entities in a network.

"I think the biggest benefit comes from the end to end visibility. So that is an area we're currently struggling with, we have quite a complex process when it comes to supply side, incoming supply chain. So, particularly in our consumable products, the products tend to move across many vendors. And we are having to interact with each of those vendors, the product kind of goes from vendor to us back to another vendor back to us back to another vendor back to us. And keeping track of that is quite a challenge. So, I think there would be a huge benefit in that space" (Participant C).

"Obviously, you are going to start from an inhouse perspective. But then that intent is to remove the boarders of the of the companies and try to expand this kind of visibility and understanding to suppliers and customers as well" (Participant E).

However, as Tjahjono et al., (2017) underlines where there are no clear boundaries between different SC functions such as purchasing, logistics, operations could result in complexities in adopting Industry 4.0 technologies. For example, as the researcher conceptualise, Industry 4.0 technology adoption will benefit on-time production. However, this may increase logistics costs with the increased number of on-time deliveries. On a positive note as participant A stated, Industry 4.0 adoption provides MSC to "highlight the risk in the SC and the areas of concern so you can focus on them proactively" (Participant A). Hence, MSC have the ability to take advantage of end-to-end SC visibility to drive Industry 4.0 adoption.

1.1.2. IT maturity

Majority of the participants identified IT maturity in their MO as a key driver, as it allows them to select compatible Industry 4.0 technologies based on their current infrastructure. According to Lin et al., (2018, p. 593) IT maturity is the "degree of the information technology adoption and implementation of advanced IT to assist the industrial production". Participant E identified lifting the level of maturity in terms of integrated business planning, sales and inventory planning, and production scheduling as one of their key responsibilities in the current role. On another aspect, Participant G accepted that sometimes the adoption of Industry 4.0 tools may depend on their current infrastructure. Hence, Industry 4.0 technologies that are correlated with existing operational values (Awa, 2016), and are compatible with current technical architecture and infrastructure (Mahroof, 2019) can be determined as crucial components of IT maturity of MSC to drive Industry 4.0 adoption.

"You have some legacy systems maybe are not compatible with the new technology. But it's true as well, that new technologies more and more are aware of that, and allow you to capture data, even from the old legacy systems" (Participant E).

1.2. Organisational drivers that influence Industry 4.0 adoption in MSC

1.2.1. Industry 4.0 readiness

When it came to organisation size as a driver of Industry 4.0 adoption in MSC, there were a number of positive and negative aspects of being an SME or a larger organisation.

1.2.1.1. Large - Resource availability and scalability

As addressed earlier, Participant B believes larger MO have the ability to take bets to experiment on technologies due to their scalability and availability of resources. These advantage in large MO is financial readiness, while Aboelmaged (2014) and Asare et al., (2016) emphasised on resource availability to facilitate new technology adoption. Similar views were shared between Participant A and D who stated human resource availability and cash flow availability as key advantages for larger MO. Meanwhile, Participant C stated firm size is a strong factor considering the technology-related awards and recognition received in the marketplace.

"I think if you look at the awards that come out, either from you know, the Gartner institute they do different analysis on how industries performing and how the different companies are performing in supply chain space. And If you look at the top 10, it is it is giants that are generally making things happen that are leading the way" (Participant C).

1.2.1.2. SME - Flexibility and agility

Participants G and H collectively stated, while larger MO have the financial capabilities, human resource availability, and scalability, the complexity could become a barrier. On the other hand, smaller MO have the flexibility and agility even if they take a longer time to adopt appropriate technologies. In support of these aspects, Mishra (2016) found SME's to possess entrepreneurial orientation and adaptable resource management to achieve manufacturing flexibilities. However, these claims contradict the statement by Participant B on SME's who states "the smaller the organisation may not be able to afford the technologies, right. They may not be able to take bets on it. Unless it's proven in the market". Although they affirm "smaller firms adoption will be slightly later in the life cycle, but it will happen". Moreover, Reid et al., (2016) emphasis on SME's ability to respond quickly to changes in the business environment. This indicates the nature of agility in terms of Industry 4.0 technology adoption as well.

Perhaps as Participant H states, "it's a question of attitude and approach rather than size", hence size could simply be an insignificant factor. In their own words;

"But the implication there is that it can only be done by big firms, then I definitely do not believe that. We are working with Manchester City Council who are working with us because we are small and agile. And they have rejected working with one of our competitors, because they're large and inflexible. So, it doesn't mean there is such thing as larger companies aren't flexible and it doesn't mean that large companies can't do it. But certainly, sometimes, smaller companies can do it more easily" (Participant H).

Therefore, cultural readiness as a theme and a critical driver for Industry 4.0 adoption in MSC was identified in the discussion.

1.2.2. Cultural readiness

In the discussions regarding the influence of organisational culture and people, Participant B emphasised "It is not about the technology it is the culture and everything else". This includes the degree to which SC managers in MSC understands and accepts Industry 4.0 technologies. As the Head of SC & Logistics UK, Participant A highlighted the importance of organisational culture from a managerial perspective;

"We're keen to drive that culture into the marketplace, which is where we operate, but also internally within the team and the organization (Participant A).

However, this cannot be achieved unless there is appropriate leadership within the team and the organisation to initiate that cultural readiness. Ilin et al., (2017) addressed the importance of proactive support from the management to drive Industry 4.0 adoption. Similarly, Participant B (EMEA SC Manager) underlined;

"… the leadership needs to be proactive and then leadership needs to encourage the ideas to adopt new technologies", supported by Participant D who highlighted "Senior management team is the one to decide the direction…they're out there in the forefront communicating and making sure those people understanding the 'why'" (Participant B).

1.3. External pressure

1.3.1. Competitor pressure

Competitor pressure was recognised as a key driver for Industry 4.0 adoption in MSC. As Participant C stated,

"…depending on what our competitors are doing, and what's happening in industry, there is an expectation or at least there is a realization that…if you're not applying latest trends and latest technology, you will not necessarily be competitive" (Participant C).

In respect of that, Hsu et al., (2014) most organisations are driven to adopt technologies to maintain the competitiveness in the marketplace, especially since competition is now between the SC (Nobari et al., 2019). In support of these views Participant B stated,

"…you may be the last person in the line to adopt, but without adopting new technologies, you may not be competitive, and you may not have customers...if the competitors are advancing in any industry, people have no choice. They have to compete it (Participant B)

Therefore, competitor pressure can be identified as a key driver for Industry 4.0 adoption in MSC.

