Circular economy in the Industry 4.0 era: Transparency's effect on the feasibility of a take-back program

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Abstract
Circular economy is receiving an increasing attention from both the academic community and practitioners due to the currently unfolding business opportunities that are concerning it. While its operationalization and the role of the internet of things as a catalyst for it have been widely discussed at a conceptual level, an empirical knowledge base is missing. This exploratory longitudinal case study investigates how the enabling of transparency across the supply chain through the integration of the internet of things is, in particular, supporting the feasibility of a take-back program in a Danish automation solutions provider.

Keywords: circular economy, internet of things, case study, take-back program

Introduction
As companies are pushed by governments towards sustainable development for reducing their carbon footprint through, for instance, the Sustainable Development Goals (UN, 2015), concepts such as circular economy (CE) are becoming something more than a buzzword. In fact, CE is considered to act as an improvement lever for the sustainability of an organization (Prosman et al., 2017; Prosman and Sacchi, 2018) and industry is currently starting to investigate and apply CE principles, aiming for a competitive advantage (Tukker, 2015).

The concept of CE consists of a system based on a restorative use of resources, hence recovering part of their value, instead of a linear one, where goods are produced from raw materials and discarded after their use (Ellen MacArthur Foundation, 2015). This can be achieved by recycling, remanufacturing or reusing products as well as by prolonging their life-cycle through design improvement, refurbishing or maintenance activities

(Geissdoerfer et al., 2017). This would close resource loops (Sousa, 2013) and avoid landfilling (Bocken et al., 2016).

The evolution towards circular business models is, today, inevitably linked with the digital transformation of industry and, specifically, with the introduction of the internet of things (IoT). This is considered to be a catalyst for this transition due to its key role in generating information visibility across the supply chain in support to decision making processes (i.e. transparency) (Ellen MacArthur Foundation, 2015; Nobre and Tavares, 2017). In particular, the availability of information concerning embedded product information, as the effective use and condition of products along their whole life-cycle, is acting as an enabler for making businesses more efficient (Ellen MacArthur Foundation, 2016).

There is an academic (Nobre and Tavares, 2017; Leider and Rashid, 2016; Srivastava, 2007) and practitioner (Ellen MacArthur Foundation, 2015) consensus about the link between IoT and the creation of CE initiatives. However, there is a severe lack of empirical research concerning how IoT is used to leverage CE, i.e. how IoT supports the transition from linear to circular business models (Pagoropoulos et al., 2017) and how to convince management of the opportunities IoT provides for circular business models (Leider and Rashid, 2016). One of the reasons for this gap in literature could be the general lack of empirical studies of CE (Souza, 2013; Vachon and Klassen, 2010), especially concerning the role of digital transformation as a facilitator for the establishment of CE related activities (Nobre and Tavares, 2017; Leider and Rashid, 2016).

This research addresses these gap through the analysis of a single case and its intention to establish a take-back program, strategic initiative leading to a circular business model. Focusing on how the digital transformation and, specifically, the deployment of IoT and the enabled transparency are supporting it, the aim of this paper is to answer the following research question:

How can IoT support the feasibility of a take-back program?

The case company selected for this exploratory longitudinal case study is an automation solution provider, currently performing unstructured take-back activities and willing to formalize them by establishing a take-back program. The available IoT platform remotely monitors the operational performance of their products and it is currently used for supporting service activities aiming at prolonging their life-cycle. The company intends to extend their use of the data made available by the IoT platform for supporting the taking back of used products that can be resold generating an additional revenue stream. The case provides the necessary foundation for questioning the support that IoT enabled transparency can provide to a take-back program.

This paper starts by investigating the literature, with a focus on the key building blocks that should be considered within the scope of this case study, i.e. the nature of the different CE loops and the key areas to be considered for establishing a take-back program. This is followed by an introduction to the methods used in the longitudinal case study for collecting and analyzing data. Then the case analysis is presented, along with its critical factors regarding the transition towards a circular business model through the establishment of a take-back program and how IoT can address them. Finally, the discussion and the concluding remarks will outline the implications of the study and its limitations, highlighting the areas for further research.

