Reducing Remanufacturing Uncertainties with the Digital Product Passport

Viola Gallina[1(✉)], Barna Gal[1], Ádám Szaller[2], Daniel Bachlechner[1], Elisabeth Ilie-Zudor[3], and Wilfried Sihn[1,4]

[1] Fraunhofer Austria Research GmbH, Theresianumgasse 7, 1040 Wien, Austria
viola.gallina@fraunhofer.at
[2] EPIC InnoLabs, Kende Street 13–17, Budapest, Hungary
[3] Institute for Computer Science and Control (SZTAKI), Kende Street 13–17, Budapest, Hungary
[4] Vienna University of Technology, Institute of Management Science, Theresianumgasse 27, 1040 Wien, Austria

Abstract. In contrast to the linear production model, the circular economy aims to close the loop of materials. One part of this approach is remanufacturing, which extends the lifetime of products. Various stakeholders in the supply chain are involved in remanufacturing. This makes the management and optimization of remanufacturing activities complex. The data required for optimization is often missing, which leads to uncertainties. A new European Commission initiative, the digital product passport (DPP), is believed to facilitate information exchange in the supply chain and cloud be a good solution to reduce uncertainties. The primary purpose of this paper is the quantification and evaluation of the advantages of the DPP. Based on real industrial data, a discrete event simulation model of a remanufacturing system with three production lines was developed. The authors suppose the hypothetical existence of a DPP and illustrate the benefits arising from its application.

Keywords: digital product passport · simulation · evaluation · uncertainties

1 Introduction

Digitization is one of the enablers of the transition towards a more sustainable circular economy. It can help closing the loop of the linear production model by providing data on the whole product life cycle. One particular tool, the DPP is investigated in this paper, which facilitates more efficient processes in the supply chain. Among others, the DPP might be an efficient tool for reducing uncertainties in remanufacturing processes. The aim of this paper is the quantification of the benefits that can be gained with the help of the DPP and illustrate it with a real industrial use case from the machine construction industry. The paper is structured as follows. The next chapter gives an overview on the state-of-the art regarding remanufacturing uncertainties, the DPP and data exchange.

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Chapter three discusses the theoretical possibilities for lowering uncertainties with the DPP resulting in an automatic efficiency increase during remanufacturing. A simulation model of a real remanufacturing system with the quantified benefits is presented in chapter four. The last chapter concludes the paper and outlines the future research agenda.

2 Literature Review

2.1 Uncertainties in Remanufacturing

Suzanne et al. [18] define remanufacturing as a recovery operation of used products for rebuilding to a like-new condition. In most cases the remanufactured products are offered with very similar guarantee conditions as new products. The six steps of remanufacturing are entrance diagnosis, disassembly, cleaning, inspection, reconditioning and reassembly [17]. The main particularity of remanufacturing resides in product disassembly. Remanufacturing is much more challenging than manufacturing in the classical linear production model. The main reason for this lies in complicating factors such as uncertainties that arise during remanufacturing. The uncertainties are well documented in the scientific literature. Junior and Filho [12] summarize these factors with a focus on the period from 2000 to 2009: i) uncertain timing and quantity of returns; ii) balancing returns and demands; iii) disassembly of returned products; iv) uncertainty in materials recovered from returned products; v) requirement for a reverse logistics network; vi) material matching restrictions; vii) highly variable processing times during remanufacturing; viii) stochastic material routings. Ropi et al. [11] concentrate on the period between 2013 and 2021 and refine the grouping of uncertainties as follows: i) demand; ii) return yield; iii) inventory; iv) cost; v) quality and vi) environment.

It must be noted that *disassembly* is not simply the inverse operation of assembly. Typically, the quality of the components of the returned products can be revealed only after disassembly and just then the classification regarding reusability becomes possible – such as reusable with or without reconditioning, or not reusable.

2.2 The Digital Product Passport

The digital product passport (DPP) has recently gained increased attention by policymakers at the European Commission, who are requiring the implementation of DPPs – facilitating the digital transformation leading to a healthier and greener society [7]. The DPP "could provide information on a product's origin, composition, repair and dismantling possibilities and end of life handling" [8].

However, the idea of gathering data on the whole product life cycle is not novel. Barco and Charnley [3] present a case study of a high pressure nozzle guide vane on data acquisition by sensors and discussed data requirement issues regarding a DPP. An immature concept of product life integration – containing design, manufacturing, packaging, customer use and finally recycling or disposal – can be found in a strategical document of Hewlett-Packard from 1995 [10]. In the context of building, the material passport is often used. The material passport is a qualitative and quantitative documentation of the material composition of a building, showing the materials embedded in buildings as well as their recycling potential and environmental impact. This enables different actors in the building sector to continuously collect and evaluate data for building components [19]. A similar data gathering approach is the cradle-to-cradle passport, that contains information on raw materials, disassembly and recycling plan on cars. In addition, individual (large) companies already have their own internal passport approaches in certain areas. They are not uniform solutions for a whole car, but island solutions for particular problems – such as Polestar‘s transparent cobalt supply chain realized with blockchain [6]. Herrgoß et al. [14] evaluate distributed ledger technology for production planning and concluded that "blockchain enables a guaranteed level of security, transparency and immutability that no centralized data storage technology can provide at this time". Kouhizadeh et al. [13] investigate the blockchain‘s potential in benefiting the circular economy and conclude that more industrial examination is needed in this context. Gligoric et al. [9] use Internet of Things concepts for building a DPP.

