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A practical ICT framework for transition to circular manufacturing systems

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Abstract

The transition towards a circular economy has become important. Manufacturing industry being a major stakeholder in this transition has started exploring the potential of this transition and challenges in implementation. Ambitious companies such as Gorenje d.d. has taken the circular economy transition seriously and aims to become a pioneer in implementing circular manufacturing systems. One vital step in this transition is the business model shift from the linear (sales model) to a circular model such as 'product as a service'. This brings new challenges to Original Equipment Manufacturers (OEMs) that have never been experienced in their conventional businesses. One of the challenges is to establish an information communication and technology (ICT) infrastructure that enables information management and sharing as well as establishes a real-time communication between relevant stakeholders. Outlining such an ICT infrastructure is the objective of this paper.

Keywords: Circular economy, Circular manufactuirng systems, Business models, ICT

1. Introduction

Economic and environmental benefits as well as sustainability aspects of Circular Economy (CE) both at micro and macro level are well-evident [1] [2] [3]. Therefore, stimulating the transition towards a circular economy has become a priority for both European Commission (EC) and for Sweden as a leading industrial nation. While EC is pushing this through an ambitious CE package [4], in Sweden the momentum has already been reached in different industrial sectors and the government has identified circular and bio-based economy as one of the strategic areas to strengthen [5].

Sustainability being the core business value for Gorenje d.d. since long has also committed to the CE approach to bring the sustainability to a new level by implementing Circular Manufacturing Systems (CMS) [1]. CMS in this context refers to recovery of value (i.e. material, embedded energy and value that are added to products during manufacturing processes) through reusing, remanufacturing and recycling in a systematic way.

Traditionally, Gorenje sells white goods and kitchen appliances together with service and spare parts, like any other manufacturers. As a step towards CMS, Gorenje aims to move from their traditional product sales model to service-based business models (SBBM) that will allow users to subscribe for clean laundry services based on a pay-per-use scheme. In this

[1] Circular manufacturing system is a system that is designed intentionally for closing the loop of products/components preferably in their original form, through multiple lifecycles. This is a value management approach which includes the phases value creation, delivery, use, recovery and reuse in a systemic perspective. [7] [15]

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business model Gorenje will retain the ownership of the machines and the responsibility of service and maintenance will also remain with Gorenje. This sort of business model is considered highly relevant for implementing CMS which in short-term meets customers' satisfaction and in long-term ensures certainty for manufacturers in value management through better control over their products throughout the product lifecycles. This business model will enable Gorenje to recover (through reusing, remanufacturing and recycling) value from used products in an efficient way which is a key element of the CE approach.

However, implementing the CMS approach in manufacturing industry that includes value creation, delivery, use, recovery and reuse will require radical changes in business models, product design, supply chains and information management infrastructures [6] [7] [8]. Furthermore, these areas are mutually dependent on each other and due to these dependencies, a change in the business model requires that product design, supply chains and information management infrastructures are also changed accordingly to fit the new business model. This work mainly focuses on ICT infrastructure and partly covers the product design aspects that are necessary to consider in order to fit the business model shift.

Having stated the above, the main objective of this paper is to outline a practical framework for ICT infrastructure which is essential for business model shift and implementation of CMS. More specifically, this work defines what features an ICT infrastructure should have and how it should function.

This research is part of a project funded by the European Commission (EC) which aims to bring forward a commercial IT-platform that can become a leading ICT solution for the implementation of CMS. This IT-platform is integrated with the hardware and software through an Internet of Things (IoT) platform for information communication and sharing. Furthermore, the aim is to implementing machine learning in order to predict the operation conditions of washing machines, which is the case study product of this research project.

2. The state-of-the-art

The state-of-the-art has two dimensions in the context of this work. The industrial state-of-the-art covers applications of service-based business models, i.e. pay-per-use or similar scheme by other actors in the market. Furthermore, Wi-Fi/sensors enabled washing machines that are developed with the purpose of implementing SBBM and/or CMS to some extent are also considered as part of the industrial state-of-the-art. The research state-of-the-art covers the area of ICT infrastructures that are developed keeping CMS implementation in mind.

