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Quantitative benefits of the digital product passport and data sharing in remanufacturing

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Abstract

As a part of the circular economy – which aims at closing the loop of materials – remanufacturing is getting more and more attention in recent years. With remanufacturing, companies are carrying out a recovery operation of used products with the aim of rebuilding a like-new condition. As various members of the supply chain are involved in this process, and product data needed for optimal operation is often missing, remanufacturing processes can become uncertain and hard to optimize. The goal of a new European Commission initiative, the digital product passport (DPP), is to facilitate information exchange between stakeholders, in order to reduce uncertainties. DPP, assigned to a product, could contain information about e.g., its origin, composition, repair and dismantling possibilities. In the paper, the essence of DPP is introduced, and a case study is presented to show the qualitative benefits of the increased amount of information about the product. A discrete event-based simulation model of three real production lines that are (re)manufacturing cylinder heads is presented. Experiments are also conducted, where quantitative benefits of using DPP are highlighted, such as decreasing unnecessary production time, increasing ratio of remanufactured parts and increasing output.

Keywords: remanufacturing; simulation; digital product passport; data sharing, simulation

1. Introduction

Limited information exchange in the supply chain is the main challenge restricting the realisation of the circular economy concept [1]. Remanufacturing companies also have to deal with uncertainties because they do not have detailed data on the product life cycle (e.g. usage, maintenance, exact arrival of parts or products). This results in increased costs leading to less attractive remanufacturing activities and more expensive products in the end. National and international policies/regulations/initiatives or economic incentives should facilitate the data exchange in the supply chain. One example of the former one is the digital product passport, that is a European initiative. An economic incentive might be a discount on a remanufactured product. The main aim is the encouragement for data sharing in the supply chain. Therefore, the paper quantifies – with the help of a real case study – the advantages of information sharing and hopefully motivates companies to do so.

The achievements presented in the paper are the continuation of a previous work, and each of those is a part of an ongoing research in circular economy [2]. About the latter, as the authors believe, it is essential for closing the loops of the linear production model and for a successful transition into a circular economy. Moreover, the authors, who are experts in optimization of production systems, are convinced, that any optimization of the supply chain (e.g. reducing the product footprint) can be realised with data exchange among all actors of a supply chain. One actor is able to determine its local optimum in the supply chain that definitely differs from the global one.

The paper is structured as follows. The next section gives an overview of the uncertainty problem, the possible solution with the digital product passport, data sharing and last but not least of the measurement metrics of a circular supply chain. In Section 3, first, an industrial case study is presented. Then, a discrete event-based simulation model is introduced, with which experiment series are performed to show the effect of increased availability of information about a product. Finally, the main

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findings are summarised, and the future research potentials are discussed.

2. Literature review

Remanufacturing is 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 [3]. According to the ambitious objectives of the European Commission (EC) [4] the recycling rate should be increased. Despite the intensified research activities (see Fig. 1) recycling rates stay low [1].

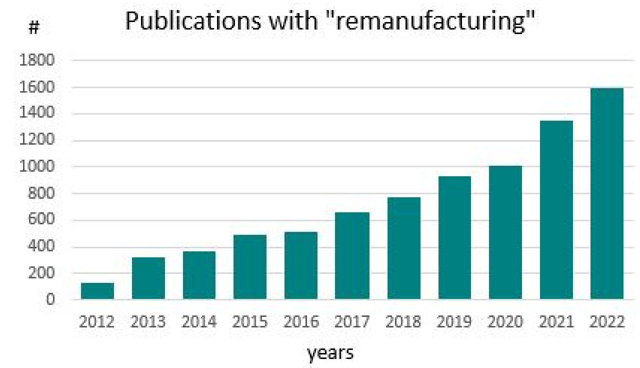

Fig. 1. Number of published papers with "remanufacturing" per year (based on Science Direct, 13.01.2023)

One of the main reasons of the low recycling rates is the limited information and data sharing – when at all – in the supply chains. Remanufacturers are not aware of the real state of the products that have to be remanufactured. In the literature, researchers deal with this problem under the umbrella of uncertainties. Possible solutions might be the digital product passport and data sharing in data spaces, aiming and facilitating the data exchange in the supply chain among the different actors. While the former will be a regulation and will be obligatory in the member states in the longer term, the latter can be realised in the short term if the operators can see their own benefits. In the followings, the state-of-the-art on remanufacturing uncertainties, data sharing and digital product passport are summarized.

