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Defining and Assessing Industry 4.0 Maturity levels - Case of the Defence sector.

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Abstract

The development of more digitalised environment is transforming the future of manufacturing. This is known as Industry 4.0. Firms do not currently fully appreciate the complex characteristics of Industry 4.0 and as a result are uncertain about what it represents for them and indeterminate as which initiatives could be beneficial to their business. In this study, an assessment model is developed to measure the level of implementation of Industry 4.0 technologies, around three dimensions 'Factory of the Future', 'People and Culture', 'Strategy'. The 'Factory of the Future' is the main dimension and is composed of eight attributes: Additive Manufacturing, Cloud, Manufacturing Execution System, Internet of Things and Cyber Physical Systems, Big Data, Sensors, e-Value Chains, and Autonomous Robots. The assessment tool measures firms' maturity in these three key dimensions, which add up to produce an overall Industry 4.0 score. The study uses a defence manufacturing firm to develop, test and validate the model and report on 12 partners. We concluded that the focal firm has an Industry 4.0 maturity level of 59.35, above the sector average of 55.58. This research contributes to the field by empirically developing and testing a model and providing a clear analysis of major firms in the Defence supply network.

Keywords: Industry 4.0; Maturity assessment; Defence sector.

Defining and Assessing Industry 4.0 Maturity levels - Case of the Defence sector.

1. Introduction

The future of manufacturing organisations is being transformed globally by the development of a more digitalised environment where value chains are connected and production systems are increasingly intelligent, autonomous and automated (Fatorachian and Kazemi, 2018; Schumacher, Erol & Sihn, 2016). These advancements are anticipated to realise huge improvements in the flexibility, efficiency and automation of manufacturing. They are welcomed by manufacturing organisations who are continually aiming to "*eliminate unnecessary production costs; improve manufacturing process and business performance; increase throughput; reduce cycle times and maintain quality*" in order to operate in changing manufacturing environments (Cottyn, Van Landeghem, Stockman & Derammelaere, 2011, p.4397). Prause and Weigand (2016) support the premise of these challenges and suggest that the changing demographics, globalisation, scarcity of resources, and dynamic technologies are key drivers, which affect the manufacturing sector and force radical change to ensure sustainability and progression. Furthermore, global competition and customer changes to product requirements and specifications have resulted in shorter, unpredictable life cycles, driving businesses to adopt new technologies to cope with customer demands such as products at low cost and high volumes, with greater customisation (Souza das Neves, Silva Marins, Akabane & Kanaane, 2015).

To respond, changes and innovations are ineluctable. Manufacturing leaders believe these changes come in the form of the next Industrial Revolution known as Industry 4.0 (EEF, 2016; Fatorachian and Kazemi, 2018). Industry 4.0 is seen to represent the transformation of organisations to digitalise their entire manufacturing process. This could include machines, people, infrastructure and new technologies such as blockchain to create fast, seamless, innovative, automated and interconnected networks, leading firms to develop e-value chains (Pulevska-Ivanovska & Kaleshovska, 2013; Schwab, 2017; Tapscott & Tapscott, 2016). It has been predicted that Smart Factories will soon be conventional, incorporating smarter products, smarter production and smarter supply chains (Gilchrist, 2016; PWC, 2016). Industry 4.0 relies on technological concepts such as the Cloud, Internet of Things, Cyber Physical Systems, Big Data, Additive Manufacturing, Artificial Intelligence, and Autonomous Robots (Fatorachian and Kazemi, 2018; Schumacher, Erol & Sihn, 2016). Erol *et al*., (2016) states that academics and practitioners envisage that the introduction of Industry 4.0 concepts will enable significant efficiency benefits for the entire supply network and firms may also become more predictive and resilient (Lucke, Constantinescu & Westkämper, 2008). This 'revolution' is not seen to be just limited to the developed economies but is a global movement, which organisations cannot afford to ignore (EEF, 2016; Rayna & Striukova, 2016). However, the 4th Industrial Revolution is bringing relatively new concepts and technologies (Lasi & Kemper, 2014; Jiang, Kleer & Piller, 2017) and is leaving a large proportion of firms to be unclear as to the effects and impacts it will really have for their business (Schuh, Potente, Wesch-Potente, Weber & Prote, 2014; Qin, Liua & Grosvenora, 2016).

Firms that are actively seeking to develop their Industry 4.0 status and strategies must begin with understanding their current level of maturity in their specific context or supply network. This will allow them to determine their areas of weakness and strength, prioritise improvement opportunities and manage development plans (Becker & Knackstedt, 2009). Nonetheless, as Schumacher *et al*., (2016) suggest, most manufacturing organisations do not have the understanding or capability to assess their Industry 4.0 maturity level due to the lack of definitions, consensus and measurement tools (Schwab, 2017; Gilchrist, 2016). Hence, to support firms in evaluating their progression, assessment frameworks and models are recommended (Proenca & Borbinha, 2016). The aim of this study is to develop an assessment framework and to measure the Industry 4.0 maturity of a focal firm: a leader in the defence sector, and compare it against 12 organisations within its supply network. The assessment revolves around three major dimensions: 'Factory of the Future' (composed of 8 technological innovations: Additive Manufacturing, Cloud, Manufacturing Execution System, Internet of Things and Cyber Physical Systems, Big Data, Sensors, e-Value Chains and Autonomous Robots), 'People and Culture' and 'Strategy'.

2. **Literature Review**:

2.1 Industry 4.0

The industrial world has experienced three significant eras in its history (three industrial revolutions) and according to various sources (Prause & Weigand, 2016; Schumacher, et al., 2016) is at the edge or is embarking on its fourth transformation : the 4th Industrial Revolution. According to Dombrowski and Wagner (2014) the categorisation of a new Industrial Revolution constitutes a significant change in the technical, economic or social systems within the industry, a paradigm shift in the production model. The terminology 'Industry 4.0' appears to have been initiated in Germany at the Hanover Fair event in 2011, representing the start of the 4th Industrial Revolution (Lee, 2013). Other countries have adopted similar terminologies i.e.: USA with 'Industrial Internet' and China with 'Internet +' (Wang, Wan, Zhang, Li & Zhang, 2016). The term Industry 4.0 is stated as one of the most popular topics for the global manufacturing sector within both industry and academia (Kagermann, Helbig, Hellinger & Wahlster, 2013), however, the academic literature on this topic remains scarce (Qin, Liu, & Groscenor, 2016). Prause and Weigand (2016, p.104) define Industry 4.0 as the *"combination of cyber physical systems with automated systems"* with the objective to create context-aware manufacturing facilities in which people and machines are in real-time alignment. A vision stated by Monostori (2014) is to have a manufacturing division, which has its machines, products and entire production facilities connected and integrated to enable partial or full automation that requires minimal or none manual operations. It is also envisioned to include *"technological concepts and solutions which will enable a combination of the economy of scale with the economy of scope"* (Dombrowski & Wagner, 2014, 101). Furthermore, according to PWC (2016), Industry 4.0 is the physical digitalisation of all assets within an organisation to create a connected infrastructure combined with partners leading to create an 'e-value chain'. The term Industry 4.0 not only applies to individual companies but also to the entire supply chain (Lanza, Haefner & Kraemer, 2015). Hermann (2015) describes two 'design principles', which are enablers to the Industry 4.0 revolution: interoperability and consciousness. Interoperability consists of communication, standardisation, flexibility and communication; whereas consciousness incorporates predictive maintenance, intelligent presentation and standardisation. Moreover, Qin *et al*., (2016) suggest there are four key elements impacted by Industry 4.0: customer's relationship, factory and production management, product design and fabrication, and business processes. Lucke *et al*., (2008) describe the idea of a Smart Factory as a network of systems, which are aware of their environment, able to assist other machines and people in routine tasks by utilising 'calm systems' while working in the background. Factories are likely to become more connected via the synchronisation of different automated systems, allowing to becoming more predictive and resilient (Lucke *et al*., 2008). This transformation leads to radically change the way firms interact with their suppliers and customers, altering the nature of business processes. It is anticipated that a positive communication network will be established between related businesses by sharing real-time status for mutual benefit. Product designs will change by incorporating embedded sensors/components capable of storing data to support production processes, quality assurance and customer experience. Lasi and Kemper (2014) describe a vision for future production, they believe organisations will develop modular products and implement manufacturing systems, where products have the ability to control their own manufacturing process. This ideology is expected to enable the manufacture of individual products in a batch size of one while maintaining the economic conditions of mass production. Stock and Seliger (2016) support the idea of true mass customisation within industry and advocate involving the customer early during the product life cycle.