The most relevant industrial example of SBBM in white goods sector is a Dutch company called Bundles as reported by Ellen MacArthur Foundation [9]. The users of Bundles can choose from two standard models of Miele washing machines and subscribe for a pay-per-use or pay-per-month scheme. However, the ICT infrastructure that is used by Bundles is limited to what Miele's standard washing machines contain with Bundles' add-on application used for usage data monitoring and billing purposes [10]. A similar service is provided by another Dutch company called HOMIE that aims to cover all home appliances but currently offers Zanussi washing machines as pay-per-use. They also use standard Zanussi machines added with their own application mainly for billing purposes and usage data collection. [11] The third example is also a Dutch company; an online renting service offered through www.wasgoed.com. The company rents a wide range of white goods on monthly payment scheme without any added application for billing and/or usage data collection [12]. There are several more actors in Europe that provide similar renting services.

There are no IT-solutions available in the market that specifically support implementation of CMS or SBBM. As part of an EC funded project called ResCoM[2], a prototype of Product Lifecycle Management tool has been developed for managing and tracing product-related data throughout the product lifecycles in the context of CMS. As part of a Vinnova (Sweden) funded project, a prototype of an IT-platform has been developed with the aim to enable implementation of SBBM. Zihan et al (2014 [13]) and Michael et al (2016 [14]) have described the ground work together with the development and testing of the IT-platform. This IT- platform is now being further developed to make it a complete ICT infrastructure which is crucial for the business model shift and implementation of CMS.

Although the project deals with a specific issue, i.e. ICT infrastructure of a specific industry, i.e. the white good sector, this approach can be implemented in various areas where cross-organization collaboration and real-time communication with multiple stakeholders is crucial.

3. The ICT infrastructure and its emergence

Our research has revealed that to succeed with the business model sift in the context of CE and CMS, it is not enough to have an ICT infrastructure consisting of machines that only collect and send usage data for billing purposes [6] [7]. A more sophisticated ICT infrastructure is required that can sense, collect, and process useful information and share that to all relevant stakeholders as shown in Fig 1.

[2] www.rescoms.eu

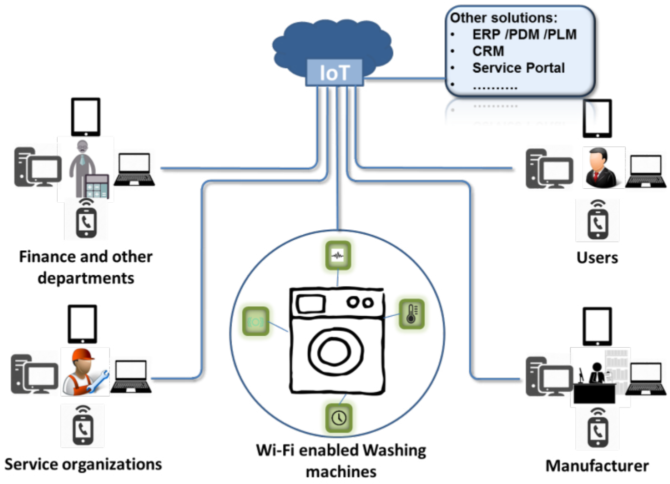

Fig 1. An overview of the ICT infrastructure.

Such an ICT infrastructure consists of machines that can sense different operational data using sensors and send the data to an internet server. The internet server which also stores a set of digital twins of the washing machines processes the data to detect anomalies. The information and data is then made accessible to different users through a web application. Further details of each part of the ICT infrastructure are described in the following sections.

3.1. Wi-Fi enabled washing machine

Connected white goods are fundamental building blocks of smart homes and the future of the whole white goods industry. This is considered as the next big paradigm shift due to the developments in the IoT industry, especially the price drop of Wi-Fi module and cloud-based solutions are making this potential more realizable. Just by extrapolating the fact that more and more devices will be connected to the internet, it is reasonable to imagine that washing machine-users will like to have a connected machine with the feature to remotely turn on/off, start a program, get statistics about power and water consumption, etc.

