THE DIRECTION OF INDUSTRY: A LITERATURE REVIEW ON INDUSTRY 4.0

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ABSTRACT

With the rapid success of the digital enterprises in the 21st Century, industrial manufacturing is expected to be approaching the fourth industrial revolution, coined Industry 4.0 (I4.0). The instrumental technology that will drive this evolution is the integration of the physical and digital factory into one cyber physical system. There is consensus among academics and industry alike that there will be an integral paradigm shift in how offerings will be developed and manufactured. While there is much confidence that the future factory will have unprecedented capabilities to satisfy complex customer demands, there is little agreement on how individual organisations can utilise these trends. This paper presents a literature review identifying reoccurring themes and trends of I4.0 and their expected effect on future manufacturing. Central characteristics, challenges and opportunities are identified and discussed. The findings can provide support in developing actionable strategies for industry to direct I4.0 endeavours.

Keywords: Industry 4.0, Innovation, Organisation of product development

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1 INTRODUCTION

Ever since the envisioned fourth industrial revolution inspired the term "Industry 4.0" (I4.0), this new paradigm shift has been the subject of global discussion (Sauter *et al*., 2015). However, keeping pace in this revolution can be challenging for small or medium-sized enterprises (SMEs). While large companies have the ability to devote substantial funds and efforts into pursuing I4.0 related trends, SMEs tend to be much more constraint (Faller and Feldmúller, 2015). This is a problem because SMEs are a valuable asset to any nation's innovation ecosystem, warranting them to receive special attention in the public eye to support their needs and facilitate their evolution (Hermann *et al*., 2016).

An industrial revolution is characterised by a new technology finding broad application in industry and thereby fundamentally changing established practices (Zhou *et al*., 2015). Such revolutions generally come in pairs, where a new technology is coupled with novel commercial logic in a push and pull scenario (Lasi *et al*., 2014). They are called revolutions because they redefine the levels of industrial performance by dramatically changing how products are produced and of the degree of productivity in value creation. Industrial revolutions have tremendous effect on the output of manufacturing and, as such, are often accompanied by macroeconomic growth and rise in human prosperity (von Tunzelmann, 2003). Examples like the advancing development of information and communication technologies (ICTs), provide organisations with opportunity to be capable of an astounding employee to user ratio of 1:1000; with Netflix (~5000 employees), Facebook (~25000), and Google (~85000) serving over 100 million users (Statista, 2018). This degree of productivity motivated Kagermann *et al*. (2013) to announce that the next industrial revolution is imminent.

The intrigue of the fourth industrial revolution is that it has not yet occurred but is expected in the near future, raising significant interest in its opportunities and implications (Drath and Horch, 2014). This has driven European and North American governments to launch substantial programs to become proactive in shaping the industrial future and not be left behind (Liao *et al*., 2017). Expectations are high to be able to utilise relevant technological advancements to address stagnating economic growth in high-cost labour nations. Initiatives are targeting organisations to help them remain competitive by imitating the example of high-tech firms and drive innovation into the I4.0 era (Zhong *et al*., 2017).

Industrial revolutions are disruptive and create a comprehensive change from design of offerings to their manufacture. SME's must be proactive in development because it is predicted that I4.0 will be as consequential in industry as the previous three revolutions. The aim of this paper is to gather an overview of literature on I4.0's relevant trends and technological developments. We seek to answer the following questions: What is the focus of I4.0 literature? What is "new" in I4.0? The research objective is to derive insights that might guide future development activities and to translate these insights into actionable strategy for organisations to direct their I4.0 endeavours more effectively. The paper progresses as follows. Section 2 will outline the scope and methodology of the literature review. Section 3 provides an answer to what will be new in I4.0. Section 4 discusses possible implications for leveraging I4.0 opportunities. Section 5 concludes with a summary and outlook for future research.