According to Fatorachian and Kazemi (2018), Lanza *et al*., (2015) and Roden *et al.*, (2017) the people and cultural aspects should also be considered when assessing Industry 4.0, as it will impact and be influenced by values such as openness in the way data are managed, the ability of the workforce to adopt new technology, continuous improvement, innovation and communication. Schuh *et al*., (2014) makes a comparison between previous Industrial Revolutions and Industry 4.0. They argue that the fourth Industrial revolution has a wider bearing within the entire value chain to maximise productivity, efficiencies, innovation, creativity and sustainability performances. This is significantly different to the previous Industrial Revolutions which predominantly changed the effectiveness of 'shop floor' based activities rather than extending the benefits to supporting functions such as design, engineering, supply chain or finance and marketing. Such a radical change or paradigm shift in manufacturing firms will no doubt lead to increased complexity of production process at a micro and macro level (Schuh *et al.*, 2014). Hence, this should naturally be translated within the strategy and the product range of a firm, demonstrated by larger investment in the digitalisation technology, IT infrastructure and the ability to increase its agile production and supply chain systems.

Schumacher *et al*., (2016) suggest that organisations are finding it difficult to relate the Industry 4.0 vision into the business in order to provide significant benefits to justify the large financial investment. Qin (2016) implies that the general population of manufacturing companies are disordered and disorganised with what Industry 4.0 brings and the challenges it introduces. Nonetheless, there are eight key technological components that are consistently linked to operationalize Industry 4.0.

2.1.1 Additive Manufacturing or 3D Printing

Additive Manufacturing or 3D-Printing is a process by which products are created on a layer-by-layer basis, using a collection of cross sectional layers (Berman, 2012; Rayna & Striukova, 2016). There are two main techniques used in industry, one method uses powder, which is built up layer-by-layer and the other uses thin layers of resin, which are solidified by ultraviolet (UV) light to create a solid structure. Typically, the products produced are designed using universal 3D CAD software tools (Casey, 2009). The popularity of 3D-Printing machines has been growing across industries, originally to support R&D activities within organisations; however, based on the 18 projections made by Jiang *et al.,* (2017) the 3D-Printing impact will be much more substantial by 2030. The attractiveness of 3D-Printing machines has been driven predominately as a result of the affordability in comparison to rapid prototyping machines (Baumers, Dickens, Tuck & Hague, 2016; Jiang *et al.*, 2017). These printing systems have been linked to the developing idea of 'mass customisation' within the Industry 4.0, whereby an organisation would have the ability to quickly and economically manufacture bespoke parts for specific product lines (Berman, 2012). Thilmany (2009) explains 3D-Printing will be going through a three-stage evolution. Phase one consists of operators of the machine creating mock-ups and development prototypes in a research and development environment. Phase two involves organisations using the technology to produce parts to be used as 'finished goods'. These products may be used for tooling or early prototypes with better functionality. Phase three expects 3D printers being used by the end customer to produce parts required within the home or business context, e.g.: parts for cars or computers. 3D-Printing capabilities have offered the opportunity for Aerospace, Medical and Automotive industries to trial complex geometric structures that conventional manufacturing techniques may find difficult to produce (Bogue, 2013). However, it has been stated that there is still a long way to go before products produced on 3D-Printers will be able to integrate with safety critical products, due to issues related to material strength, longevity, resistance to heat and moisture and precision (Petrovic, Gonzalez, Ferrando, Gordillo, Puchades & Griñan, 2011). The work of Gebler *et al*., (2014) shows that as 3D-Printing becomes more popular for the actual production of products in industries such as aerospace and medical equipment, the balance of offset/offload labour will shift, with the predominate source of production taking place in the consumer country.

2.1.2 Cloud

The term 'Cloud Manufacturing' can be represented by a combination of various IT packages including: Internet Services, Web Based Application and System Management (Helo, Suorsa, Hao & Anussornnitisarn, 2014). Lan (2003) describes Cloud-Based solutions as a Web Based application of which information is stored on external servers and is primarily accessible via the Internet. Ren et al., (2017) describes the philosophy of Cloud Manufacturing as a 'smart networked manufacturing model', which supports product individualisation, greater global collaboration, knowledge intensive innovation and a quicker ability to respond to market trends. Xu (2012) explains Cloud Manufacturing is set to transform the manufacturing organisation from Production Oriented Manufacturing to Service Oriented Manufacturing. Thames and Schaefer (2016), describe Cloud Manufacturing as a Networked Manufacturing System, which uses free access to common, diverse and varied collection of manufacturing resource. They explain that these resources enable temporary cyber-physical production lines, which have more advance efficiency gains, lower unit production costs and better-utilised physical resources to respond to customer demands on a flexible basis (Li, Zhang, Wang, Tao, Cao & Jiang, 2010). The Cloud enables organisations to virtually store and organise their production resources within a central location in order for a shared platform to allow all partners to access this information, real-time in a collaborative method (Hao & Helo, 2015). These advancements in 'connectability' between customers and suppliers are critical to the success of the e-value chain concept.

2.1.3 Manufacturing Execution Systems (MES)

Software companies have developed what is being called Manufacturing Execution Systems (MES), to provide data management capabilities and a 'common user interface' for operators, which bridge the gap between automated production capabilities and the organisations ERP system (Choi & Kim, 2002). Saenz de Ugarte *et al*., (2009, 526) define a MES as: "*a system that delivers information to optimise production activities from order launch to finished goods, using current and accurate data. A MES guides, initiates, responds to and reports on plant activities as they occur. The resulting rapid response to changing conditions, coupled with a focus on reducing non-value-added activities, drives effective plant operations and processes. The MES improves the return on operational assets as well as on-time delivery, inventory turns, gross margin and cash-flow performance*". Valckenaers *et al*., (2007) describes MES as a system, which reflects reality to an adequate level, enabling production management teams to track, monitor and command all manufacturing activities. Furthermore, the tool offers organisations the ability to control inventory and provides functions to assist management planning (Helo, Suorsa, Hao & Anussornnitisarn, 2014). Hwang (2006) states that MES performs a central distribution of data role within the heart of the production system, collecting, processing, analysing and acting upon materials, products and equipment data.

