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GREEN MANUFACTURING IN MACHINERY INDUSTRY

Green manufacturing cuts across every aspect of manufacturing including product development, process technologies, energy consumption and material flow. Becoming green can be viewed as a process where we start using more eco-friendly manufacturing resources that have low embedded energy and come from renewable resources. Green Manufacturing covers the whole life cycle of product, from requirements specification, design, manufacturing, and maintenance to final discarding. Green design is the most significant part of product's life cycle. Term "green" means that design should consider the product's impact on the environment and causes minimal pollution. This term includes such important approaches as design for the environment (DFE), design for disassembly (DFD), and design for recycling (DFR). Manufacturers can think about the end-of-life approaches across a wide range of products they use in production processes, for example, different machines, machine-tools, material handling equipment, cranes, etc. The analysis of current end-of-life practices identifies significant improvements to product design that reduce the impact of manufactured goods on the environment as whole. The scope of this paper is to describe possible product's end-of-life strategies on the basis of material handling equipment case study.

1. INTRODUCTION

What is Green Manufacturing? There is no exact definition of this new direction in manufacturing community. Green manufacturing paradigm covers the whole life cycle of product, from requirements specification, design, manufacturing, and maintenance to final discarding. Research topics in green manufacturing include [1]:

- *Green design* (also called design for environment) considers the product's impact on the environment during the design process, designing a product that causes minimal pollution. Multi-life-cycle design, which considers multiple uses of most parts and recycling one-time-use parts, has received much attention.
- *Green materials* involve development of materials that can be easily recycled.
- *Green production* involves developing methods to reduce wastes during the production process.

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- *Green disposal:* developing new methods to recycle the discarded products.

Green or Environment conscious manufacturing (ECM) is an emerging discipline that is concerned with developing methods for manufacturing new products from conceptual design to final delivery, and ultimately to end-of-life disposal, that satisfy environmental standards and requirements. Green manufacturing cuts across every aspect of manufacturing including product development, process technologies, energy consumption and material flow. Many of the decisions manufacturers make are based on cost, function, and quality. Now there is another dimension to consider – environmental sustainability. Green manufacturing is a key component of operating a sustainable business that helps to uncover hidden value for business, and create value for the environment. There is very serious interest in green manufacturing within the manufacturing community. Becoming green can be viewed as a process where start using more eco-friendly manufacturing resources that have low embedded energy and come from renewable resources.

Many manufacturing firms use a variety of management system standards and business excellence frameworks to effectively manage their processes for eco- efficiency. Reducing energy and water use are the most common and simplest places to start when it comes to turning plant green. Eliminating all wastes from all business practices is an important mid-term goal.

This paper describes and compares several alternative strategies to reducing end-of-life waste within the context of extended producer responsibility: namely repairing, reconditioning, remanufacturing or recycling. It also introduces a more robust definition of remanufacturing, validated by earlier research, which differentiates it from repair and reconditioning. [2].

The scope of this paper is to describe possible product's end-of-life strategies on the basis of material handling equipment case study. There are two core parts of this research. First, the methodology determines what end-of-life strategy is possible according to the product's technical characteristics and condition. Second, the research validates the method by comparing the proposed end-of-life strategies with current industry practice. Product design requires analysis and evaluation from the various aspects of a design activity.

The objective of the research was to extend the working life (maintenance, repair, upgrading and adaptation of the product), and by recovery strategies at the end-of-life (direct reuse of components, and recycling materials in the primary production cycle or in external cycles) and to develop a methodological support with aim to study of product architectures and investigate their environmental efficiency.

2. END-OF-LIFE STRATEGIES IN GREEN MANUFACTURING

It is claimed that every product has a life period, it is launched, and it grows, and at some point, declined. One of the points of green manufacturing should give us an idea what to do with old products and wastes. It is clear that products become obsolete because of the next general reasons: Technical, Environmental or chemical degradation, Damage, Wear out. All of those reasons can be referred to industrial equipment, for example: it can hardly do its job because of more complex requirements; it can cause pollution or consist of non-environmentally friendly materials; it might by damaged or deteriorated during its lifetime; it might become malfunction.

