



Integrate Remanufacturing In The Design Process:

Design For Remanufacture (Dfrem)

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Abstract

Companies that deal with the theme of Recovery in the development phase of a new product, abandon the traditional logic-based assessments at the end of the life cycle in order to verify the feasibility of the recovery itself and to identify the most appropriate strategy. In this case the recovery strategy is defined in advance and evaluated over a longer time horizon, so combined with the competitive edge. Addressing the issue of remanufacturing of a product in the design phase allows you to grapple with this challenge, in the stadium where there are fewer constraints and at the same time the best opportunities to simplify treatment, which is particularly complex and characterized by peculiar problems.

The aim of this paper is to present the state of the art on Design for Remanufacturing and control this type of design as part of a broader business strategy, with a view to a sustainable business of remanufacturing.

Keywords: Re-Manufacturing, Sustainable Business of Re-Manufacturing

Introduction

In this paper we analyze how the "Design for Remanufacture" is a useful tool, able to reduce the cost and increase the profit margins of a company that aims to protect the environment to make a sustainable economy.

As part of ecodesign - an instrument which aims the reduction of 'environmental impact of production and the entire life cycle of the product thanks to the improvement of manufacturing operations - remanufacture is becoming a common technique, which is to regenerate a new product from an obsolete or a one who reached his end of life.

The concept of "design for Remanufacture" (DfRem) stems from the awareness that the decisions made during the design process can have a dramatic effect over the efficiency and effectiveness of the remanufacturing process.

This paper is divided into six sections and place the order to highlight how valid as economic, social and environmental choice to integrate the remanufacture in the design process.

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Recovery of the product at the end of its useful life

Recovery of the product, alternative to the traditional disposal, is a response to environmental protection. Recovery, in fact, minimizes the demand for energy and raw materials, and the environmental impact of the refusal, and also gives the opportunity to start a profitable business. The environmental issues and eco-sustainability on one hand, and, on the other hand, the cost of the process, are, then, combined.

A sustainable type of closed loop must be adapted to some basic principles:

- Reducing waste by extending the useful life of the product;
- Re-use of the product / waste through practices reconstitution;
- Recycling of waste for the recovery of raw materials still useful;
- Use of landfills for the disposal as a last alternative.

A closed loop system includes distribution, product recovery and the final rejection management. Products and / or components that come back through the system of reverse logistics can be directly sold, recovered or disposed.

The products which are located in the last stage of their life cycle can be recovered through the use of 5 alternative strategies that have different levels of efficiency. They are: reuse, repair, reconditioning, remanufacture or recycle.

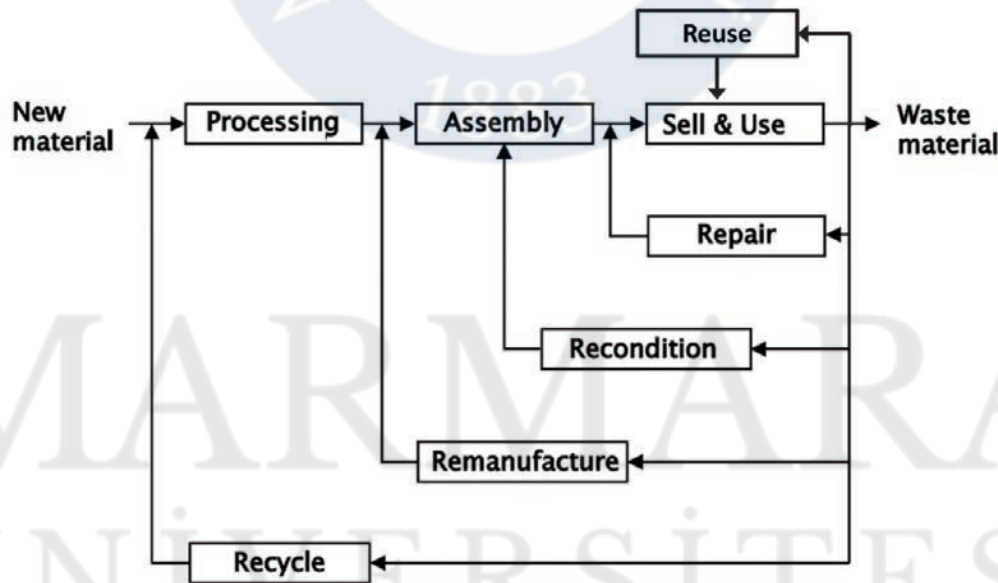


Figure 1. Closed loop design through reuse, repair, reconditioning, remanufacture or recycle