2.1.4 Internet of Things (IoT) and Cyber Physical Systems (CPS)

Shaev (2014) defines the Internet of Things to be a process of changing the nature of information and network technologies in the world today to seamlessly unite people and things. Shaev (2014) expands by suggesting the Internet of Things optimises connectivity, not just the connectivity of people but also that of machines and devices. It is suggested this concept incorporates the perfect blend of sensors and objects communicating seamlessly using a common platform to benefit various users (Yang, Yang & Plotnick, 2013). The optimisation of existing networks combined with the establishment of smart connectivity is described as a critical element to the success of the Internet of Things concept (Gubbi, Rajkumar, Slaven, & Marimuthu, 2013). There are three important enablers which should be established to facilitate the introduction of the Internet of Things: i) machines and the users distribute information about their live situation, ii) the availability of software architectures and universal communication systems to process and distribute information to where it is required, and iii) the processing and analysis tools in the Internet of Things that aim for independent and smart performance. Gilchrist (2016, p58) states the main aim of the Internet of Things is to "*provide enough connectivity and functionality to enable a computer system to sense information autonomously without the interaction of humans*". As Fatorachian and Kazemi (2018) explained the Cyber Physical Systems enable fast and reliable data exchange for effective communication between the different systems: machines and products as well as humans.

2.1.5 Big Data

Intrinsic to the development of Industry 4.0 are two important aspects, the availability and the manipulation of Big Data (Gu, Jin, Ni & Koren, 2015). As a result of developments in the manufacturing industry, organisations are now utilising more complex manufacturing processes, equipment and products, and are therefore obtaining more data (Windmann *et al*., 2015; Pethig, Kroll, Niggemann, Maier, Tack & Maag, 2012). It is believed that successful implementation of the Smart Factory concept requires the combination of smart machines and products with big analytical data abilities. Wang *et al*., (2016) explains this will initiate flexibility and promote efficiency. However, Gu *et al*., (2015) suggests that 95% of data currently generated within manufacturing organisations is unstructured and non-analysed. This type of data does not currently add value to manufacturing organisations without the capability. However, Roden *et al.,* (2017) have illustrated the potential of Big Data in four cases: Ebay, Volkswagen, Philips and Walmart comparing its role and impact on the different components of a firm operational model.

2.1.6 Sensors

The Industry 4.0's vision presents a manufacturing system filled with sensors integrated into processes and equipment in order to retrieve, monitor and report information to the user or decision-makers (Babiceanua & Sekerb, 2016). The application of smart sensors provides a foundation for connecting the products, equipment and physical facilities within the cyber world of Internet Applications and the Software Environment (Babiceanu & Seker, 2015). The introduction of smart sensors into manufacturing organisations can provide numerous benefits, one of which is the idea of predictive maintenance.

2.1.7 e-Value Chains

Becoming more digitalised offers organisations the opportunity to become more connected, smarter and highly efficient within their supply chains (Schrauf & Berttram, 2016). The introduction of digitalisation within organisations is helping to overcome previous barriers between key partners and starts to create e-value chains, which connect the entire supply network from suppliers, to distributors to the end customers (Schrauf & Berttram, 2016). Pulevska-Ivanovska and Kaleshovska (2013) in their paper provide a deep insight into the concept of e-supply chain, which can be considered as the precursor of the e-value chain concept. If the internet enabled to develop agile and flexible information systems that led partners organisations to share data and optimise their supply chains (Giménez & Lourenço, 2008; Pulevska-Ivanovska and Kaleshovska, 2013); the aim, within Industry 4.0, is to focus on the value creation and optimisation via the application of these new technologies. For instance, by combining additive manufacturing, sensors, IoT and Big Data, a worldwide distributed network of firms will be able to predict, manufacture and serve a bespoke demand for a specific item almost in real time (Lee, Kao & Yang, 2014). Furthermore, Schwab (2017) expresses that firms that focus on establishing an e-value chain will have a unique insight on their customers and asset performances, which will enable to develop a platform for R&D, marketing, sales and distribution and optimise the quality, innovation, speed and cost of their products and services. In the future, robust e-value chains will need also to rely on Smart Contract and the Blockchain technology (Tapscott & Tapscott, 2016). McKinsey (2016) explains that organisations will show signs of improvement as a result of the introduction of smart or e-value chains. They will provide the ability to manage suppliers in more detail and have complete transparency between suppliers and customers, improving suppliers' network by becoming more resilient, flexible and agile. Pearson (2013) explains that e-value chain will enable firms to have the ability to reduce lead times, minimise inventory costs, enhance customer experience and optimise supplier performance by integrating data from the entire value chain in real time with great accuracy. The availability of real-time data between customers and suppliers and the associated transparency will become more frequent as the revolution develops and becomes more widely used. Furthermore, through the advancement in technology and organisations adopting Industry 4.0 concepts and technologies, the methods by which businesses manage their supply chains will be changed drastically and enable manufacturers to achieve true mass customisation (Geissbauer, Weissbarth & Wetzstein, 2016) especially with the enhanced use of 3D-Printing.

2.1.8 Autonomous Robotics

A high proportion of automation for machines and robots is required in order to achieve the efficiency and effectiveness gains predicted within the Industry 4.0 revolution (Wu, Greer, Rosen & Schaefer, 2013). Gray (2016) states that advanced robotics are one of the critical activities developing within the manufacturing industry. Advanced robots also known as collaborative robots (cobots) are a key enabler for the introduction of Industry 4.0. Pfediffer (2016) agrees, emphasising that smart robots, embedded with sensors, dexterity and increased artificial intelligence and machine learning, is one of the key technologies driving the progress of the Industry 4.0 revolution. The use of automation within manufacturing industries is enabling organisations to deliver more output than what they would normally be capable of doing (Gray, 2016). The use of autonomous robots is vastly improving the productivity of the automotive industry by being faster, stronger and more precise than human workers (Better Policies for Better Lives, 2016). Furthermore, autonomous robots have been found to be more practical than humans in some instances (Pfeiffer, 2016). Although, Markoff (2016) acknowledges the importance of master craftsmen within some industries and provides an example stating that Toyota had tried to eliminate the human interaction within the manufacturing process entirely, but found the need for master craftsmen was essential. One of the opportunities provided by autonomous robots, which links to an objective of Industry 4.0, is the ability for organisations to implement mass customisation (UK Network, 2016). Lorentz *et al.*, (2015) details the advancements in autonomous robots and describes how they can now imitate the actions of humans, work autonomously, are consciously aware of their surroundings and adapt to unexpected scenarios. As advancements in robot technology progress, the range of a robot's capability increases (Gray, 2016). Today, robots are not only used for the highly repetitive, low-skilled jobs but are now being implemented in medium skilled, highly routine activities (UK Network, 2016).

2.1.9 Summary of the technological concepts

Table 1 below summarises these 8 key technological concepts behind Industry 4.0 and acknowledges some of the main studies.