2.1. *Uncertainties in remanufacturing*

In a remanufacturing system, uncertainties can occur from uncertain consumer demand for remanufactured goods, and the uncertain quality of the returned product [5]. Apart from these, manufacturers also have problems due to the quantity of returns caused by the inconsistent supply of returns. We et al. [6] points out that uncertainties in the core acquisition of remanufacturing, in terms of cost, quality, quantity, and customer attitude are still the main barriers to achieving profitability. Liu et al. [7] highlight the fact that the uncertainties concluding from remanufacturing also make the cycle time uncertain within a company.

Therefore, a stronger coordination is needed between the various members of the reverse supply chain [8]. Govindan et al. [9] state that a properly designed contract is one way of coordinating the chain. This contract enables partners to choose order quantities that are optimal for the entire supply chain [10] and also inspires retailers to order more, thereby increasing the market availability of products [11].

Ziyue and Lizhen [1] summarize in their review paper that just 3% of the reviewed 289 papers contain some kind of solution for the uncertainty problem in remanufacturing – meaning that 97% of the papers either just mention the problem but do not propose any solution or do not mention it at all. Jäger-Roschko and Petersen state that typically economic incentives are the motivation for information sharing and uncertainty reduction. [12].

2.2. *Digital product passport*

A digital product passport (DPP) is a structured collection of product related data across a product's lifecycle – beginning with raw material extration in mines, through manufacturing and distribution till end-of-life handling – to advance the transition to a circular economy and thereby support economic growth. The DPP is receiving more and more attention, not only on European but on already national level in various Member States as well. Sweden is very active in the electronics and furniture industries [13]. Germany had launched the national Battery Pass project focusing on data specifications and standards for batteries made or placed into service in the EU and will create a minimum viable product [14].

The European Green Deal mentions an electronic product passport providing information on materials' origin, production, compositions, repair and end-of-life handling [4]. As it was originally intended, it might facilitate environmentally conscious decisions of the consumers and boost energy and resource efficiency. The DPP will provide reliable and comparable product sustainability information not just for businesses, but for policymakers as well. With the increased transparency, traceability and consistency, it will result in standardised reports on sustainability indicators in the short term. The application of a DPP on mid-term – with the ultimate goal of redesigning products and value chains – might affect the company competitiveness, and will lead to new business models and investment decisions. The DPP will enable the upscaling of circular economy strategies and beyond on the long term [13]. From its nature, it might be designed to solve some of the uncertainty problems of remanufacturing acting as a "track and trace" solution for pooled product unique data [15].

The content of DPP and the functioning of the underlying system are not yet well defined [16, 15]. However, there are several points that are already fixed and were communicated by the EC in the form of reports [13], interviews [17], etc., such as:

- the *Ecodesign for Sustainable Products Regulation (ESPR)* – previously known as Sustainable Products Initiative or SPI – serves as a dedicated *legal basis* for the DPP and focuses on the life cycle environmental impact;

- *product specific information* will be defined in the applicable delegated act;
- the first *product category* is battery for which the DPP will be mandatory (01.01.2026.) – further product categories with high environmental impact will be defined later on continuously (as food is not regulated by the ESPR, it is out)
- DPP will be applicable for *all of the products sold in the EU* and the economic operator placing the product on the market is responsible for making available the DPP;
- a *decentralised approach* will be applied to the information storage, the only central element will be registration in the CERTEX system of the EC;
- the DPP will be horizontal and vertical *interoperable*, meaning that all actors of the supply chain have to deal with it;
- *no proprietary solutions* will be used, meaning that all information will be written in an open and standard format and will be machine-readable, structured, searchable with different access rights;
- the DPP contains unique *product specific information*;
- the *granularity of information* will be structured and it will refer to the product model, production batch and unique item.