The German Government picked up the discussions on the DPP at the European level and developed a political concept on the DPP. The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) defines the DPP as a data set that summarizes the components, materials and chemical substances or also information on repairability, spare parts or proper disposal for a product [1]. According to the BMU, the DPP should be applicable to all products and services – including foodstuff – and the Ministry proposes the Commission to focus on textiles, electronics, construction, packaging, batteries and electric vehicles. Totaro [2] extends this list with fashion, furniture as well as "high impact intermediate products" such as steel, cement and chemicals.

The DPP is seen as a tool for enabling holistic and comprehensive data recording of environmental and social sustainability aspects. It gives the possibility to"track and trace" information on the whole supply chain. Doing so, it might overcome one of the biggest hurdles of the circular economy model, namely the lack of information on the various stakeholders of the supply chain. The benefits of a transparent supply chain are manifold: i) producers and retailers: competitive advantage; ii) users: more environmental-conscious product consumption, increased trust in case of buying used products; iii) remanufacturers: decreased uncertainties, access disassembly guides and components, cost and time efficient disassembly; iv) certifiers:

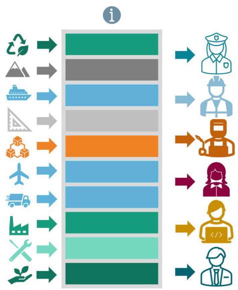

Fig. 1. Schematic visualization of the DPP content (own illustration according to Luscuere [16])

collect data more easily – to name just a few. Introduction of a DPP can have high significance also in regard to waste management, in two distinct phases: process control, respectively decommissioning (disposal or recycling). Expected benefits of a DPP supported waste management are: i) reduced time-in-storage of dangerous wastes; ii) decreased storing costs of parts; iii) reduced emissions; iv) production optimization to avoid waste and energy losses.

The various stakeholders might gain the above mentioned benefits based on different information obtained from the DPP. However, the content of the DPP is generated by different actors of the supply chain. Figure 1 depicts the actors involved in the context of DPP. E.g., the manufacturer on the left side (including product designers and production engineers) can give information on the materials and components of a product. The consumer on the right side can make his or her product choice not just based on the information created by the manufacturer, but on the environmental information provided by different certification bodies. Another beneficiary on the right side, such as a remanufacturer, however, needs more detailed information regarding disassembly and and previous life of the product. This means that the product information can be relevant to different groups with different levels of detail. Berger and her coauthors give a conceptual overview on battery passport containing three information levels [4]. This paper focuses on remanufacturers as a stakeholder group: their data requirements and the benefits they might gain are investigated. In the industrial use case, manufacturing and remanufacturing take place in the same company, on the same shopfloor, but on different production lines. With the existence of the DPP, the remanufacturer might have access to information that leads to increased efficiency.

2.3 Transparent and Secure Infrastructure and Proper Governance

Potential stakeholders are aware that information exchange in the supply chain may well be beneficial for society as a whole or for some stakeholders, but may also bring disadvantages for others [5]. The fact that laws may be violated (e.g., data protection, intellectual property, liability) or trade secrets may be compromised leads to reluctance to exchange information. If stakeholders are not forced to exchange information, they will weight opportunities and risks carefully. Other than the Supply Chain Act, which is likely to result in some form of DPP – but aimed at eliminating production processes and working conditions that violate human rights rather than enabling or supporting remanufacturing activities – there is no expected legislative pressure related to information exchange in the value chain. It is also not foreseeable for the time being that dominant suppliers or customers will force their business partners to exchange information that facilitates remanufacturing. Therefore, DPPs must be designed to convince a critical mass of relevant stakeholders. This means that DPPs must use a transparent and secure infrastructure, which ensures that stakeholders retain sovereignty over their data [1]. In addition, proper governance is required to ensure fairness and accountability. Gaia-X, an open data infrastructure based on European values that is currently being implemented, could be suitable as foundation for DPPs.

3 Possibilities for Uncertainty Reduction with the DPP

One of the biggest problems is that remanufacturers do not have any information on the *quality* of product components before the disassembly is finished. Two identical components from two different products can have various conditions. It might result in different process flows with diverse material and component routings with highly variant process times and lead times. In the DPP, the product users might share information on the usage, maintenance and repair activities on the product – in the optimal case, in an automated way. A higher level of information regarding the quality of the product and its components might lead to processes with lower variance, better predictable production schedules and in the end better logistical KPIs: lower work-in-progress and inventory levels, reduced average lead times, higher capacity utilization and higher adherence to schedules.