Factory of the Future practices	Studies	Description and Characteristic
Additive Manufacturing - 3DP	Berman (2012); Bogue (2013); Gebler, Uiterkamp & Visser, (2014); Jiang, Kleer & Piller (2017); Rayna & Striukova (2016); Schniederjans (2017); Thilmany (2009).	Additive Manufacturing is a process by which products are produced autonomously layer-by-layer. Additive manufacturing is a key technology to enable mass customisation through the ability to produce bespoke parts quickly, combined with the transformation in customer supplier relationship with customers having the ability to produce their own spare parts, plus the ability to avoid purchasing new capital equipment for new product introduction. The technology is more commonly used for rapid prototyping and the creation of bespoke tooling.
Cloud	Helo, Suorsa, Hao & Anussornnitisarn, (2014); Lan et al (2003); Ren et al., (2017)Thames and Schaefer (2016); Xu (2012).	Cloud is describes as a web-based application of which information is stored on external servers. It is represented by three IT combinations: Internet Service, Web Application and Information Management. Cloud manufacturing relates specifically to the Industry 4.0 concept. It acts at the backbone to support the Internet of Things, MES and the connectivity of sensors. The cloud manufacturing concepts creates a central platform which allows common access to data from across the e-value chain to enable flexibility efficiency gains.
Manufacturing Execution System (MES)	Choi and Kim (2002); Hwang (2006); Saenz de Ugarte, Artiba & Pellerin (2009); Souza das Neves, Silva Marins, Akabane & Kanaane, (2015).	MES provides data management capabilities and a ‘common user interface’ for operators. A MES system is a useful tool for organisations that have a demand for accurate traceability of component parts and assembly activities to monitor quality, cost and lead time. A MES system also provides a central distribution of information role.
Internet of Things & CPS	Fatorachian and Kazemi (2018); Gilchrist, (2016); Gubbi et al (2013); Lopez, Ranasinghe, Harrison & McFar (2012); Shaev (2014); Yang et al (2013).	The Internet of Things is described commonly as the connectivity of ‘Things’ within manufacturing. The term ‘Things’ fundamentally represents anything within the manufacturing environment: products, people, machines, or parts. The concept is enabled through the application of smart sensors. To enable the success of the concept, a common platforms and Cyber Physical systems are used to create an environment were all things are connected.

Big Data	Babiceanu & Seker, (2015 ; 2016); Erol et al (2016); Gao et al (2015); Gu et al (2015); Roden et al (2017);Windmann et al (2015).	The availability and interrogation of data is a key feature of Industry 4.0. Through the advancements in technology, the readiness of data is common, however the collection, analysis and presentation of this data is rare within organisations. The use of data enables the ability to effectively plan, control and respond to production processes, systems and networks. The literature suggested 95% of data generated within manufacturing organisations is not processes and used effectively.
Sensors	Babiceanu & Seker (2015); Brintrupa et al (2010); Vadde, Kamarthi & Berry (2005); Valckenaers, Van Brussel, Verstraete, & Saint Germaine (2007).	The use of smart sensors within manufacturing organisation enables the generation of important and useful data, which can then be retrieved, monitored and reported to the user. Sensors also provide the platform for digitalising 'things' to support the Internet of Things concept. A common sensor used within manufacturing organisation is the RFID sensor, which is used to collect and transmit data back to a common platform like the manufacturing cloud.
e-Value Chains	Geissbauer, Weissbarth & Wetzstein (2016); Glas (2016); McKinsey (2016); Ronchi, Brun, Golini & Fan (2010); Schrauf & Berttram (2016).	The e-Value Chain concept is enabled through the Industry 4.0 concepts which support digitalisation and therefore allow seamless connectivity, collaboration and cooperation between supplier and customer. This concept also includes the concept of Procurement 4.0 which reduces lead times, inventory costs, customer experience and supplier performance by integrating data from the entire value chain. Connectivity across the value chain provides opportunities for transparency to create a live environment to support the customer and supplier activities.
Autonomous Robots	Gray (2016); Lorentz et al (2015) ; Markoff (2016) ; Wu et al (2013);	Autonomous or Smart Robots are described in the literature as a key part of Industry 4.0 success. The use of Smart Robots is increasing throughput, product quality and reducing unit production costs. In some instance the use of Smart Robots is more practical than humans. Advancements in the activities robotics delivers has transformed from repetitive low-skill work to repeatable medium-skill work. This concept is also supporting the Industry 4.0 objective of mass customisation. Advancements in robotics allow the systems to imitate the actions of humans, work autonomously, are consciously aware of their surroundings and adapt to unexpected scenarios.

2.2 Industry 4.0 Assessment and Maturity Models

It has been stated within the literature that manufacturing organisations do not have the understanding or capability to assess their own Industry 4.0 level and/or maturity (Schumacher, Erol & Sihn, 2016). Qin *et al*., (2016) suggest that the criteria which define the successful implementation of Industry 4.0 have yet to be fully agreed and that a roadmap would clarify the path to Industry 4.0. Even if, Schumacher *et al*., (2016) identify nine characteristics: Strategy, Leadership, Customers, Products, Operations, Culture, People, Governance and Technology to determine the maturity of the Industry 4.0 concepts within organisations.

Becker and Knackstedt (2009) suggest maturity models have been proven to be an important instrument as a result of their ability to position organisations against the concept being assessed and help find better solutions for change. Maturity assessment models are described as a framework for systematic and continuous performance improvement (Langstone & Ghanbaripour, 2016). Backlund *et al*., (2014) support this by suggesting the capabilities of an organisation can be managed as a framework and thus be measured for maturity.

There are two Industry 4.0 assessment models developed and published by consulting firms: IMPULS and PWC both in 2016. These two assessment models use slightly different methods to analyse the implementation of Industry 4.0 concepts within an organisation. The first model offered by IMPULS provides feedback on an organisations preparation for Industry 4.0 and delivers improvement advice. This model is characterised by six foundations: 'Strategy and Organisation, Smart Factory, Smart Operations, Smart Products, Data Driven Services and Employees'. Within these six categories the model scores an organisations progress on a scale of 0-5. After completion of the model, the organisation is ranked according to its progress by six levels: Outsider (0), Beginner (1), Intermediate (2), Experienced (3), Expert (4) and Top Performer (5).

The second model developed by PWC offers organisations an opportunity to understand where they are on their journey within the Industry 4.0 and provides advice on the next steps. This model uses six different categories to analyse the organisation: 'Business Models, Product & Service Portfolio, Market & Customer Access, Value Chain & Processes, IT Architecture, Compliance, Legal, Risk, Security & Tax and Organisation & Culture'. The model requires users to self-assess the organisation by interpreting the state of maturity on a scale of 1-5, followed by indicating a target maturity level on a scale of 1-5. Subsequent to completion of the model, the organisation is categorised depending on maturity, into four sections: Digital Novice, Vertical Integrator, Horizontal Collaborator and Digital Champion.