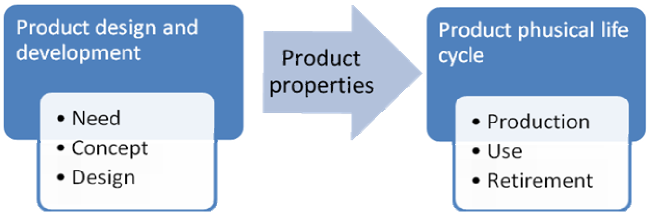

Fig. 1. Life Cycle approach in product design

Obviously engineer's and product designer's job is to fight those problems by preventing possible faults, inspecting machine's work, fixing and repairing. Moreover, industrial product's life extension should improve situation and make one business more competitive. A very important goal for machinery industry nowadays is to be as 'green' as possible. Term 'green' states that produced product tend to be manufactured using renewable energy and using it as less as possible. Product tends to be made from renewable resources. And after product reaches its end-of-life stage, it should not be wasted, but should be serviced in one of the next ways: repaired, reconditioned, remanufactured, recycled or reused (partly or totally) according its condition.

Speaking about wastes that comes from machinery industry it is important to mention that there is four-level waste strategy exists. Four levels, being – in order of preference [3]:

1. Waste reduction (such as extending product durability, common goal of GM);
2. Waste reuse (such as remanufacturing products for a second life, life extension);
3. Waste recovery (such as raw material recycling), and lastly;
4. Waste landfill (as the last resort).

There are only two possible long-term fates for waste materials: reuse (closed loop) or dissipative loss (open loop). This is a straightforward implication of the law of conservation of mass. Thus, a relatively simple proxy for 'sustainability' in environmental terms is the ratio of recycled/reused material to the total supply of virgin and recycled/reused material [4].

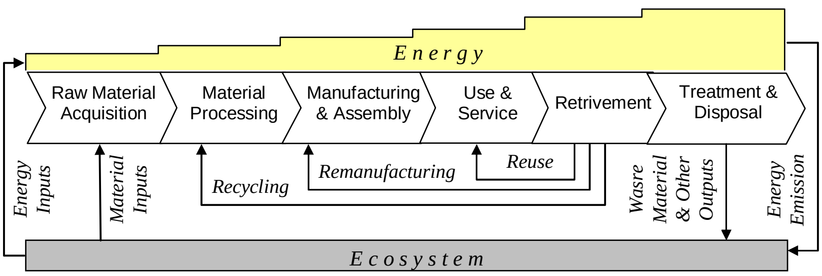

Fig. 2. Closed loop through repair, remanufacturing or recycling

In order to achieve a step change in practice, designers need to consider the entire ‘life-cycle’ of a product from raw material extraction, through manufacturing, product use and final disposal. From doing this, a key concept to true sustainability is identified as ‘closed loop design’, where disposal streams are diverted to become new raw material/manufacturing streams. This is illustrated in Fig. 2.

2.1. END-OF-LIFE CYCLE APPROACHES AND THEIR INFLUENCE

There are several approaches when we speak about “what to do with an old product”. The most typical approaches in terms of end-of-life approaches (EOF) are: Reusing, Repairing, Reconditioning, Recycling and Remanufacturing.

Reuse means to use an item more than once. This includes conventional reuse where the item is used again for the same function and new-life reuse where it is used for a new function. By taking useful products and exchanging them, without reprocessing, reuse help us save time, money, energy and resources. In broader economic terms, reuse offers quality products to people and organizations with limited means [5].

The product will bear the manufacturer’s name in its second life too, not the name of the firm that has repaired it. Reuse has almost no affects on product’s quality, except maybe that reused product is not new and some components are worn out and sometimes no or little warranty available.