2 SCOPE AND METHODOLOGY

We deliberately tried not to delimitate the breadth and scope of our literature review on the topic of I4.0 a-priori, but to collect a broad range of relevant sources and then select the 50 most pertinent ones in terms of discussion of I4.0 characteristics, trends and expectations for systematic review. The selection of literature sources was guided by the following criteria:

1. published after 2013, the year the final report of the Industry 4.0 Working Group was presented at the Hannover Fair by Kagermann *et al.* (2013);
2. must have "Industrie/Industry 4.0" in the title to ensure direct relevance to the research topic;
3. subject-area within engineering and/or manufacturing.

Using established literature databases like Scopus, Web of Science and Google Scholar we identified previously cited (as of Sept 2018, an average of 110+ citations) literature sources. In order to reduce the influence of bias in selecting the research focus of the literature, we made no emphasis for discipline specific keywords within the given criteria. All references were analysed by the research team using inductive coding to grasp emerging themes at different levels of abstractions. The results were processed iteratively and assigned categories to differentiate between design and/or manufacturing-oriented foci. We paid special attention to definitions and proliferations of I4.0 discussed in literature for (1) relevant

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technologies, (2) industrial expectations and (3) challenges for I4.0 implementation and adaptation, particularly in the context of SMEs. Finally, we sought to establish what literature considered (4) best practice in I4.0 and which prerequisites are essential for companies to achieve this.

3 MANUFACTURING IN TRANSITION

The findings discussed here should establish insights into what the reviewed literature finds to be influential in the new paradigm of industry. This section will detail the focus of the reviewed literature and categorise the findings into overarching themes. The themes will substantiate the discussion in how organisations can benefit from and prepare for I4.0.

3.1 Industry 4.0 manufacturing technologies

The fourth industrial revolution has not yet occurred; however, there are several technologies which will drive its development forward. Figure 1 summarises which technologies are considered to be instrumental within the reviewed literature. The frequency indicates the number of papers that focus on a particular key technology. Of the 17 listed technologies, 15 have a specific similarity. Despite being categorised as industrial technologies they are not intended to affect individual production cells in the process of machining, joining, forming, etc. Their functionality serves to gather, network and manage the data of the factory in order to streamline and optimise the production sequence (Schmidt *et al.*, 2015). Other than robotics and additive manufacturing, the remaining technologies use information as a means of utility in the value creation chain.

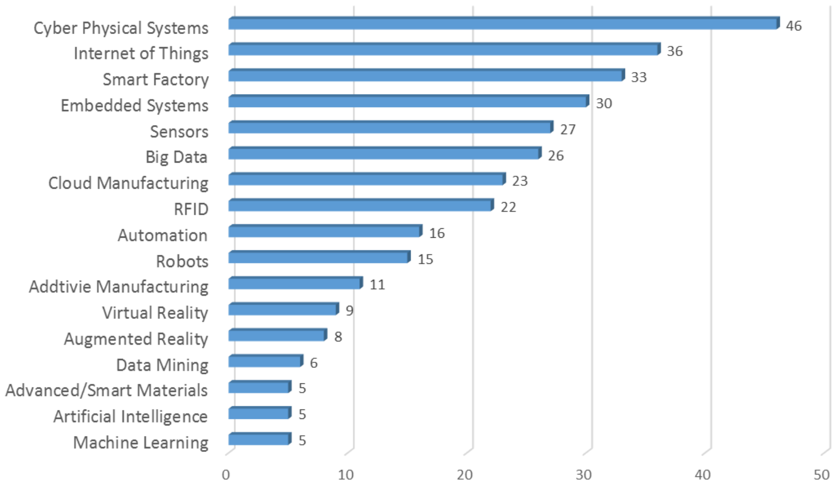

Figure 1. Key technologies instrumental to industry 4.0

The prevalent technologies fall under the category of ICTs. They enable interoperability; the comprehensive communication of factory production systems. Since they are a means of communication, it is unlikely that they will be deployed as individual technologies. The top four mentions have many synonymous characteristics and cannot be isolated from each other. As there are many overlaps in functionalities and characteristics it is worthwhile to define the technology to be most instrumental to I4.0, the Cyber Physical System (CPS).