The remanufacturers are also not familiar with the *timing and quantity* of returned products. The product mix requiring remanufacturing and competing for scarce resources is not known well before and it makes production planning even more challenging. Information content regarding timing and quantity of the returns in the DPP – in an aggregated way according to product or product variants – might result in more effective and optimized remanufacturing production plans.

4 Simulation Model of a Real Remanufacturing System

In a remanufacturing plant for gas engines, the uncertainties presented in previous chapters could be observed. The condition in which the cylinder heads arrive at the remanufacturing plant only becomes apparent after the gas engines have been disassembled and, in some cases, after the cylinder heads have been machined. Today, instead of a DPP, markings are mechanically placed on the cylinder heads with a center punch to indicate the number of life cycles before the heads become scrap. In the present manufacturing process, cast casings of reclaimed cylinder heads are disassembled, machined, and reassembled after reaching end-of-life status. This results in new remanufactured cylinder heads, which are essential assemblies to overhaul gas engines and can be used for a maximum duration of three product life cycles in gas engines. The uncertain timing, the quality and reusability of the reconditioned components and assemblies pose special problems for the manufacturer. In order to keep supply and demand in balance, the manufacturer has to accept both increased stock-keeping, the provision of increased production capacities available at short notice, and the regular use of cost-intensive new parts. This results in monetary losses and waste in production for the manufacturer as well as bottlenecks in material supply for gas engine assembly.

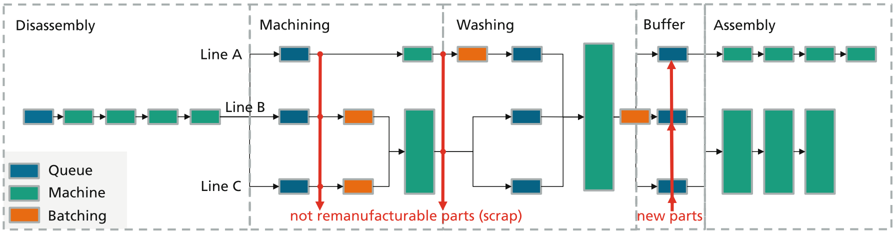

Fig. 2. Flowchart and simulation model for evaluating the effect of the DPP

Discrete event-based simulation (DES) models are used to support decision making, evaluation of a system operation and for riskless comparison of different scenarios in manufacturing systems [15]. To investigate the effect of the DPP, a DES model of a real remanufacturing line was created in Siemens Tecnomatix Plant Simulation, and it was also validated using KPIs from one month of production. With the built-in Experiment Manager tool, experiments were performed to investigate the difference between applying or not applying the DPP. The current situation corresponds to the case "Without DPP". This means that the information on the previous life cycle is only revealed after disassembly and machining – if necessary. In the case "With DPP", the information is already available before disassembly. This allows the removal of scrap at an earlier stage (marked as "not remanufacturable parts" in 2). As Table 1 shows, the comparison of two scenarios was made based on different system KPIs measured on running one month of production. For each scenario, 15 experiments were performed with the same parameter set but different random seed, and the average of the results are presented in the table.

Surprisingly, the output of the remanufacturing system was reduced a little bit when applying the DPP, and the average lead time was increased. The reason for this is the following: as the scrap rate is lower, the proportion of good products (that are not exiting the system, thus generating lines and slowing the other products down) is higher, causing longer waiting times in the system. In contrast, the number (and ratio) of scrap products was reduced, meaning that in the modelled one month, the approx. 0.6% output decrease came with an approx. 18 % scrap decrease.

Table 1. Evaluation of the simulation highlighting the quantitative benefits of a DPP

	Output (pcs)	Avg. lead time	Dev. of lead time	Scrap rate (%)	Scrap prod. (pcs)	New parts (pcs)
Without DPP	1744	6 d 8 h	3 d 19 h	25.31	441.33	159
With DPP	1733	7 d 12 h	4 d 10 h	7.25	125.67	141

5 Summary and Future Work

In this paper the remanufacturing uncertainties were presented and it was discussed how the DPP can contribute to a more efficient remanufacturing process. With the help of a simulation model it was illustrated, that the digitization of some product life cycle related information might result in more efficient remanufacturing. The reduced scrap rate and lower number of new parts needed for the end product lead in the end to smaller carbon footprint.

As a next step, lead times and output will be analysed and it will be investigated whether they can be improved with sequencing. In the longer term, the involvement of various stakeholders will be considered. The presented use case might be extended with data on usage (working hours, maintenance, etc.), which could lead to an additional remanufacturing efficiency improvement.

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