Repairing is the most logical approach to closing the loop on product use – simply to repair and extend the product’s life. Repairing is the correction of specified faults in a product. Generally, the quality of repaired products is inferior to those of remanufactured and reconditioned alternatives. When repaired products have warranties, they are less than those of newly manufactured equivalents. Also, the warranty may not cover the whole product but only the replaced component.

Reconditioning involves less work content than remanufacturing, but more than repairing procedures. This is because reconditioning usually requires the rebuilding of major components to a working condition that is generally expected to be inferior to that of the original model. All major components that have failed or that are on the point of failure will be rebuilt or replaced, even where the customer has not reported or noticed faults in those components. The fact that a reconditioned product is clearly not new (and thus not offering the latest functionality or aesthetic styling of new product) means that it has the same market acceptance issues as products that have been repaired.

This practice is well established and has created what is called a “grey goods” market where original “white goods” products are reconditioned after a single life and returned for sale as “grey goods”. The visual image is clear that the product is not returned to its original condition but has been improved to allow extended functional use. Often such products are either sold on “secondary market” for lower price – a very common situation in material handling market. The exact scheme of such transformation is described in Case study. There is no doubt reconditioned products have reduced quality and more affordable compared to normal products, but if we take into consideration the situation on market and in economics the reconditioned products will find their customers easily.

Table 1. End-Lifecycle approaches and their influence

	End-of-life approach	*Positive aspects*			*Negative aspects*		
		Quality level	**Life extension**	**Envir. impact**	**Energy consumption**	**Resource consumption**	**Time taking**
1	Product reuse	intermediate	highest	lowest	-	-	-
2	Repair, service	low	high	low	lowest	intermediate	intermediate
3	Reconditioning	intermediate	intermediate	low	low	intermediate	intermediate
4	Remanufacturing, component reuse	highest	high	intermediate	high	intermediate	highest
5	Recycling with disassembly	middle to low	intermediate	low	high	high	high
6	Recycling without disassembly	lowest	intermediate	low	high	high	high
7	Disposal (incineration)	-	-	highest	high	-	intermediate
8	Refurbish or minor	intermediate	high	low	lowest	intermediate	lowest

Table 2. Advantage and disadvantage of different end-of-life approaches [3]

Option	Advantages	Disadvantages
Repair	1. It minimises the amount of energy needed to keep product in use	1. Very little infrastructure is in place to provide this service
	2. It minimises the amount of material needed to keep product in use	2. Customers do not receive updated models
Recondition	1. It allows new low-skilled labour markets to establish new jobs	1. Customers do not receive updated models
	2. Relatively low cost of reconditioning means product is ideal for low income families	2. Few products can be economically reconditioned and then resold at a profit
Remanufacture	1. As-new product has the potential to be upgraded	1. Difficult to reclaim products efficiently
	2. This may provide sufficient added value to render product economically viable	2. Products tend not to be designed for ease of disassembly
Recycle	1. Relatively easy to collect waste material through existing disposal routes	1. Existing energy within product is lost during recycling process
	2. Existing wide public understanding	2. Quality and supply of recycled materials is difficult to guarantee

Recycling is 'the series of activities by which discarded materials are collected, sorted, processed, and used in the production of new products' [6] Thus, it is clear that it is environmentally better to recycle materials rather than take them to a landfill site. Indeed, for aluminium, the energy saving can be as high as 91% by recycling scrap compared with the process of using the primary raw material, bauxite [7]. In many cases recycled product (material) decrease its characteristics and quality. Also recycling can be separated to primary recycling where material recycled into the original application, and secondary recycling, where material quality does not meet the original specifications.