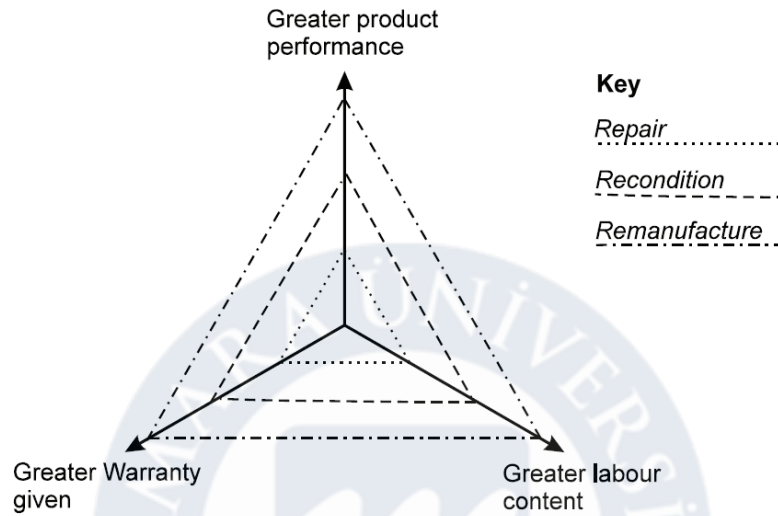


Figure 2. Hierarchy of recovery processes (Ijomah W., 2002)

In the figure above the fundamental differences between the strategies remanufacture, reconditioning and repair, based on three dimensions, are highlighted; the three dimensions are: level of offered warrant; promised performance; the content of work required in the treatment. It's clear that the best strategy is remanufacture.

The meaning of remanufacture

The definition that best expressed the meaning of remanufacture is to Ijomah:

" Among the different recovery options at the end of life, this is the only one that shows the products used at least to the specific performance of the Original Equipment Manufacturer (OEM) and, at the same time, provides a guarantee equivalent to that provided for new."

(Ijomah, 2002)

Moreover, we can also define remanufacture as an industrial process in which the product and its functional core is restored to life.

During this process the product passes through a series of steps: inspection, disassembly, replacement / reconstruction of parts, cleaning, assembly, testing and trials. All this allows this technique to be mainly applicable when recovered products maintain a relatively high added value compared with the valuation of the market or to their original cost.

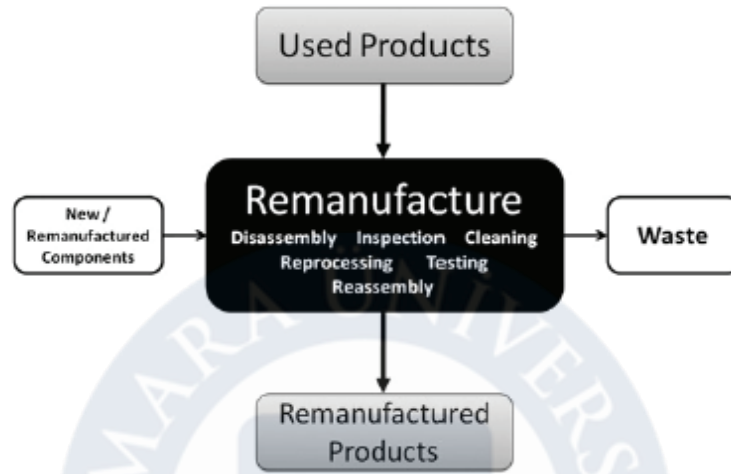


Figure 3. Illustration of a process of remanufacture

Among all the practices that invest used products intended to be reusable, this requires the highest use of resources and offers superior quality and durability. This is justified by the fact that the product needs to be removed in all its components that will be subjected to restoration or replacement, depending on the case.