1.3.2. Customer expectations

Another key driver derived from external pressure was customer expectations. Participant B acknowledged evolving customer expectations forces to adopt new technologies such as Industry 4.0 in MSC.

"…especially when it comes to new technologies in the supply chain manufacturing customer expectations will change, that will force people to adopt. It maybe today, if not today, it could be down the line. But it will happen" (Participant B).

Furthermore, Participant C highlighted the commitment to meet customer expectations that has a direct impact across downstream and upstream SC.

"…it is not just visibility of products, it is you know, what commitments have you got in terms of customers? How is your supply chain performing both upstream and downstream? (Participant C).

In support of their views, Marilungo et al., (2017) found Industry 4.0 technologies such as CPS and other ICT to provide manufacturers an opportunity to develop SP and improve service functionalities for the customer. As Participant I also added, this enhances the quality of the products and entire customer experience, which will eventually improve the stakeholder value of the company.

"…it will be the usual drivers that would influence us in adopting any technology. That would be around improving the quality of the product for the customer, improving the customer experience with Company I, and improving the stakeholder value within Company I" (Participant I).

1.3.3. Supplier capabilities

It was apparent that some of the MO participants are significantly reliant on their suppliers to the extent Participant F stating, "we do rely on our suppliers, maybe more than we should" to

drive adoption of new technologies. The underlining reasons to rely on their supplier capabilities was explained by Participant I;

"I would outline the capability of our supply chain as one of those external factors… I'm sure there are vendors within our supply chain who are much more advanced than we are in terms of technology…we're currently conducting to look at setting up a digital twin on a number of suppliers. We will be over the next month evaluating the capabilities of our key suppliers in order to identify some for some pilot and projects" (Participant I).

For example Arunachalam et al, (2018) argues, to adopt big data analytics MSC requires diverse capabilities such as analytics, visualisation and data integration, generation and data management. In the practical world, Participant H agrees they are building a partnership with some of the technology suppliers since they do not have adequate knowledge or capabilities. So, they let the suppliers lead them towards adopting AI and certain cloud computing capabilities.

"we're in the process of becoming a Microsoft partnership organization. Mainly this stage for the purposes of meeting other Microsoft partners who do know more about AI than we do and offer AI kind of services. So that's the direction of travel" (Partcipant H)

1.3.4. Government policies

The government policies as a driver was also identified during the discussions. For instance, Participant E identified political support as a key external driver that influences Industry 4.0 adoption in their MSC.

"I think political support is a key point. So, depending on how the government can put aside support or provide some support a company with some support that is essential" (Partcipant E).

Meanwhile, Participant I acknowledged the UK government support in terms of funds and improvements to the national infrastructure, as well as adequate policies that drives technology adoption in their industry. For example, it was mentioned increasing awareness of carbon footprints across SC can be only achieved through government support, which will ultimately increase the SC efficiency and effectiveness to benefit new technology adoption. Durrani & Forbes (2018) also believe government funds are important for MSC to confidently enter the Industry 4.0 era, while Ilin et al., (2017) believe government resources and government regulations are equally important.

"To be honest, the funding that's available from government would be another factor with our associate here. On the political side, definitely I think government could support probably with funds… the increasing awareness of carbon footprints and the need for companies like ourselves to be using the [inaudible] resource more efficiently and effectively. I think that we certainly should drive" (Participant I).

Table 6.2 shows the technological, organisational and environmental. drivers of adoption of Industry 4.0

Table 6.2: Industry 4.0 adoption drivers findings & results (compiled by author)

TOE perception	Key drivers	Sub drivers	Source
Technological	Perceived benefits	Operational improvements	Participant B, Participant G, Chen et al., (2015)
		Customer service improvements	Participant D, Participant B, Participant H, Participant I, Ilin et al., (2017), Tao et al., (2018)
		End-to-end supply chain visibility	Participant G, Participant C, Participant E, Participant A, Tjahjono et al., (2017)
	IT maturity		Participant E, Participant G, Lin et al., (2018), (Awa, 2016), Mahroof (2019)
Organisational	Industry 4.0 readiness	Large firm: Resource availability & scalability	Participant B, Participant A, Participant D, Participant C, Maduku et al., (2016), Aboelmaged (2014), Asare et al., (2016),
		SME: Flexibility & agility	Participant G, Participant H, Mishra (2016), Reid et al., (2016)
	Cultural readiness		Participant B, Participant A, Participant D, Ilin et al., (2017)
Environmental	External pressure	Competitor pressure	Participant C, Participant B, Hsu et al., (2014), Nobari et al., (2019)
		Customer expectations	Participant B, Participant C, Participant I, Marilungo et al., (2017)
		Supplier capabilities	Participant I, Participant H, Arunachalam et al, (2018)
		Government policies	Participant E, Participant I, Durrani & Forbes (2018), Ilin et al., (2017)

1.4. The barriers to Industry 4.0 technology adoption on MSC

1.4.1. Technological barriers

1.4.1.1. Lack of standardisation

In Participant G's own words:

"…if I look at the barriers to adoption, I think one of the biggest issues is a lack of standards. I think, you know, you can look at a number of different solutions, and they're fairly limited standards between different solutions, which can be worked around, but it adds complexity, and it adds cost and it slows things down" (Participant G).

Thus, lack of system and process standardisation becomes a key barrier for Industry 4.0 adoption. Similar views were found in literature. Because of lack of system and process standardisation system defects and poor performance (Majeed & Rupasinghe, 2017), as well as high capital expenditure costs (Kamigaki, 2017) we reported. Although, in Participant A's

view unless Industry 4.0 technologies answer a business problem, there is no purpose of standardising them.

1.4.1.2. Technology compatibility & complexity

Technology compatibility and complexity seemed to go hand in hand when it comes to Industry 4.0 adoption barriers in MSC. For instance, Participant F considers cross-technology compatibility may not be an issue for their current infrastructure. However, during the discussion they agreed their current production process may require system updates to tackle the inefficient supply-demand capacity, to optimise resources and to receive information quickly from their SC. As Schmidt et al., (2015) explains it is compulsory to tackle disruptive changes to SC. Hence, technological compatibility directly or indirectly associates the complexity in adopting new technologies. In Leung et al., (2015) perspective, this could negatively impact Industry 4.0 adoption across the SC. Participant D commented, the main and the foremost challenge is the high cost followed by complexity, which was also recognised by Kamigaki, (2017).