A CPS is a combination of ICTs and production technologies (Niesen *et al.*, 2016) to act as the enabling intelligence in a "smart" factory (Zhou *et al.*, 2015). A smart factory is synonymous with a system of systems that receive data from a multitude of sources gathered from within and beyond the factory machine-park (Liu and Xu, 2016). As the production systems will be increasingly embedded with awareness (sensors), intelligence (processing) and at least passive communication capabilities (RFID's) (Grangel-Gonzalez *et al.*, 2016), the volumes of data will be unprecedented. This abundance of data, when processed and categorised, will enable replicating the performance (state and behaviour) of the factory in a virtual (cyber) space in form of a digital twin (Posada *et al.*, 2015). Depending on the detail of the gathered data, production processes will become transparent and individual events accurately traceable (Shrouf *et al.*, 2014). This is where the CPS brings about its greatest potential in the form of optimisation. Once all production systems have been digitised a core component of the CPS is to process this data into an operational understanding using artificial intelligence (Wang, Wan, Li *et al.*, 2016a),

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machine learning (Lee *et al.*, 2015) or data mining algorithms (Niesen *et al.*, 2016). This new understanding can create meaningful insights for decision making and will be automatically fed back into the production stream with provisions for optimisation (Wang, Wan, Zhang *et al.*, 2016b).

3.2 Industry 4.0 benefit propositions

An industrial revolution advances the paradigm of best practice within manufacturing and enables previously inaccessible levels of productivity; I4.0 is predicted to be no different (Schmidt *et al.*, 2015). Academics and manufacturers alike have high expectations of this evolving paradigm to create extraordinary opportunities for the creation of increased revenue and/or productivity (Liao *et al.*, 2017). Figure 3 highlights most prevalent benefit propositions that the literature predicts will be characteristics of future manufacturing. These emerging characteristics are specified to be in direct relation in pursuing I4.0 and benefits of the next industrial revolution.