Very often remanufacture is considered the final most advantageous option to make the product, even the most evolved form of recycling. Indeed, researchers Gaudette and Giuntini say that the energy consumed to start the product to a new cycle is, on average, approximately 20 - 25% of that required for brand new production, while the final cost is approximately 60% of that of first manufacture.

It's important to note that, recycling, in a profitable and environmentally sustainable model as the remanufacture, must represent the last step after the product is returned at the end of its life cycle.



Design for Remanufacture

The concept of "design for Remanufacture" (DfRem) stems from the awareness that decisions made during the design process can have a significant effect on the efficiency and effectiveness of the process of remanufacture.

Research has shown that the efficiency and effectiveness of the process of remanufacture are very decisions dependents during the design process (Ijomah et al., 2007). There are certain characteristics of the product that influence remanufacturability, and, therefore, have effect on the feasibility and profitability of this business strategy (Charter and Gray, 2008), as well as environmental saving (Kerr and Ryan, 2001).

Companies that deal with the theme of the recovery in the development phase of a new product forsake the traditional logic based on evaluations at the end of the life cycle, in order to verify the feasibility of the recovery itself and identifying the most appropriate strategy. In this case, the recovery strategy is defined *a priori* and evaluated over a longer timescale, so combined with the competitive edge.

Product remanufacturing addressing, during design phase, allows to simplify the treatment in the stadium where there are fewer constraints and, at the same time, the best opportunity to simplify and speed up a complex process characterized by peculiar problems. In this type of design is essential to pay attention to logistics, demand and technology of the recovery process of the generic product.

Remanufacturing starts from the core. Aspects such as the shape, the material, the connections between the components / modules may affect the way they approach the process. Design for remanufacture has a key role in the development of this business. The design itself can be considered a variable profit.

The remanufacturability of a product through a targeted design is affected by its physical characteristics determined during the design phase. The DfRem facilitates the treatment and can be understood as a two levels methodology:

- Configuration of the business model and product strategy (sales, marketing, after-sales and reverse logistics);
- Design and engineering of the product, strictly speaking.

Designing for the remanufacture means optimizing the process, configuring and establishing *a priori* the start of a business, defining the cost structure, the image, the company policy and evaluating the intensity of competition, the feasibility and potential gains (Willim et al., 2001).

Usually, using the definition of Design for Remanufacture, reference is made to the design in a strict sense, shifting the emphasis from the business model and strategy product.

The four areas of intervention, at the time in which it develops a product that will undergo a process of remanufacture, are:

- Its complexity;
- The coupling methods;
- The tools for assembly and disassembly;
- The increasing fragility of the components.

The company, in order for earn profit from the rework of the product, need to minimizing operating costs during consumption and maximizing the value of the product at the end of the life cycle.



DfRem is divided into a series of submethodologies that may also have divergent objectives according to the cases. These techniques, known as "Design for X", focus attention on different activities of the entire process of remanufacturing as is shown below.

Table 1. Design for X in the stages of a process of remanufacture (Gray, et al., 2007)

DESIGN STRATEGY	REMANUFACTURE PROCESS						
	Core Collection	Inspection	Disassembling	Cleaning	Restoring	Assembling	Testing
<i>Design for Core Collection</i>	✓	✓					
<i>Design for Disassembly</i>		✓	✓	✓	✓	✓	
<i>Design for Multiple Lifecycles</i>				✓	✓		
<i>Design for Upgrade</i>					✓		
<i>Design for Evaluation</i>		✓					✓

The following table lists the typical design problems that must be addressed in the various phases. An approach that follows the logic diagram of the table simplifies recovery and improves remanufacturability.

