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Concept For Data-Based Sales And Resource Planning For Re-Assembly In The Automotive Industry

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Abstract

In linear economy, the growing wealth in the world is linked to a growing resource consumption and greenhouse gas emission. This results in a shortage of primary resources, environmental destruction through resource extraction, and global warming. A high productivity of the manufacturing industry, overcapacities and a decrease in the value of existing products intensify this situation. Circular economy offers resource-efficient value addition by multiple utilization of resources. One challenge in this form of value creation is the duration of reconditioning processes and the lack of product innovation in reconditioned products. To bring products back to the market as quickly as possible, the method of Re-Assembly is introduced and focused in this paper. Re-Assembly can be defined as reconditioning old products into new or higher-valued products, by assembling new or remanufactured parts and components after disassembly. However, manufacturing companies face difficulties in industrialization of such methods. In practice, one of the biggest challenges is the mid- and long-term planning of the reconditioning process. Due to uncertainties in the quality and quantity of the returning end-of-life products the resulting reconditioning process is challenging to predict in terms of process time and production costs. To encounter this, this paper presents a concept for sales and resource planning in the context of Re-Assembly. In the first step the uncertainties for the long term production planning and the resulting data requirements are identified. Based on this, a concept for sales and resource planning is presented. The approach is based on the Internet of Production reference framework and includes data from the whole product lifecycle. As the area of application, the automotive industry is chosen as it is the largest manufacturing industry in Germany and already leading in the recording of usage data of their products.

Keywords

Production Planning; Sales Planning; Circular Economy; Re-Assembly; Internet of Production

1. Introduction

Since the beginning of industrialization, raw materials have been consumed to produce products that are disposed at the end of their life. Among other things, this causes environmental pollution and biodiversity loss. In addition to these threatening aspects, this linear economy leads to many social problems such as land displacement and forced relocation of the population. [1] The circular economy seeks to counter the challenges of linear economy and bring the economic system into a cycle by decoupling economic growth from finite resources and returning used products to the user cycle. It also aims to use renewable energy, minimize toxic chemicals, and eliminate produced waste. [2] In order to reuse products that have already been disposed, strategies have been developed that can be summarized in a so-called *9R Framework*. This framework includes strategies such as reuse, remanufacturing and recycling. One of the central strategies is remanufacturing, which is characterized by an extended value creation opportunity and at the same time is

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more resource-efficient than recycling [3,4]. For the automotive industry, remanufacturing offers the possibility of attractive product differentiation in an already competitive and saturated market. Several Original Equipment Manufacturers (OEM) are already using the remanufacturing method to recondition spare parts and offer them as an alternative to newly produced spare parts [2]. Completely remanufactured vehicles have not been offered in large quantities yet. This is due to challenges associated with the transition to the circular economy and remanufacturing-specific uncertainties. Remanufacturing is characterized by various uncertainties, for example in the quality and availability of the cores as well as the processes needed for the reconditioning, that complicates the resource planning in particular [5]. Also the sales planning is facing new challenges for example product cannibalization, which means the drop in sales of a product that results from the introduction of a remanufactured product from the same company, brand or product line [6].

To enable the remanufacturing of complete vehicles, a new type of remanufacturing the Re-Assembly is introduced in this paper. In the following chapter related literature from the sales and resource planning in remanufacturing is presented and research gaps are identified. Chapter 4 presents the concept for a databased and integrated sales and resource planning for the remanufacturing industry using the reference architecture of the Internet of Production (IoP).

2. Theoretical Background

In the circular economy technological processes are differentiated in the R-Strategies such as recycling or remanufacturing. A broad variety of definitions for these strategies ranging from four to nine different methods is given in the literature. KIRCHHERR ET AL. give an overview of different definitions of these strategies and the circular economy [3]. The strategies differentiate in their circularity as well as in the possible innovation of the reconditioned product. Circularity is defined by a set of circularity indicators. A higher circularity means a lower resource consumption and more benefits for the environment. Contrary to the higher circularity, the possible innovation in the reconditioned product is lower with a higher circularity. For example the possible innovation reached by a new product made of recycled material is higher than the possible innovation in repairing a used product [7].