1.4.1.3. Selecting the right technologies

As Participant B states, one of the biggest challenges In Industry 4.0 adoption is to identify the right technology out of the varieties of technologies that are available. According to Participant A, lots of technologies such as Industry 4.0 technologies in MSC are forced upon by IT functions, without understanding the business needs or customer needs. They further state, “business should drive the tools, not the tools drive the business”.

Similarly, Sung (2018) and Ali (2020) underlined the difficulty for any organisation to identify the suitable technologies to achieve the maximum benefits. Meanwhile, Participant H foresee a different aspect of the situation. In their opinion excitement to adopt Industry 4.0 technologies is shared across the SC may mean it is easier to drive the adoption, however it also means “you may well adopt more things that are unnecessary and if you're cynical about it, you will only adopt what's really good for you”. This also associates the risks around the complexity of the technologies that may never deliver results and never reach provision despite the amount of money spent (Participant I).

1.4.1.4. Data ownership barriers

All participants identified data ownership as a key barrier for Industry 4.0 adoption in MSC within two aspects. This theme follows the data ownership aspect in terms of visibility in data sharing (Handfield, 2017) and cybersecurity threats (Alaba et al., 2017), associated with recent cyber-attacks and GDPR (2018) policies.

Data visibility has become a key barrier in terms of adopting new technologies because different entities across the SC has become very protective of their data. According to Participant G, data visibility has become a key concern for their B2B customers who simultaneously sell their competitive products. In Williamson's (2017) opinion, to decide who owns the data at various stages in the SC is never an easy question to answer or resolve. Hence, the lack of ownership to access crucial data could become a barrier to adopting Industry 4.0 technologies.

"Yes, it can do we've actually come across this one. We've been talking to customers for instance, about extending into the customer space where they get very protective of their data. They don't want us to see, you know, our customers sell our products, but they also sell our competitive products. So, they become quite protective, in that area" (Participant G).

In contrary, participant A see having too much data in multiple systems as a potential issue. They believe too much data will make the decision-making rather complicated, which is a potential risk they foresee across their MSC.

"I think the other risk we have here is having so much data, and actually it becomes confusing. I know it becomes a fog, rather than helping you in making good decisions. So again, it's how you manage the tools and manage the system to ensure you actually get added value from it" (Participant A).

Cybersecurity and privacy threats are seen as a key barrier in the view of all participants. In recent literature, Babiceanu & Seker (2016) states certain Industry 4.0 technologies such as CPS could be exposed to cyber risks. Similarly, Participant B identified the urgency of the cybersecurity matter over and beyond their focal firm and their MSC to a national point of view. Participant E from the Automotive and Aerospace industry identified security as the most crucial matter in their hands prior to enabling data visibility and introducing any new technologies.

"Yes! Security. I think this is the first especially in my current industry. Yeah, I think security always is a key point and we need to make sure prior to introduce any enabler of visibility because industry 4.0, and they enable visibility, right. So, I think security is the first point" (Participant E).

Commenting on Participant H said, data security has become one of the key priorities since GDPR policy updates. In their own words;

"…for me it's a nightmare at the moment. I am receiving on an almost weekly basis, cyber security questionnaires from all of our customers to complete. Asking questions that I don't know the answers to, I know the answers to some of them, but not all of them. And it clearly is a massive issue. It's probably my biggest worry at the moment, I mean, it slightly associated with GDPR. Because it's the mechanism for making sure that what you're trying to do with the GDPR actually works. And, it's the one that's the most worrying for me at the moment, because I'm not sure how we're going to deal with it" (Participant H).

Therefore, in their opinion, GDPR is also associated with cybersecurity concerns across their MSC. Alaba et al., (2017) also see the privacy matter as a significant barrier for manufacturers. In contrary, Participant F believes GDPR is simply a part of the rules set up in their process and it has not changed how entities across their SC view the security matters at hand.

"The reason being is since GDPR come in I know we all adhere to all of the rules. But I don't hear anyone talking about it. I don't hear from suppliers or customers say to me, we need to make sure that we set up our processes, treat ourselves in line with GDPR. Nothing is changed. All we've had to do is make sure we're covered internally" (Participant F).

1.4.2. Organisational barriers

1.4.2.1. Lack of skills and understanding

Lack of Industry 4.0 knowledge and understanding was one of the barriers shared among all MO and industries participants were representing. Participant D identified their IT teams are not up to speed with the new technologies and lack the understanding and expertise to help adopt new technologies. Likewise, the lack of skilled people (i.e. SW) is also a reason for unmet expectations. Participant C reported "lack of understanding by senior management on all the benefits of adopting these technologies" as a significant barrier to introducing Industry 4.0 technologies. As Participant B questions,

"how do you know what is good for you? Who is going to tell them about it right? So, it's about lack of understanding, right?" (Participant B)

As Kamble et al., (2018) states, lack of skills will result in the lack of awareness. Unless there are skilled employees who are matured with adequate competencies, and the senior management communicating the benefits, MO may remain heistant to continue Industry 4.0 adoption. The same view was shared by participant I from the machinery industry;

"I don't believe there is sufficient expertise currently in our industry to be able to fully understand the benefits and articulate those benefits in a way that will release the required financial investment" (Participant I).

1.4.2.2. Fear of uncertainties (i.e. redundancies)

While participants B, C, and I did not view fear of redundancies due to drastic automation as a threat in the Industry 4.0 era, Participant E identified the situation as;

"…fears about losing jobs or losing skills. Because the required skills are changing…" (Participant E)

Similarly, Huxtable & Schaefer (2016) viewed absence of IT competencies as a key reason for employees to fear the uncertainty. Participant H found it as a non-concern in their organisation, however agreed it could be a concern in general in the manufacturing sector. Meanwhile, participant G believes it is a fear that was spread across their organisation at initial stages of the adoption process, but later the employees were seen to grasp the requirements and become more competent. Hence, redundancies could be seen to cause temporary fears and may depend on how the senior management tackles the situation.

"We've actually seen the people who felt that they were at risk have actually been significantly upscaled and become more competitive in the market" (Participant G).

1.4.2.3. Increased decentralised decision-making.

Participant B considered decentralisation to impose negative impact on overall decision-making due to bias decisions on different functional levels in the SC. Hence, they strongly believe decision-making should be centralised. Bröring, et al. (2017) also states decentralisation will result in lack of control for the focal firm. Similarly, participant I view a decentralised operational model or a business model as an obvious barrier for change, because "you're just trying to convince more people about the need to work together". In contrary Participant D believes it could be a potential strategy to adopt similar technologies across MSC by overcoming slow and bureaucratic centralised decision-making processes. Similarly, participant G saw the benefits of local decentralised decision-making in real-time that could aid in measuring the impact of technology adoption decisions and actions as they happen.