Table 2. Product design in order to simplify the steps of a process of remanufacture (Shu et al., 1999)

Process	Design Drivers	Motivations
Collection	Eliminate protrusions in the product's geometry	- Minimize possible damage during the transit - Simplify the storage
Disassembling	Reduce the quantity and variety of closures Use standard closures	- Reduce the tools to use - Reduce the time of the operation
Sorting	Using identical or similar parts	- Reduce the resources required to separate parts
Cleaning	Avoid forms that tend to attract dirt like grooves and recesses Use appropriate materials, shapes and colors	- Improve access to tools and cleaning fluids - Reduce exposure to dirt and possible damages during this phase
Inspection	Thoroughly and explicitly indicate the remaining life of the components	- Reduce efforts to verify the reusability of the component
Restoring	Design components that do not break; or concentrate defects and wearing course in removable or replaceable parts	- Reduce the need to resort to methods of labor-intensive or capital-intensive to restore

Implementation Strategies of DfRem

According to Hatcher, Ijomah and Windmill, the most effective way to promote the remanufacture is an integrated approach to the design process and product.



Production process level, it is possible to record economies of scale and development of skills in managing large variety of products, aiming to eliminate non-value added activities, based on feedback from an integrated production system. From this, Design for Remanufacture arises, that is, a sensitive design from a point of environmental view, and, in particular, oriented to the product remanufacturing.

Product development, in a strict sense, kicks off with the definition of the concept, an approximate illustration of the operating principles, shape and technology.

Among more concepts, which take form by the improvement of different aspects of the same idea, it's possible to select the one considered the most efficient and that better responds to the customer's needs. Later it's moved to the overall design process, in which we have the definitions product architecture, to achieve harmonization of the components and to translate the expectations of consumers in terms of technology, functional or market. The development cycle is closed with the phase of experimentation and testing, that validates the solution waiting for mass production. The decision to proceed with core or end-of-life product remanufacturing is take during the development and design stage, in order to eliminate or at least reduce the constraints that may arise as a result (Sundin, 2004).

Pursuins a remanufacture oriented strategy, according Hatcher, Ijomah and Windmill, should not lead to neglect other recovery options at the end of life. When it is not profitable to continue with the remanufacture, it is proceeded with residual options, such as recycling of materials.

From what was said, it is clear that a remanufacture strategy consists of three levels corresponding to the same number of treatments, which will be implemented according to the conditions of the core:

- Products remanufacture;
- Cannibalization of components;
- Materials recycling.

Only cores that meet prefixed standards are full recovered, while for others recovery is focused on individual parts or the simple recovery of the raw material.