Remanufacturing is a key strategy in this context. An industrial remanufacturing process is used to recondition old parts, so-called cores, to as-new or upgraded condition. This involves the steps of inspection, disassembly, reconditioning, Re-Assembly and final testing. [8] The process allows to add new innovations to products during the remanufacturing process. Challenges for this strategy are the time that products are taken off the market for the reconditioning processes and an increasing complexity of the process with more complex products. To reduce the complexity and the off-market-time the method of Re-Assembly is proposed. The Re-Assembly process consists of the disassembly of modules of the product and the assembly of either new, remanufactured or upgraded modules. Extracted old modules can either be reconditioned in a separate process by the same manufacturer (e.g. an OEM in the automotive industry) or a supplier for the module. The product itself is send back to the market with the changed modules without the delay of the reconditioning process. Also the Re-Assembly processes allows to upgrade the product with new innovations which were developed after the first sale of the product. This enables the manufacturer to increase the value of the product. To enable and accelerate this strategy of the circular economy a precise planning is needed which is discussed in this paper.

The sales planning describes the process of planning how many products of a specific product type will be sold in a defined time period. This information is used in the resource planning to validate if the production is capable of producing the products from the sales planning. Especially in the area of remanufacturing these methods need to be integrated with the core-acquisition. Core acquisition is defined as the active management of core sourcing, to achieve a better balance between return of cores and demand for remanufacturing. [6]

3. Related Work

This chapter presents recent work and concepts of sales and resource planning in the field of remanufacturing and refurbishment as the closest R-strategies to the new concept of Re-Assembly.

WALTHER gives an overview of the sales and production planning for products and components. The process is divided into the three components *product reconditioning*, *component reconditioning*, and *disposal*. An integrated model is used to describe the interactions between the components and is exemplarily applied to a vending machine manufacturer. The model does not integrate the demand of the reconditioned product nor upgrades or other technological innovation. [6]

NADAR ET AL. develop a dynamic model to describe the sales planning problem of a company with combined sales of new and remanufactured products. Demand in the model is described by a modified Bass Diffusion Process. The authors concluded, that depending on the sales scenario a partial fulfilment of the demand can lead to a profit optimization even though, there are no constraints for new-item manufacturing. The model does not integrate the possibility to update products or products with a longer lifespan such as cars. [9]

MATSUMOTO AND IKEDA assess the quality of demand forecasting by time series analysis in remanufacturing and propose a forecasting method including expert knowledge. The developed method is mainly for independent remanufacturers with incomplete information regarding the sales numbers of new products. As a result the authors distinguish between three different curves based on their trend behaviour and propose a forecasting method for each of these categories. To distinguish between these types of curves the authors recommend the involvement of human experts. The developed method does neither include the number of available cores nor the difference in quality of remanufactured or upgraded parts. [10]

MUTHA ET AL. present a core acquisition strategy for independent remanufacturers to optimize their costs during core acquisition. In their work they model two difference scenarios, one scenarios includes the acquisition of bulk of cores with a random quality and therefore a random cost for the remanufacturing process. The other scenario includes the acquisition of cores with a certain quality level but a higher price. Using the model, the authors propose a strategy to buy cores with an uncertain quality in the first period to minimize the acquisition cost under uncertain demand and change to a reactive acquisition of higher quality cores from the second period on. [11]

YANG ET AL. develop different methods to optimize the core-acquisition-process under incomplete information regarding the core quality. The paper is motivated by the missing historical data of the available cores in the market. The quality level is therefore often explained by discrete quality levels for the products and forecasted using nominal or asymptotic distributions. The authors develop two linear models to minimize the cost of bad quality cores. Even though the models work in the proposed way, the authors conclude, that the main part of the costs can just be minimized by using a multisource information fusion method to receive a more realistic distribution of the core quality to close the gap between the estimated and real quality distribution. [12]

The presented approaches from the literature each include solutions for a specific area in resource and sales planning using analytical methods and data from the past. An exception is YANG ET AL who propose the usage of multisource information. This approach is just used in the specific application and does not take into account the integrated planning of sales and resources which is needed for remanufacturing [6]. Therefore an approach to combine the usage of multisource real-time data in the integrated planning is missing.

