Operationalizing Industry 4.0: Understanding Barriers of Industry 4.0 and Circular Economy

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Abstract. The manufacturing industry has to withstand an increasing competition requiring customization of products, shorter time to market and a transition towards more sustainable operations and products. There is a need for a transition to business models that incorporate sustainability while keeping business activities profitable. Leveraging the advantages of new technologies within the concept of Industry 4.0 is seen as an important factor to maintain competitiveness while responding to the sustainability challenge. Changing the way businesses operate is not easy as is evident from studies that have identified many barriers, including costs, lack of competence, loss of jobs, and process, product or production facilities not suitable for Industry 4.0. Due to these barriers, firms are slow to make a transition towards customized products, shorter lead times and more sustainable operations and products. The commitment for sustainability includes a shift towards Circular Economy (CE) that poses additional barriers like geographic dispersion, product complexity, and lock-in to the contemporary linear 'take-make-consume-dispose' model of operation. This paper addresses how manufacturers perceive Industry 4.0, what motivates their investments in Industry 4.0, and what barriers they see in adapting Industry 4.0 followed by a literature review identifying barriers for adhering to CE in the manufacturing industry sector. The study offers empirical insights identifying a need for a roadmap for implementation of Industry 4.0 to support CE as well as providing directions for future research.

Keywords: Industry 4.0, manufacturing technology, sustainability, circular economy.

1 Introduction

Recently there has been an upsurge of interest on the potential of new technology in manufacturing through digitalization. Concepts used interchangeably for digitalization are "Industry 4.0" [1], "Industrial internet" [2], and "Industrial Internet of Things" [3]. These are based on innovations in technologies, smart materials, Big Data and manufacturing operations, brought together by the accelerated use of Internet of Things (IoT)-technologies [4, 5], or "Cyber-physical systems" (CPS) [6]. These initiatives enable servitization and new business models in which one extend product-based offerings to a focus on customer value and performance [7]. The future is becoming increas-

ingly digital and networked, changing businesses and private life radically [8]. Simultaneously, businesses need to respond to environmental concern from customers by providing more eco-friendly products and services. The circular economy (CE) model is based on the concept of changing the take-make-use-dispose pattern into closed-loops of material flows through processes such as maintenance, repair, reusing, refurbishing, remanufacturing and recycling [9]. Supply Chain Management (SCM) is considered vital for the implementation of the CE model, because of the need for a joint effort of suppliers, manufacturers and customers. Co-operation and co-ordination between supply chain upstream and downstream partners is essential as upstream partners obtain eco-friendly inputs cooperating with downstream partners for environmental management practices such as product return, reuse and recycling [10]. The transition to CE is not easy, which is evident from several studies that have identified many barriers. Due to these barriers, firms are slow to make a transition towards CE [9, 11]. This paper aims at exploring the barriers that manufacturing companies experience when implementing new technologies related to Industry 4.0, and the transition towards sustainability and CE.

2 Definitions

2.1 Industry 4.0

The term "Industrie 4.0" was coined at the Hannover Fair in 2011, describing how digital technologies will revolutionize the organization of global value chains [12]. In the context of manufacturing, Industry 4.0 focuses on intelligent products and production processes [13]. Brettel et al. [13] point out that the concept of Industry 4.0 is being used in different contexts, but is lacking an explicit definition. Based on a literature review, Hermann et al [14] provide the following definition of Industry 4.0:

> *"Industry 4.0 is a collective term for technologies and concepts of value chain organization. Within the modular structured Smart Factories of Industrie 4.0, CPS monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the IoT, CPS communicate and cooperate with each other and humans in real time. Via the IoS, both internal and cross-organizational services are offered and utilized by participants of the value chain." [14] p. 242.*

This definition itself contains several terms and concepts, as Internet of Things (IoT), Cyber Physical Systems (CPS) and Internet of Services (IoS). The core of this definition is that items, systems and humans communicate with each other over the Internet in real time implying that everything is connected. The second main aspect is the development of services based on this connectedness. The extreme connectivity enables global and instant communication, allowing for the development of new business models. The development of new business models is also made possible by the advances in data processing capacity enabling analysis of Big Data and machine learning.

2.2 Circular Economy (CE)

We adopt the understanding of CE given by [15]:

> "*A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models." (p. 7)*

In this model of circularity, reuse at the product level is the most important in terms of positive environmental impact, followed by reuse at the component level and reuse at the material level respectively. Shifting towards a circular economy model requires a deep focus on raw materials and energy. When producing a product, the focus should be on minimizing the entire product life cycles negative effects on the environment from the very early stage of material extraction towards the product disposal. In [16] the authors describe how to adapt product design and business model strategies to a CE. CE activities require new business models in which one pursue the opportunities for a shift from an 'end-of-life' focus a cradle-to-cradle cycle, from using un-renewable energy towards using renewable, from using toxic chemicals to their elimination, from waste to eliminating waste by design of materials, products, systems and business models.