The DPP can help companies and organisations in the twin transition. It brings a range of *benefits* for each actor in the supply chain [18], e.g.:

- *producers and retailers:* gain a competitive advantage, develop better products, buy back products for remanufacturing purposes;
- *purchasers:* more effective inventory control, increased efficiency of R-strategies of the 9R Framework (remanufacturing, refurbishment, repair);
- *end consumers and users:* more environmental-conscious product consumption, increased trust in case of buying used products;
- *service and support agents:* easy check and update of the service history, easy access to troubleshooting;
- *remanufacturers and refurbishers:* decreased uncertainties, access repair and disassembly guides.

2.3. Data sharing

The new Circular Economy Action Plan emphasises the importance of digitization of product information and highlights the European data space for smart circular applications [19].

The European strategy for data formulates the ambitious goal for Europe to ”become a leading role model for a society empowered by data to make better decisions – in business and in private sector”. However, several challenges arise during the realisation of this vision, such as: i) availability of data; ii) imbalances in market power; iii) data interoperability and quality; iv) data governance; v) data infrastructures and technologies; vi) empowering individuals to exercise their rights; vii) skills and data literacy; viii) cyber-security. Based on these identified problems several activities have been started in the last few years focusing on cross-sectoral governance framework, infrastructure for interoperability, competences and common European data spaces. Regarding the latter, it is stated the EC supports the establishment of a common European industrial (manufacturing) data space together with eight other data spaces – in full compliance with data protection rules and according to the highest cyber-security standards [19].

Since 2015, a worldwide alliance of companies and organisations called International Data Space Association has been elaborating a standardised reference architecture for data sharing platforms [20]. GAIA-X was launched in 2019 to create a trusted data infrastructure for Europe. It is defined as an ecosystem, where data and services can be made available, collated and shared in a trusted environment [21].

Several use cases are being developed in data spaces and justify the value creation with data exchange in supply chains [22]. It might be a volunteer alternative of a DPP.

3. Case study

3.1. Research methodology

The research method of this research was divided into five steps, which includes problem identification, goal definition, development, demonstration, evaluation, and publication. The focus is on the development and demonstration, in which the DPP is implemented for the simulation use case. The exact implementations of the methodology can be seen in Table 1.

Table 1. Conceptual Framework for this research after Pfeffers et al. (2007)

Steps from Pfeffer et al. (2007)	Implementation
i) problem identification and motivation	uncertainties can occur from uncertain consumer demand for remanufactured goods, and the uncertain quality of the returned product
ii) defining goals for a solution	decreasing production time and increasing the ratio of remanufactured parts by increased uncertainty level
iii) designing and developing	constrain a DPP concept for the given industrial use case
iv) demonstrating	implementing and validating DPP concept in Plant Simulation
v) evaluating and publishing	evaluate DPP concept with industrial data and publish findings

3.2. System description

The subject of this case study is the remanufacturing of cylinder heads for stationary gas engines for power and heat generation by the manufacturer in a dedicated remanufacutring line. The remanufacturing process includes disassembly, machining, cleaning, and reassembly. In the process, cylinder heads of different series and variants are remanufactured and, in accordance with the definition of remanufacutring, reach a standard that is equivalent to a new fabrication. The cylinder heads also differ in the type of fuel used, e.g., natural gas, bio-gas, bio-methane, landfill gas, sewage gas, etc., which has different effects on service life and remanufacturability.

