A Decision Concept for the Economic Evaluation of Different Recycling Paths in the Dismantling of End-of-Life Vehicles

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Abstract. Due to the scarcity of raw materials, the recycling of end-of-life vehicles is becoming increasingly important. The essential decision for the cycle of materials is made in the dismantling company which disassembles the vehicle parts and determines the further recycling path: reuse as a replacement part, specific substantial exploitation or exploitation by shredding. This decision is the central aspect of this paper, taking into account the economic aspects, the uncertainties of the market and the applicability of the method. Therefore a detailed cost analysis model is presented, including a method for prediction of the replacement part market. In addition an IT concept is presented to visualize the result of the analysis and support the decision making.

Keywords. decision concept, end-of-life vehicles, recycling, IT concept, app concept

Introduction

Due to reduction of natural resources and an increase of environmental awareness, conservation of resources has become increasingly important in recent years. Among resource conservation approaches, recycling of products at their end of life contributes to the preservation of natural resources. To achieve this goal, reusing and recycling of used vehicles and their components is a point of interest. With regard to this, the decision on the most economic recycling path with the highest revenue is an essential factor which needs to be considered by dismantlers. In this work a method combined with an IT concept is introduced that can be used as a decision tool by dismantlers.

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1. State of the Art and Related Work

In this chapter an overview of the state of the art for the recycling of end-of-life vehicles (ELVs) is given, focused on the dismantler. Figure 1 shows the cycle of materials for recycling of ELVs that has been established in practice (cf. [1,2,3]).

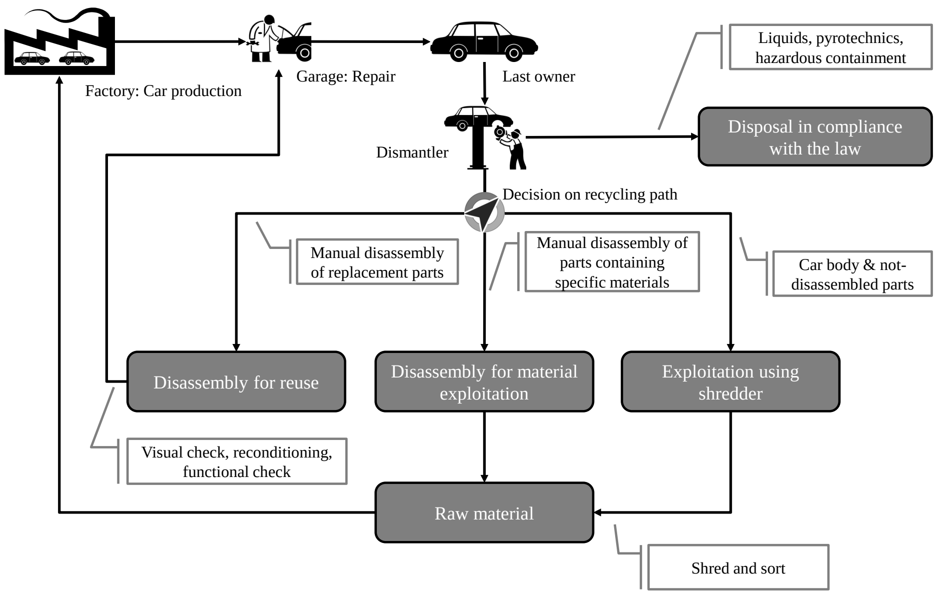


Figure 1. Cycle of materials for recycling of end-of-life vehicles

The first instance in the cycle of materials is the car dismantler which receives ELVs from the last car owners and whose job it is to disassemble the cars and deliver each part to a suitable recycling method. After performing certain recycling steps that are regulated by law, the general dismantling process of car components can be started [2,4]. At this point the dismantler has to decide which recycling path to choose for each individual component of the ELV. There are three decision options:

Reuse of car components. After the disassembly of selected car components, their operability has to be checked. In case of a successful functional test and they are in good condition, they can be sold as replacement parts to private consumers or garages [2].