Literature review

The CE concept is described by the Ellen MacArthur Foundation (2015) as composed by a number of resource loops, representing different CE levels. At the first level, companies can *recycle* raw materials, entailing the product is irreparably out of order, recovering them e.g. through a melting process. At the second level, companies are *remanufacturing* products, entailing that the product is disassembled and the components refurbished to be able to be used again in the forward supply chain. At the third level, products are *reused*, entailing that they still have value and remaining lifetime, and therefore can be sold again after being refurbished. At the fourth and final level, the focus is on *prolonging the life-cycle* of the products through service and maintenance activities (Ellen MacArthur Foundation, 2015; Bocken et al., 2016; Blackburn et al., 2004).

A take-back program represents a strategic initiative to enable a circular business model, as it focuses on recovering value from used products according to the addressed CE loop (Guide Jr. and Van Wassenhove, 2009). This initiative implies the need for a reverse supply chain, which has three key activity areas to be considered: product returns management, remanufacturing operational issues and remanufactured products market development. These are related, respectively, to the need for a sufficient availability of used products in terms of, for instance, quantity or quality; the need for a positive business case relating the recovered value to, for instance, remanufacturing or reverse logistics costs; and the presence of a market for used products (Guide Jr. and Van Wassenhove, 2009). One tangible example of how the availability of product information across the supply chain (and, therefore, IoT) supports one of these critical areas is related to reverse logistics, i.e. by being able to assess the quality of the product that is taken back (Blackburn et al., 2004). This assessment has been labelled *preponement* (Blackburn et al., 2004) as it is inspired by the forward supply chain postponement concept. In essence, it focuses on having an efficient reverse flow of products by returning recoverable products only and sending the rest directly to scrap.

In summary, the literature on CE focuses on the need for closing resource loops and retaining value from them, thus creating a financial incentive for CE. Under a conceptual point of view, the use of IoT in support of CE has been discussed in relation to remanufacturing operational issues and, specifically, concerning its assistance in assessing the condition of products to be taken back. However, there still is a lack of scientific knowledge regarding how this is supporting CE in practice.

Methods

The method used to perform this investigation is a longitudinal case study (Voss et al., 2002) investigating the support that IoT and the enabled transparency is providing to the establishment of a take-back program in the case company context. The longitudinal data allows the researchers to follow the case company from the implementation of the IoT platform, building an understanding of the collected data and of how the company is using it to create value as well as of the company effort in using it to address CE.

The main method for data collection is interviews. The primary data source is the company’s product manager, who is internally responsible for the digital transformation agenda and in charge of current business development activities, including the ones related to CE. Besides meetings with the primary contact person, several employees of relevance have been interviewed during different stages of the case study. One researcher acted as the primary contact person and interviewer during the longitudinal study, building an understanding of the company business, operations and IoT platform, while specific data about the current company conditions and needs concerning the establishment of a take-back program was analyzed within a team of multiple researchers.

Case analysis

The case company is a medium-size Danish automation solution provider. The firm operates worldwide, though mostly within the Scandinavian and North American markets, selling automation solutions to large as well as small and medium enterprises (SMEs).

The products consist of either stand-alone automation solutions (i.e. industrial or collaborative robots, autonomous guided vehicles, palletizers) that the company programs for the customer, or automation cells (i.e. consisting of a number of mechanical and electronic components, often integrating robots, palletizers and autonomous guided vehicles as well as conveyor belts). These can be more or less customized due to clients' needs, going from a standard "on the shelf" solutions to completely customized ones.

The company business includes initial consulting and feasibility analysis activities, automation solutions' design, manufacturing of some of the components, assembly, sales and after-sales, consisting of service support, maintenance and solution optimization activities.

The introduction of IoT

The firm started in 2016 to investigate new possibilities for increasing the performance of their after-sales activities. This led to a more structured approach of the company's digital transformation and, in particular, to the investigation and integration – currently through a pilot project together with one close customer – of an IoT based platform for remote monitoring of the performance of the operating automation solutions. By interconnecting the case company with their operating products, this digital infrastructure generates transparency across the automation solutions provider's downstream supply chain.