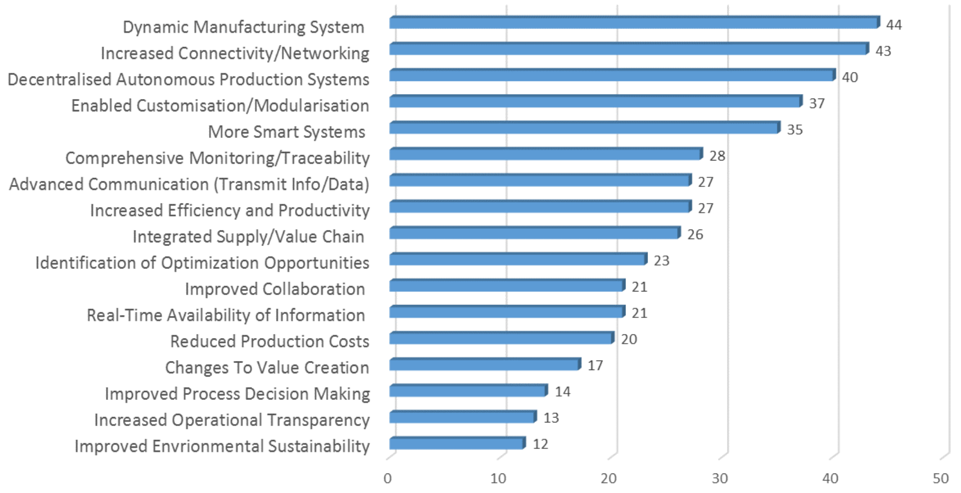

Figure 2. Industry 4.0 manufacturing benefit propositions

With the implementation of I4.0 technologies, the factory will be enabled to dynamically change its organisation and performance levels to meet fluctuating demand (Schuh *et al.*, 2014; Wang, Wan, Li *et al.*, 2016a). With networking of the complete value chain, the production systems will be able to update down/up-stream processes (work stations) of their status (Weyer *et al.*, 2015). With the given information, smart systems will be able to perform limited decision making tasks autonomously (Zhou *et al.*, 2015) immediately reacting to production fluctuations. This decentralised system will speed up the response time as immediate decision making will continuously optimise the production flow into a synchronised tact-time (Almada-Lobo, 2016; Sanders *et al.*, 2016). In essence, the factory will develop from a passive networked system to a responsive collaborating system of systems creating value together (Wollschlaeger *et al.*, 2017). This collaboration of systems will propagate beyond the value chain of the factory to a highly integrated supply chain of businesses working together. With advanced communication and shared data, the logistics between businesses will become the subject of great improvement (Hofmann and Rüsch, 2017; Tamás *et al.*, 2016). Procurement will become robust against the bull whip effect by benefitting from digitalised production orders, shared data, and advanced forecasting solutions. Not only will efficient logistics bring profit to an organisation and its customers but it can also meet societal needs for sustainability (Kagermann, 2015; Prause, 2015).
The agile factory with I4.0 capabilities will also bring benefits to its customers (Qin *et al.*, 2016). The continuous optimisation activities can create tangible reductions in lead time and thereby the cost per unit (Schuh *et al.*, 2014). These savings can be passed on to the customer but the most decisive characteristic for the customer will be affordable customisation. With the help of I4.0 technologies, unique offerings can be tailored for individual customers yet be manufactured both efficiently and profitably (Drath and Horch, 2014; Lasi *et al.*, 2014; Saldivar *et al.*, 2015). This will be essential to the competitiveness of a factory as customer expectations become increasingly unique (Sauter *et al.*, 2015) and their pursuit of alternative business models (Müller *et al.*, 2018) could fundamentally change the meaning of value (Kagermann, 2015).

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3.3 Industry 4.0 implementation challenges

Despite the predicted benefits, there are still considerable challenges to overcome for I4.0 to be successfully realised in industry. Figure 3 summarises what the reviewed literature considers as central challenges still requiring research and development from academia. It shows a strong consensus that there is a need for a guide in implementation and questions on how to manage the expected increase in system complexity. The literature shows that the greatest driver of unresolved complexity is networking a heterogeneous factory so that all production systems can autonomously connect and communicate (Li *et al*., 2017; Lin *et al*., 2016). There is no standardised solution that facilitates the networking of vendor specific interfaces and communication protocols (Wan *et al*., 2016). Figure 3 illustrates that there are efforts to normalise networking methods; however, standardisation is slow and individual vendors are unlikely to wait and thus potentially lose market opportunity (Weyer *et al*., 2015). The research in developing a successful CPS must continue to seek a robust method that enables all production systems to connect to the network, communicate its status and react to updated information (Lu, 2017).

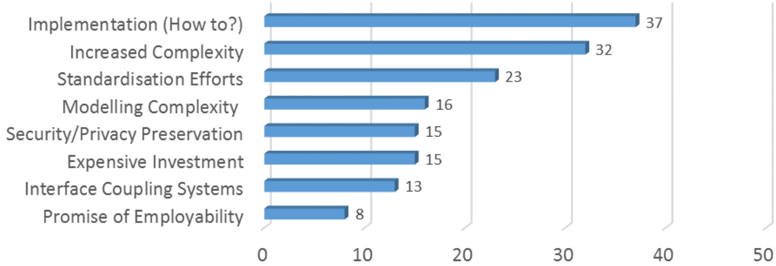

Figure 3. Industry 4.0 challenges of implementation

However, contrary to accessible networking capabilities, there is the additional requirement of privacy preservation and to restrict access to unwanted users (Anderl, 2014; Thoben *et al*., 2017). While many industries perceive data sharing as a driver for operational performance, some industries show considerable resistance to such transparency. There is a lingering user resistance in SMEs who are vulnerable to, and do not have the infrastructure against, a cyber-attack (Müller *et al*., 2018). The preservation of privacy is not only a critical concern maintaining digital trust of SMEs (Oesterreich and Teuteberg, 2016), but in some cases it becomes a security risk to life and property. On the one hand, a network must be easily identifiable and ready to provide the needed service, on the other hand, it must be safe from exploitation and unauthorised, mal-intended manipulation.