Material exploitation of car components because of the value of contained materials (e.g. copper content of defective car starter motors and generators or precious metals in catalytic converters) [2].

The third decision option is **shredder exploitation**. After removing all usable components, the car body and the remaining components are shredded. Then the metal contents are recovered and recycled into new raw materials [2,3,5,6,7].

The cycle of materials (see Figure 1) shows that the decision of the dismantler on the recycling path has a big influence on the economic recycling of ELVs. Because of that, the decision process is considered in the following in more detail.

1.1. Decision Process on Reusing or Material Exploitation of Vehicle Parts

The decision on which car parts to dismantle or use for material exploitation depends on the following boundary conditions. Firstly, there are **legal regulations** for dismantlers. Certain laws (e.g. in Germany: End-of-life vehicle regulation (Altautoverordnung [4])) require the dismantlement of components containing hazardous materials like lead, cadmium or mercury before shredding, as well as car liquids and pyrotechnics (cf. [2,4,8,9,10,11]). For the remaining vehicle components the dismantler can decide on removing them or not. Typically, that decision is based on the **individual experience of the dismantler** [2,3]. The main source of income for car dismantlers is the sale of replacement parts. Therefore, vehicle components which lead to a profitable business are dismantled for reuse [1]. Components like the combustion engine, gearbox, electric machines or body parts are typical replacement parts which are dismantled, repaired and sold to private consumers or garages [2,3,5].

1.2. Analysis of Decision-Making Methods and Optimization Potential

In this section an overview of different methods is given, which support the decision process and provide important information to make economic decisions. First of all, evaluation criteria have to be defined that are necessary for a decision support method in the context of a dismantler. The cost effectiveness is the first criteria as each company strives for the maximum benefit. To deal with the specific conditions in the regarded domain the method has to deal with market uncertainty and it has to be usable with a holistic information system in day-to-day work. Based on these criteria several decision methods are presented and evaluated.

Floel developed a **cost calculation model** for modern dismantlers [1]. With a detailed cost structure, dominant cost drivers can be identified and business processes can be evaluated economically. He considered costs and revenues for different dismantling depths for the scenarios *reusing of car components* and *material exploitation* and made a suggestion to calculate an optimized dismantling depth [1]. This approach clearly focuses on the criterion cost effectiveness, providing a very detailed model for this domain. However, the degree of detail worsens the usability in the daily work and it is almost impossible to insert reliable data considering the uncertainty of the market.

Another method is the **consumption-oriented demand determination**. This method has been established in business management, especially supply management, for inventory planning. The basis for the use of the method is a data base from the past. If the inventory falls below a certain level, an order is placed to refill the inventory. Useful methods to determine the consumption are the ABC- and XYZ-analysis [12,13,14]. These methods analyze the sales aiming at determining the orders. In the context of a dismantler it is not possible to pass up orders, instead the company has to deal with the ELVs it gets. Therefore, when considering uncertainty, this method is not applicable to the regarded domain. Furthermore, this method doesn't treat cost aspects and usability at all.

In another paper, *Afrinaldi et al.* focus on the **decision on the disassemblability and recyclability** [15]. They concentrate on the material exploitation of ELVs, providing a software tool to calculate the benefit of the raw materials compared to the labor costs. They provide a specialized tool for the calculation of material benefits that gives detailed information on the recycling costs. Nevertheless the examination is limited to the material exploitation and does not consider the reuse of the components. Furthermore, this paper doesn't deal with the uncertainty of the market.

In summary it can be stated that none of the described methods fulfills all criteria. This illustrates the necessity for developing a concept that fulfills the named requirements and criteria in a wide band. This is the aim of this work.

2. Decision Support Concept

The focus of this method is to come to a decision on an optimal way of disassembly, which has to be taken by the dismantler. For this purpose the dismantler must take a decision for each component of an ELV. For each of the three recycling scenarios, the individual cost aspects are analyzed and quantified. These contrast with the revenue that can be achieved in the considered scenarios. The profit is calculable as the difference between potential revenue and cost for each component.