However, it is felt that there is a gap in the academic sphere enabling assessing and reporting the level of practices that firms demonstrate against the major Industry 4.0 technological constructs. The published academic and scientific literature is still limited and at its pre-paradigm stage (Brettel *et al*., 2014; Lee *et al*., 2014; Qin *et al*., 2016; Robleck *et al*., 2016). Moreover, governments and policy makers have echoed researchers and call for shedding some light on these new technologies (Great Britain, Department for Business, Energy and Industrial Strategy, 2017). In particular, the ability to gauge and measure a consolidated Industry 4.0 implementation strategy rather than a singular topic area i.e. 3D printing (Schumacher *et al.*, 2016), which is the aim of this study. Hence, starting from the available literature and the consulting frameworks, the following model was created around the three main dimensions and 13 key attributes, as per Figure 1, which is used to assess the maturity of a defence manufacturing world leader and 12 other firms in its supply network. The 'Factory of the Future' dimension of the framework focuses specifically on the eight key technologies and concepts behind Industry 4.0 (Brettel *et al*., 2014; PWC, 2016; Qin *et al*., 2016). These were each identified within the literature as key attributes of Industry 4.0. The 'People and Culture' dimension is a fundamental part of implementing Industry 4.0 due to the value and power of the people within organisations (Schwab, 2017). A culture of innovation and continues improvement is one which embraces change and thrives at new opportunities (Fatorachian & Kazemi, 2018; Lanza *et al*., 2015; Roden *et al.*, 2017; Stock & Seliger, 2016). Finally, a robust and clear strategy, an ambitious and well thought out technology investment plan and an agility vision as are also important characteristics of an organisation Industry 4.0 maturity (Erol *et al.*, 2016).

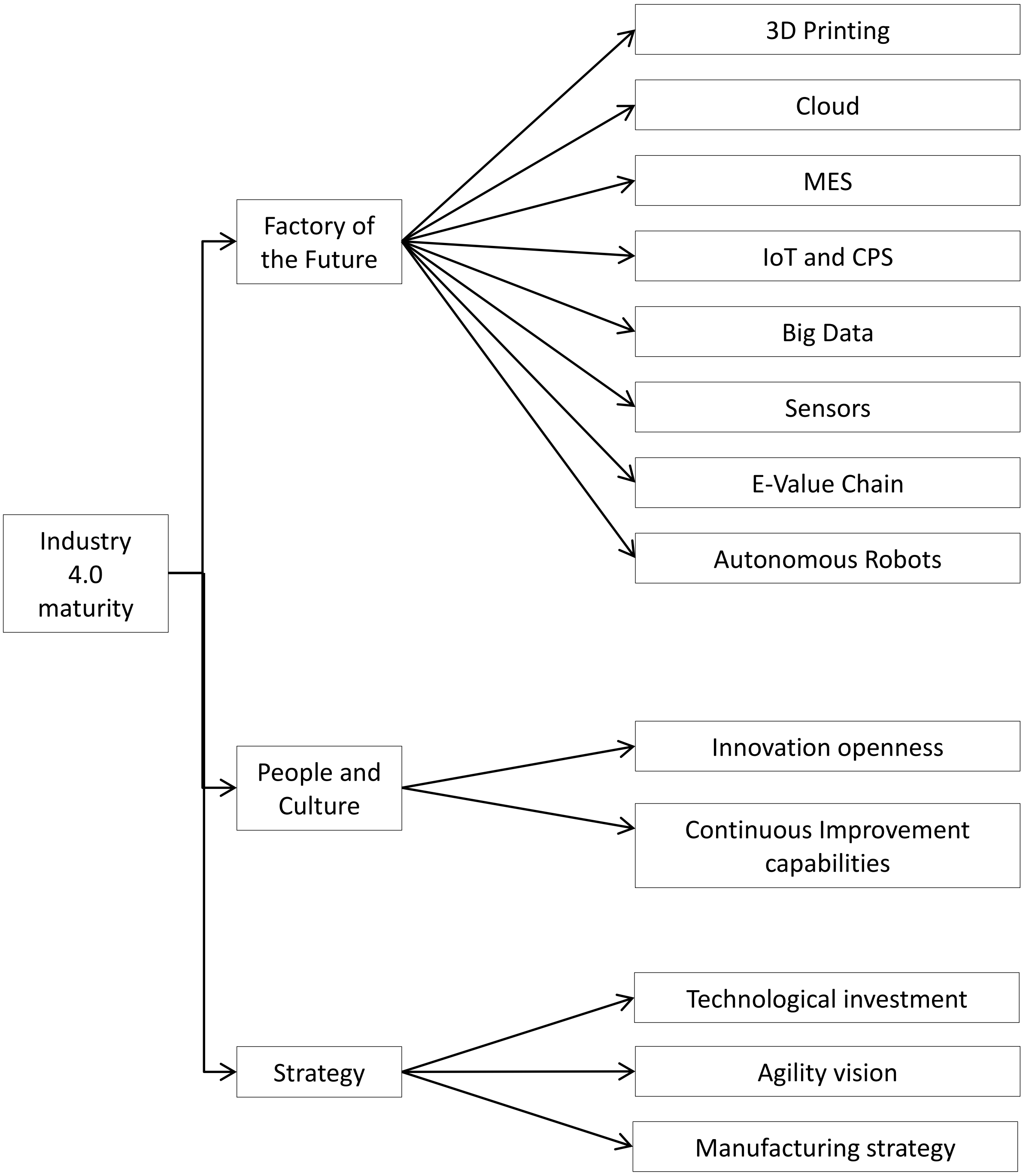

Figure 1. Industry 4.0 conceptual framework.

2.3 Technology Adoption in the Defence Sector

The effective and fast adoption of these new digital technologies and implementation into manufacturing processes are critical in order to optimise the suggested gains offered by Industry 4.0 (Ebner & Bechtold, 2012). Ebner and Bechtold (2012) discuss the differences between sectors and their ability to embrace technology evolutions. It is suggested that the automotive industry is capable of adopting new technologies and of transforming quicker than the defence and aerospace sector. However, the defence sector has traditionally been at the technological forefront (Boddy, 2017; Bitzinger, 2015), due to a range of internal and external parameters, the culture and people as well as the overall strategy.

Hence, this leads to set the research question: *How and to what extent can the current maturity level of Industry 4.0 be assessed within the defence sector?*

3. Methodology

The study sets out to research, investigate and assess the advancement or maturity of Industry 4.0 concepts within the defence sector, as per the aforementioned research question. To do so, the study utilises a combination of data collection methods including: semi-structured interviews, workshops and items scoring, which are embedded within a case-study logic, in order to test and validate the model leading to generate the empirical data of the study (Dehe & Bamford, 2015). Voss *et al*., (2002) describe case studies as a useful technique for exploring a phenomenon or in a theory building research. Furthermore, Yin (2003) suggests the use of case studies as a research method to create a sound platform to develop knowledge and shed some light in a specific area, which is the rationale and objective of this research. Hence, both qualitative and quantitative data were gathered and analysed during the study.

The main contribution of the research is based on the findings from the focal firm, a world leader in the defence sector with a workforce of between 1001 and 5000 employees and a revenue exceeding £ 500 Million based in the UK. The company was used as the test-bed, to validate the model and derive from it its maturity assessment tools (IMPULS, 2016; Goodson, 2002; PWC, 2016). Three iterations of the tool were generated before the maturity assessment items were presented to 20 employees within the focal firm during a workshop and the feedback was gathered and the framework modified accordingly.

Once the model was validated and accepted, 14 experts from within the focal firm were asked to complete the maturity assessment for the organisation. Table 2 details the expert selection and the justification for their participation in the study. The experts selected have been approached specifically based on their wide knowledge of the firm's manufacturing processes and strategies, as well as their ability to visit, access and communicate with the external organisations. This led to the focal firm maturity assessment results.