"…it's real time. So those decisions and those actions are happening immediately. And you can then also see and measure the impact of those decisions and actions and ensure that it's happening the right way. So, I think to answer the question, I think it actually empowers the local decision making" (Participant G).

1.4.3. Environmental barriers

1.4.3.1. Political uncertainty (i.e., Brexit)

Brexit was seen as a barrier for Industry 4.0 adoption in a number of ways. On the one hand, Participant B addressed the implications in terms of needing a separate MSC system across the

EU and the UK to process goods which will cost more to implement. Therefore, they propose a robust mitigation plan. Participant D see the Brexit uncertainty could delay Industry 4.0 adoption because companies may divert their investments and prioritise business-as-usual operations in case of a no-deal Brexit. As Baynes (2019) states, Brexit has caused supply-demand chaos in the UK manufacturing sector resulting in a seven-year low manufacturing output. Participant H believes this could have a big influence on where the data is stored, particularly considering the GDPR policies, which is also believed to cost the UK-EU business partners disruptions to cross-border data flows (Boffey, 2018). On the other hand, participant C, E and G do not think there are any long-term implications. Participant G see the situation as a hype, but a challenge that can be tackled. For instance, participant E states;

"…yeah, it could be at the very beginning, but then the supply chain will, all supply chains will react accordingly. And the balance will be re-established" (Participant E).

1.4.4. SC alignment barriers

1.4.4.1. Lack of SC integration & collaboration

Lack of SC integration and collaboration was seen as a key barrier. As participant C stated it is about convincing the stakeholders across their MSC. Similarly, participant I addressed the importance of supplier coordination to integrate Industry 4.0.

"The poor integration between the suppliers of the services making it difficult businesses like ourselves to implement some of integration that is fundamental within industry 4.0" (Participant I).

Simultaneously, in participant C's view, the main underlining issue goes back to lack of visibility across the overall view of the MSC, which leads to no coordinated effort from the stakeholders since there is no single approach to guide the appropriate adoption across the MSC. As Peters (2019) supports, zero-sum games will not benefit MSC in the Industry 4.0 era. Hence, a collaborative approach which benefits both the manufacturer and their suppliers will aid Industry 4.0 adoption.

1.4.4.2. Silver bullet chase

Silver bullet chase is referred to as the unrealistic belief of expecting a new system to solve all business problems (Xu, 2014). According to participant I, some businesses follow these unrealistic expectations towards Industry 4.0 as well.

"Too many businesses believe that, okay I've got a new technology, therefore everything's going to be okay… I think the problem you have is many people think there's a silver bullet, a precedent. And suddenly, I've transformed my manufacturing. Well, actually it's not".

The issue with silver bullet chase is significant because not only the focal firm is involved in the adoption process but other entities across their MSC are also involved. Therefore, expecting an immediate solution to all problems could sound unrealistic and misleading. Hence, Gonzalez (2017) recommends SC practitioners to not consider Industry 4.0 technologies as an immediate problem solver or a performance improver. Although, that is what most organisations tend to do. As participant G states;

"I think that there is a risk in the hype, that there's a lot of hype. And, there is risk that you make an investment without properly researching it, and then you find that you don't actually get value from that investment. I think it's extremely important to be clear in advance of what your goals are what you want to achieve. And ensure that the investment is aligned with those goals in mind" (Participant G).

1.4.4.3. Over-reliance on suppliers

During the discussion, it was apparent that many of these SME to large MO are considerably dependent on their suppliers to adopt Industry 4.0 technologies. For instance, participant F accepted that they are reliant on small suppliers who do not have the expertise or the resources to fulfil some of the critical technical requests. This could be mainly because some manufacturers are solely focused on partnership relationships as opposed to transactional relationships in nearly half of their supplier relationships (Churchill, 2018). Participant E stated, although it is debatable how capable their suppliers are, they still rely on the suppliers more than they should.

"...we rely on a lot of our suppliers to have that technical expertise. So, when they're connected to like cloud based companies, and with a lot of our freight companies for example, we expect them to connect to sea carriers and vessels on an IT level, so that they get information quicker and real-time, And, then they can pass that information on to us and ultimately our customers. Again, that's still debatable about how connected they are. So, we are, we do rely on our suppliers, maybe more than we should". (Participant E).

1.4.4.4. Supply disruptions

Meanwhile, Participant G view the situation in another aspect. In their opinion, Industry 4.0 adoption and the speed of development could be a slow process. Also, the technology keeps updating and there is always a new technology available in the market. Hence, there is this fear that the technology you chose could be easily replaced by a newer version. A potential example could be if a fifth industrial revolution occurs, new technologies may disrupt day-to-day business operations with continuous system updates. Therefore, MO are forced to choose between adopting Industry 4.0 at an early stage or to wait a little longer (Schmidt, et al., 2015).

For instance, Participant I foresee the disruptions in three directions. Firstly, if the chosen technologies do not achieve expected performance, reverting to previous systems could impact daily operations. Secondly, significant investments in Industry 4.0 adoption could result in lack of funds for other business developments. Thirdly, any SC disruptions due to new system updates may result in significant non-supply of goods and services from suppliers.

"If we invest in the required technologies and they do not reach provision. Because the technologies have not matured sufficiently. And we reverse any steps we have taken, that becomes much, much more difficult to convince people to do again, the next thing. So, risk of the ongoing development of our business. Of course, any money that we invested in industry 4.0 means of less money to invest in other things within the business [inaudible]. Then there a risk of supply chain disruptions, in terms of poorly executed approach. I mean everything eventually has a financial impact. There is a risk of simply non supply. Yeah, very much" (Participant I).