4. Concept for databased sales and resource planning for Re-Assembly in the automotive industry

The following chapter is presenting a concept for databased and integrated sales and resource planning which minimizes the impact of the uncertainties from Re-Assembly. To lower the information uncertainty in sales and resource planning databased methods have been proven to be a solution.

The IoP reference architecture can be used to combine different data sources and IT-systems from various domains and lifecycle phases. The IoP is divided into three cycles of the products lifecycle: development-cycle, production-cycle and user-cycle [13]. Due to its capability to aggregate data from the usage phase of a product as well as from the production IT-systems it is ideally suited to support the decision making process in a circular economy. A major part in the IoP are Digital Shadows, which consist of data provision, analysis methods and information requirements. The different levels of the digital shadow can be seen in Figure 1. Goal of the digital shadow is to provide information needed for a decision in the production environment by aggregating and analysing data from multiple data sources. [14]

Especially the production planning and control (PPC) in the automotive remanufacturing is challenging due to uncertain information. [5] To overcome these challenges the uncertainties need to be identified and analysed. For this case an identification process is used. From the uncertainties the data needs for the planning method are derived. The concept can be seen in Figure 1. After introducing the process for uncertainty identification, the following chapter describes the three main components of the digital shadow in detail.

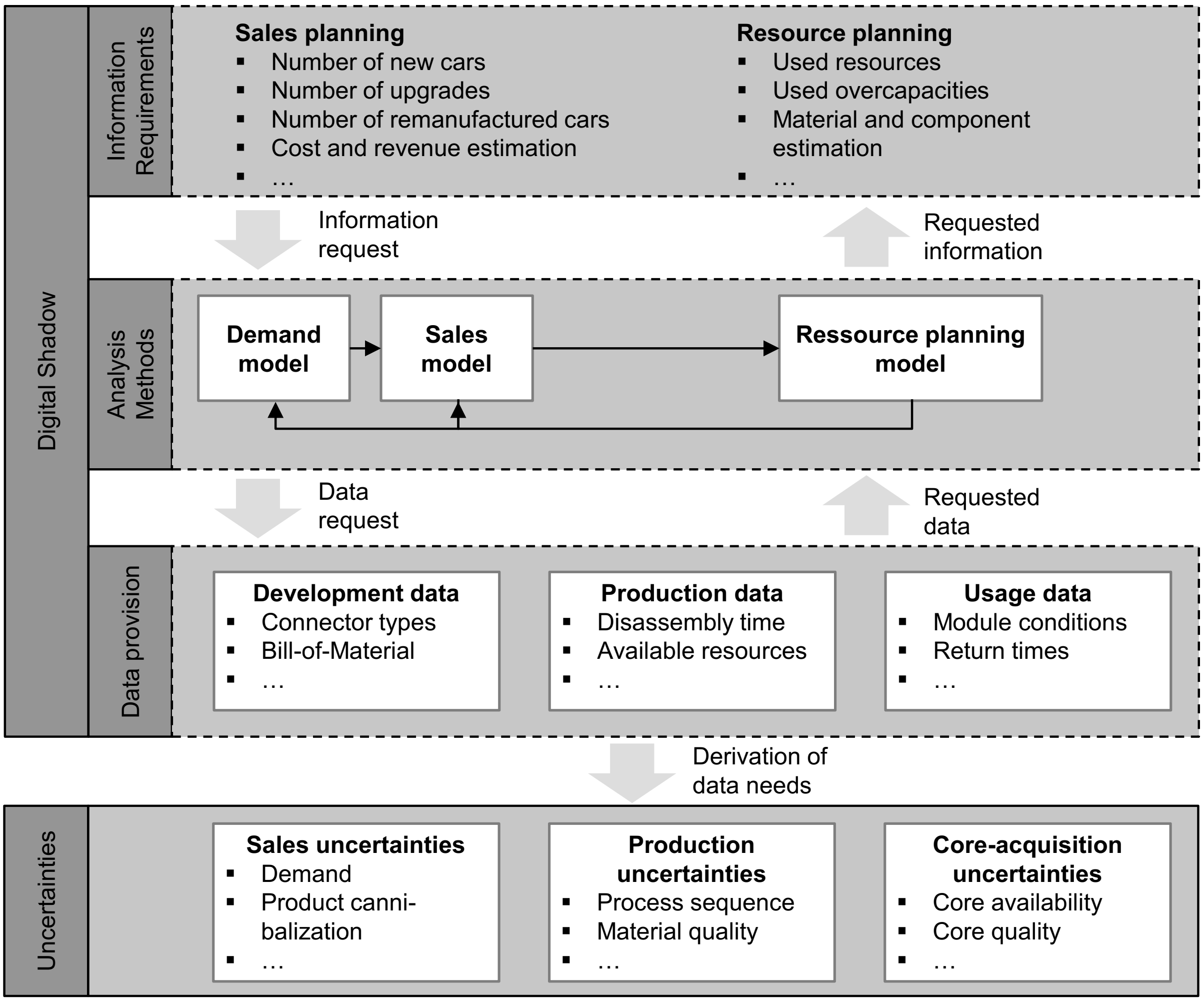

Figure 1: Concept of the digital shadow for sales and resource planning in Re-Assembly

4.1 Identification of uncertainties in Re-Assembly