Remanufacturing is the only process where used products are brought at least to original equipment manufacturer (OEM) performance specification from the customer's perspective and, at the same time, are given warranties that are equal to those of equivalent new products [7], the reasoning here being that if a remanufactured product has quality equal to that of a new equivalent then its warranty must also be the same. Of all the current 'secondary market' (used product) processes, remanufacturing involves the greatest degree of work content and as a result its products have superior quality and reliability. This is because remanufacturing requires the total dismantling of the product and the restoration and replacement of its components. Remanufacturing is particularly applicable to complex electro-mechanical and mechanical products, which have cores that, when recovered, will have value added to them that is high relative both to their market value and to their original cost [8]. Remanufacturing, however, is the only method in which the performance of a used product is returned to at least the OEM's performance specification. In addition, remanufactured items possess a warranty which is equal to that of equivalent new products. Table 1 represents all possible EOL approaches and their influence on product, relations with different aspects and processes, Tab. 2 and Fig. 3 shows advantages and disadvantages of different EOL approaches.

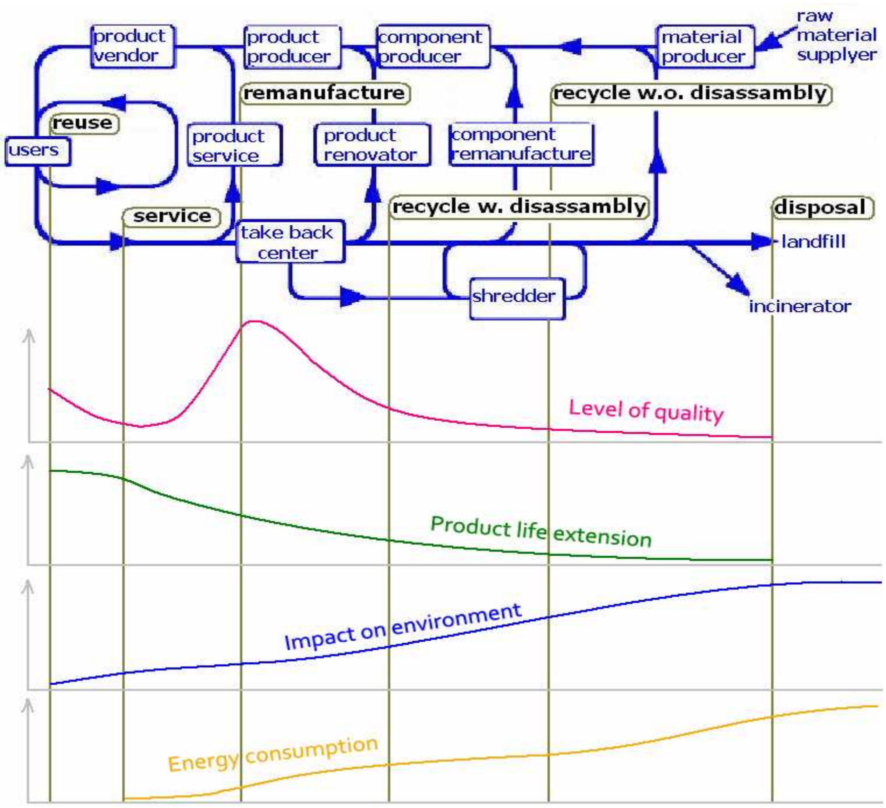

Fig. 3. End-of-life approaches influences: graphical interpretation

3. GREEN DESIGNS

The idea of a design activity directed at reducing the environmental impact of processes and products has become widespread in the last ten years and has crystallised in new activities conducted with the specific objectives of integrating environmental requirements into traditional design procedures. This has given rise to a new approach to the design activity known as Design for Environment (DFE) or Green Design (GD).

Design for Environment can be defined as a design methodology directed at the systematic reduction or elimination of environmental impacts involved in the processes and life-cycles of products. In the specific context of Product Design, DFE is interpreted as investigating the optimal product architecture (layout, geometry, materials, juncture systems of parts) so as to guarantee an efficient life-cycle, envisioning better use and recovery of the resources involved. Here the design activity takes into consideration all the phases of the product's life-cycle (development, production, distribution, use, maintenance, disposal and recovery) in the context of the entire design process, from concept definition to detailed project development [9].