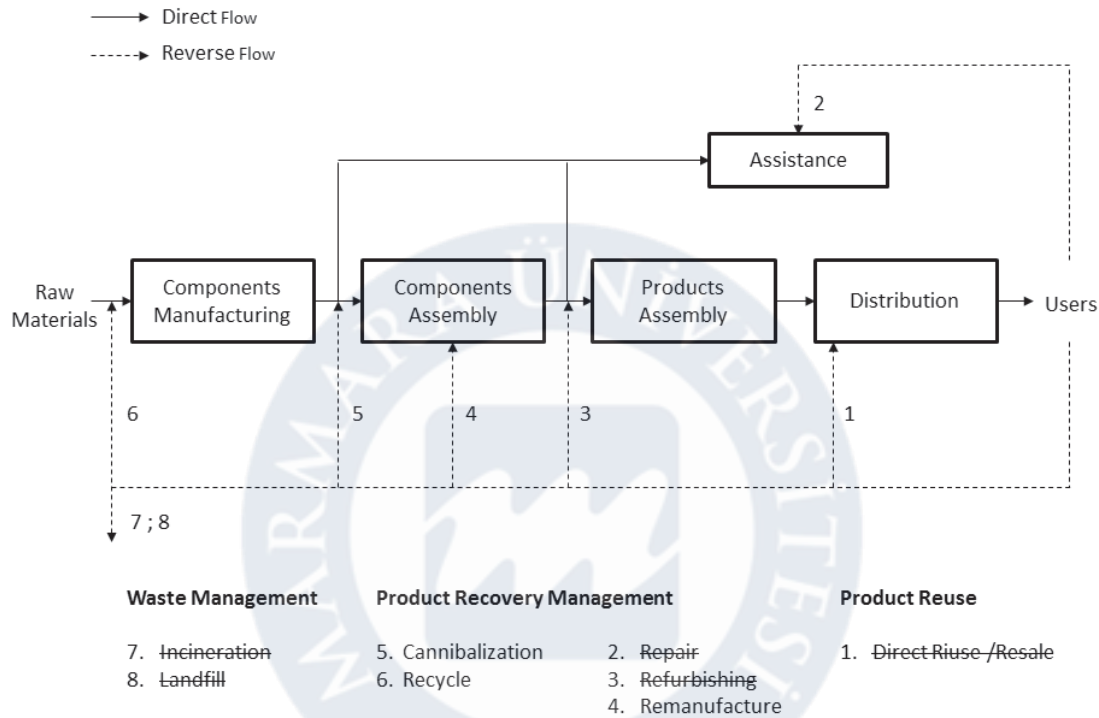


Figure 4. Mix of remanufacturing strategies (Thierry, et al., 1995)

As shown in the figure above, the goal, therefore, is to close product cycle, before it becomes waste. At the same time, however, to maximize the final result, it's not considered to direct reuse the good and repair as a compromise option, due to their unattractiveness, according to the business model outlined.

Benefits of the Design for Remanufacture

Environmental's Returns

Through a process of remanufacture and the integration of the same in the design process you can get a greater recovery of resources compared to other forms of recycling. According to the Energy Systems Division of Argonne National Laboratory, through this kind of activities it is allowed to save the equivalent of 422×10^{21} J of energy per year. This energy, in terms of traditional production, would be used to build new components, and so it saves about 80%.

Products that have undergone a process of remanufacture, are kept out of the waste cycle for a long time, preserving landfill space.

Economic Issues

The recovery of the product can be a profitable business. The Design for Remanufacture, in particular, can allow a reduction in prices of 35 - 40% compared to new products and margins on average increased by 20% (Nasr et al., 1998).



Cost reduction can ensure appropriate returns on giving the company a competitive advantage and benefits to the consumer. Cost reductions not only affect the recovered product, but also first manufacturing goods. When selling recovered products, the consumer can take a threefold function: buyer of new products, buyer of products recovered but, first, a provider of end of life products. The company can exploit this situation to his advantage, especially when the markets are distinct and there is no danger of demand substitution.

Among the benefits of a design that integrates the remanufacture we can find the attainment of economies of scale due to the experience.

Hatcher and Ijomah, note that ethical and environmental reasons are not enough to justify investment by businesses. Each company makes investments with the aim to have profit, therefore it is necessary that they find affordability recovery.

In most cases, it's legislative obligations, government incentives, subsidies by agencies and the possibility of being able to have tax breaks, to push companies into the remanufacture.

Company Policy Motivations

Aspects concerning policy and business strategy, although not related to the immediate-profit, are particularly important for OEMs. In this set are included the connotation of the brand, the company's image, the aftermarket, and feedback on products. The image is a very critical factor in a successful business because it is built only through shrewd marketing policy and huge investments diluted over time.

The company that gives value to its greater environmental awareness, also guaranteed by the remanufacture, may create an environmental friendly image. A fundamental element, so this approach is awarded by eco-friendly market, is its fair presentation highlighting the commitment made by the company and providing data that emphasize the benefits obtainable by consumers and all stakeholders.

Basically, the information can be of two different types: it can be associated with the least environmental impact of good and / or linked to its performances. These two types are not mutually exclusive with each other but, rather, is on their synergy that the company can achieve the best results in terms of image return.

Start recovery activities, through the collection of end of life products is a way to preserve the aftermarket by competitors or potential parties.

The Design for Remanufacture allows to constantly monitor customer needs and constraints of the products. Specifically, the most critical data are those which relate to the deterioration during the use since many conditions are impossible to simulate in the testing phase.



Guidelines and Design Standards

According to Ijomah, an approach based on the design for remanufacture should rotate primarily on:

- Coupling Methods;
- Product complexity;
- Used materials.

The complexity of coupling methods has an impact on the resources necessary to proceed to disassembly, in some cases, making it impossible.