2.1. Market Analysis of Replacement Parts

The challenge of market analysis is to determine the sales options of the replacement parts during the disassembly of the vehicle. Thus, an analysis for each component must be conducted to predict its demand trend. The result of this analysis is the characteristic value of the market index, which describes the probability that the replacement part is going to be sold. The most important factor influencing the market index is the development of demand. The predicted value is therefore the number of expected sales of the replacement part in the coming year. The prognosis is made for one year, as this is a realistic lead time in a dismantling company and allows for seasonal effects to be neglected. The challenge of the demand prognosis is the question of how the presented information, the demand, can be predicted for a particular component in the coming year.

In the following a calculation method is proposed to establish a connection between the registered vehicles and the demand for replacement parts. The basic idea is shown in Figure 2. The historical data is used to analyze correlations between these variables. From these functional dependencies, it is possible to create a prognosis of replacement part demand in the future using current vehicle registration numbers. Based on this basic idea, the *sales prognosis SP* is calculated (see equation 1).

$$SP_{part,dismantler} = RP_{car} * PI * DI \tag{1}$$

The *registration prognosis* RP_{car} is based on the currently registered vehicles. The value represents the number of registered vehicles in which the replacement part under consideration may be used. For example, if the sales of a particular type of blinker are predicted, the registration prognosis gives the total number of vehicles which are equipped with this blinker type. The *part index PI* (see equation 2) is used to determine the average demand for replacement parts for a particular component. This value is derived from historical data and describes how large the demand for this type of replacement part is in relation to the registered vehicles.

$$PI = \frac{1}{n} \sum_{i=1}^{n} \frac{SaS_{part,i}}{RS_{car,i}} \tag{2}$$

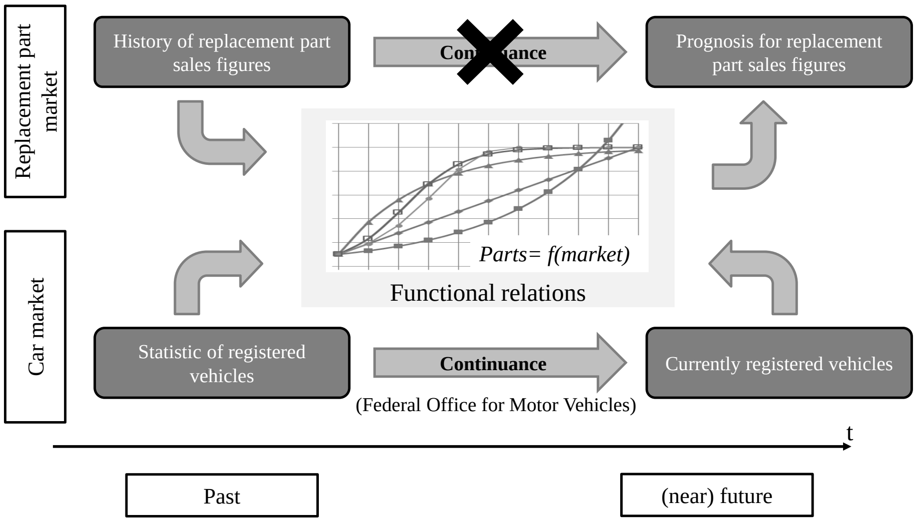


Figure 2. Basic idea for demand prognosis

The *sales statistics* $SaS_{part,i}$ describes how many units of the considered part have been sold within the year i, whereas the *registration statistics* $RS_{car,i}$ represents the number of vehicles registered. Using statistical averaging over n years, the quality and reliability of the prediction can be improved. The *dismantler index* DI (see equation 3) represents the relationship between the global replacement part market and the demand at the specific dismantler. The sales potential of the dismantler is determined in comparison to the overall market, with respect to the vehicle manufacturer.

$$DI = \frac{1}{n} \sum_{i=1}^{n} \frac{SaS_{manufacturer,dismantler,i}}{SaS_{manufacturer,global,i}} \tag{3}$$

The numerator contains the number of all parts of the manufacturer, which were sold by a specific dismantler. The denominator contains the total global demand for replacement parts of the manufacturer. This is on the one hand the market share of the dismantler and on the other hand takes region-specific characteristics into account.