The fundamental principles of DFE suggest reducing the volumes of the materials used in manufacturing process, extending the product's life, closing the cycles of the resource flows by recovery operations. Therefore, environmental quality is sought through the optimisation of strategies to extend the working life (maintenance, repair, upgrading and adaptation of the product), and by recovery strategies at the end-of-life (direct reuse of components, remanufacturing and recycling materials in the primary production cycle or in external cycles).

If we deepen into green design hierarchy we could see that there are many eco-design approaches exist. The core term is Design for Environment, including other conceptions suitable for more particular situations in terms of green manufacturing (Design for waste minimization and Design for recovery and reuse – see Fig. 4).

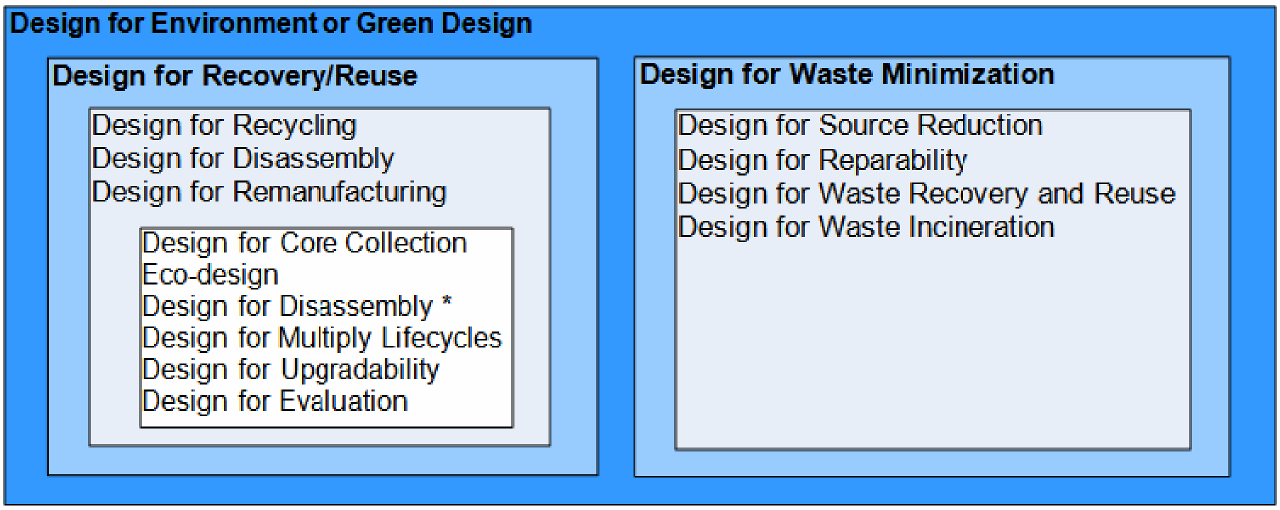

Fig. 4. Hierarchy of different Green Design conceptions

Current practices of recycling and remanufacturing are the basis for future environmentally-conscious engineering. In recent years, the need for new design approaches that could offer more efficient and environmentally sound products has become a high level issue for a successful design process. New methodologies such as design for manufacture and assembly (DFMA), concurrent engineering (CE) and design for disassembly (DFD) were developed. However, design for environment (DFE) has become the most promising methodology to reverse decades of environment neglect by manufacturers and engineers. DFE encompasses all the new methodologies, while focusing on the minimization of manufacturing environmental impacts by introducing modifications early in the product design process [10]. Practically all production-oriented industries could benefit from the application of “green engineering”, including all raw material producers, manufacturers, product users, recyclers, and waste handlers. To achieve this goal a more efficient and modern manufacturing is guided towards green engineering requiring the application of DFE methods.

Many products are now marked with a variety of recycling symbols meant to help consumers and waste managers in separating recycled products and materials. Not all materials and products can be recycled, however. Those designed for disassembly or made from one material are the easiest.