The infrastructure of the obtained IoT platform connects the operating automation solutions to the automation solution provider (i.e. the case company). The needed data is extracted from the PLCs, which collect all the signals registered by the sensors located on the machines and transmitted to a cloud-based database, where they are stored and made available to the automation solution provider through a dashboard. Currently, the platform makes available to the case company data regarding the performance of its automation solutions in terms of operating hours and performed cycles as well as the experienced errors.

This platform is currently being utilized by the case company for providing customers with an indication of their performance and of the related loss causes and for providing the after-sales department with a support for improving the efficiency of its activities. The remote detection of errors or performance losses in near real-time is providing a tangible support for improving service support responsiveness and for improving the efficiency of the adopted preventive maintenance policy, moving the service department towards a condition-based maintenance. The availability of historical data regarding errors and related performance losses acts as a support for improving both the planning of future maintenance activities and for identifying and quantifying solution optimization potential, see figure 1.

The experience gained from this pilot activity has enabled, from the company side, a life-cycle perspective of the product. This, along with the availability of a digital infrastructure (i.e. the IoT platform) that allows to remotely monitor how products are operating, paved the way for a number of investigations related to new strategic initiatives enabled or facilitated by the generated transparency.

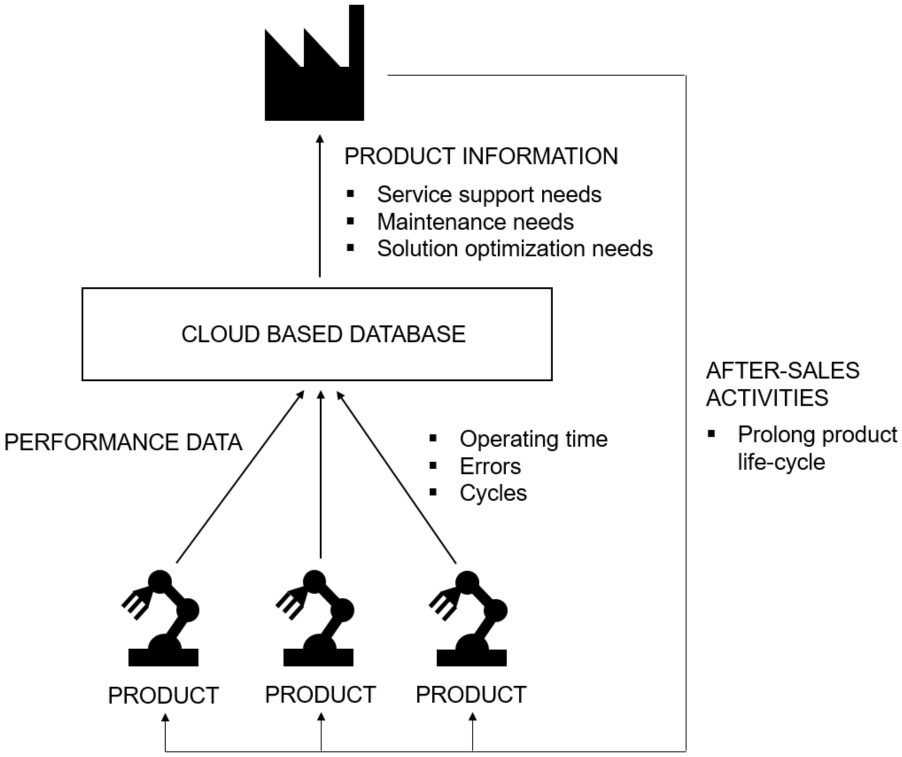

Figure 1 – IoT platform generic infrastructure and current use at the case company.

Towards a circular business model

Through the current use of the IoT platform, the company is already moving towards a circular business model addressing, specifically, the highest value recovering loop, consisting in prolonging products' life-cycle by supporting service support, maintenance and solution optimization activities. However, this activity is not covering the totality of the provided automation solutions, as a number of users experience the need for either new or different automation solutions to deal with new efficiency or process requirements. With the establishment of a take-back program, the case company aims at covering this area and entering, with the returned solutions, the used products market. The goal consists in generating a new revenue stream consisting of the many SMEs that, due to the price, cannot afford to buy new automation solutions. The availability of refurbished ones at a lower price would facilitate, therefore, the company's access to this new customer segment.