Table 6.3 shows the technological, organisational and environmental. Barriers of adoption of Industry 4.0

Table 6.3: Industry 4.0 adoption barriers findings & results (compiled by author)

TOE perception	Key barriers	Sub barriers	Source
Technological	Lack of standardisation		Participant G, Participant A, Majeed & Rupasinghe (2017), Kamigaki (2017)
	Technology compatibility & complexity		Participant F, Participant D, Participant I, Schmidt et al., (2015), Leung et al., (2015), Kamigaki, (2017)
	Selecting the right technologies		Participant B, Participant A, Participant H, Participant I, Sung (2018)
	Data ownership	Data visibility	Participant G, Participant A, Williamson (2017)
		Cybersecurity/privacy threats	Participant B, Participant E, Participant H, Participant F, Alaba et al., (2017), Babiceanu & Seker (2016)
Organisational	Lack of skills & understanding		Participant D, Participant B, participant I, Mello et al., (2015), Kamble et al., (2018)
	Fear of uncertainties (i.e. redundancies)		Participant B, Participant C, Partcipant I, Partcipant H, Partcipant G, Participant E, Huxtable & Schaefer (2016)
	Increased decentralised decision-making		Participant B, Participant I, Participant D, Participant G, Bröring, et al. (2017),
Environmental	Political uncertainty (i.e. Brexit)		Participant B, Participant D, Participant H, Participant C, Participant E, Participant G, Baynes (2019), Boffey (2018)
	Lack of supply chain alignment	Lack of supply chain integration & collaboration	Participant C, Participant I, Peters (2019)
		Silver bullet chase	Participant I, Participant G, Xu (2014), Gonzalez (2017)
		Over-reliance on suppliers	Participant F, Participant E, Churchill (2018)
		Supply disruptions	Participant G, Participant I, Schmidt, et al., (2015)

1.5. The influence of Industry 4.0 drivers and barriers on Key innovative practices

It was identified Industry 4.0 in MSC is still at a lower level in many MO and industries despite being global leaders or SMEs'. The results suggest many MOs are continuously working to adopt Industry 4.0 technologies by stimulating the drivers and taking various steps to overcome the barriers (see Table 6.3).

1.5.1. Building an Expert Team

1.5.1.1. A committed tech-savvy leadership.

First of all, leaders were identified as the key drivers of Industry 4.0 adoption. As participant B states;

"Leadership is a crucial role right in terms of adopting new technologies. Leader is the one who needs to take that and propose to adopt new technologies. So, obviously it all starts with leadership. I mean you maybe the best person on planet, working for the best company, right. But the end of the day, you know, it's about leadership decision" (Participant B).

However, it is not simply the role of the leadership, in the fourth industrial era, it is about employing a tech-savvy leadership and their full commitment to drive the change (Participant E). In support of these views, PwC (2017) highlights the importance of leadership competencies such as data analytics to transform the corporate environment during the Industry 4.0 transformation. According to participant D;

"Leaders that are more forward looking, more technology savvy, they are in touch of the latest developments in technology will be benefiting or be positively influencing the implementation of these new technologies" (Participant D).

Agreeably, Bolden & O'Regan (2016) believes in the digital era an influential leadership is required as opposed to a leadership with power and force. And as participant F states, "not only within our own organisation but with our customers, suppliers, all our external stakeholders and internal stakeholders". Therefore, leadership extends to all entities across the MSC network. This point is further explained by Participant C who is the Global SC Director for Company C;

"we can positively influence. Um, I guess to you know, if we were to adopt the process then, through our influence into our supply chain, into our suppliers and into our customers, Because, that would probably mean that, you know, it's a bit of a snowball thing. So, there are a few people adopt, and then they push other people to do it. And then so on and so forth" (Participant C).

1.5.1.2. Creating an innovative culture with diverse capabilities

The next practice will be to create an innovative culture with diverse capabilities through appropriate education and training to produce champions within and beyond the organisation. Participant I see the importance of involving younger generation managers who embrace technologies to be part of the process, coupled with senior management to be the best approach to overcome traditional manufacturing practices that are barriers for Industry 4.0 adoption. Therefore, MSC should be able to detect Industry 4.0 champions to effectively drive Industry 4.0 adoption process and demonstrate the benefits among their teams (World Economic Forum, 2019). While participant I believes champions should be created both internally and externally across the MSC, participant G believe it is more important to create internal champions.

"…we feel that the adoption is far greater if people internally are engaged in it. So, we do use partners for some aspects, but wherever possible, we've trained our people internally. So, they are the champions and they're the internal experts" (Participant G).

Meanwhile, participant E provided the practical example of their SCM excellence program for leaders which communicates Industry 4.0 adoption as a business process rather than a technical process. Therefore, to successfully drive the adoption cross-functional teams also should be involved (Bär et al., 2018).

"We have an already launched and established program for training business leaders to supply chain management excellence. So, to lift and raise their understanding about supply chain management and about how it is really not a technical issue or point, but it is a business process" (Participant E).

1.5.1.3. Creating an Industry 4.0 Adoption Champions Committee

Meanwhile, participant I highlighted the lack of expertise across the industry that prevents MSC in understanding the benefits of Industry 4.0 technologies. In their opinion it is high time to create champions internally and externally across the MSC, to set the SC alignment crucial for Industry 4.0 adoption. It could be the champions that have already set good examples in other organisations and proved the benefits or champions (SW) in the current MSC who can understand the benefits by looking at established best practices. As Smit et al., (2016) state, a potential approach could be to integrate into existing SC with Industry 4.0 champions and benefitting from their know-how. In addition to that, these champions committees could be created by driving the current workforce to enlarge and enrich their position in the organisation. As participant E believes;

"…we should try to look at our workforce and see how they can maybe work differently in the future. And, explain them why you couldn't be better, because their work conditions can be changing to a better condition. Or maybe they can for the ones still like to learn, they can learn new things. So, it's that their jobs profiles could be enlarged or enriched. So that that is the approach I generally use" (Participant E).

1.5.2. Establish a systematic change management process

1.5.2.1. Initiate a coherent adoption plan

It was a shared opinion among the majority of the participants to support the adoption via a coherent adoption plan, which was also mentioned as a coherent roadmap to achieve the business objectives (Participant A), or a business case to defend the adoption in a cost-benefit point of view (Participant D).

"…the coherent group map and plan that shows you what we're trying to achieve, what is the strategy, what is the goal and how these different elements help to achieve that goal? (Participant A)

"Let's assume that we're implementing something. It's more related to building a case. And defending the implementation from a cost-benefit point of view. That would be one of the ways to overcome any barriers for drawbacks for the implementation" (Participant D).

If incorporates the steps from Festo (2017), MSC should start by communicating the contributions, benefits throughout the adoption process managed by a tech-savvy leadership.