Besides all the outstanding technological innovations there is also a need to address the future employee. Based on the capabilities of the future factory it can be argued that routine work might be eliminated (at least to a large extent) and that employees must become skilled in different competencies like flexible problem solving, creativity and strategy development (likely across disciplines). I4.0 does have means of supporting the employee through means and tools, such as augmented reality glasses or self-diagnosis technologies, but employees must continuously be trained in interdisciplinary understanding (Gorecky *et al*., 2014). There is an unsettled dispute about the concern over the workerless factory but there is relative certainty that job descriptions and responsibilities will change (Bonekamp and Sure, 2015).

Many of discussed concepts include inherent complexities that will prove to be difficult to resolve with a generic solution. However, there is progress and the literature indicates measures that are already possible that will substantially help in harnessing the full potential of I4.0.

3.4 Prerequisites for industry 4.0 practice

An industrial revolution is not limited to the implementation of technology but extends to pursuing novel commercial logic (Lasi *et al*., 2014). The reviewed literature indicates a change in industrial practice that will enable and accommodate state of the art technologies in order to best benefit from this industrial revolution. Figure 4 summarises the changes that are speculated to be prerequisites for I4.0 practice.

The immediate observation from Figure 4 is that there is much less consensus compared to the prior discussed categories (a maximum of 24 out of the total of 50 repeated an emerging prerequisite) about the future of industrial practice. The reviewed literature focuses on necessary changes that need to occur in pursuing the improvement of existing practice. They outline that there must be a considerable change

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to the organisation rather than an isolated upgrade to its technologies and production systems. In order to truly progress into new era manufacturing, the entire organisation must undergo a transformation.

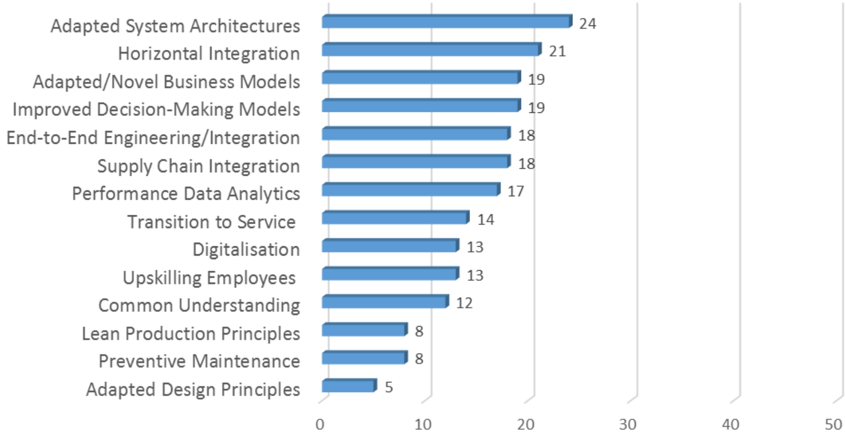

Figure 4. Industry 4.0 prerequisites

The most repeated prerequisite of I4.0 practice is adapting the system architectures. Adapting system architecture has been explained in a range from the networking of production systems within the factory (Schlechtendahl *et al*., 2014), business sectors within a company (Liao *et al*., 2017) to the extremes of inter business relationships (Kagermann *et al*., 2013). This prerequisite, instructs that all interfaces be taken under deliberation to identify which complementary systems could or should be networked.

Another prerequisite that the reviewed literature identifies in adapting system architectures is a shift toward horizontal integration of business processes. This is one of the prerequisites to enable a decentralised production system, as information is shared and processed along the value chain (Almada-Lobo, 2016). This new logic of integration is supported with end-to-end engineering (Kagermann *et al*., 2013; Saldivar *et al*., 2015) and the establishment of improved models for decision making (Lee *et al*., 2014). It focuses on the complete value creation chain of the offering and defines which interfaces are decisive to network. End-to-end engineering can be as far reaching as the integration of the supply chain of the offering's complete lifecycle (Liao *et al*., 2017).