The complexity of the product depends on the number of components, their internal allocation and the use of a modular design.

Designing durable and wear-resistant components, favors the preservation of the value added and simplifies the operation to be carried for the restoration and cleaning of the same.

As for the components' durability we need to consider that a too pusher design on this aspect could run the risk of extending the useful life of the good over the cycle of the technology; therefore, a differential design could be considered: ie, designing a structure in which the parameters of strength and durability are less stringent for some components easily subject to change.

Factors affecting the DfRem

Generally these factors fall into three main classes: technical factors, market and operational. The research carried out by Ijomah (2007), have also led to the development of a set of guidelines that may be followed by a designer in order to improve the ability to apply the remanufacture to a product. The figure below shows an overview of these technical factors.

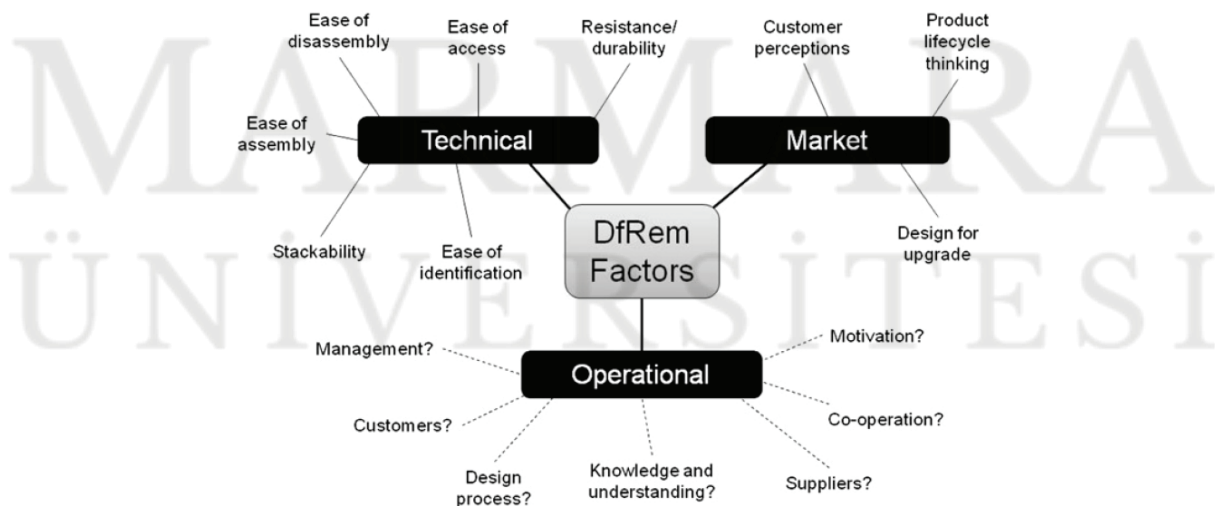


Figure 5. Map of the factors influencing DfRem (Hatcher, Ijomah - 2012)



Technical and market factors stem from research on remanufacture. The operational factors stem from research on eco - design and can be applied to the Design for Remanufacture, as will be explained later.

Technical Factors

Hatcher (2011), states that, in recent decades, DfRem was one of the topics more thorough researched on remanufacture. Most of the publications to date has focused more attention on technical factors that influence the remanufacturability of a product: product characteristics and features that can make a positive impact, or negative, on the process of remanufacture, depending on decisions taken during the development of new products.

Sundin (2004) presents a particular diagram, called "RemPro Matrix," which provides a detailed scheme of these technical factors, specifying which factors have a greater impact on each stage of the process of remanufacturing. Below is reported a generic diagram "RemPro Matrix".

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

Figure 6. Example of RemPro-matrix that illustrates the relationships characteristics sought in the product

The identification of technical factors contributed to the development of a number of methods and design tools in order to help designers to adapt their products to remanufacture. Some of these methods and tools have been developed specifically with the objective of integrating remanufacture in the process of product design and consider both purely quantitative characteristics, in particular metrics, qualitative, as the selection of the core. More complete methods have also been proposed, already used in the design, such as QFD (Quality Function Deployment) or FMEA (Failure Mode and Effect Analysis).