1.5.2.2. Align the adoption process with the needs of the customer and the business.

According to participant A, Industry 4.0 adoption should be aligned with the business needs in a coherent way and not forced upon by the IT functions without understanding the needs of the business. As participant C states, it is the realisation "…to be best in practice, we want to be best in class". In a business perspective, it will deliver potential process-reengineering opportunities for the manufacturers (Zhong et al., 2017). However, as participant B and H emphasises, the adoption should be seen from the customers' eyes. Participant H clarifies Industry 4.0 adoption as a way of fixing the problems that are shared from their customers, which will then be transferred as a practice across the organisation. Such alignment will ensure service quality improvements (Ilin et al., 2017) and value-added products and services for the customers (Tao et al., 2018). Participant B views this as a "honour commitment, make the promise keep the promise". They further explain;

"…it's all about what the end customer wants. Generally, all our thinking starts there, right? how we can better serve customer, how we can better impress customer, how we can keep more trust with customer, how we can keep promises to customer, you know everything starts from customer. Whoever is closer to customer, that is where the initiative starts" (Participant B).

1.5.2.3. Communicate the benefits.

According to participant E, change management has been drastically overlooked, although it should be "embedded in the company's DNA". In their view, organisations prioritise technologies but do not consider the coping difficulties for the people involved. World Economic Forum (2019) finds demonstrating the benefits among teams is critical in Industry 4.0 transformation. Participant F believes change management for adopting technologies is about addressing the people why they need the technology. In return, it will stimulate the rate of adoption to receive the rewards from the investments. On the other hand, it seems to impact the Industry 4.0 readiness and culture readiness as specified in the adoption drivers.

"It is lot about transforming the attitudes and you know, making sure that your fundamental processes and the way you work as an organization is correct. And I think that's where I think most or many of these programs fail, you're not treating it as a change management process. You're looking at as a technology solution. That's my view (Participant I).

However, as Festo (2017) states, communication should be tailored according to the audience (i.e. MSC stakeholders). As participant H addresses, the key is 'the communication'!

"Communication, I'd say. In order to do it, leaders need to talk to each other understand why things are being done, get everybody on board with adoption. And I think that's probably the main thing. And, trusting that machine learning will work. So, actually making sure that the first instances of what you try to do are understandable to people, people can see how the machine learning has come to the conclusion because it's a conclusion that they can visualize and understand and believe it. So, I'm building people's confidence that it's working, which includes building my own confidence … It's all about telling people what you're trying to do and why you're trying to do it" (Participant H).

1.5.3. Actively involve suppliers in the process

1.5.3.1. Promote open innovation as a norm

During the discussion, it was apparent that not many of the participants understood the concept of open innovation as an innovative practice to aid Industry 4.0 adoption in MSC, although they seem to follow the concept in practice. According to McMahon (2015), open innovation

disrupts traditional SCM processes by systematically creating a solid B2B relationship across the SCN via shared platforms. Participant I elaborated on open innovation as below;

"Many of our suppliers are common across our industry. So, you've got multiple customers working with same suppliers. So, that why a more consistent approach potentially on an industry basis might make it easier for those suppliers, sometimes make it cheaper for them. But, also have a one set of approaches and standards and so on and so forth. But that would need government support, because then you are entering potentially a competition law" (Participant I).

Therefore, manufacturers and suppliers, even if they are competitors in the industry can initiate joint innovation with their core SC partners, and share resources within and beyond their organisational boundaries. In this scenario, one more aspect seems to be important. As explained by participant G, it is critical to be transparent in the research phase which suppliers are critical and beneficial to work with. Similarly, UK manufacturers should identify for which partners open innovation equally matters.

1.5.3.2. Establish a Business Continuity Plan (i.e. enhance Cybersecurity)

All participants agreed that cybersecurity as a paramount component when adopting any type of technology. Participant E addressed security has become critical because Industry 4.0 technologies will enhance MSC visibility. Some believed the most appropriate response is to establish a detailed, robust, well-tested Business Continuity plan (BCP) and a crisis management procedure (Calder, 2019). This is to ensure in case of an attack the whole MSC is able to respond immediately and appropriately, contain the incidents, and bounce back to the business-as-usual state.

Participant G sees the gravity of the increased data-driven decision-making and its consequences in terms of cybersecurity.

"I think as we become more data driven in our decision making, then we're pulling more and more data together, which becomes much more valuable if it's in the wrong hands. Similarly, it's not just our data. When we start integrating our supplier's data and our customers and even our consumer data, then the responsibility for treating that in the proper way becomes even more important and more key. And without that excellent level of cybersecurity, you're unlikely to get the trust from external partners to adopt. And if you do have a breach, then any adoption is likely to disappear extremely quickly. And then rebuilding that trust. could take months, if not years" (Participant G).

1.5.4. Continuously monitor the adoption journey

1.5.4.1. Implementing a shared knowledge base

Sung (2018) believes a shared knowledge base creates a virtual copy of the physical world. In the Industry 4.0 adoption process, it will be helpful to guide technology users in the SMSC environment. Participant H believes having a shared knowledge system across their SC could be an effective innovative practice. According to Zangiacomi et al., (2018), a knowledge base which is shared across the MSC will encourage knowledge transfer. This in return will develop specific skills (i.e. create smart people) to overcome resistance to change and lack of Industry 4.0 expertise in MSC. Participant A anticipates having a shared knowledge base could be the biggest opportunity to assist Industry pre and post 4.0 adoption. In their opinion;

"…this is a huge opportunity, I think with the 4.0 and the data transparency and availability. If we have that data transparency across the supply chain would be a huge opportunity. Probably the one or if not, the biggest opportunity we have" (Participant A).

Similarly, Bag et al., (2018) believes knowledge transfer and awareness creation to suppliers in multi-tiers will mitigate risks of the Industry 4.0 adoption in MSC followed by information transparency from supplier to customer.

1.5.4.2. Establish data-driven measures (i.e. KPI's).

According to Groger (2018), KPI's can be used to manage data-driven decision-making (i.e. Quality measurements) and to adapt reconfigurable manufacturing systems to reduce disruptions during Industry 4.0 adoption (Park, 2017). Participant E confirms, "Well, when we adopt any new process, what we introduce is measured". As participant B comprehensively describes, the purpose of adopting data-driven measures such as KPI's allow them to compare the human-machine performance forecasts vs actuals, to improve machine capabilities (i.e. CPS, AI performance).