3 Implementing Industry 4.0 and a Circular Economy focus

In order to prepare a strategy for implementation of Industry 4.0 related technology and concepts, knowledge is needed regarding the present level of technology implementation, as well as barriers to implementing these. In this regard, previous studies have mainly focused on technological readiness and maturity levels [17, 18]. However, Industry 4.0 applies not only to the purely technical aspects, but involves the socio-technological systems, as intelligently networked objects in manufacturing is expected to constitute tasks distributed in time, space and content, and thereby change the content of work [8]. Hence, implementing Industry 4.0 concepts require not only implementing new technology and infrastructure, but to adopt a completely different organizational setup, and a set of processes that are different from those found in traditional manufacturing [19]. How companies perceive these changes will affect how they approach and operationalize elements associated with Industry 4.0. These are aspects that have gained less attention in the literature so far [20, 21]. Consequently, in this study we focus on the organizational knowledge related to the implementation and barriers for implementation of Industry 4.0. Furthermore, the commitment for sustainable growth includes a switch towards CE, which puts forward a need for innovative business models that keep business activities profitable while implementing new practices adhering to the CE.

Companies need to develop knowledge on how to operationalize activities in a manner adhering to CE and to develop organizational knowledge of barriers for moving in this direction. We address this by the research question: *What barriers do manufacturing companies see in moving towards Industry 4.0 with a circular economy focus*? Relatively little literature on barriers towards CE adoption has focused on the manufacturing industries. This study aims at contributing to fill this gap in the literature.

4 Methodology

Two approaches were used to answer the research questions. First, structured interviews provided an indication of the general level of understanding of a set of manufacturers, while a case study of one company gave in-depth knowledge of their approach towards Industry 4.0. Structured interviews (N=23) were carried out in a cluster of small and medium sized companies representing different industries, but with short geographical, social and cognitive proximity to each other. At the time of the survey, the cluster consisted of 31 members, covering manufacturing companies, service and engineering companies. For CE barriers, we followed a qualitative approach method using data from semi-structured interviews. We interviewed two manufacturing companies, and a consortium of all manufacturing companies (and other companies) supporting product identification, labelling and information flow. The consortium work closely with the manufacturers in their move towards CE with appropriate standards, giving them a first-hand knowledge of barriers for CE adoption for the manufacturing industry as a whole.

5 Findings

5.1 Conceptualization of the term "Industry 4.0"

The structured interviews revealed that all except of one the companies had heard about the term, and that the companies emphasize the Industry 4.0 concept differently. The answers could be grouped into three main categories; 1) new business models, 2) more efficient and automated manufacturing internally to the company, and 3) the value of localization. A large share of the respondents (10) emphasized the possibility to improve the efficiency of manufacturing processes. Fewer (5) mentioned the possibility to develop new services, but of the ones that did, they mainly related to monitoring and maintenance. These kinds of services involve sharing of data, which involves integration with external companies. We noted that none of the companies mentioned integration with their own suppliers and the use of track and trace technology as important for their main understanding of the concept of "Industry 4.0". However, this does not rule out that the companies also are concerned about this aspect. Several respondents had no clear definition of the concept "Industry 4.0, which was reflected in more general terms as "we need to follow the development in the industrial world", and "this opens up a new universe". One of these respondents expressed concern about how this could alter the competition, and was uncertain how to approach this. Finally, a respondent was skeptical to the whole concept and claimed "4.0 is only a buzzword used by many nowadays".

5.2 Barriers for implementation of new technology related to Industry 4.0

In the study, the companies were given a set of possible barriers that they could rank. These were costs, lack of competence, loss of jobs, process not suitable for Industry

4.0, product not suitable, and production facilities not suitable for Industry 4.0. Ranging from great, medium low, and not relevant.

Compared to the motives, the barriers were considered less important than the motives. The factor that was identified as the most important barrier for implementing Industry 4.0, was the cost associated with the investment in new technology. This factor was also reflected in the open comments, where it was emphasized that for small and medium sized companies, the cost is the main challenge for implementing new technology. Another argument here was that the technology needed to be developed and commercially available before the company could invest, as it is too expensive to be a first adopter. One of the companies expressed that they were not able to invest in new technology, as they were a subsidiary of a large multinational company (MNC), who made the investment decisions.

Competence was the second barrier that was identified as being of above medium importance. Less important, but above medium, was that the product was not appropriate for Industry 4.0. This was also reflected in the open part of the questions, were the respondent could express barriers that were not part of the predefined motives. Here standardization was mentioned as a barrier. Related to this, one of the respondents responded that the low volume of the manufactured product made it less suitable for industry 4.0. We note that this might be based on the presumption that automation is associated with repetitive actions in mass production. However, an important advantage of Industry 4.0 is exactly that the use of technologies support customization and one-of-a kind production (mass-customization). Supporting customer-oriented flexible markets is an advantage of industry 4.0 that promise to help in reducing the gap between the manufacturer and the customer. Other barriers ranked below medium, were loss of jobs, and that the process and production facilities were not considered appropriate for Industry 4.0.