Additionally, the necessity in adapting system architectures is not limited to engineering systems and production process. The literature also suggests rethinking the entire value proposition and commercial logic with which to capture value (Burmeister *et al*., 2015). The reoccurring prerequisite for adapting the business model is the increasing focus on including services to the offering, before, during or after sales (Kans and Ingwald, 2016). No matter how these offerings incorporate a service, the literature highlights the need to develop the organisations' customer/user knowledge by doing meticulous customer research or by analysing the usage of deployed offerings (Zhong *et al*., 2017).

Another consideration is made for how I4.0 will shape working conditions for future employees. Section 3.3 already outlined how monotonous repetitive operations will be replaced with non-routine tasks requiring creativity and problem-solving skills. However, employees must first have a common understanding of company goals (Sanders *et al*., 2016) and keep pace with industrial trends (Burmeister *et al*., 2015). Organisations must strive to employ capable individuals and encourage them to continuously seek further training (Gorecky *et al*., 2014). Along the lines of continuous improvement, there is limited focus on Lean Production principles (Ohno, 1988) and their relevance in future manufacturing. The few papers which do explicitly define Lean Production systems state that they will remain instrumental for operational success (Erol *et al*., 2016; Kolberg and Zühlke, 2015). Adhering to Lean Production principles will continue to have relevance and will be significantly enabled using I4.0 technologies. Pursuing preventive maintenance and monitoring key performance indicators are key features of I4.0 capabilities.

Finally, the focus on design principles indicates that there is a gap in current practice (Hermann *et al*., 2016) but they are only marginally addressed. While 37 of the reviewed papers highlight there are remaining questions for how to proceed in implementing I4.0, there is limited emphasis in addressing design principles applicable for developing novel solutions. Only five authors indicate that in order to progress with industrial trends, an organisation must adapt their engineering approaches (Mosterman and Zander, 2016) and design principles (Hermann *et al*., 2016) concurrent to development.

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4 INSIGHTS ACHIEVED THROUGH LITERATURE

This review analysed a sample of literature sources specific to I4.0 to identify themes of this anticipated industrial paradigm. The content of the reviewed literature was categorised into four themes that emerged from the analysis. The literature focuses on novel I4.0 technologies, the benefits of realising I4.0 in the factory, the challenges of implementing I4.0 in the organisation and what future industrial practice would require. We intend for this discussion to support SMEs in providing clarification for understanding I4.0 and recommending means for implementation. This section discusses our observations about how I4.0 supports improvement activities and how organisations can leverage the activity of offering development to prepare for I4.0 endeavours.

4.1 Industry 4.0 will support improvement activities

I4.0 has become a synonym for the aspired ideal of advanced manufacturing and innovation. However, it is worthwhile to consider that not everything discussed under the banner of I4.0 is new. Examples like the aim of dynamic manufacturing to create customisable offerings and pursuing Lean Production principles to raise productivity are all established objectives in industry. These are valuable discussions even without consideration of I4.0. The objectives remain the same, but the process becomes faster, more precise and, most importantly, supported by more information.

The "new" of I4.0 is the great abundance and added precedence of applying information. I4.0 technologies are mainly a means for extracting data, communicating it, processing it into information and sharing it among a connected value chain. Sensors are being progressively developed as turn-key ready solutions providing adaptable means to extract data of many features of any process (Stock and Seliger, 2016). The increasing connectivity of production equipment helps compile captured data into large comprehensive data sets for substantiated assessment. With the advancements in data analysis techniques, unknown relationships can be identified and translated into improvement of value creation. This enhanced learning potential can make strategic decision making for improvement more traceable, precise and reliable. The application of I4.0 technologies allows organisations to learn more about their processes and offerings than was previously possible.