"You don't want to adopt new technologies for the sake of adopting it. It is about how efficient it is…We have machine learning based forecast, created with machines. And then we also have actuals. So, we compare what did machine tell us, what did we humans' stock, and then what the actuals are. So, then we know if the machines are predicting better or if the humans are predicting better. So, we obviously want to continuously teach machines to predict better. We need to teach all the situations to machines before machines can give the best numbers. So, demand forecasting accuracy, aged inventory, we have other KPI's like in stock % for our major partners. For example, Dixons, or media marketing in Germany, so basically, we track in stock %. We expect our products to be 100% on sale available for customers. Also, we have other metrics for manufacturing as well. So, what I'm saying is in general, KPI's are a crucial part of any business. We actually actively measure how technologies are performing" (Participant B).

Meanwhile, other participants utilise KPI's to measure the rate of adoption and return on investment (Participant F), adoption progress impact (Participant G). Participant I clearly mentioned how these Industry 4.0 technologies allow adding value to the customer.

"We measure machine up times, we measure service fulfilment in terms of how long the machine has a problem. How quickly are we able to, you know, restore the machine to normal working. With that measurement also, but not the availability of spare parts. We measure the machine in terms of you know, the performance, the consumptions that are building, you know, so, again, it's about trying to build together a package of measures that allow the customers to understand the total value that 'Company I'" (Participant I).

In support of these findings, Bär et al., (2018) agree that KPI measures could assess the optimum Industry 4.0 status and desired status towards successful Industry 4.0 adoption.
Table 6.4 shows the key practices of teamwork, change management and continois process development and monitoring as main practices of adoption of Industry 4.0

Table 6.4: Industry 4.0 adoption innovative practices findings & results (compiled by author)

Key Innovative practices	Sub innovative practices	Source
Building an expert team	Incorporate a committed tech savvy leadership	Participant B, Participant E, Participant D, Participant F, Participant C, PwC (2017), Bolden & O'Regan (2016)
	Bridge an innovative culture with diverse capabilities	Participant I, Participant G, Participant E, World Economic Forum (2019), Bär et al (2018)
	Create an Industry 4.0 champions committee	Participant I, Participant E, Smit et al., (2016)
Establishing a systematic Change Management Process	Initiate a coherent adoption plan	Participant A, Participant D, Festo (2017)
	Align adoption process with needs of the customer and the business	Participant C, Participant B, Participant H, Zhong et al., (2017), Ilin et al., (2017)
	Communicate the benefits	Participant E, Participant F, Participant H, World Economic Forum (2019)
Actively involving suppliers in the adoption process	Promote open-innovation as a norm	Participant I, Participant G, McMahon (2015), Ozkan (2015), Frishammar et al., (2019)
	Establish a Business Continuity Plan (i.e. include cybersecurity)	Partcipant E, Partcipant G, NCSC (2018), Calder (2019)
Continuously monitoring the adoption process	Implement a shared knowledge base across the supply chain network	Partcipant H, Partcipant A, Sung (2018), Zangiacomi et al., (2018), Bag et al., (2018)
	Establish data-driven measures (i.e. KPI's)	Partcipant B, Partcipant E, Partcipant F, Partcipant G, Partcipant I, Groger (2018), Park (2017), Bär et al., (2018)

Research Framework:

Using a thematic analysis, this research has identified five key drivers that encourage Industry 4.0 adoption, and nine key barriers that resist Industry 4.0 adoption and these were presented underpinning the TOE framework. These drivers and barriers encourage four innovative practices that support Industry 4.0 adoption as key themes. These key themes are then segmented into a number of sub-themes as summarised in the framework below (***Figure 7.1***). In this framework, arrows are used to indicate the direction of adoption stages and the relationship between different main themes and sub-themes. Double arrows indicate the two-way interdependency and influence (i.e. Industry 4.0 adoption drivers in TOE dimensions are interdependent and influenced by each other), while single arrows indicate one-way influence from one factor to another (i.e. technological drivers result in technological barriers).

It was found in the study that the industry 4.0 barriers are consequences of Industry 4.0 drivers. Results suggest these drivers are the opportunities, benefits, enablers, or influencers that encourage Industry 4.0 adoption. As it stands out in the findings, these drivers allow MSC to investigate barriers which are the threats, challenges and financial or non-financial risks that prevent Industry 4.0 adoption. Moreover, these results highlight the TOE link between drivers and barriers. Additionally, to overcome the barriers and to stimulate the drivers, innovative practices are proposed to support successful Industry 4.0 adoption in the UK MSC. Taken together, these results suggest that there is an association between drivers, barriers and innovative practices. Hence, the UK MSC should consider these factors during their Industry 4.0 adoption journey. Finally, this framework also illustrates the industry 4.0 base technologies and smart technologies to help provide the reader better understanding of the final outcome of the adoption process.