4. CASE STUDY FOR MATERIAL HANDLING EQUIPMENT

A case study is discussed to show the effectiveness of the Green design implementation in material handling equipment rebuilding in order to minimize the unforeseen expanses what are usually quiet high in machinery industry. The case study is on how to use Green Manufacturing principles in the used material handling equipment reconditioning or remanufacturing.

The rebuilding of the forklifts consists of all re-processes: re-use, re-conditioning, re-manufacture, recycling. How to choose the forklift you are going to refurbish? However, it can be very difficult to make the right choice unless you are an expert. A forklift may appear to be in good mechanical condition but internal moving parts may be worn and the hydraulics ready to start leaking. The “Hour” meter on a forklift, like the odometer on a car, is an unreliable guide to condition and seller’s descriptions such as “no smoke” or “work ready” aren’t much help. It takes training and experience to assess the mechanical conditions of used forklifts, things such as how well the unit was maintained and what is the remaining useful life of the components. Each forklift component is individually evaluated by a trained mechanic who records its mechanical condition. The Inspection Report is easy-to-understand and has to guarantee the condition of all key forklift components. We will use such Report to investigate our example.

It is known there are three types of counterbalanced forklift trucks (see Fig. 5): combustion motors (diesel, gas (LPG)) and electric engines. In the current case, we explore the used counterbalanced forklift truck with IC engine (internal combustion). The lifting capacity is 3 000 kg. Main technical characteristics are: triplex mast with 4 350 mm lifting height, pneumatic tires, working lights, side shift, forks length 1200 mm, and cabin with heating. The year of manufacture is 1994 and the forklift has done 10428 working hours for now. It means that forklift worked 1303.5 normal 8-hours working days. It's a normal working capacity for the counterbalanced forklift truck with internal combustion engine. In general, the forklift has done the third part of its standard life cycle. The forklift life cycle is directly depending on the forklifts "heart" - engine resource. Theoretically, the IC engine can work without its overhaul about 20 000 working hours. When the renewal is executed the engine will have 75% resource referring to new one or 15 000 working hours. For example, the transmission components with the whole hydraulic system can normally work without any rebuilding approximately 25 000 – 30 000 working hours. Of course, it doesn't mean that small repairs can be done during this period. Also the important lifting assembly is the chain of mast has to be checked very strictly. The measurement of chain components wear has to be performed according to the maintenance schedule. The life cycle for the mast chain is about 12 000 – 15 000 working hours. The forks have absolutely the same wearing period as chain components. As practice shows, these components are controlled very weakly and may cause much unexpected consequences. The tires are used to be the most wearable assembly on forklift. Normally, the company has to change them after 1 500 – 2 000 working hours. There is no doubt that the most wearable components in forklifts with IC engine are filters, liquids and oil, what are usually changed during the maintenance procedure every 500 working hours. Definitely, the wear of forklift components is depending on working conditions and operator. According to working experience, the operators cause the biggest problems to material handling equipment life cycle. By the way, the maintenance has to be executed every 500 working hours or once per year on forklifts with IC engines.

Fig. 5. The counterbalanced forklift truck discussed in case study

At the moment, the analysed machine is out of order and the case study is to make the decision what scenario to follow. We have 4 different possibilities: repairing, reconditioning, remanufacturing and recycle. From the Green manufacturing point of view the best choice is to prolong the life of the product. In order to make the right decision, there is a specific procedure to follow. First of all, the Inspection Report has to be done. The name of this step is Diagnostics. It will help to spot the size of “catastrophe”. According to it the approximate cost of the whole procedure can be calculated. Of course, this procedure is decisive for the product. The Inspection Report consists of 8 independent parts: inspection details, equipment information, attachments, forks/tires inspection, battery/charger, equipment condition inspection, equipment condition question, general comments.

The qualified engineer has to inspect the machine as a whole according to the Inspection Report to fix all the problems it has. This will give the deep overview of the machine current condition. When the Inspection Report is done the Service Manager has to decide which scenario to follow in order to get the best result for the reasonable money.