Another novel concept of I4.0 is that this learning potential can be decentralised with the increased capability of embedded systems to autonomously use information. Where previously automated systems are passively controlled within predefined limits, integrated autonomous systems are able to use shared information and adapt in real time. Technical systems can be enhanced with machine learning capabilities to adapt to fluctuating manufacturing information to best suit the performance of the value chain (Zezulka *et al*., 2016). With a comprehensively connected value chain, everyone (including some technical systems) can be enabled to proactively collaborate toward improvement (Wan *et al*., 2016). The literature establishes that I4.0 will provide the enabling tools to connect and integrate a complete value chain to become a CPS. This review recognises the novelty of I4.0 in a CPS, an intensively interconnected system where physical and computational entities are proactively collaborating to achieve improvement in order to create generous benefits for value creation (Brettel *et al*., 2014).

4.2 Development activities as a means to prepare for industry 4.0

As a defining feature of an industrial revolution, novel technologies are paired with novel commercial logic. This remains true for I4.0 as the value of offerings will change due to the shifted emphasis toward information. Next generation offerings can have an entirely new component of value as they should create means of learning and improvement for the customer. This extra component, possibly a marketable feature, consequently changes how offerings are developed in a fundamental way. Because the realisations in developing these additional features can create new opportunities, there is indication that the activity of offering development has the leverage to prepare an organisation for I4.0.

The possibility of using information for different applications, encourages a shift beyond upgrading technical equipment. Discovering novel applications requires a holistic analysis in how offerings are integrated in a greater value chain and how the offering enhances the creation of value through information. This analysis would be different to improvement activities because rather than optimising existing indices it seeks to identify entirely new components of value and how information can provide greater benefit. This analysis should be extensive enough to encapsulate the perspectives of many

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stakeholders along the complete life-cycle of the offering (in form of end-to-end engineering) and to understand how information is connected in a system.

The resulting findings could provide inspiration for new business cases tailored to maximise value capture of information. Entirely new business models can be derived from marketing additional services around and for information. It would be worthwhile for organisations to develop concepts where their offerings are comprehensively interconnected to provide information (learning potential) to a greater system (Theorin *et al*., 2017). Subsequently, developing new offerings and creating new business cases achieve profound changes for an organisation having the added benefit of motivating an internal revolution. The conceptualisation of an offering defines the subsequent characteristics (function, user, manufacture, system-architecture, value capture, etc…), making the development of next generation offerings a valuable activity that could transform an organisation (Burmeister *et al*., 2015).

The literature provides no evidence to describe an offering as an "I4.0 Product" but there is potential for an I4.0 ready offering capable of being integrated and valuable in a digitally interconnected industry. There are I4.0 design principles (Vogel-Heuser and Hess, 2016) already defined to support retrofitting industrial equipment to be in step with I4.0 technology. However, in order to leverage maximum potential of I4.0, the activity of developing fundamentally novel offerings is the most compelling. Based on the findings presented in this paper, it is recommended to complement current development activities by addressing the question of how to generate information along the life cycle of offerings and how to utilise it effectively for increasing value for the user, customer, organisation, society and environment.

5 CONSLUSION

This study analysed a sample of the literature to provide an outlook for how industry will transform through the fourth industrial revolution. The literature indicates that I4.0 will provide opportunities to thrive by embracing technologies that enable technical systems to actively collaborate within the value chain and achieve improvement through information. Organisations will be enabled to optimise current levels of manufacturing to an unprecedented degree requiring them to differentiate and compete with new components of value. I4.0 has the potential to be disruptive and have far-reaching effects beyond manufacturing. This anticipated industrial paradigm will transform industry, change the way users interact with offerings and proliferate to other parts of society. Like in previous revolutions, many organisations will be replaced if they do not fundamentally address the new paradigms of industry. They might not be replaced by competitors, but by entirely new sectors. Many organisations are no longer only competing within their sector; they are now competing to stay relevant as an entire industry. They must compete for relevance as their existing business models become outdated.

The banner of I4.0 has accelerated development and it has shaken many business leaders to speculate about their industry's future. Many organisations want to be proactive in the pursuit of innovation and next generation offerings; however, they are hindered by lack of consensus and ambiguity. The findings of this study illustrate that the power of I4.0 is the emphasis on applying information to derive improvement. It finds that the development of novel offerings capable of creating information and connecting with a larger value creation system is most compelling to transform an organisation to become I4.0 ready.

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