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A STEPWISE METHOD TOWARDS PRODUCTS ADAPTED FOR REMANUFACTURING

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1. Introduction

Remanufacturing is an important component of a resource-efficient manufacturing industry (see e.g. [Steinhilper 1998], [Rose and Ishii 1999], [Sundin and Lee 2011]). By keeping components and their embodied material in use for a longer period of time, significant energy use and emissions to air and water (e.g. CO_2 and SO_2) can be avoided. According to Sundin and Lee [2011], environmental comparisons of remanufacturing versus new manufacturing and/or material recycling show environmental benefits for remanufacturing. This is due to alleviation of depletion of resources, reduction of global warming potential, and better chances to close the loop for safer handling of toxic materials [Sundin and Lee 2011]. In addition to its environmental benefits, remanufacturing provides opportunities for the creation of highly skilled jobs and economic growth.

In order to make remanufacturing businesses more beneficial, product information should be accessible for the remanufacturing personnel and the products should be adapted for the remanufacturing process [Sundin and Bras 2005]. Although previous research identified information that could be fed back to the design phase from remanufacturing (e.g. [Lindkvist and Sundin 2012]) (see Table 1), such information is not often available in the design phase [Lindkvist and Sundin 2015]. Design for remanufacturing (DfRem) aims at facilitating the remanufacturing process so that e.g. disassembly, cleaning, reprocessing and reassembly are facilitated [Sundin and Bras 2005]. However, products are often not designed for remanufacture [Sundin and Bras 2005], [Hatcher et al. 2011], although there do exist guidelines for design for remanufacturing (see e.g. [Sundin and Bras 2005], [Charter and Gray 2008]).

Successful integration of DfRem requires support on a strategic as well a tactical level, i.e. both what to do and how to do it [Yang et al. 2014]. Further, Hatcher et al. [2014] point out a gap in research regarding the operational factors influencing DfRem integration into the design process. In their findings, external factors such as customer demand and internal factors such as the OEM-remanufacturer relationship were identified. This paper addresses the combination of the strategic and tactical approaches, targeting the internal factors affecting DfRem integration into the design process. The proposed method is directed at companies that include both design and remanufacturing in their operations, and specifically supports integration of information from remanufacturing into the design process in order to better adapt products for remanufacturing.

Table 1. Different types of product life-cycle information feedback from remanufacturing to design (adapted from Lindkvist and Sundin [2012])

Type of information feedback	Feedback content	References
Remanufacturing process data	Evaluating how well the product was adapted to efficient remanufacturing	Doyle et al. [2011], Lee et al. [2011], Hatcher et al. [2011], Zhang et al. [2012]
Remanufacturing personnel data	Suggestions for improvements	Zhang et al. [2012]
Wear on components	Evaluating how well the product was adapted for its calculated life-cycle	Fathi and Holland [2009], Abramovici and Linder [2011], Dienst et al. [2011]

1.1 Aim

The aim of this paper is to describe a stepwise method towards products adapted for remanufacturing.

2. Methodology

The methods used for this paper consisted of both a literature study of design for remanufacturing and a case study. The outcome of an initial descriptive empirical study was based on data gained from interviewing remanufacturing personnel and product developers at companies performing remanufacturing. When the current state was assessed, the results have been adopted to create the stepwise method presented in this paper.

3. Design for remanufacturing

When adapting products for remanufacturing, all of the operation steps, e.g. inspection, disassembly, reprocess, reassembly and testing, need to be considered [Sundin and Bras 2005]. For instance, if one step such as reassembly is very difficult to perform on a product, it does not matter, with respect to remanufacturing, how much effort has been put into adapting the product for disassembly. One should remember that the essential goal in remanufacturing is part reuse. Thus, if a part cannot be reused as is or after refurbishment, the ease of cleaning or reassembly will be of no consequence in the case of remanufacturing [Shu and Flowers 1998]. This means that much effort can be made in product design without obtaining any expected benefits.

Furthermore, there are design guidelines developed for design for remanufacturing (DfRem); see, e.g., Ijomah [2008]. In addition, Bras and Hammond [1996] used the Boothroyd and Dewhurst design for assembly metrics [Boothroyd and Dewhurst 1986] as a foundation to create remanufacturability assessment metrics based on product design features. A decision support tool developed by Mangun and Thurston [2002] was presented to help determine when products should be taken back as well as the most appropriate component end-of-life options. Moreover, Amezquita et al. [1995] developed guidelines based on design features that assist remanufacturing, and used these to identify design changes to improve automobile door remanufacturability.