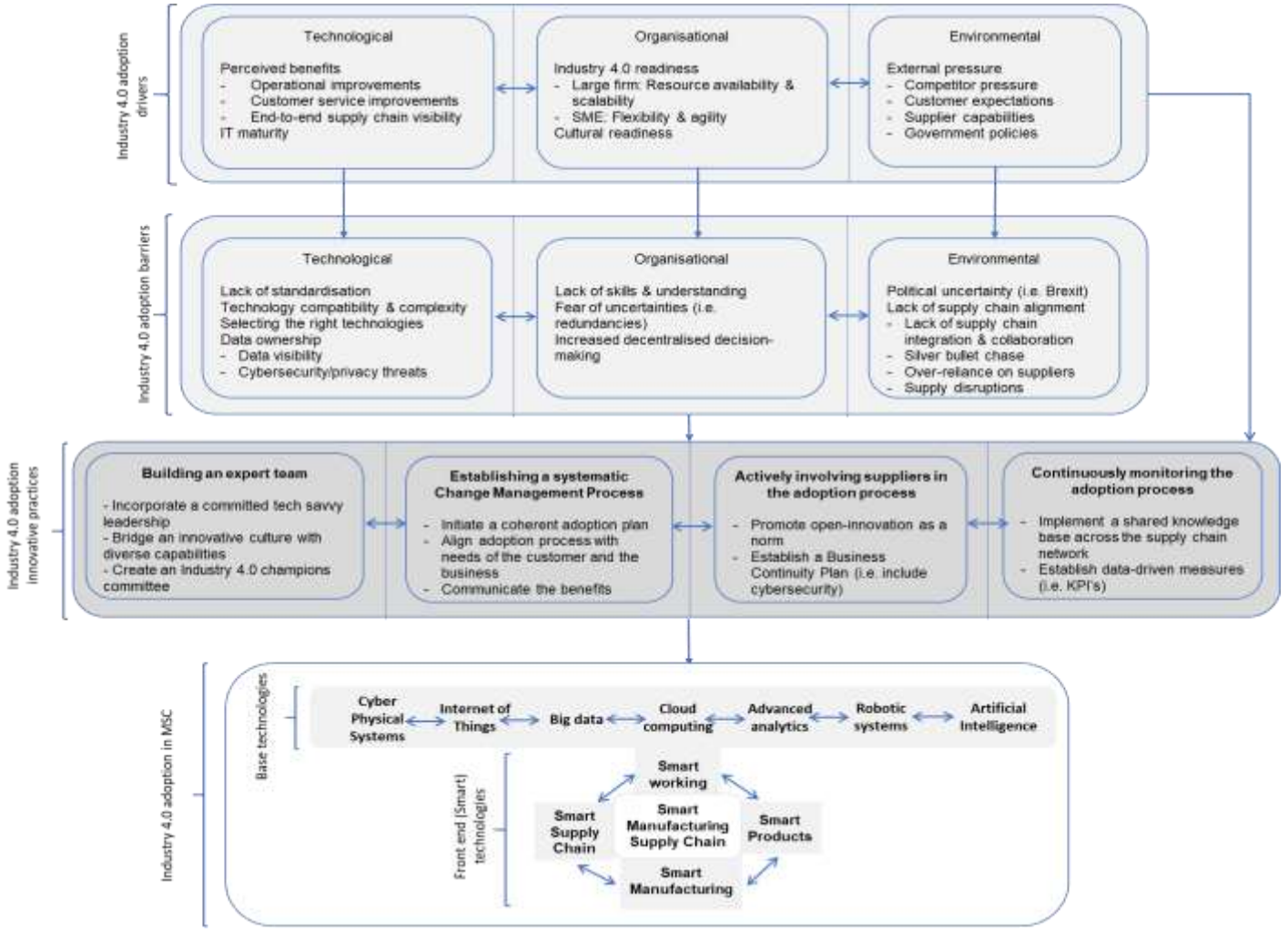

Figure 6.1: Conceptual Framework- Adopting Industry 4.0 Technologies in the UK Manufacturing Supply Chains

Conclusion:

This study aimed to identify key drivers and barriers followed by innovative practices within the process of Industry 4.0 adoption in the UK MSC. The research results showed that various TOE drivers aid Industry 4.0 adoption. However, they also result in barriers that may prevent and disrupt the adoption process. Firstly, this research showed how these drivers and barriers are linked to each other. Secondly, it showed how to stimulate the drivers and how to overcome the barriers by proposing a set of innovative practices discovered in the sample studied. According to our findings, to successfully adopt Industry 4.0 technologies manufacturers should implement innovative practices that are influenced by the drivers and barriers, but those practices should be determined from both the people and technology dimensions.

Theoretical implications

As a unique contribution to theory, this research presents how Industry 4.0 technologies are currently adopted or will be adopted in the UK MSC based on industrial evidence. While a significant number of Industry 4.0-based literature in MSC is presented from a technical perspective, this study aims to contribute to the business perspective. Additionally, this research should also contribute to informing drivers and barriers to applying Industry 4.0 in manufacturing supply chains in the Emerging market context. Since Industry 4.0 adoption in MSC is a novel topic, the volume of literature is relatively limited and still emerging. Hereby, this study developed a framework to combine three focus areas of Industry 4.0 adoption in MSC; drivers, barriers and innovative practices and closes the research gap in application to MSC in the UK. Furthermore, previous studies only focused on identifying Industry 4.0 drivers in application to TOE perceptions. To the best of our knowledge, this is the first study that connects Industry 4.0 barriers prompted by Industry 4.0 drivers in TOE perceptions.

Practical implications

This research can contribute to the UK manufacturing organisations that look for Industry 4.0 adoption in their MSC. While most of the Industry 4.0-based literature is presented from a technical perspective, this framework details how the drivers and barriers influence innovative practices from a broader TOE business perspective. This broader perspective is important for SC managers to measure ongoing uncertainty surrounding disruptive technologies and to determine the level of planning and preparation required to implement innovative practices across their MSC. This is also important to note that, the manufacturing supply chain in Emerging markets faces with several challenges in adopting innovative technologies. The framework, developed in this study and lessons learnt from applying digital transformation in UK companies can provide invaluable insights for the firms in emerging economies. It is worth

noting that this study is not proposing these findings as the definitive components or the ideal framework for Industry 4.0 adoption in the UK MSC, but just the present-day situation based on the experience, knowledge and practices analysed from the sample UK SC experts that were studied. Therefore, components in this framework can be compared with similar studies proposed in the literature such as Lin et al., (2018), Kamble et al., (2018), Büyüközkan & Göçer (2018), Makris et al., (2019) and Bär et al., (2018).

Limitations and Future Research Implications

There are several limitations of this research which highlight the scope for further studies. Firstly, this research selected a small sample from the manufacturing sector in the UK which limits the scalability of the research. Furthermore, companies selected in this research are SME to large organisations, from 9 different industries, with adoption status varying from 0%-90%. This means the drivers, barriers and potential innovative practices in the findings could be significantly distinct from each other. Moreover, knowledge, expertise, and awareness of Industry 4.0 technologies varied among the sample of SC experts and their knowledge from current and previous industrial experiences could limit the applicability of research findings in specific contexts. Therefore, the adoption framework proposed in this study should be considered based on its limitations as a specific model for Industry 4.0 technology adoption in the MSC.

To recommend for future studies, the findings of this research should pave the way for further investigation given Industry 4.0 is an emerging novel concept. This research could be further extended to emerging market contexts and other sectors, industries, and geographies for further empirical pieces of evidence to validate the findings. To strengthen the generalizability, a survey based on a large sample size could be useful. A longitudinal approach with a larger sample size could highlight interesting findings.

This research mostly focused on identifying and evaluating drivers, barriers, and innovative practices in Industry 4.0 adoption. Hence, how industry 4.0 technologies will be adopted was not considered as it was out of the scope of this research. Therefore, the application of this framework for adopting specific technologies could be helpful for further investigation of theory and practice. Whether digital transformation could lead to sustainability in the manufacturing supply chain could also be a focus for further study. Thirdly, this study focus was on SC in general and did not consider different areas of the MSC; namely, all processes from procurement, logistics, fulfilment etc (Tjahjono et al; 2017). Nevertheless, this research has moved one step towards this direction with a more general focus. Therefore, to

quantitatively and/or qualitatively analyse the impact on different areas of the SC by adopting the proposed framework could be an interesting area for future research.

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