Although these features are interesting and desired, they cannot alone justify implementation of the IoT in white goods. Firstly, because in future these features are going to be essential and expected and secondly, only limited number of people will be willing to pay extra for such features. Therefore, to exploit the features of connected washing machines, Gorenje must develop new use cases beyond these essential features. The potential lies in improving after sales services through predictive maintenance and by providing customized services, collecting usage data to optimize operations and utilization of machines with software updates. All these are vital elements of business model shift and crucial for implementation of CMS and therefore, Gorenje's research and development activities are moving towards this direction.

Unlike usual research projects and feasibility studies, Gorenje has started with an off the shelf hardware to minimize risks and costs of development. In this case, a well-recognized and popular IoT platform called Raspberry Pi (Rpi) is being used. Raspberry Pi is a credit card size microcomputer, with 1.2 GHz ARM microprocessor and integrated wireless card. Most importantly, it has 17 general-purpose input/output (GPIO) analog/digital channels and strong user-based support. The electronic parts of the washing machine are connected to Rpi through a motherboard developed especially for this purpose. Rpi typically comes with a Linux operating system, which automatically takes care of Wi-Fi connection and makes it easier to add as well as manage multiple sensors. The Rpi platform is useful for an easy and fast deployment of connectivity feature which also resembles to electronic devices that are ready for production. In general, Rpi provides an easy and cheap way for testing new ideas. This has cut down the development cost and enabled Gorenje to focus on the implementation of the SBBM rather than only focus on technical development.

3.2. Integration with method and model for predictive maintenance

As mentioned earlier, just the Wi-Fi enabled washing machines that collect basic operational data will not win users and create a business case for OEMs in long-run. It is essential that such features provide competitive advantages to Gorenje or create a solid ground for business model shift. With this in mind, an integration platform (as shown in figure Fig 2) is being developed which will serve as a back-end for data collection (from the washing machines) and present the information to multiple users by using the IT-platform. Furthermore, a methodology and operational model for maintenance and prediction of remaining lifespan (by predicting the health of different components) of the washing machine's sub-systems is being explored. The key features of this methodology are to,

- use accelerated test at existing product test facilities as data source,
- use this data to train a machine learning (ML) model and
- operationalize the model using a server solution.

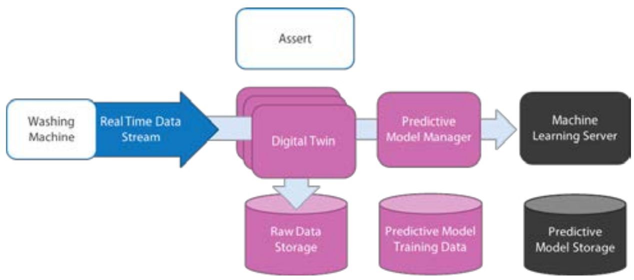

Fig 2. An overview of integration and predictive maintenance mechanism

The objective in this case is to prove that the data collected during the accelerated life testing can be used to create data models that are useful when predicting the lifespan of components or sub-systems of complex products like washing machines. This approach is highly relevant since machine learning implemented to failure/lifespan predictions are based on the collection of sample data from real failures occurring during operation of machines. In this research, sample data on failures that occur in the heater, bearings as well as water inlet and outlet pipes are being prioritized and being collected from the Gorenje's test facilities.

The data that are collected from the washing machines and processed to predict failures need to be presented to users of the information, i.e. OEM, service organization, end users etc. in a useful form. This purpose will be fulfilled by the IT-platform described below.

3.3. The IT-platform

The IT-Platform is a solution that allows manufacturers to manage and publish technical information from multiple sources to one website. Through the developments in this project, following applications have been added to the IT-platform:

- Asset management: to be able to handle individual machines.
- Machine cards: to keep track of the machines' real composition.
- Integration to IoT platforms (ThingWorx in this case): to get real-time operational data and predictive maintenance notifications.
- Integration to ticketing systems (Jira in this case): to handle the process for planning and processing the predictive maintenance.
- Uploading of maintenance protocols: to document the predictive maintenance activities.