In addition, [Sundin and Bras 2005] have studied which product properties are important to facilitate remanufacturing. By looking at what properties are suitable for the different remanufacturing steps (inspection, cleaning, disassembly, storage, reprocess, reassembly and testing), a matrix called RemPro, shown in Figure 1, was created. The remanufacturing company should first investigate which steps are crucial for its specific remanufacturing business area and thereafter try to facilitate this according to the RemPro matrix, as well as place effort on making the crucial steps in the remanufacturing process as efficient as possible. The RemPro matrix then shows the designers which product property facilitates each remanufacturing process step. It does not, however, provide a method for reaching those product properties.

Product Property \ Remanufacturing Step	Inspection	Cleaning	Disassembly	Storage	Reprocess	Reassembly	Testing
Ease of Identification	×		×	×			×
Ease of Verification	×						
Ease of Access	×	×	×		×		×
Ease of Handling			×	×	×	×	
Ease of Separation			×		×		
Ease of Securing						×	
Ease of Alignment						×	
Ease of Stacking				×			
Wear Resistance		×	×		×	×	

Figure 1. The RemPro matrix, showing the relationship between the essential product properties and the generic remanufacturing process steps [Sundin and Bras 2005]

Only products satisfying environmental legislation can be introduced into the market. Thus, DfRem guidelines must help to ensure that products can meet current environmental legislative requirements and have at least good potential to satisfy future ones, either in their original design or because of their ease of redesign after first life. Since products may have different types and levels of environmental impacts at different stages, DfRem guidelines must consider the whole life-cycle to target key environmental impacts and therefore reduce potential penalties. However, research by Ijomah et al. [2007] indicates that there appears to be a lack of DfRem guidelines based on life-cycle thinking.

Many EoL issues stem from design; hence, it is most effective to incorporate the EoL management consideration into the forefront product design stage. The product developer has to adopt a system perspective in designing the product as a system solution. The considerations for the features that facilitate EoL processes are necessary. This is demonstrated in the case of single-use cameras by Kodak [Bogue 2007] and Fujifilm [Sundin and Lindahl 2008]. In the case of remanufacturing, one important criteria is that the parts that are to be replaced in repair and remanufacturing must withstand the treatment of being assembled and disassembled several times [Sundin and Bras 2005]. Harjula et al. [1996] contend that typical design changes according to DfA methods will be equally beneficial in simplifying disassembly at the EoL stage.

Furthermore, Harjula et al. [1996] state that DfD changes that simplify the removal of critical items should also be considered. This is advantageous for products such as flat panel displays containing mercury back-lights [Elo and Sundin 2014]. This is also beneficial for small electrical products, where the batteries need to be removed easily for proper disposal, and to preserve the value of the remaining materials for recovery purposes. There are also tools available for DfEoL and to aid in decision making at the EoL stage, e.g. ELDA [Rose and Ishii 1999] and DELII [Lee 2008].

4. A Stepwise method – The Remdesign Strategy

As Design for Remanufacturing does not occur at manufacturing companies to a large extent, although many currently contract or have contracted companies for remanufacturing (see e.g. [Hatcher et al. 2011]), there is a need to develop methods that are easily implemented with good results. In addition, methods like the RemPro matrix [Sundin and Bras 2005] do not provide the methodological approach that is needed at the companies, and thus there is a need for methods that support the methodological approach of implementing remanufacturing aspects in the product design process. In addition, research by e.g. Kurilova-Palasitenene et al. [2015] shows that there is an abundance of information within the products' life-cycles that can be used to achieve better product designs, and thus more efficient remanufacturing processes. Based on this lack of methodological approach, a stepwise design for a remanufacturing method is developed.

4.1 Method objectives

The overall objective of the method is to feed back relevant information from remanufacturing to product design. The long-term effects of using the method would be that more products are designed for remanufacturing, which leads to a more efficient remanufacturing process with less waste.

