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METHODS ANALYSIS OF REMANUFACTURING OPTIONS FOR REPEATED LIFECYCLE OF STARTERS AND ALTERNATORS

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Abstract: *The Design for Repeatedly Utilization (DFRU) is a proposed concept to be used in the product realization process to ensure optimum useable life (for instance in terms of economy, resource usage, environmental impact etc.) of products or parts of products enabling multiple lifecycle. In the DFRU approach products are restored as new like products through remanufacturing processes. The term remanufacturing has been interpreted differently by different researchers and the industries that are involved in remanufacturing business use different approaches to remanufacture their products. In this paper the starter motor and alternator of automotives has been used to demonstrate the novel concepts. The purpose of this paper is to express what remanufacturing means in our concept, model their major lifecycle aspects and create a simulation model from it. This is a preliminary work towards defining and specifying the processes, methods and design properties in DFRU. The work will be further extended to a holistic business model which can facilitate DFRU approach in an efficient way. In future the model will be developed and adopted to create new models for other products appropriate for remanufacturing and eventually DFRU.*
Key words: Starter motor, alternator, remanufacturing, systems dynamic, DFRU

1. INTRODUCTION

The challenge for sustainable economic development is to increase the economic welfare and well-being of society while, at the same time, reducing resource requirements to a level consistent with the natural carrying capacity of ecosystems. Much of the impact on the environment is a direct result of the manufacturing of goods and related services. Furthermore the manufacturing sector is being challenged by the ever increasing pressure and stringent legislative requirements from environment and resource utilization. Production and consumption by human societies have always been linked with the use of natural resources, which, in turn, can often have negative environmental effects. The challenge for sustainable economic development is to increase the economic welfare and well-being of society while, at the same time, reducing resource requirements to a level consistent with the natural carrying capacity of ecosystems.
Due to these, remanufacturing is becoming more and more attractive to industries and researchers. Automotive is one of the oldest and leading sectors in the remanufacturing industries. In 2007 approximately 18.7 million (assumed as average) motor vehicles were registered in the EU [1]. Most of the vehicles require at least two starters and alternators during its life [2]. This shows a high demand of average 37.4 million starters and alternators in the EU region. There are thousands of manufacturers' worldwide producing starters and alternators in a mass production basis. However, there are only about 100 remanufacturers (out of 300 worldwide) active in the EU who remanufactures mainly starters and

alternators [3]. It means that there is a large market connected with the remanufacturing of starters and alternators.
In addition, the environmental impact associated with starters and alternators are significant. A typical starter motor (Bosch) is 240 mm in length and the diameter is 82.5 mm and the alternator (Bosch) is 176 mm in length and the diameter is 56 mm[4]]}. It can be summarized that 37.4 million starters and alternators require approximately 64195 m^3 spaces for landfilling at their end-of-life (EoL). On the other hand considering the average weight of a starter and alternator is 4 kg, it requires recycling (considering 80 % of starters and alternators is recyclable) of approximately 239360 tons of material. Remanufacturing can considerably lower the solid waste generation, reduce energy and material consumption as shown in the figure 1.

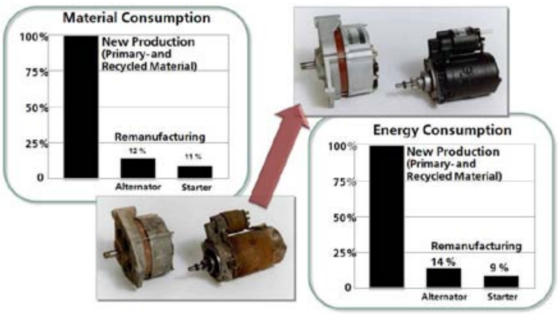


Fig 1. Resource savings in remanufacturing compared with new manufacturing [5]

In addition, the price of remanufactured starters and alternators is 50% lower than the price of new ones and it is also worth mentioning the reduction of the green house gases trough remanufacturing intervention. The benefits of remanufacturing can be further maximized if parts of starters and alternators can be used for multiple lifecycle.
Despite the huge opportunities involved in the remanufacturing of starters and alternators, it hasn't been progressed much. The remanufacturing is still mainly dependent on craftsmanship. One of the main reasons is that the remanufacturing industries do not have an established holistic industrial model to support the strategies and processes to enabling re-entering of parts into the supply network and integrate efficient parts, materials or energy recovery option and supporting technologies.
In this paper an initiative has been taken to build a holistic business model which can facilitate multiple lifecycle through remanufacturing in an efficient way. A clausal loop diagram (CLD) is created considering major aspects of product lifecycle using systems dynamic principles. The CLD is further developed as a simulation model to assess how much material can be saved through multiple lifecycle and reduce solid waste generation.

1.1. Definitions

Before going into the details it might be useful to define the key terms used in this paper. *Remanufacturing* is the process of - restoring a product to like-new condition by reusing, reconditioning, and replacing parts [6]. The new parts that replace the degraded parts are either manufactured from primary material or recycled material. *Recycling* is the process of- taking component materials and processing them into the same material. *Manufacturing* is the process of making new products either from primary material or recycled material. *Primary material* is the material that is coming from mines and never been used before.