Cylinder heads have a shorter life cycle than the short block (crankcase, pistons, cylinders etc.) of the gas engine. As a result, cylinder heads are remanufactured both during the life cycle of the engine but at the latest after the end of the engine life cycle.

After a cylinder head has reached the end of its service life, it is sent back to the manufacturer's production site, either individually or as part of the engine. As soon as a customer order for a remanufactured cylinder head or engine is received, disassembly is started. In the process, add-on parts such as valves, valve seat rings, gaskets etc. are removed, partially reconditioned and the cast iron block of the cylinder head is reused. During machining, for example, the seat for the valve seat rings is machined to the next oversize. This results in material limits for the number of possible reworkings. Due to different types of operation, different types of gas, etc., it is also not guaranteed that the number of possible reworkings is constant. The number varies between a maximum of five and zero if, for example, irreparable mechanical defects occur.

During the remanufacturing process, cylinder heads can be ejected from the process at different points. For example, the material has reached an unacceptable stage of wear, cracks, fractures, etc. to be further processed. In the ERP system or in the manufacturer's master data, it is not possible to record the actual condition of the individual cylinder heads. Furthermore, there is no information about the previous life cycles of the cylinder heads, in which it could have been fueled with a more corrosive gas type that still has effects on the cast iron block. Such information could be used to minimize the number of unnecessary remanufacturing attempts by developing an appropriate model for condition assessment over several life cycles and storing important information from all previous life cycles. By having more information about the condition of a product (e.g., how many times it has been started, number of working hours, number and content of maintenances, degree of wear), it might be revealed sooner whether a component could be used again or what steps are required for remanufacturing it. This could reduce uncertainties about the condition and thus make remanufacturing more efficient and sustainable. A digital product passport or data sharing in data spaces might provide a solution to achieve these objectives.

3.3. Simulation model

The remanufacturing system is analyzed with a discrete event simulation model created in Siemens Tecnomatix Plant Simulation. As one can see in Fig. 2, different steps of manufacturing, such as disassembly, machining, washing and assembly were modelled with parallel resources dedicated to the specific line for each product type. Not remanufacturable parts are removed from the system before and after the machining step (marked with red arrows in Fig. 2). New parts are sent to the system before the assembly step: if the number of parts in one of the three buffers drops below four, a new cylinder head is pulled into the system to ensure the continuous working of assembly stations.

Depending on the amount of information available about a used product (this information is stored in the DPP), it could be easier to determine if it is remanufacturable or a scrap. If more information is available, the scrap products can be removed from the system in an earlier phase of production processes,