General comments
Left lower side of load backrest is cracked at carriage bolt; also the upper right side of load backrest is bent. Engine is running good, no smoke. Starter is out of order. Hydraulic leak in engine compartment at hose connectors under hydraulic pump. Rear centre steer wheel/tire, some wear - front 2 tires normal wear, LF tire 3". Side cut (did not get tire or fork measurements). Front 2 & right rear spot lights missing, brake lights are in good condition. Vehicle over all condition is good

Fig. 6. The main part (General comments) of Inspection Report

By virtue of the results (General comments, see Fig. 6) of the Inspection Report we can conclude that there is no needs in recycle, due to all main assemblies are working properly. Repairing procedure will give a good result, but it will solve the problems partly. It will be impossible to give any warranty for this machine. Last two scenarios are left: remanufacturing or reconditioning. The fact is the remanufacturing can give the best results for product’s life extension. In general, the main assemblies (engine, transmission, hydraulics) are in good condition. There is no need to dismount all these components. The best decision in current situation is to perform the reconditioning procedure. It will cost less and give an opportunity to provide the warranty. To draw up the total pre-calculation of the whole process we have to know the prices for needed spare parts and technician labour cost. For now we can only calculate the labour time and cost of the whole process (see Tab. 3). Some spare parts can cause a lot of problems due to their complexity and take more time from the technicians to solve the problem.

Table 3. Labour time and cost for reconditioning procedure

	Time spent, %	***Time spent, Hr***	***Cost, %***	***Cost average, EUR***
Diagnostics	15	6	15	135
Reconditioning	80	32	80	715
Quality control	5	2	5	45

The defective spare parts will be totally replaced by the new ones; some of them will be renewed or remanufactured. It is absolutely possible the engineers can rebuilt the system inside the forklift because the machine is old and the solutions used in 1994 are not the same what the manufacturers are using now. In this specific case the next spares will be replaced or reconditioned (Tab. 4).

Table 4. Spare parts status

Spare Part	***Recondition***	***Replacement***
Seat	Yes	No
Seat Belt	No	Yes
Head Lights	No	Yes
Paint works	Yes	No
Load Backrest (LBR)	No	Yes
Hydraulic Pump	No	Yes
Parking brake	Yes	No
Engine	Yes	No
Horn	No	Yes
Backup Alarm	No	Yes

According to Table 4 the pre-calculation has to be done, see Tab. 5.

Table 5. Spare parts costs

	Approximate cost, EUR	***Labour time, days***	***Cost average, EUR***
Spare parts for reconditioning	~1463	14	1463
Spare parts for replacement	~1354	14	1354
		Total sum	2817

Table 6. Cost comparative table

	The cost, EUR	***Functionality, %***	***Warranty conditions***
New forklift	~20000	100	2 years or 2000 Hrs
Reconditioned forklift	~8000	100	6 months or 500 Hrs

When the reconditioning process is ended the technician has to check again all the functions and components condition. Only after that the forklift can be over given to the user. Quality control will give a possibility to decide about warranty conditions. Normally the warranty for the reconditioned and replaced spare parts is 6 months or 500 working hours. For sure, the technician has to confirm that all the assemblies are running well and the warranty can be given. In Tab. 6 is introduced comparison between new and remanufactured forklift cost.

The difference between the new and reconditioned forklift is 3 times. The functionality of both machines is absolutely the same. The reconditioned forklift can meet all the user's needs and has got the „second life“. If the user fulfils the maintenance schedule the reconditioning procedure of the forklift was cheaper, easier and faster.

5. CONCLUSIONS

Green Design is an emerging concept that borrows from the fields of design for disassembly, reuse, remanufacturing and recycling in the consumer products industries. Its overall goal is to reduce waste and increase resource and economic efficiency, in adaptation and recovery of components and materials for reuse, re-manufacturing and recycling.

This work underlines the importance of integrating environmental considerations throughout the whole life cycle of products. Remanufacturing has become increasingly prominent as a method for waste disposal. The product analysed in the case study has proven that there is not only environmental benefit, but also the economical one.

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