4.2 Assessment of the current state and vision

Initially, the current situation regarding the information feedback flows is assessed. The assessment is done via interviews with stakeholders in the product development department and within remanufacturing; in this case, relevant staff within the product development department such as managers, design engineers, and project managers were interviewed. Likewise, within the remanufacturing organization, managers and remanufacturing technicians may be interviewed. These individuals, representing one of the appointed stakeholders (e.g. project manager), should preferably be interviewed separately in order to obtain answers reflecting reality rather than what is accepted internally as policy, etc. A preferable approach for performing these interviews is to illustrate the information flows on e.g. a whiteboard while the interview is carried out. Thus, as a stakeholder is brought up in the interview answer that stakeholder is also written down, and likewise links between the stakeholders illustrate an alignment with the relevant information exchanged. The intention in this step is to capture the actual situation in a way that is illustrative of the reality. This might bring clarity to the current situation, and not only to the interviewer, but also to the interviewee. The illustration can then be used as a communication tool when merged together with the answers of the other relevant interviewees.

If carried out correctly, the assessment of the current state should be disseminated throughout the organisation and areas for improvement clearly pointed out. Preferably, those areas for improvement should be discussed, clarified and summarised. Thus, when the current situation is mapped, analysed and communicated, the logical next step is to identify a vision of a desirable scenario: in other words, what the ideal scenario looks like concerning how feedback from remanufacturing should reach product design and be integrated in the product design process.

When the initial mapping of the current stage and a clear vision have been established, there will be a gap between the current stage and the vision. That gap is addressed via a proposed method for integrating feedback from remanufacturing to product design. Hence, a method is proposed: The Remdesign Strategy – Stepwise integration and evaluation integration of feedback from remanufacturing into the design process (Figure 2).

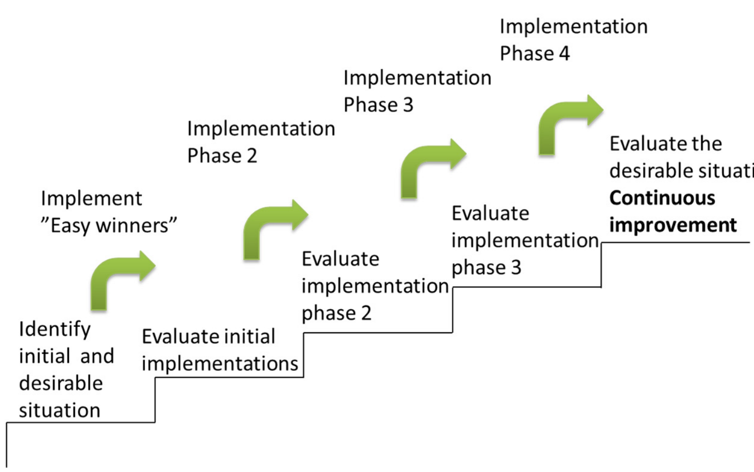

Figure 2. The Remdesign Strategy –Stepwise integration and evaluation integration of feedback from remanufacturing into the design process

4.3 Improvement strategies

There are several strategies that could be applied to establish information feedback channels that remanufacturing can utilize. A number of examples of strategies are listed below, in order of complexity, starting with the assumed least complex action to take. It should be pointed out, however, that not all of these measures need to be taken; the best combination is to be decided by each company based on their assessed current stage:

- Feedback from technicians in the remanufacturing facility, collected via a software application
- Genchi gebutsu ("go see"), where the design engineers visit the remanufacturers to learn about the remanufacturing process and specific issues.
- Workshops/integration events, where remanufacturing and product designers meet to learn from each other and solve problems
- An ombudsman for remanufacturing, appointed to speak for the remanufacturer in the product development projects
- A fully integrated product development process, where remanufacturing is also represented as one of the stakeholders and value providers in the value chain

The method is a ramp-up method, where strategies are implemented stepwise. The idea is that once the current stage and vision are clarified, different strategies for integrating feedback into the product development process should be discussed. The strategies should be chosen based on the level of appropriateness for the specific case company. When promising strategies have been chosen, they should be ranked accord to how easy they are to implement. Initially, easily implementable strategies should be adopted. It is better to start taking actions in the aimed direction than to do nothing and wait for major changes if the different actions are not heavily interdependent.