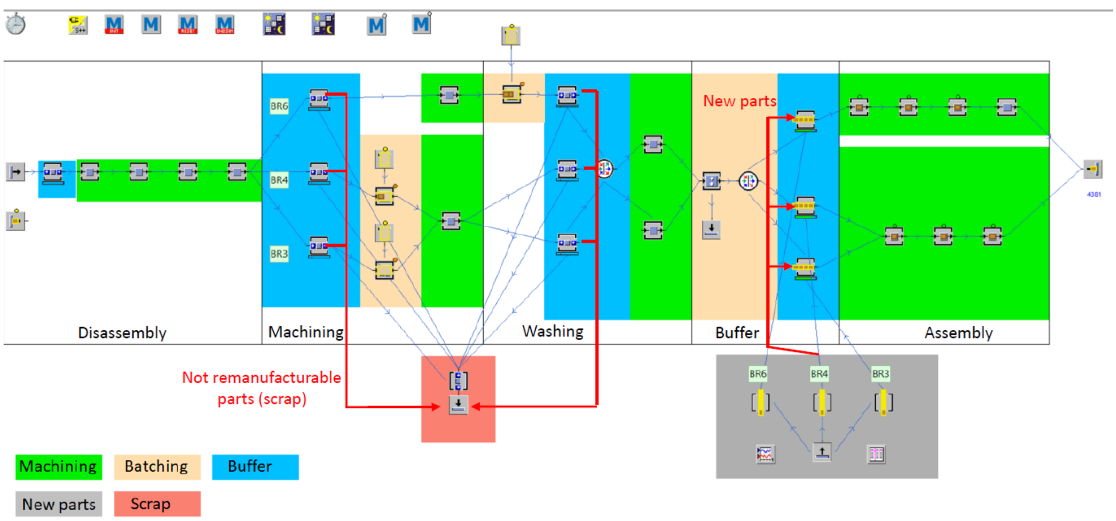

Fig. 2. Simulation model of the investigated manufacturing system

this way saving valuable machine time. If the scrap products are identified in a later production step, some manufacturing time is wasted on products that will be removed from the system anyways. On the other hand, information stored in the DPP can also be used to reduce uncertainty in the cycle times, which results in a more efficient production system (as mentioned in subsection 2.1).

The simulation model was used to run experiments in three different experiment series, which aimed at investigating the effect of applying the DPP concept. In our approach, data collection from the cylinder heads through their whole life cycle is needed, as the amount of available data affects production planning [8]. This information included size, material, weight, CO2 expenditure for the primary life cycle, maintenance data and the life time (maximum three life times where possible through remanufacturing before recycling the cylinder head). Based on the information available in the DPP, it is possible to reduce unnecessary production time and uncertainties caused by unknown quality of the cylinder heads. In the experiments, for each parameter set 10 simulation runs were performed and their average is presented in the diagrams. Process cycle times were modelled by using a truncated normal distribution, where the deviation was 100% of the expected value, and values lower than 50% or higher than 500% of the expected value were removed. The information available in DPP was modelled incrementally. The DPP will be launched with a basic information content and will be extended later on step-by-step (see subsection 2.2). Our approach mirrors this incremental development.

3.4. Experiment series 1: Fixed number of used products

In the first experiment series, the number of products to be remanufactured were fixed (2000, with 20% scrap rate), and the proportion of the 400 products that were found to be scrap on the first inspection was changed between 0% and 100% by 5% (the remaining part of scrap will be identified at the second point, after the machining step). The main KPIs were the overall production time needed to process these fixed number of products, and the non-productive time lost because of processing scrap products.

The results show that, as the amount of available information increases, the non-productive time (together with the overall production time including the non-productive time as well) decreases (see Fig 3). Naturally, the amount of information can be increased in discrete steps in reality and these steps depend on the product type; the goal of the paper is to show the trend if more information is available, the effectiveness of the production system increases. However, there are approximately 5 days of non-productive time in the end, because – due to specific product properties – some disassembly steps have to be done on the product before the first quality check. The ratio of the non-productive time compared to the overall time decreased from 42% (first experiment in the series) to 28% (last experiment in the series). This can be explained by the following: since a higher amount of scrap products is identified in an earlier phase of production, they can also be removed from the line earlier, allowing the line to produce faster.

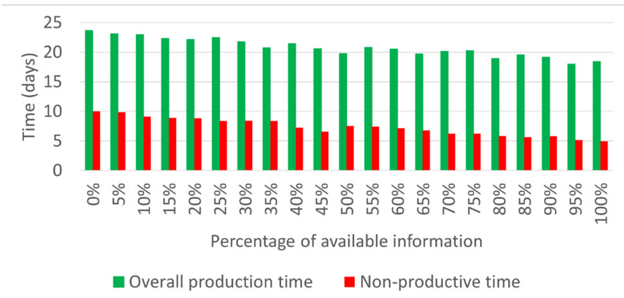

Fig. 3. Overall production time and non-productive time when different amount of information is available in DPP

3.5. Experiment series 2: Fixed production time

In the second experiment, not the number of remanufacturable products, but the production time was fixed (30 days), and the amount of available information through DPP was modified in the same way as in the first experiment. The scrap rate also remained 20%, but here the goal was to investigate the output and the remanufacturing ratio (ratio of remanufactured parts compared to all the parts produced). The flow of incoming parts is assumed to be continuous.