The identification process is shown in Figure 2. In the first step of the method uncertainties are identified using a literature review in common scientific research databases. The titles and abstracts of the found literature are screened, filtered and the relevant literature is analysed.

Figure 2: Method for the identification of uncertainties

The second step consists of interviews with experts from industry regarding uncertainties in their remanufacturing and service system. These interviews can be conducted by using expert-workshops to receive information about uncertainties from the practical day to day work in the remanufacturing industry.

The third step is the categorization of the identified uncertainties in the main areas of the sales and resource planning in the remanufacturing industry. In the linear economy this planning is done in the close exchange between the sales and production department. Due to integrated planning of the core acquisition this category is also added to the categorization [15]. Next to this three categories the external uncertainties following the PESTEL (political, economic, social, technological, ecological and legal) criteria [16] are also added to the framework to include fundamental external uncertainties. Figure 3 gives an overview of the framework.

During the categorization of the identified uncertainties the framework is further detailed to ensure a better understanding of the uncertainties. The sales category was split up into the categories *quantitative* and *qualitative*. The quantitative uncertainties include the demand of remanufactured products [17] and the reduction of the total cost of ownership for the customer [5]. Qualitative uncertainties are for example the customers perception of the quality of remanufactured products [18]. Core Acquisition is split up into the four categories *quality*, *quantity*, *cost* and *time* of the cores. These categories are also proposed by WEI ET AL. [15]. The production uncertainties can be divided into elementary factors of production [19] and the different steps of a remanufacturing process following for example OKORIE ET AL. [20] to identify critical process steps.