Due to its current infrastructure and internal capabilities, the case company, under a CE point of view, would not be able to recover value through the generation of energy or the re-use of raw materials (i.e. *recycling*). The focus is, therefore, on addressing *remanufacturing*, consisting in reusing product components integrating them in new or refurbished products, and *reuse*, consisting in reusing recovered products after refurbishing them in order to be able to re-distribute them in a used-product market, see figure 2.

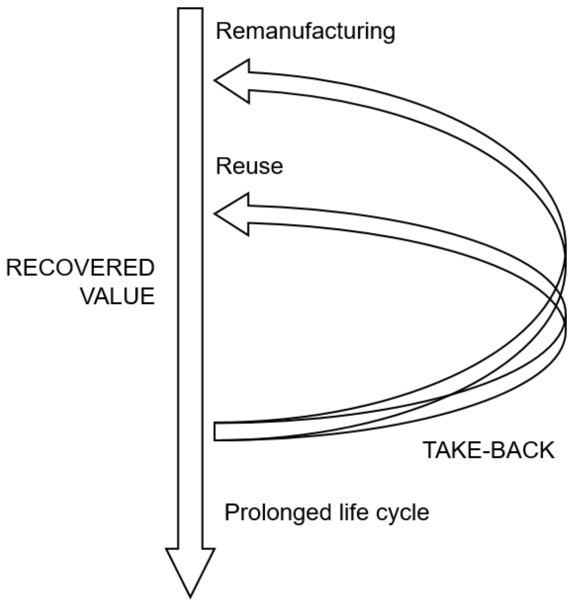

Figure 2 – Circular economy loops available for the case company.

Critical factors

From the longitudinal case study carried on at the case company and according to data collected through multiple interviews with the company product manager, a number of factors concerning both product returns management and remanufacturing operational issues, critical for the feasibility of such a take-back program, emerged.

First of all, quality is considered as the most critical factor due to the fact that a key competitive task for the case company is represented by the provision of products that guarantee a high level of uptime, as the productivity of the customers is highly dependent on them. Because of this, the case company has to be able to guarantee the quality of its new products as well as of the quality of the refurbished ones. This requires the company to be able to measure the quality conditions of its recovered components or products and to take care of any component that could jeopardize the overall quality of the refurbished product.

Flexibility is also considered to be a critical aspect in relation to product development since it represents another key competitive capability of the case company, as its core business consists of providing customized solutions. The establishment of a take-back program is considered to be a limitation for the design of new customized solutions, as future solutions will have to be reconfigurable and able to be either integrated into recovered ones, either refurbished by recovered components.

Finally, cost is identified as a critical factor due to the need for establishing a reverse supply chain in order to support a take-back program. This includes activities such as reverse logistics, disassembly, quality inspection and remanufacturing for all the returned products.

IoT as a feasibility driver

The integration of an IoT platform that generates transparency makes it possible for the company to have a constant overview of the performance of the provided automation solutions during their life-cycle, identifying eventual critical situations (e.g. systematic errors or loss of performance), and quantifying the effective operating time, see figure 3.

This capability allows to address some of the critical factors related to the establishment of a take-back program in the case company.

Under a quality perspective, this supports the feasibility of a take-back program by providing the necessary information to keep this parameter under control in the addressed circular economy loops. The availability of product information regarding the performed cycles, the amount of operating time and the experienced errors can be used as a foundation for estimating the remaining life-cycle of the product or of its specific components. Thus, it makes possible for the company to identify and plan the needed maintenance or refurbishing activities for re-selling products or components without jeopardizing the guaranteed quality.