2. REMANUFACTURING PROCESS OF STARTERS AND ALTERNATORS

Remanufacturing today is a key industrial discipline at the end of a product's life cycle which reaches annual turnovers comparable with the steel industry [7]. According to Steinhilper [5] remanufacturing is the ultimate form of recycling and is performed in a well structured industrial surrounding – often at the quantity level of series production. Remanufacturing starters and alternators typically involves manual operations due to a high variety of part numbers and automation is hardly applicable. This variety stems from different influencing factors which are typical for this branch. Remanufactures usually cover:

• Many product generations (from today's to classical cars).

• Different OE (original equipment) manufacturers (e.g. Bosch, Valeo, TRW).

• Different type series (depending on the motorization of the vehicle).

• Different configurations (upgrades, updates, customizing).

• Different quality levels of cores (new, used, dirty, worn).

The process steps for remanufacturing starters and alternators are shown in the figure 2.

Fig. 2. Starters and alternators: Five steps of industrial remanufacturing

3. THE DFRU CONCEPT

The traditional way of designing with respect to a product end-of-life is characterized by:

• Products are designed for single life and disposed at their end-of-life and sometimes recycling is carried out to recover material from end-of life products.

• In design for disassembly/ reuse/ remanufacturing etc. focus on the easy disassembly of products at their end-of-life to facilitate the recycle and part recovery.

There are several problems associated to the traditional way of designing:

• Parts with high residual value (in terms of remanufacturability) are recycled or landfilled.

• Quality (remaining life, re-usability, physical/functional condition etc.) of the products/parts at their end-of-life varies widely and is in most of the cases unknown.

• Resources in terms of manpower, energy, transportation etc. are invested in product collection, disassembly and testing to find out the product does not have any residual value to perform remanufacturing.

• The time or the location of recollection is not coordinated so the supply chain is expensive and faces uncertain performance.

The DFRU approach is different from traditional design approach in many ways:

• Products are designed for optimum life (in terms of design, economical, environmental properties) to ensure multiple lifecycle and re-entering of useable parts back in the supply chain.

• Appropriate time for each particular cycle to perform remanufacturing is preset at the design phase based on the user locations (urban or rural areas, extreme cold or hot weather etc.), user conditions (heavy or light duty) and more.

• Each product has a unique identification mechanism to track its location, physical condition and residual life during the end of that particular cycle.

4. THE MENTAL MODEL OF THE LIFECYCLE SCENARIOS

Undoubtedly, the lifecycle scenarios of the starters and alternators form a complex dynamic system. There are large numbers of variables that are interconnected to each other. Sometimes the variables and their relations are obvious and sometimes beyond our imagination. It is therefore, important to identify various variables and their causal relations to create a sustainable business model. The casual loop diagram (CLD) which is sometimes addressed as mental model, is a powerful tool. The tool is extremely useful for capturing the hypothesis about the causes of the dynamics, eliciting and capturing the mental model and communicating the important feedback responsible for the dynamics of the system [8]. Moreover, a comprehensive mental model is a gateway for the perfect simulation model. Figure 3 presents a mental model of the lifecycle scenarios of starters and alternators.

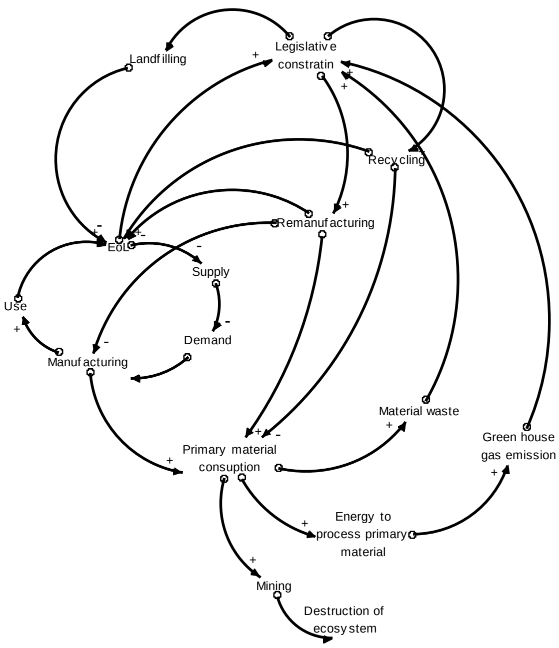


Fig. 3. A closed loop diagram of lifecycle of starters and alternators

The model emphasizes four major dynamic relations that exist in the lifecycle of starters and alternators. The supply demand loop of the starters and alternator is a positive loop implies that with the increase of demand new products will enter into the market causing a huge amount of solid wastes at the end-of-life. The legislative constrains are currently in place to minimize the end-of-life solid waste which results in two balancing loops (recycling and remanufacturing) and one positive loop (landfilling). The positive loop (landfilling) is then further balanced by increased tax (not shown in the model) on solid waste generation and landfilling. With increase of demand of starters and alternators the demand of primary material is increased, which has a negative effect on environment, ecosystem and emission of the green house gases. The environmental sustainability and reduction of the primary marital use can be achieved through recycling and remanufacturing. The model shows that the legislation playing an important role in promoting recycling, remanufacturing and at the same time discouraging landfilling and use of primary material. There are other motives that have made remanufacturing one of the most attractive options for both original equipment manufacturers and third party remanufacturers [9]. Shown in the next section; a simulation model has been developed from this CLD to show the material consumption and solid waste generation in DFRU approach.