Table 2. List of the 14 selected experts

Title	Quantity	Justification for Selection
Principle Manufacturing Engineering	2	Chosen for their knowledge of Industry 4.0, and their ability to access external manufacturing organisations.
Principal Supply Chain Engineer	3	Chosen for their Industry 4.0 understanding and their ability to take a Supply Chain overview.
Manufacturing Systems Controller	3	Chosen for their basic Industry 4.0 knowledge and their ability to take an objective overview of the tool.
Senior Manufacturing Engineer	2	Chosen for basic Industry 4.0 knowledge and their ability to access other organisations.
Head of Manufacturing	1	Chosen for their Industry 4.0 knowledge and their ability to gain access to other manufacturing organisations.
Procurement Manager	2	Chosen for their Industry 4.0 knowledge and their ability to gain access to other manufacturing organisations.
Industrial Validation Manager	1	Chosen for their Industry 4.0 knowledge and their ability to gain access to other manufacturing organisations.

The rating scales used a Likert scale scoring system from 1 to 5; ‘1’ being the lowest possible score to ‘5’ being the highest possible score.

After each section of the maturity assessment (‘Factory of the Future’, ‘People and Culture’ and ‘Strategy’) the scores are aggregated to provide a total score. At the end of the assessment model the scores from each section are then used in relation to an Industry 4.0 Maturity table, as per Table 3. For each section of the model, the minimum and maximum scores were determined and then divided to make four equal maturity bands: ‘Minimal’, ‘Development’, ‘Defined’ and ‘Excellence’. ‘Factory of the Future’ had 16 Likert scale items, the points can range from 16 to 80. ‘People and Culture’ had 3 items, the points range 3 to 15. Finally, ‘Strategy’ had 4 items, so the points range from 4 to 20.Table 3 shows the final scoring bands to represent Industry 4.0 maturity. At the present moment it was assumed that a linear relationship exists between the categories. However, with 16 items the ‘Factory of the Future’ is the most important area, which is in line with our interpretation of the literature.

Table 3. Maturity Scale

	Level 1: Minimal	Level 2: Development	Level 3: Defined	Level 4: Excellence
Factory of the Future	16-32	33-48	49-64	65-80
People and Culture	3-6	7-9	10-12	13-15
Strategy	4-8	9-12	13-16	17-20
Overall	**23-46**	**47-69**	**70-92**	**93-115**

A score between 23 and 46 would lead a firm to have a Minimal level, not exposing any technical or behavioural attribute linked to Industry 4.0. A total score between 47 and 69 would be associated with the Development level, where some of the practices are visible with clear intention to develop this further. A total score between 70 and 92 would indicate a Defined level, with well-established practices and behaviour. Finally a score between 93 and 115 would indicate aspect of best practice or excellence as described in the Literature Review section.

Finally, 12 partnering firms were selected, based on their relative importance to the focal firm. The data collected and assessment of these partners' organisations was made in collaboration between one of the experts from the focal firm and the head of manufacturing or their equivalent within the external organisations. The score recorded was based on their consensus (Dehe & Bamford, 2017).This enabled building certain robustness and confidence in the assessment. The collation of the data allowed benchmarking the Industry 4.0 practices against each other and with the focal firm. Hence, the framework was used by the focal firm to assess the maturity of 12 of their major supply network partners. The rationale was to appreciate how was Industry 4.0 understood within their network and shed some light on this technological phenomenon from a supply network perspective. Table 4 below provides details about the profile of these 12 partners' organisations.

Table 4. Sample of the 12 Partners Firms

sample	**focus**	**workforce**	**revenue**
P1	Defence	5001+	> £ 500 M
P2	Engineering/Metrology	1001-5000	£ 250-500 M
P3	Digital signage	51-100	£ 1-10 M
P4	Defence	1001-5000	> £ 500 M
P5	Aerospace	51-100	£ 1-10 M
P6	Defence	1001-5000	£ 250-500 M
P7	Defence	1001-5000	> £ 500 M
P8	Defence	101-300	£ 10-50 M
P9	Defence	301-1000	£ 50-100 M
P10	Aerospace	1001-5000	> £ 500 M
P11	Defence	5001+	£ 250-500 M

P12	Defence	101-300	£ 100-250 M

4. Maturity Assessment Findings

4.1 Maturity Assessment Results – focal firm

The 14 respondents within the focal firm completed the Industry 4.0 maturity assessment, which led to the results compiled in Table 5. The results show that the Industry 4.0 maturity level of the focal firm was (39.08 + 8.49 + 11.78) = 59.35 points. This would position the firm in the Development segment (level 2) of the maturity model. The 'Factory of the Future' area achieved a score of 39.08; this signifies that the company resides in the Development section of the maturity scale of this criterion. The 'People and Culture' criteria was assessed and scored 8.49 points, which is also equivalent to the Development level. Finally, for 'Strategy', the results also show a score of 11.78 points corresponding to the Development level. Across the three areas, the focal firm was scored at the level 2 of the framework. This means that in term of technology implementation, culture, workforce and strategy, the organisation as a perceived similar level of advancement regarding the Industry 4.0 concepts and does not have any excelling or lacking specific areas.

Table 5 shows the descriptive results and presents each dimension, their associated criteria, as per Figure 1, and the derived items that formed the maturity assessment, which were scored by the experts. The individual score based on the weighted average, and the aggregated and total scores are reported in Table 5.

Table 5. Details of the focal firm assessment results

Area	Criteria	Maturity Assessment items	Score based on the weighted average	Aggregated score	Total score
Factory of the Future	3DP	The organisation uses a 3DP machine for the creation of tooling, prototypes or spare parts	3.93	5	39.08
		The organisation's 3DP machines use metal alloys as its raw material	1.07		
	Cloud	The organisation store information within a cloud network	2.79	4.65	
		Hard resources (e.g. machines and robots) and soft resources (e.g. data, documents & software) are connected to a cloud	1.86		

	MES	The organisation has the ability to see live manufacturing systems and make changes immediately	2.43	6.29	
		The organisation uses digital media to bring information directly to the workforce	3.86		
	IoT & CPS	The organisation uses advanced connectability technology between equipment, products and people	2.93	4.93	
		There is evidence that the organisation has embraced digitalisation for product, parts & machinery	2		
	Big Data	The organisation has the ability to access data quickly and effectively from equipment, products, machines, facilities and systems	2.93	5.86	
		The organisation has the ability to analyse process data in order to make decisions, share information and improve negative trends	2.93		
	Sensors	There is evidence that the organisation is using sensors on products and supplied parts	1.14	3	
		Intelligent sensors are used within the organisation's manufacturing process to support automation	1.86		
	e-Value chain	The level of connectability and collaboration the organisation has with its suppliers is high	2.64	3.71	
		Customers have the ability to access the organisations systems to view manufacturing progress and delivery dates	1.07		
	Autonomous Robots	The organisation's machines have the ability to be run autonomously or via an external system	2.57	5.64	
		The level of automation is evident within the production area	3.07		
People and culture	Innovation openness	There is evidence to suggest the majority of the workforce is familiar with the Industry 4.0 innovations	3.07	5.78	8.49
		The organisation operate using ‘zero paper’ to control, display and transport data	2.71		
	CI culture	There is a sense of continuous improvement culture within the company	2.71	2.71	
Strategy	Technology investment	There is evidence that the organisation is investing in industry 4.0 technology and IT infrastructure	4.07	4.07	11.78