Using the prognosis of replacement parts of a specific type, the market index can be determined. It is defined as the probability for the sale of a disassembled replacement part. The most important influence factor is the *inventory* I, that has to be built up with regard to the sales prognosis. For the decision, whether a part should be disassembled or not, both the *inventory* I and the *sales prognosis* SP have to be regarded. The market index is calculated using the rule shown in Figure 3.

The market index decreases with increasing inventory. In the critical range of inventory parts around the sales prognosis, a linear function is proposed. This range can be determined by the company, taking into account their experience, strategy and storage capacity.

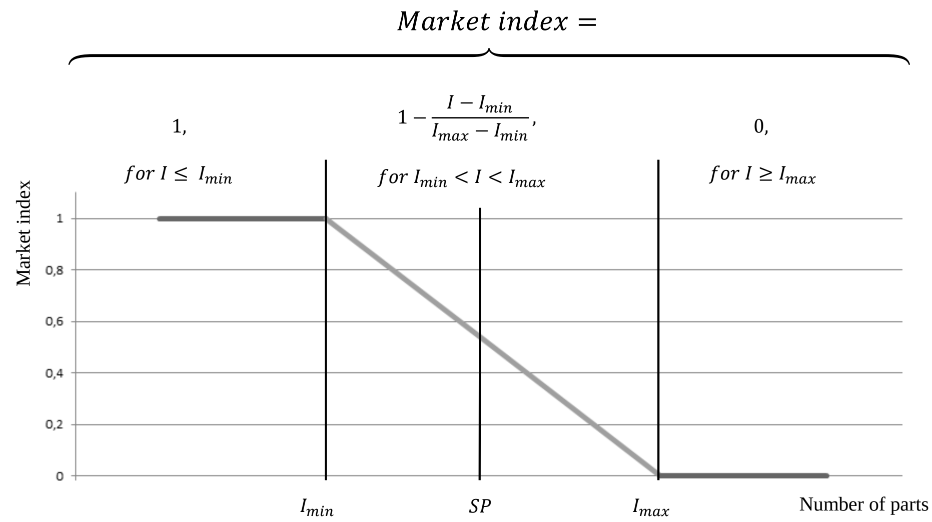


Figure 3. Calculation and visualization of the market index

2.2. Economic Evaluation of the Recycling Scenarios

For each part of the ELV, the decision has to be taken which recycling scenario to choose. The proposed monetary evaluation considers the profit for each of the three scenarios. In the scenario **reuse as replacement part** the total costs sum up over several factors: Disassembling the part generates costs for the working time and the infrastructure of the garage, functional testing verifies the correct operation of the replacement part, reconditioning the replacement parts includes cleaning as well as visual and technical rework. Finally, inventory and distribution costs model the effort until the part is sold. The revenue in this scenario is defined as the product of the sales price and the market index. This takes into account that there is no revenue for the recycling company by just disassembling the part and labeling it with a certain price. Only selling the part realizes the revenue. The scenario **specific substantial exploitation** causes costs for disassembling the part and the separate logistics. The revenue of this scenario depends on the commodities market prices and the offer from the exploitation company which is subject to considerable uncertainties and turbulences. **Shredding** the part with the car body leads to a revenue depending on the weight of the part and the market price of scrap metal.

2.3. Taking the Decision

The calculated profit of each scenario serves as the basis for the decision. The detailed and comprehensible presentation of values and effects helps the recycling company to take insightful decisions. Nevertheless, it is the user of the method who has to make the final decision, taking additionally into account the condition of the part and the availability of staff, technical equipment and storage space. Combining the detailed economic analysis with the situation-based and experienced evaluation of the feasibility in the recycling company ensures the maximum quality of the decision.

3. IT Support for the Decision Support Concept

To provide a real benefit for the dismantler and allow for a more effective and efficient execution of the disassembly processes, it is important that the developed decision support concept is usable intuitively and effortlessly. Because of that, the approach for an IT system and an app were developed, that implement the concept and provide a clean presentation of all relevant data necessary for the decision process at the dismantler company.