5.3 Barriers for a move towards Circular Economy

Based on our findings, the manufacturing companies have special attention towards sustainability, including actions on regeneration of resources, charging customers a recycling fee that is transferred to recycling funds to handle recycling and adopting certifications with ISO-standards ensuring they comply with the rules and regulations of the environmental management system. The following six barriers to CE adoption were identified by the companies:

1) Disassembly of products. The disassembly of products is considered to be an important element as most products have some amount of disassembly that is not just the reverse process of assembly due to elements like irreversible joints, maintenance, and up gradation and degradation during use. All the respondents said that the disassembly of products is not easy and it expensive and time-consuming because of complex nature of products.
2) Supply chain complexities. The complexity barrier results from an increase in the number of components of different nature with complex assembling procedures.

3) Coordination problem. The coordination among companies is a barrier because it needs multiple companies to adjust their daily operations.
4) Lack of CE in design and production. The products that are produced lack a circular design which is the reason the production and the reusing, disassembly, remanufacturing etc. is hard.
5) Quality issues. Companies' reluctant attitude towards CE is their concern regarding the quality of materials. They fear materials would be chosen based on the environmental aspects instead of quality of performance.
6) High start-up costs. In the long run the CE model is assumed to bring sustainable benefits and increase growth but in the short run, the start-up costs are considered high.

6 Discussion and conclusion

The findings in this study reflect that the companies put different meaning into the concept "Industry 4.0". A central aspect of Industry 4.0 and the associated concepts is connectivity across traditional domains of humans, machines and products. From the structured interview as well as the in-depth case studies, it is clear that this issue is not very prominent among the interviewed companies.

When exploring how the companies in the study perceive the concept Industry 4.0, the connectivity aspect was only mentioned in association with developing new business models, based on data collected from sensors on sold products within monitoring and maintenance. Hence, down-stream integration is mainly considered as an opportunity to create new value propositions to customers, while integration of machines, products and humans across the value chain this has not been emphasized.

When it comes to enhancing efficiency, the companies are primarily concerned about the potential for internal improvements in the company and for the case company within certain departments, and to a lesser extent improvements in external supply chains through connectivity with other companies.

The study reflects the inherent duality or ambiguity of the Industry 4.0 concept, in that it represents both innovation (exploration) and efficiency (exploitation) [22]. New business models involve radical and sometimes disruptive innovation, which is associated with exploration, while increasing efficiency of manufacturing reflects exploitation of existing assets. This may create a tension that needs to be handled by the management of each company.

Regarding what barriers manufacturing companies see in implementing Industry 4.0 technologies, the highest ranked factors were the cost associated with the investment in new technology, as well as the concern that the technology was widely available and not on the development stage. Competence was identified as a barrier, as the workforce need to adopt to new ways of executing processes involving a more intensified digital involvement. Also, with above medium score was the perception that their product and/or the production environment was not appropriate for Industry 4.0. The other barriers with below medium score were fear of loss of jobs, and a lack of standardization. Thus, Industry 4.0 is well known to most companies at a general conceptual

level. Especially, the ambition to exploit Industry 4.0 technologies is high among top management. However, implementations of Industry 4.0 technologies at the tactical and operational level are harder to achieve. The insight provided by this study, shows that the Industry 4.0 represents a complex and unclear concept to many companies, and that there is a need for a roadmap for implementation of these concepts, starting with a strategic process of what to deliver to whom, leading towards a culture change at the tactical and operational level. As such, this study offers empirical insights providing directions for future research on what factors to address in a roadmap.

By carrying out case studies of three Norwegian companies, we found that the major barriers for implementation of CE were a quality issue in recycled materials, supply chain complexities, coordination problem between companies, design and production of the product, disassembly of products, and high start-up cost. Our findings show that the companies interviewed are well aware of the challenges of moving towards the CE, but that the link between digitalization and CE needs further exploration. A shift to the CE model or any other business models for sustainability of the economy requires a dramatic change for the whole company including all the stakeholders. This shift is somewhat disruptive in nature because the current mode of working would also be changed due to the new solution of the CE model.

As companies need to address both Industry 4.0 and CE barriers, it is important to investigate how these barriers relate to each other. Even if our data were collected separately using different methodological approaches for the two topics, we find that cost is a common barrier, as was expected from the literature [23, 24]. For the remaining barriers, a different methodical approach would be needed to find possible connections. However, we contend that from the perspective of a viable business model of a company, Industry 4.0 and CE are convergent, since both strongly depend on digitalization to succeed. Digitization is at the very core of Industry 4.0, and for CE, a profitable model depends on detailed planning and control for each individual product. Since each individual product has its own life cycle, each unique product must be managed across its entire unique life cycle, which in practice is only achievable through digitalization. In conclusion, our findings show that the companies interviewed are well aware of the challenges of moving towards Industry 4.0 and CE, and through our discussion we find companies should put their attention towards digitalization and individualization as these are fundamental properties of emerging business models.

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