	Agility vision	The organisation has the ability to quickly and easily customise products to a customer's request whilst maintaining the same service quality	2.07	5.14	
		There is evidence of partnering with external organisations related to deploying Industry 4.0	3.07		
	Manufacturing strategy	There is a clear Industry 4.0 roadmap available	2.57	2.57	

Remarkably, for the 'Factory of the Future' criteria, the focal firm demonstrates advanced practices and usages of the Manufacturing Executive System (6.29). The organisation has invested a large amount recently (Circa £3 million) to optimise its purposed built new production site. Moreover, Big Data (5.86) has been a specific area of focus and data analytics systems are currently been deployed to support the firm to capitalise on it, for instance for understanding even more precisely quality statistics and predicting maintenance of machines and products. Autonomous Robots (5.64) has been an area of focused in the past 2 years, especially with the design of the purpose built new factory, realising substantial productivity gain and quality improvement. Finally, 3D-Printing (5) is also certainly a technology that the firm is consciously taking advantage of for prototyping, with the intent to use it for finish product in the near future. On the other hand, it can be noticed from the results that Sensors (3) and the e-Value Chain (3.71) practices are less advanced. The firm has not fully embraced or invested in the sensors technology and could enhance its collaboration by increasing the level of connectivity and the real-time data sharing practice with its suppliers. It seems, understandably, that security is the major barrier preventing the focal firm in enhancing utilisation of these technologies.

4.2 Maturity Assessment Results – External partners

For the assessment to be more relevant and meaningful, 12 partners organisations were identified as being adequate to assess and benchmark their score in order to capture best practices and identify the areas for improvement. The results are summarised in Table 6.

Table 6. External Organisations Industry 4.0 Maturity Assessment Results Analysis

Partners Firms	Factory of the Future	People and Culture	Strategy	Overall	Maturity level
P1	37	9	7	53	development
P2	50	9	13	72	defined
P3	38	7	11	56	development
P4	31	7	6	44	minimal

P5	39		8		17		64	development
P6	35		9		8		52	development
P7	34		7		9		50	development
P8	26		6		6		38	minimal
P9	29		10		9		48	development
P10	48		9		10		67	development
P11	46		8		9		63	development
P12	43		8		9		60	development
average	**38**	**development**	**8.08**	**development**	**9.50**	**development**	**55.58**	**development**
stand dev	**7.59**		**1.16**		**3.09**		**9.99**	

On average for the 12 partners firms the total score reaches 55.58, with 38 for the 'Factory of the Future'. Only one firm (P2) is at the Defined level (level 3) and 2 firms (P4 and P8) are ranked at the Minimal level (level 1).

Additionally, Table 7 shows the scores for the assessment of the 12 firms belonging in the same supply network for the 'Factory of the Future' criteria.

Table 7. 'Factory of the Future' Assessment of external partners

Partners Firms	**3DP**	**cloud**	**MES**	**IoT& CPS**	**big data**	**sensors**	**e-value chain**	**autonomous robots**	**Total score**	**maturity**
P1	7	2	5	6	6	3	4	4	**37**	development
P2	10	6	5	5	7	5	5	7	**50**	defined
P3	2	8	7	5	5	4	5	2	**38**	development
P4	3	5	3	5	6	2	3	4	**31**	minimal
P5	2	2	6	7	8	3	5	6	**39**	development
P6	3	2	5	5	8	3	4	5	**35**	development
P7	7	2	5	4	5	4	3	4	**34**	development
P8	3	2	4	4	5	2	2	4	**26**	minimal
P9	3	2	4	5	6	2	2	5	**29**	minimal
P10	8	6	6	5	7	4	6	6	**48**	development
P11	8	4	5	6	8	4	7	4	**46**	development
P12	8	2	4	5	8	4	7	5	**43**	development
Total	**5.33**	**3.58**	**4.92**	**5.17**	**6.58**	**3.33**	**4.42**	**4.67**	**38.00**	
max	**10**	**8**	**7**	**7**	**8**	**5**	**7**	**7**	**50**	
min	**2**	**2**	**3**	**4**	**5**	**2**	**2**	**2**	**26**	

On average Big Data (6.58) and 3D-Printing (5.33) are the most advanced technological practices, whereas the Cloud (3.58) and Sensors (3.33) are much less used. Table 8 provides the details of the strongest and weakest Industry 4.0 area for each firms.

Table 8. Strongest and weakest Industry 4.0 areas

Partners Firms	**Strongest I.40 area**	**Weakest I4.0 area**

P1	3DP	Cloud
P2	3DP	MES, IoT&CPS, Sensors, e-value chain
P3	Cloud	3DP, Autonomous robots
P4	Big data	Sensors
P5	Big data	3DP, Cloud
P6	Big data	Cloud
P7	3DP	Cloud
P8	Big data	Cloud, Sensors, e-value chain
P9	Big data	Cloud, Sensors, e-value chain
P10	3DP	Sensors
P11	3DP, Big data	Cloud, Sensors, Autonomous robots
P12	3DP, Big data	Cloud

5. Discussion

According to Schumacher *et al*., (2016) most organisations do not have the ability to assess their own Industry 4.0 maturity. Furthermore, Becker and Knackstedt (2009) explain it is important for an organisation to assess the maturity of a concept in order to continually improve from their current position and also to highlight areas of development, allowing prioritisation to occur. Therefore, to start addressing these issues, an Industry 4.0 framework was developed, tested and used with the focal firm. As the ability to embrace Industry 4.0 is a key to the future success, the framework enables the firm to achieve its forecasted ambitious objectives (Erol *et al*., 2016). To operationalize this further and allow progress on the implementation of the Industry 4.0 technologies, the benchmarking exercise to assess the current position and best practices was undertaken (Langstone & Ghanbaripour, 2016).

The results illustrated the focal firm's technical strengths and weaknesses for the 'Factory of the Future', which is the main area of focus. It shows that MES is currently the strongest 'Factory of the Future' criteria. The company has invested approximately £3 M to develop this state of the art system, which allows a high level of data management, by collecting, processing, analysing and acting upon the information regarding materials, products and equipment in an optimum and integrated manner (Hwang, 2016). According to Simão *et al*., (2006), it is increasingly common for defence firms to operate using an integrated MES as a result of their high dependency and obligation to demonstrate an accurate level of traceability within their manufacturing process. However, the relatively high score for the concept of MES, 6.29 out of a potential score of 10, also suggests that there are improvement opportunities. When the focal firm was measured using the assessment framework, the MES was in the early stages of operational use. Potential improvements to the maturity of the MES may develop naturally over time. However, quick improvement opportunities for the focal company could be to transition more paper-based processes on to the MES system, which are not specifically, related to the product production processes. As an example of a potential improvement, the MES could integrate the goods receiving or despatch transactions to its current database. These areas have a high intensity of transaction in order to complete the processes and any efficiency benefit would be an attractive improvement opportunity for the firm.