Central component of the envisioned architecture is the Dismantler Decision Support Platform (DDSP). It implements a rule engine based on the decision support concept introduced in section 2 as a cloud service and is available via a Software as a Service (SaaS) model to the dismantler. Since this allows for a usage-based accounting model, the dismantler has very low initial costs and therefore a low investment risk. The DDSP can be used by the dismantler via the app on nearly any existing device like tablet computers, mobile phones or personal computers, which further reduces the initial costs. The cloud architecture also has the advantage, that all calculations, especially those requiring large amounts of data, can be executed using the cloud's computing power. Furthermore, a cloud architecture makes it easier to integrate all systems and databases supplying data, since they don't need to be directly accessible for every single dismantler. This also remedies security concerns car manufacturers might have when supplying data or providing access to their databases.

The DDSP connects to several, already existing, databases and systems that provide information necessary to calculate the recycling recommendations. Those systems are mostly developed and maintained by car manufacturers and their subcontractors or by governmental institutions like the *Federal Office for Motor Vehicles*. To calculate the market index (see section 2.1), statistics of vehicle registrations are needed as well as sale statistics of other dismantlers. Systems like the International Dismantling Information System (IDIS) or the International Material Data System (IMDS) provide information about the disassembly of car parts and the raw materials contained in those parts. To calculate the raw material value of parts, a connection to the commodities exchange is also required.

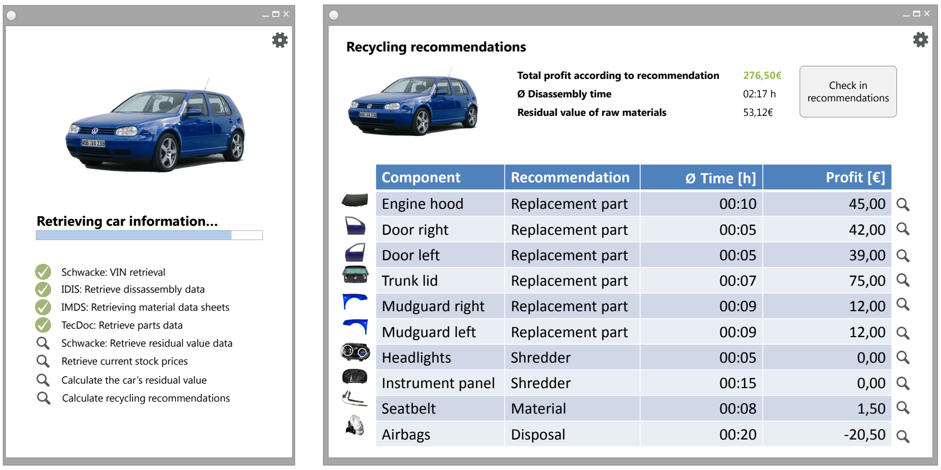
The DDSP itself keeps a statistics database, containing all sales data from the connected dismantlers, shared anonymously between them and used to calculate their respective *dismantler index*. It also keeps dismantler-specific data like hourly mechanic or garage rates as well as the complete inventory data for each dismantler.

Using this data, the DDSP is able to calculate the recycling recommendations for all parts of an ELV, according to the equations presented previously.

3.1. App Concept

While the DDSP is the basis for the recommendation calculations, the staff at the dismantler have also to be able to use the system in day-to-day work. To achieve this, an app concept is proposed that supports the staff of the dismantler in the decision making process. Based on the app concept, a user interface prototype was developed. With the help of this prototype, the concept will be described in more detail in the following section.

After an ELV is delivered to the dismantler, it is entered into the IT system using its Vehicle Identification Number (VIN) [16] and manually supplemented with additional information about the previous owner.



(a) Retrieval of vehicle information (on a mobile phone).

(b) Overview of recycling recommendations (on a tablet computer).