5. THE SIMULATION MODEL

Three different simulation models have been created and run for three different scenarios, which are,

- Scenario 1: Manufacturing of starters and alternators from primary material without any end-of-life treatment.
- Scenario 2: Manufacturing of starters and alternators from combination of primary and recycled material.
- Scenario 3: Manufacturing of starters and alternators from combination of primary and recycled material with remanufacturing as one of the options at the end-of-life.

5.1. Assumptions

Data that are input in the model are based on following assumptions supported by findings from the literatures.

- Material in this simulation considered to be ferrous metal.
- 95% of the solid waste generated from end-of-life starters and alternators are recyclable [10].

• At the beginning of the simulation the material inventory contains 10 units of primary material.
• Remanufacturing consumes only 16% material of what it would have consumed by manufacturing.
• Some fraction of the products is neither recyclable nor remanufacturable, which is eventually landfilled.
• The simulation has been run for 12 years period.

5.2. Scenario 1

The quantity of material in the inventory, used and the solid waste generated over 12 years period has been shown in the figure 4. It represents that in scenario 1 the quantity of primary material used and solid waste generated is high and remain constant for the infinity.

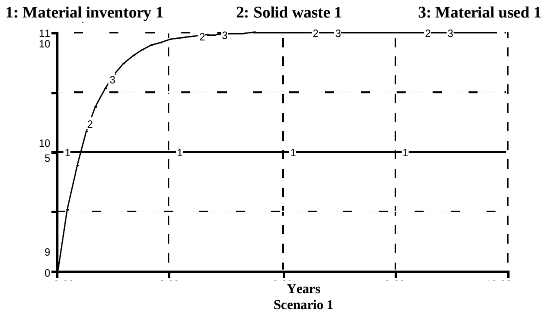
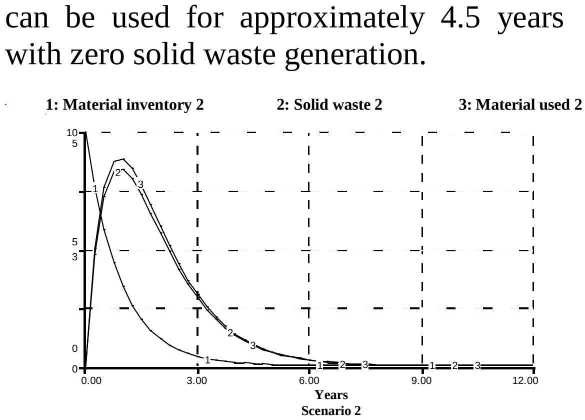


Fig. 4. Material used and solid waste generated in single life with waste disposal

5.3. Scenario 2

In figure 5 it shows that hypothetically the same quantity (as scenario 1) of material can be used for approximately 4.5 years with zero solid waste generation.



ig. 5. Material used and solid waste generated in single life with recycling

5.4. Scenario 3

If remanufacturing is performed (shown is figure 6) using combination of primary and recycled material hypothetically same quantity (as scenario 1 and 2) of material can be used for approximately 12 years without leaving any solid waste at the end.

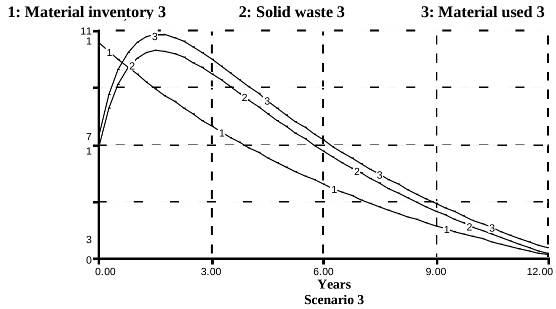


Fig. 6. Material used and solid waste generated in remanufacturing with recycling

Further interpretation

The outcome of the simulation can be further interpreted in terms of energy, green house gas emission (preservation of the ecosystem) and cost of energy. Since material consumption and solid waste is directly linked with these issues the scenario 3 is the ideal situation. However, if DFRU is considered to be an option, the benefits are even wider

6. CONCLUSION AND FUTURE WORK

The work presented in this paper attempted to define the state-of-the art of remanufacturing process of starters and alternators. An initiative has been taken in order to establish a holistic industrial model to support the strategies and processes for enabling DFRU. However, there is a long way to go before the model can be used for strategic decision making and design efficient remanufacturing process. The future work will focus on making a comprehensive simulation of the multiple lifecycle scenarios of starters and alternators. Appropriate product and process design properties and methods for DFRU will be identified.

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