What is seen as an easy strategy or a difficult one will depend on the specific company. In the process of working with implementing certain strategies it is likely that some support will be created and updated for the involved parties, such as design checklists and guidelines for the designers. When the strategies have been implemented and at a certain time interval (e.g. 6 months), an evaluation follows (as seen in Figure 2) before an implementation phase begins and a new strategy should be applied, etc., until the goal is reached. Continuous improvement should then be applied.

4.4 Evaluation

The evaluation phase consists of two parts. The first is the success criteria that will indicate whether or not the increase of information feedback from remanufacturing to product design has led to DfRem. Here, a design for remanufacturing checklist (e.g. Table 2) could be used to verify the actions that have taken place during the implementation phases in order to promote design for remanufacturing. Hence, the provided checklist should be filled in to verify what components were modified and to meet the requirements from remanufacturing. For instance, component thickness may have been increased to allow regrinding of the goods, or a more durable material may have been used on a critical component to prolong its predicted lifetime. Thus, the outcome of the continuous improvements of the feedback integration can be monitored and followed up between the respective implementation phases.

Table 2. Short version of an example of the Design for Remanufacturing checklist used to evaluate the success of implementing feedback from remanufacturing

Design for Remanufacturing criteria	Component/ Module	Achieved green	Partly achieved yellow	Not achieved red
Use of standardized parts				
Robust material selections				
Modularization that facilitates upgrading				
Materials that are easy to clean				
Assembly methods that allows for non-destructive disassembly				

The second part of the evaluation is an assessment of how the implementation of feedback from the remanufacturers proceeded, i.e. whether the implementation occurred as planned and what unforeseen factors may have influenced the outcome. In this stage it is also relevant to re-evaluate the implementation plan. Since companies operate in a changing environment, it is possible that the vision and/or the implementation plan must be revised. Alterations of the market, financial situation, technology developments or intra-organisational restructures, etc., may impact the plan. Hence, this part of the evaluation step adds a dynamic aspect to the method. The main reason for this dynamic dimension is that the method need not be discarded even though external or internal factors may interfere with the initial implementation plans.

5. Information flows at the case company

The proposed method is to be verified at a case company that has proven suitable for verifying the method. Relevant characteristics of the company are presented below.

5.1 Case company characteristics

The case company designs, manufactures and sells its own products. The majority of its machines are leased, as the company is a PSS (Product Service System) provider. Further, the company has been established in remanufacturing for ten years in order to manage the return flow of leased products. The machines are leased on a short or long-term basis, varying from one day up to five years, and remanufacturing enables the same machines to be leased several times. Remanufacturing takes place both between leasing contracts and before the machines are sold as remanufactured products. The leasing of machines has expanded over the years, although the remanufactured machines remain a minority compared to the newly manufactured machines. Regardless, remanufacturing sales did not drop during the economic recession that Europe recently experienced, opposite to the decline in sales of new machines.

The product is fairly complex and available in many models and customized variants. The product is also robust, but not designed for remanufacturing. Organisationally, the company consists of two main entities: a producing unit and a sales organisation. Design and production are included in the producing unit, while service and remanufacturing are included in the sales organisation.

This organisational structure affects decisions made in for instance the design phase. When a new product is planned for, the budget is foremost based on the cost of producing the product, including the development cost, while the total life-cycle cost is not considered. The company is applying lean principles in the organisation, and recently this has also included product design.

5.2 Information feedback

When the machines are designed, consideration is taken foremost for the final customer and end user, but service and production aspects are also considered. The product development process is relatively newly defined as an integrated development process, including production feedback already in the early phases. Service also has representatives in the product development projects who contribute with their points of view. It also uses expert representatives from amongst the service technicians working in the field as sources of information that it can then bring in to the product development projects. The service technicians receive information about problems with the machines first-hand. They also establish good contact with the end customer, learning about their business and application of the machines.

Information feedback from the service technicians in the field is communicated to design via the marketing department. Service technicians, in turn, receive information feedback from the customers when they perform service in the field. In service meetings that are held at least once a year at the customer's site, service questions the customer about their satisfaction with the service, machines, and how frequently they use them, and makes sure that the customer follows the terms in the leasing contract (PSS). Service sometimes participates in pre-delivery inspections at the customer's site and thus sees first-hand how the products are used.