The objective is to provide each relevant user-category an appropriate home page for the individual machine. For instance, an end user will have an interface (as shown in Fig 3) with basic information such as number of washes, when next service/ maintenance is due, cycles per day, quantity of detergent used and weight of the laundries etc.

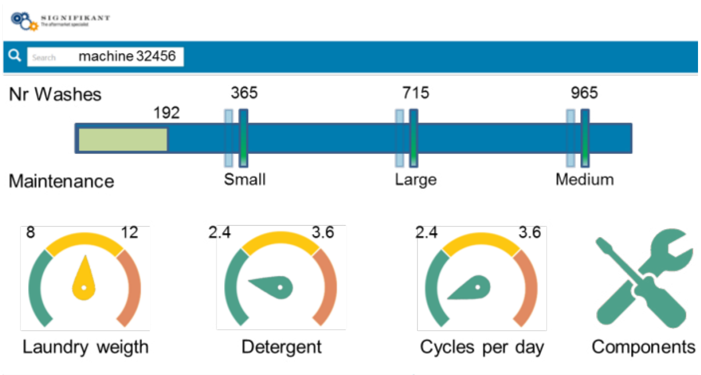

Fig 3. An example of the interface designed for single machine and end user

Similarly, the service organization will have the interface layer where information about several machines will be displayed as shown in figure Fig 4.

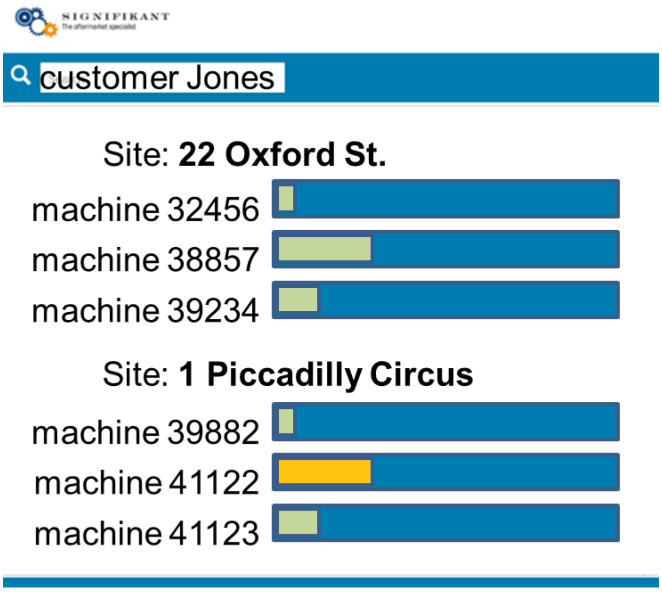

Fig 4.An example of the interface designed for multiple machines and service organization.

To summarize, the web application includes information from several sources in order to guide different stakeholders in what actions to be taken and when. Furthermore, it will help the users to perform their tasks effectively through making the correct documentation available and make it easier to order the correct spare parts on right time and quantity. Presenting real-time operational information will also inspire the end users to use their machines cost effectively or in an environmental friendly manner.

4. Conclusions

This paper presents a practical ICT framework that is necessary to shift from traditional product sales models to service based business models. The need for such a framework has emerged from the fact that to achieve the goals of CE, manufacturing industry needs to adopt a CMS approach. In this transition, embracing the SBBM has become inevitable and, for a smoother shift from the conventional sales model to performance focused SBBM, sophisticated ICT infrastructures are needed. The state-of-the-art review shows that although existing solutions are creating a business case for some small companies, for a better management of the value starting from the creation to the recovery and reuse, existing solutions need to go beyond their current functionality. Furthermore, the existing solutions only cover the basic features which will become outdated with the fast development in the field of IoT. The framework presented in this paper will not only create a business case for OEMs today but will tackle many challenges of implementing circular manufacturing systems in the long run.

Nevertheless, all innovations bring challenges that need to be dealt with. In our view, the IoT development that is necessary for the business model shift has become matured enough and therefore, technical challenges are less likely to become an issue. Consumers' acceptance of fully connected machine with the risk of invasion of personal information is a great challenge. Furthermore, there are legislative fireworks that may make both implementation of IoT and CMS approach challenging.

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