Under a cost perspective, this supports the economic feasibility of a take-back program by increasing the efficiency of the remanufacturing operations. In particular, by being able to quantifying the remaining life-cycle of a product and to identify the needed maintenance and refurbishing activities, it is possible to estimate the EoL value of the product, deciding accordingly if to take-back a product or not. A direct consequence would be the reduction of needed capacity for the reverse supply chain activities (e.g. reverse logistics and refurbishing) and the use of this capacity for value-adding activities only (i.e. dealing with products or components that can be reused or refurbished with a positive business case). In addition to that, the availability of information regarding the performed cycles and the experienced errors makes possible for the company to identify which refurbishing activities need to be performed and on which components, minimizing them and the related cost as well as the inspection cost and the spare parts stock needs.

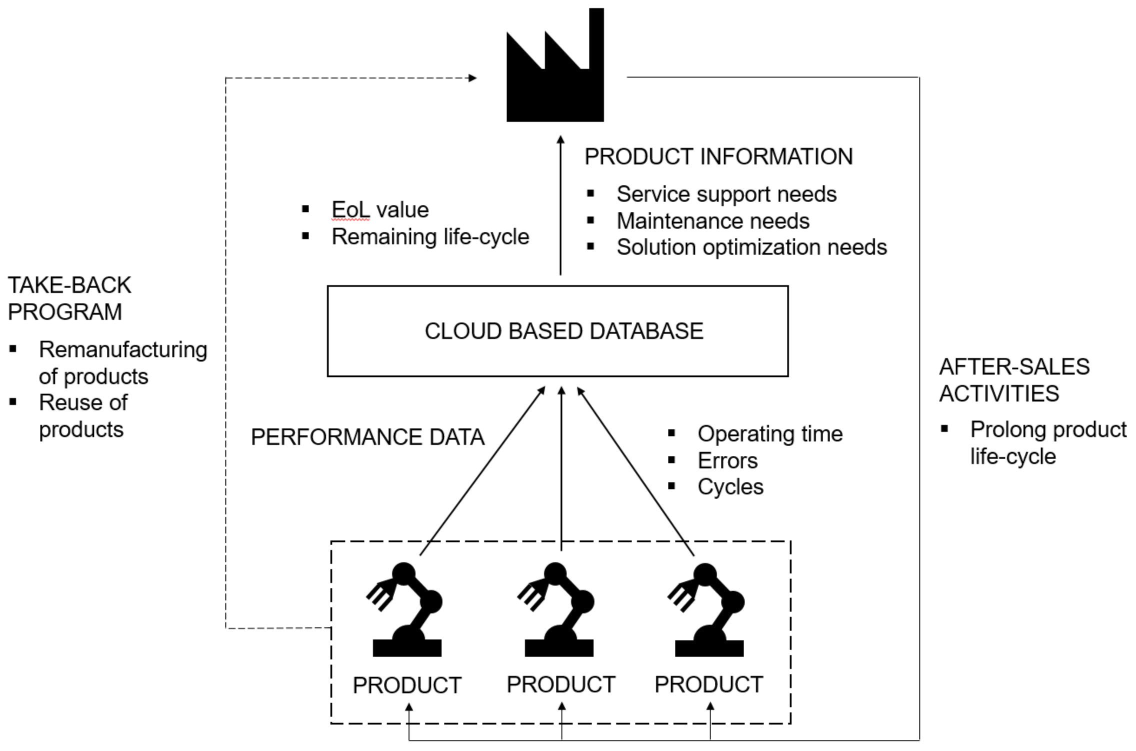

Figure 3 – IoT platform generic infrastructure and use at the case company in support of the take-back program.

Discussion

The establishment of a take-back program in the case company is challenged by issues concerning the need for ensuring a certain quality level to used products' customers, the need for maintaining high customization capabilities and the need for coping with a cost increase due to the need for reverse supply chain activities. The availability of data regarding products' operational performance and enabled by the presence of an IoT platform sets the foundation for obtaining information regarding their residual life-cycle. This supports the identification of the needed maintenance and refurbishing activities to perform on recovered products or components, making possible for the company to re-sell them being able to guarantee the expected quality level. The estimation of the remaining life-cycle and the identification of maintenance and refurbishing needs provides the company with a support for estimating the EoL value of these products. This provides a foundation for minimizing reverse supply chain activities – reducing the related cost - by only taking back products that can provide a positive margin once resold and by minimizing the respective refurbishing or remanufacturing activities according to the effective needs, see table 1.