Tasks concerning quality and suggestions for improvements (related for instance to service-related costs caused by low quality) are communicated to service via the quality department. On occasion, service

provides feedback to production if malfunctions are frequently discovered. Production receives information about problems with the machines in use from the market via the quality department. Remanufacturing rarely receives information from the service technicians about aberrations, and if it does it depends on the individual, not on a system of information exchange.
An overview of the information flows in the case company can be found in Figure 3. The figure includes information flows to and from the departments of design, production, service and remanufacturing. As seen in the figure, remanufacturing is separated from product design organisation-wise and also lacks a connection via feedback.

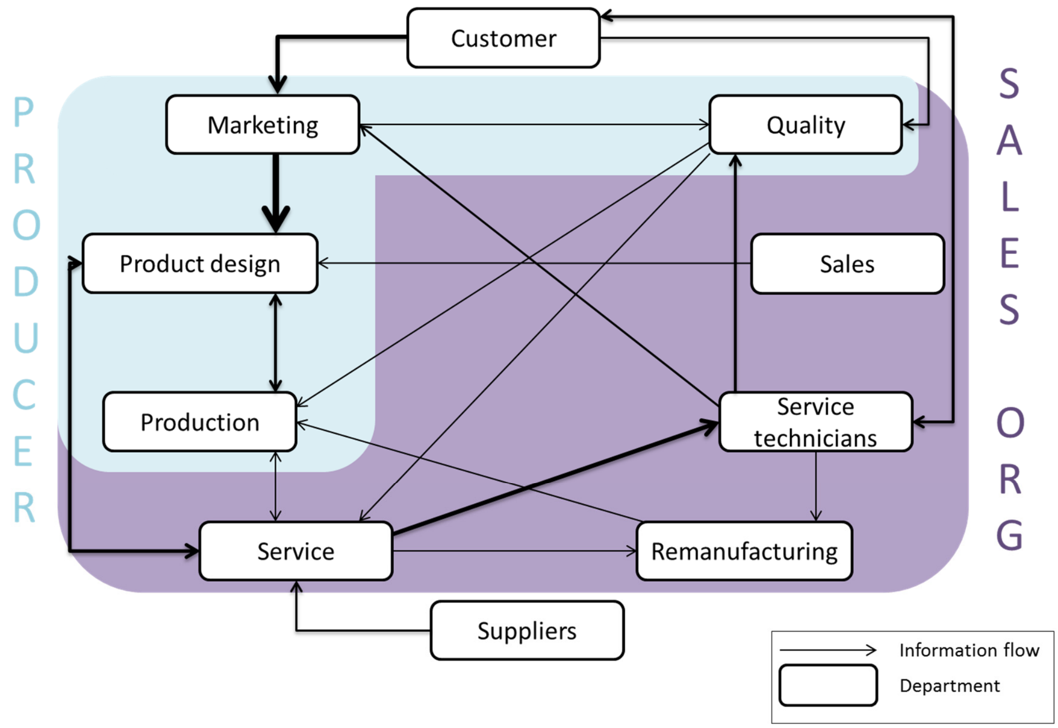

Figure 3. The relevant information flows in the case company. The departments shown in the boxes correspond to the ones mentioned in the interviews. The thicker the arrow, the more frequent the information flows are used [Lindkvist et al. 2013]

5.3 Possibilities

The lack of knowledge of remanufacturing and its activities might be a hindrance for design for remanufacturing. Design does not regard remanufacturing as a crucial part of the organization, based mostly on its minor share of the total turnover, but sees similarities with its activities and service activities. However, the remanufacturing part of the business is steadily increasing, supported by the increase of leased products that need remanufacturing after they are returned from the customers. There are potential benefits with open communication and knowledge sharing between the two parties.
Previously, communication between production and design and other departments was poor, but it has improved greatly, and now they are integrated in the design process. Production sees that it has quite a lot in common with service, since both assemble to a certain degree and they could gain from further information exchange. As more and more of the turnover is based on services provided by the company, not least leasing, service is increasingly included as a partner in the design process.
Service sees possibilities with simulating service instructions in the future. Such instructions could also be used for disassembly and service. Service would also like to back up all the information in a central computer system so that paper copies do not risk being lost and updates neglected, resulting in e.g. wrong spare parts being ordered, information that might also be useful for remanufacturing.