Although this type of approach has the advantage of being easily integrated, these methods and tools, however, do not address all the technical factors that influence the remanufacturability of a product.



It remains to find an appropriate approach to ensure that these factors are successfully integrated throughout product development process.

Market Factors

Instead of technical factors, market factors have been widely neglected in studies and in articles published until now (Watson, 2008). However occasionally it is possible to find references to the challenges that the market factors faced by companies involved in the design and sale of remanufactured products.

When the remanufacturing is a successful business venture, there is often a strong market demand for remanufactured products. However, there is a significant challenge in overcoming the perception of the consumer that a reconstructed product is not a product of "second-hand" and therefore of lesser quality than an equivalent newly manufactured. This difficulty is reflected in the fact that the remanufactured products are generally sold at a lower price (despite the same quality of a new Product) due to the lack of knowledge of the process of remanufacture by the customers. Therefore, customer acceptance is clearly an important factor in determining the success of the remanufacture.

Other market factors that pay attention are the life cycle of technology and fashion. To overcome this problem the authors suggest that the product should be rebuilt an easily upgradeable with the latest requirements or specifications most requested by customers.

Industry Implication

As claimed by Hatcher, Ijomah and Windmill, each management team, which tries to integrate issues related to remanufacture in its product development process, must be aware of operational factors, as well as the technical requirements.

Among the factors previously identified, some are easier to control than others. It is unrealistic to expect that you modify a business model to achieve the application of DfRem; on the contrary, any approach to DfRem must be adapt to the business model.

Attitudes and levels of commitment are difficult to change, even if it is not impossible with the right level of knowledge and understanding by managers and designers. Indeed, the designers often need to know practical examples of green design, that is, they need some kind of "inspiration".

The communication between the corporate body responsible for remanufacture and the designers plays a key role in a company. The company must always strive to actively improve the communication factor. Communication must influence and inspire the designer.

The details of the design process are further checked by the project manager. As well as the simple introduction of new technical guidelines, an additional tool to control are the design reviews, which provide an opportunity for the adoption of proactive measures to integration of DfRem.



Next steps: mapping the DfRem integration

Hatcher, Ijomah and Windmill point out that product development can be described as a "human system - activities", this means that it is unlikely that the factors influencing the integration of Design for Remanufacture are effective even considered individually, because they are interdependent. It is, therefore, important to be able to develop a model of "integration network of DfRem". An understanding of the relationships and priorities between the various factors will allow the project team to see a company overview, enabling a more effective approach in making decisions that affect the integration of DfRem.

CONCLUSIONS

Today, all that might at first glance be considered a refusal, can be almost always looked in a different light, in some cases becoming a source not only of energy but of income, this is the case of remanufacture.

The possibility of applying the remanufacture of a product depends on a combination of variables, passing from the analysis of the application, the stability of the technology, the process and by their low environmental impact. Undoubtedly the remanufacture is a viable alternative for the recovery of the product come to the end of its useful life, but it is even more so if it is a conscious decision taken already during the design phase. The integrated design should be considered by companies as a very attractive business opportunity because it is able to generate competitive advantage.

The Design for remanufacture allows manufacturers to create environmentally friendly image for the company that can bring more opportunities to profit given that today more and more consumers decide to buy according to their own values. This, blended with a more customer information and greater public awareness of the social benefits of a remanufactured product, would alleviate the distrust of buyers so that they no longer have a wrong perception of the product.

The improvements due to the integrated design of the product are not only in terms of environmental impact and sustainability, but are translated into lower costs for companies which limit the supply of raw materials from suppliers and maximize the added value of its products, resulting in change of added benefits not only on the image, but also in terms of feedback on products, customer relationships and increased profits.

Although a good integration of DfRem requires substantial investment by companies, they should try to win their resistance to change, reconfigure their activities in order to obtain the best performance, but, above all, to create a cultural change, understood as a transformation of their mentality so as to achieve the possibility to capitalize on their product know - how generating economies of learning, based on the application of remanufacture, that lead to a clear reduction of time and costs of production.



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