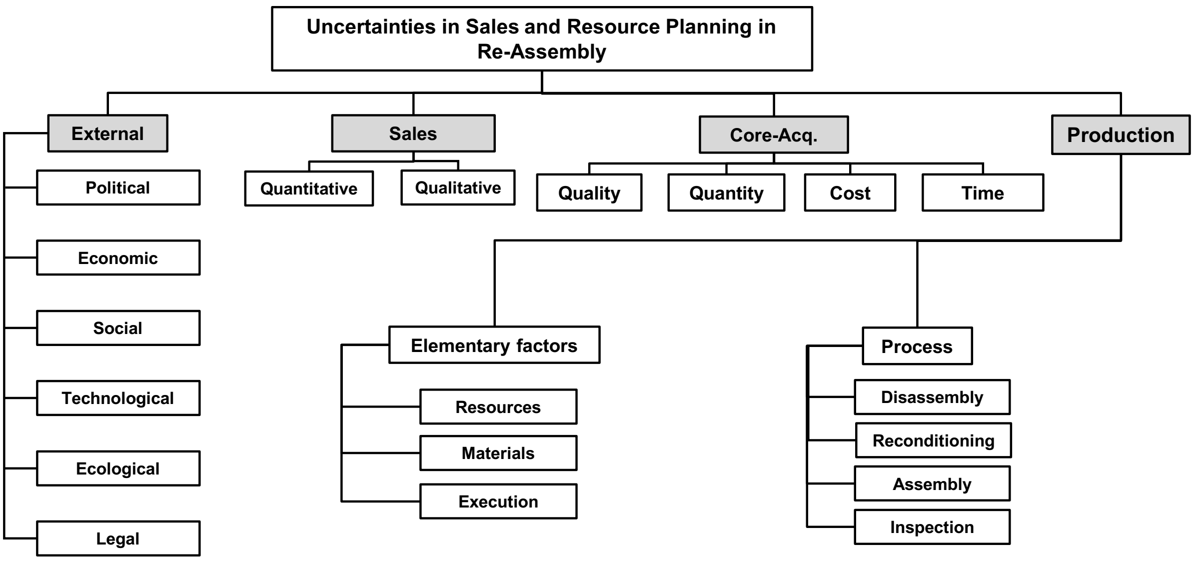

Figure 3: Detailed framework for the categorization of uncertainties in Re-Assembly

4.2 Data provision in the digital shadow

In accordance with the reference architecture of the IoP, the data provision is based on data from the development, production and user-cycle of the vehicles. To identify the data requirements for the use case the uncertainties identified as described in chapter 4.1 as well as the data requirements for a sales and resource planning in the linear economy can be used. Using the categories described in chapter 4.1 the relevant uncertainties for the sales planning can be taken from the sales and core acquisition branch. Therefore not all uncertainties need to be inspected. However the identified data from this step needs to be modelled in a data model to give an overview of the elements and their relations [14]. It is noticeable, that much of the data used is produced in the user-cycle and might be provided by the aftersales department or external market research-agencies. The planning will be done in discrete time periods which can for example be defined as one month or one quarter.

The data needs for the resource planning can be derived analogue to the sales planning from the uncertainties identified in the categories of production and core acquisition. The core acquisition is also needed in this step to make sure the resource demand can be identified based on the availability and condition of the core. The data from the production and the capacities can either be extracted from the Manufacturing Execution System (MES) or the Enterprise Resource Planning (ERP) System and is assigned to the production cycle. Data regarding the condition of the cores can be extracted from a storage connected to the controller area network (CAN-Bus) or independent sensors in the vehicle. The used data might range from the mileage of the car to specific vibration data from the drive train.

4.3 Analysis methods

The first step in the analysis level of the digital shadow is the data pre-processing to structure and aggregate the data from the data provision in a way they can be used by the analysis models [14]. This pre-processing step can also be used to bring the data in a storage where different stakeholders from the circular economy can access them. An example for such a data structure is the digital product data pass as proposed by the European Union [21]. Further, the pre-processed data is used by the different models which interact with each other for the combined planning of sales and resource planning. The models and their interaction is shown in Figure 4.