Big Data and Autonomous Robots are also well scored, as discussed previously. On the other hand, the weaker criteria identified were the use of Sensors (score of 3.00) and the e-value chains. It would be important to enable product and machine to communicate further to highlight potential process inefficiency, which may be evident. Furthermore, the interaction between sensors and machine could highlight areas of defect and help progress to a predictive maintenance approach to calibration methodologies. The advantages of partners being more connected through an e-value chain would help promote a more trusted, honest and open relationship and share scheduling, work in progress and non-conformance data. Perhaps in the future blockchain and smart contract are the technologies enabling the implementation of effective and efficient e-value chains (Tapscott & Tapscott, 2016). All this fundamentally reduces excessive human interaction for non-value added routines.

It was analysed from the findings that on average the focal firm resides in the ‘Development’ (level 2) section of the Industry 4.0 maturity scale for all three categories: ‘Factory of the Future’, ‘People & Culture’ and ‘Strategy’. When analysing the scores from the maturity assessment, it is apparent that the focal firm is close to achieving the ‘Defined’ (level 3) maturity level. This could be achieved in the short term if the organisation enhance its use of 3DP for production, increase the range of activities of its autonomous robots, and/or link its use of Big Data and its systems with sensors. Furthermore, a focus to develop an industry 4.0 culture through a leadership shift towards a digital methodology would be another way to achieve a more developed Industry 4.0 maturity. Once the firm’s community has bought into the technology evolution of Industry 4.0, other initiatives will be progressed and be implemented.

The application of Sensors within an organisation’s manufacturing process is a critical concept to embrace further, for successfully transition within the 4th Industrial Revolution and for optimising the usage of others technologies. Sensors offer opportunities to retrieve, monitor and report information to users and decision-makers (Babiceanua & Sekerb , 2016) and enable other technologies usage to be enhanced (i.e: MES, Big Data). Hence, the focal firm should use this information based on the assessment to prioritise its Industry 4.0 investments, which will allow enhancing its maturity level.

Moreover, the Industry 4.0 maturity assessment framework was used to assess 12 external manufacturing organisations from the defence sector. The results show that overall the focal firm Industry 4.0 maturity is above average for the three different categories 'Factory of the Future', 'People & Culture' and 'Strategy', as illustrated in Table 9.

Table 9. Results comparison between the focal firm and its supply network

	Focal Firm	Supply Network Average
Factory or the Future	39.08	38.00
People & Culture	8.49	8.08
Strategy	11.78	9.50
Total	59.35	55.58

By analysing the results, it can be identified that Sensors, e-Value Chains and the Cloud are the concepts and technologies which organisations are finding more difficult to embrace and implement. However, the results show that Big Data (6.58), 3DP (5.33) and IoT and CPS (5.17) are technologies which defence organisations have embraced the most and demonstrate higher maturity levels.

The results show that firms: P5, P6, P11 and P12 are relatively mature in their use of Big Data with a score of 8. However and paradoxically they all have a low score in the use of the Cloud, respectively scoring 2, 2, 4 and 2 and the Sensors, respectively 3, 3, 4 and 4, as shows Table 7. Both the Cloud and the Sensors are key enabling technologies to optimise and enhance Big Data usage. This highlighted the limits as well as the substantial room for improvement, justifying the average level 2. Organisations that use Big Data effectively (in line with their use of Sensors and the Cloud) have the ability to optimise greatly their planning, controlling and responding activities to achieve agile production processes, systems and networks in order to improve quality, increase yield and reduce lead time (Erol *et al*., 2016). Deficiency in the use of the Cloud and e-Value Chain would suggest an inability to collaborate in real-time with partners and customers and to share information across a common platform for the mutual benefit of all supply networks partners (Hao & Helo , 2015). The low maturity in the Cloud and e-Value Chain can be explained by the high and general nervousness of the defence firms about the risk of storing and sharing information from a security perspective (Mangiuc, 2011).

This Industry 4.0 Maturity framework should provide a roadmap for firms to assess their level and make relevant and informed decisions to transition in the 4th Industrial

Revolution. This enhanced technological awareness could lead firms to increase their productivity, innovation and sustainability KPIs (Schuh G. , Potente, Wesch-Potente, Weber, & Prote, 2014). Finally, firms in the same supply network could also view this assessment as an opportunity to transfer best practices and knowledge between key partners.

6. Conclusion

The study aimed to develop and test an Industry 4.0 maturity assessment framework, providing i) an understanding of the focal firm strengths and weaknesses in regards to the transitional technological phenomenon and ii) a clear indication of the defence sector maturity level.

The study concludes, based on the results of the Industry 4.0 maturity tests, that the focal firm: a world leader in the defence manufacturing sector resides in the 'Development' band (level 2) within the overall Industry 4.0 maturity scale, with a total score of 59.35 points. The results also suggest that the focal firm strengths reside in its MES, Big Data Autonomous Robots and 3D-Printing with e-Value Chains and Sensors identified as the greatest areas for improvement. This robust assessment should support the firm in prioritising its areas of improvement and sustainability. The information should be used to allocate funding streams, focus resource and set targets for progression.

Furthermore, when comparing the focal firm against 12 other manufacturing organisations in its supply network, it was revealed that it performs above average (55.58). Interestingly the trend seems to be similar where Big Data and 3D-Printing are the most advanced features and Sensors, the Cloud and the e-Value Chain are the least developed technologies, often for security purposes. Having said that it is a clear sub-optimisation as the Sensors, the Cloud and the e-Value chain are the enablers to push organisations to fully utilise Big Data and the MES and to transition in the new era: the 4^{th} Industrial Revolution.

It is recommended that the focal firm uses this assessment results to share best practices and knowledge with its key partners, so a long term and comprehensive roadmap can be implemented.

We acknowledge the key limitations of the study. First, the sample for the external assessment is reasonably low, which make the generalisation of the results to be taken with precautions. However, gaining access to defence firms can prove difficult and we strongly believe that as a first study, it contributes to understanding further the defence sector level and practices in term of Industry 4.0. Second, the empirically developed measurement items constituting the maturity framework could be developed and validated further, this would enable the decision-makers to have an even greater confidence in the results. Finally, we recognised that the current design of the framework might favour an organisation that perform very well at one technological characteristics (i.e: 3D-Printing), as it would significantly increase the overall maturity level, as opposed to a firm that has consistent and balanced technological strategy and practices. It is recognised that gaps may be present in the design of the conceptual framework, as concepts such as Cyber Physical Systems, machine learning, blockchain, smart contract and virtual and augmented reality have not been fully captured individually within the Industry 4.0 framework.

The areas for future research should focus on improving the accuracy of the assessment tool, as well as testing its generalisation to other firms and in other sectors, for instance in the aerospace, pharmaceutical and automotive industries. To improve the accuracy of the assessment model, a larger sample of participants would increase the credibility of the model outputs.

At the macro level, we believe this study will enable firms to have a deeper understanding of this new technological phenomenon: Industry 4.0, and will allow organisations to appreciate the features and characteristics that will define the 4^{th} Industrial revolution. Certainly, at the micro level, the focal firm and the partners' organisations are capitalising on these findings to prioritise their Industry 4.0 strategy and they trust this is critical to remain ahead of the curve. These consist of the main practical contributions of our study. Moreover, from a theoretical perspective, this research will impulse the discussion around the definition of Industry 4.0 and provides a first academic led assessment model. It will also set an early measurement point for the future, when scholars will analyse the evolution of Industry 4.0 and establish how the trends will have evolved.

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