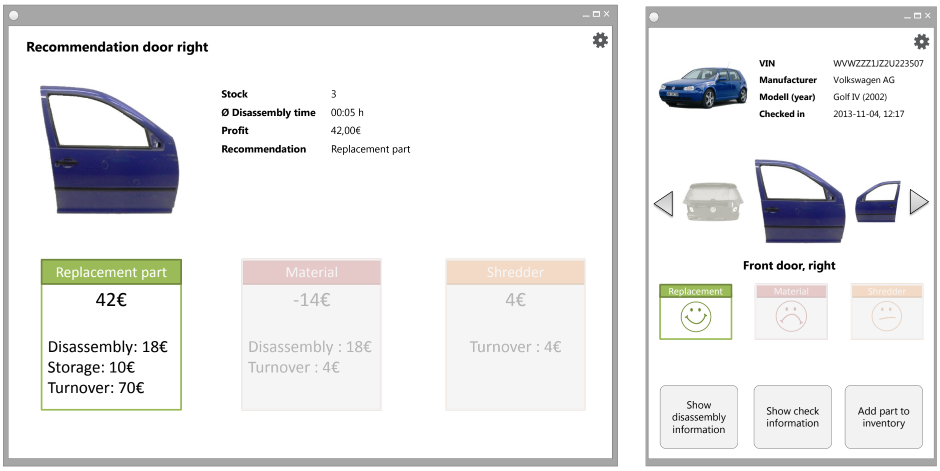
Figure 4. App user interface concept.

In the next step (Figure 4a), the DDSP retrieves all information necessary for the calculation of the recycling scenario for all car parts from the connected databases and systems. After the calculations are completed, the user gets an overview of all car parts (as shown in Figure 4b) including the respective recycling recommendations, disassembly times and the profit prognosis. The user now has the possibility to change the recommendations based on the actual condition of the respective parts. For example, body parts might be in bad shape after a crash, so they don't qualify for reuse. Based on the profit prognosis, the user has an economically sound basis to decide whether he wants to share a part of his profit with the last owner of the car. This could lead to more competition between dismantling companies, because car owners would be able to obtain quotes from different dismantlers and sell the car to the one paying the most. Also, this could reduce the loss of raw materials due to exports, because more car owners would sell their ELVs to dismantlers instead of selling them to used car exporters.

Additionally, the user is able to review the details of the recommendation and the values it is based on, as shown in Figure 5a. Since the law regulates the principle of resource-conservation, the weighting of alternatives with the same profit follows the rule *replacement part* before *material exploitation* before *shredder*. After possibly changing the recommendations, the user can check the car into the system.

Besides supporting the decision process, the app also supports the mechanic during the actual disassembly of the car. While this is also a tool to optimize the overall process at the dismantler, it is not part of the decision processes any more, and therefore only a short overview of that functionality is given.

Based on manufacturer data retrieved from the aforementioned system *IDIS* and the recommendations calculated previously, the app guides the mechanic through the ELV disassembly. For each part, the mechanic is shown the recycling recommendation as well as disassembly information or information about the functional testing of the currently selected part (see Figure 5b).



(a) Detailed view of recycling recommendation for right front door (on a tablet computer).

(b) Disassembly process support (on a mobile phone).

Figure 5. App user interface concept.

The app further optimizes the inventory management by providing the functionality to directly print inventory labels or to use the tablet pc's integrated camera to photograph the disassembled part. These pictures, as well as the part data retrieved previously, could than be automatically published in the dismantler's online shop or on platforms like eBay.

4. Conclusion and Outlook

From the environmental and economical perspectives, recycling of end-of-life vehicles and their components has become increasingly important. A comparison of different decision-making methods shows the need for a more economic method for the evaluation of different recycling paths that leads to an improvement in IT transparency and cost and revenue calculation. Therefore, a comprehensive decision support concept was developed in this work. With it, the dismantler can choose the most efficient recycling path which leads to the highest revenue.

An application of the presented method in practice, requires a software technical implementation of the cloud-based IT infrastructure as well as the app. Since the developed decision support concept is not restricted to ELV recycling, its applicability to other markets, for example production machines, could be evaluated.

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