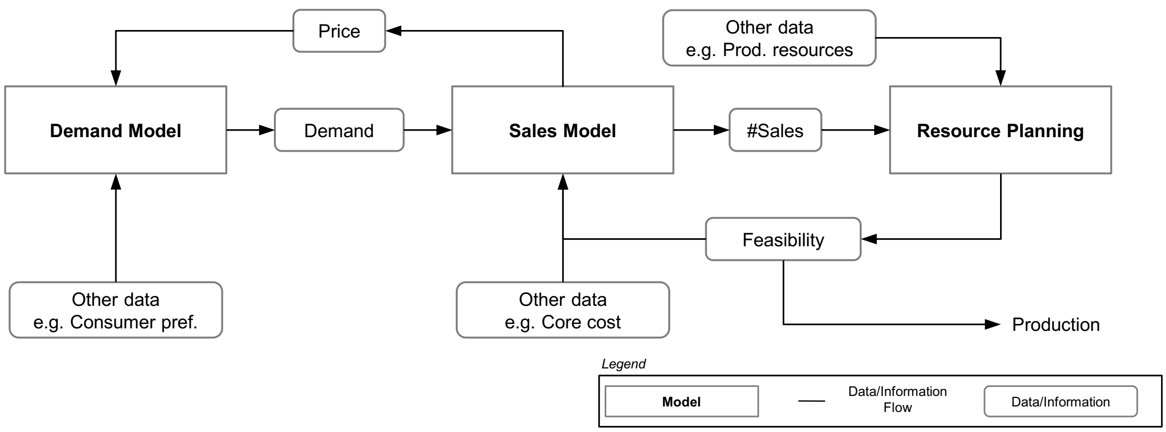

Figure 4: Models of the analysis method

In order to create the sales plan, it is first necessary to determine the demand for vehicles in the market. This estimation can take place, for example, via the customer behaviour on the market and the possible vehicles offered. A demand model that can be assigned to the category of consumer behaviour, but also takes aspects from the other categories, is the overall market model according to [22]. Especially the discrete choice model is included in the overall market model. The model is characterized by the fact that both the demand for individual vehicle models and the demand for different segments can be determined using a product space to describe the vehicles. This product room of the model can be extended with Re-Assembly specific properties such as technical upgrades and number of previous owners.

The demand specified by the demand model serves as the basic input for the sales model, which is intended to formulate profit-optimized sales for a vehicle model and the associated remanufacturing variant. Thus, the inherent factors of remanufacturing must be taken into account. While product cannibalization is already addressed in the demand model, sales planning should reduce uncertainties regarding core availability. Uncertainties in the case include the timing and volume of core returns as well as the quality of the returning cores. The sales model aims to optimize vehicle sales for profit over several periods. Therefore, the model has a dependency on the time dimension. For a consistent overall planning, the observation frame is adopted from the overall market model. Thereby, all vehicles to be sold are sold at the end of a period and produced or refurbished in the same period. Planning over several periods means that optimization can also take into account the sale of new vehicles for holding cores in subsequent periods.

To validate the feasibility of the proposed sales program from the sales model a resource planning model is needed. This model optimizes the production resource usage under the restrictions given by the production capacities. The resource planning need to be done under uncertainty in the duration and sequence of process steps as identified in chapter 4.1. Such models which can handle uncertainty in resource planning are already established for the optimization of production programs in the linear economy with uncertainties in the demand [23]. These models must be extended and tested to include the specific properties of Re-Assembly. If the model determines that the proposed production program is not feasible even with capacity expansion, alternative sales programs must be identified and validated by adjusting the sales planning conditions.

4.4 Information requirements

The information requirements for the sales and resource planning in Re-Assembly include the information requirements from the linear planning as described in [24]. Next to this information also Re-Assembly specific information is needed. This information includes, for example, the number and type of upgrades to be performed and the sale of remanufactured vehicles. Another important information that is needed in the planning is the number of cores in the different quality levels which need to be procured to realize the sales plan even with uncertainties in the quality level of the cores.

5. Summary and outlook

The implementation of a circular economy is necessary for economic, ecological and social reasons. In the implementation of the paradigm, Re-Assembly offers an innovative approach to minimize the reconditioning times of complex products and thus maximize the time products are used during their lifetime. However, the methodology encounters a number of uncertainties that hinder the planning and implementation.

In this work, the uncertainties for Re-Assembly were systematically identified and assigned to the individual planning and implementation steps using a classification method. Based on the identified uncertainties, a concept for data-based sales- and resource-planning was presented. This concept is based on the structure of a digital shadow in the reference architecture of the IoP. The core of the concept is represented by three interfering models for demand-, sales- and resource-planning, which are used to cover the information requirements.

In further research, the components of the digital shadow need to be detailed and tested on real data. For this purpose, it is also suitable to use data from the long-established supplier market for automotive components, since remanufacturing as a superordinate strategy of Re-Assembly has been widespread in this market for a long time.

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