However, in order to be able to build the necessary knowledge for supporting these actions, it is necessary to have a solid understanding of how the products are deployed and the context they are deployed in along their complete life-cycle. This is translated into the need for a huge amount of historical data, which the company has to be able to analyze and translate into tangible indications about products' operational behavior. In this way, a solid foundation for estimating the residual life-cycle of monitored products or components can be provided, as current data can be compared to a reference. In other words, IoT is not naturally translated into CE effects as data can be utterly meaningless unless it is tightly connected to performance criteria and unless we understand their consequential effects.

The discussed IoT platform is not dealing with the need for flexibility the company has and it is, therefore, not compensating the limitations that a take-back program would imply. However, the company is currently addressing this issue through the introduction of modularization in the design phase of their products. This has the aim of maintaining a high customization level increasing, at the same time, the degree of standardization of the manufactured components, making new products reconfigurable and new components reusable in different configurations.

A further reflection has to be made in regards to the addressed critical factors concerning the establishment of a take-back program. What emerged from the case analysis is related to the product returns management and the remanufacturing operational issues domains, two of the three key areas that have to be taken into account while investigating a take-back program (Guide Jr. and Van Wassenhove, 2009). However, critical factors concerning remanufactured products market development – the third key area – and, therefore, the presence of a market for used products, have not emerged. A reason could be that the presence of a market for used products has been considered as a given aspect by the company as the possibility to add a new revenue stream by penetrating a new market (i.e. used automation solutions) represent the main driver for the company to start a take-back program. However, it is worth to consider, while assessing the feasibility of the take-back program, the effective existence of this market, its penetrability and the potential cannibalization that this strategic initiative could imply on the new products' market.

Table 1 – IoT mitigation of take-back program critical factors

Critical factor	Criticality	IoT mitigation
Quality	Ensure to used products' customers the expected quality (i.e. uptime) levels	Identify needed maintenance and refurbishment activities by calculating remaining products' and components' life-cycle
Flexibility	Customization possibilities limited by the use of used components	-
Cost	Build a reverse supply chain to take-back products	Minimize reverse supply chain activities by assessing products' remaining life-cycle and EoL value and perform take-back activities accordingly

Conclusion

This paper provides an investigation of how IoT and the enabling of transparency across the supply chain are supporting the feasibility of a take-back program. In particular, it contributes to the body of literature concerning CE and to the literature gap regarding how digital transformation and, more specifically, IoT is supporting strategic activities (i.e. take-back program) leading towards a circular business model (Pagoropoulos et al., 2017). By contextualizing this discussion with the support of a longitudinal case study, the authors address the current lack of empirical research in this field (Pagoropoulos et al., 2017), which has been pinpointed as one of the possible causes for the current literature gap (Souza, 2013; Vachon and Klassen, 2010; Nobre and Tavares, 2017; Leider and Rashid, 2016).

The research contributes to the existing knowledge regarding the product returns management and the remanufacturing operational issues domains, two key areas to be addressed for establishing a reverse supply chain and a circular business model (Guide Jr. and Van Wassenhove, 2009). Specifically, it argues about how IoT and operational performance data can provide a support for assessing and guaranteeing product quality in a circular business as well as how cost related to reverse supply chain activities can be reduced by minimizing these activities according to the effective product condition.

This research provides the basis for further investigations regarding the quantification of the impact of IoT on the establishment of a take-back program in terms of business case. This requires the collection of quantitative data from the case company related to the actual cost of the reverse supply chain activities that the company would perform. Another topic to be investigated, in order to provide a more operational indication of how to use IoT to support a take-back program, consists of identifying specific product data – as well as data use – for supporting reverse supply chain activities. This investigation requires a more in-depth understanding of a take-back program and of how reverse supply chain activities are planned to be performed in the case company, of which decisions are needed to operationalize them and of which information is needed to support these decisions.

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