As shown in Fig. 4, with increasing the amount of available information, the output of the production system does not change significantly. Nevertheless, the number of new parts decreases, consequently, the remanufacturing ratio increases with approx. 7%. This means, for creating the same amount of products, the system was able to use a higher ratio of remanufactured parts. The cause of this is the same effect identified in the previous experiment series: the machining and washing machines can produce more remanufactured parts, and the need for sending new parts in the system before assembly is lower. If the remanufacturing ratio increases, it also affects the amount or weight of used material that is necessary to produce a certain amount of products – that could be an important KPI for remanufacturing companies. In the modelled system, different product types weigh 25, 35, 55 and 65 kgs, and this can cause approx. 100.000 kgs of reused material if 100% information is available in DPP.

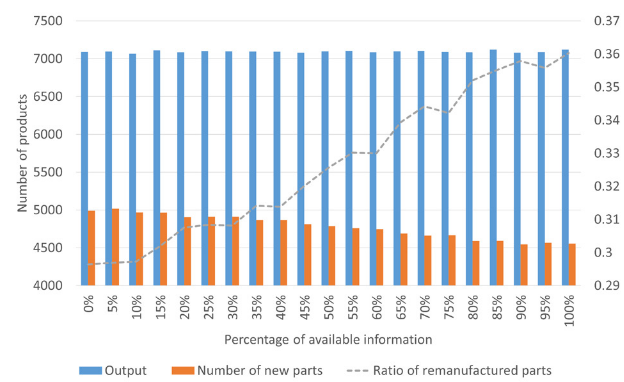

Fig. 4. Output, number of new parts and ratio of remanufactured parts when different amount of information is available in DPP

3.6. Experiment series 3: Deviation in cycle times

In this experiment series, 40 experiments were conducted with fixed production time (30 days). Here, the deviation was decreased in the cycle times from 200% to 5% of the expected value (as mentioned earlier, cycle times were generated from a truncated normal distribution.). It is important to mention, that the change only affected the used products; the new ones were manufactured with 100% deviation. Here, 50% of the scrap products were identified in the first inspection point. It is shown in Fig. 5, as the deviation in the cycle time decreases due to more information stored in the DPP, the ratio of the remanufactured parts increases, causing the overall output to increase, also.

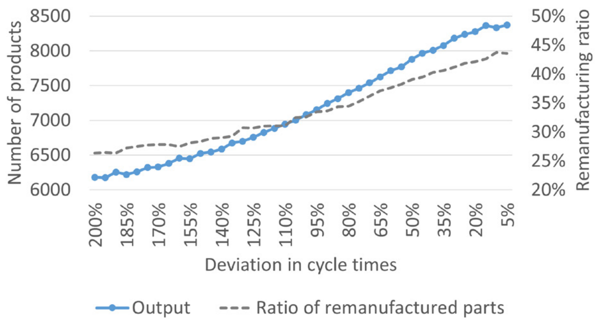

Fig. 5. Effect of decreasing the deviation in cycle times with DPP

4. Conclusion and outlook

Reaching the overall objective of circular economy, namely the waste reduction and the prioritisation of secondary raw materials, requires collaboration and information exchange in the supply chain and application of different KPIs. The more information available from a product might be realised with a DPP or in data spaces. In a transparent and trustworthy environment, the remanufacturing uncertainties might be decreased.

On the basis of the experiments performed with a discrete-event simulation model of the production line, the following conclusions can be drawn. With using DPP, not only the overall production time can be decreased by the reduction of unnecessary production time, but the ratio of remanufactured parts can be increased, and it is also possible to reach a higher output level.

In the near future, our research will consider the application and combination of economical and environmental indicators. Their effect on the business models will be also investigated.

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