5.4 Current situation

Identified challenges for achieving DfRem were as follows:

- There is a need to further improve communication between the different actors in the product life-cycle, and especially remanufacturing, in order to achieve design for remanufacturing.
- Information from the 400 service technicians in the field is not fully utilized. They utilize a few selected experts from the service fields as information sources in the design projects. There is great potential in utilizing the information they provide in their service reports.
- Remanufacturing personnel do not see a need for more information at present, as they are managing and adapting to the current situation. Furthermore, there is no method for utilising it in a beneficial way.
- Designers cannot yet see the full potential benefits of involving remanufacturing to a greater extent in the information exchange. The design process is not supporting true life-cycle thinking, as it retains a traditional focus on manufacturing.
- There are difficulties to overcome regarding how to adhere to design for remanufacturing aspects. Lately, remanufacturing notices a trend to include more plastic details in the machine's design. This becomes a cost during remanufacturing, as more parts need to be exchanged.
- Remanufacturing cannot use the service-specific software that the service technicians utilize in their process. Since a more comprehensive database of parts is needed when performing remanufacturing, parts that need to be changed during service differ from those replaced during remanufacturing and are generally fewer.

Based on insight in the product development process and knowledge about the lean philosophy adopted by the case company, a first step towards integrating information feedback in their design process might be to let the designers go and see the remanufacturing process with their own eyes, i.e. according to the to the *genchi gembutsu principle*. As they have started to integrate service more and more in the design process, and coupled with the increased amount of leased products that need remanufacturing, the threshold for also integrating remanufacturing in the future might be lower. However, the visions for integrating should be carried out by the case company to truly fit with their activities.

6. Discussion

The stepwise method presented here aims at addressing the gap between the DfRem methods available and their lack of use in industry. Previous research has identified available information feedback from remanufacturing to product design, as well as the lack of transfer of such feedback (e.g. [Lindkvist and Sundin 2012, 2013]). Other researchers have also pointed out the lack of communication between the OEM and the remanufacturer as influencing the DfRem integration into the design process (i.e. [Hatcher et al. 2014]). Indeed, Hatcher et al. [2014] points out three success factors for the integration of DfRem into the design process: management commitment, designer motivation and designer knowledge and understanding. In order to integrate information feedback into the design process, the DfRem Strategy proposes addressing all of these factors. It is not suggested that e.g. educating designers about remanufacturing would be enough to get DfRem aspects integrated into the design process, but rather that it is a fair beginning of a understanding and transition into a more complete alteration of the way the organisation could tackle DfRem in the future.

Further, the DfRem Strategy aims at a strategic level to help supporting companies regarding what to do in order to integrate information feedback into the design process. On a tactical level, there are tools pointing out how to do so, e.g. DfRem checklists and guidelines (e.g. [Yang et al. 2014]). The DfRem Strategy encourages the use of such tools by integrating a DfRem checklist as an evaluation tool. However, the exact design approach is left for the individual company to identify, as all products and companies are unique.

Thus, the DfRem Strategy aims at providing holistic support for companies striving to integrate DfRem into the organisation via use of information feedback from the remanufacturers. Hence, its goal is to support knowledge and understanding of the remanufacturing process, as well as to refine ongoing

DfRem activities. Similar approaches considering feedback as part of the method can be found in other DfX methods (e.g. the DfM approach [Kuo et al. 2001]), and might be the next step in defining a more strategic aspect to DfRem.

7. Conclusions

The aim of this paper was to describe a stepwise method towards products adapted for remanufacturing. The framework step method, described in Section 4 of this paper, has yet to be tested and implemented in the case company. The method was developed based on years of research and collaboration with the case company. The model is based on previous research on how models aimed at product designers should be developed, as well as theory of design for remanufacturing and information integration in the product development process.

The framework is based on an initial evaluation of the current information feedback transferred from remanufacturing to product design, as well as setting the vision for what the feedback should look like in the future. The model in the centre of the framework consists of a stepwise implementation process that is divided into four phases, and is distinguished by an evaluation step that verifies the success of the implementation as well as allows for alterations of the implementation phases to come, as external influences (such as market situation) may alter the planned implementation.

The method in its current stage has yet to be implemented and tested. Whether there is a possibility to expand on the model and improvements to be made is the scope of future research.

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