

Viktoria BASHKITE<sup>1</sup>  
Vadim MOSEICHUK<sup>1</sup>  
Tatyana KARAULOVA<sup>1</sup>

## **COMBINATION OF END-OF-LIFE STRATEGIES FOR EXTENSION OF INDUSTRIAL EQUIPMENT LIFE CYCLE**

As many manufacturing companies are changing their production philosophies from a traditional focus on the manufacturing of the physical product towards a focus on the life cycle of the physical product, it is becoming important to engineer product's life cycle. Even more, many industrial researchers of the last decade see product's life cycle prolonging activities as a business opportunity both in economical and environmental ways. As a result, more focus is now put on the use phase and end-of-life phase, including maintenance and remanufacturing. 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. Life cycle engineering and product take-back is a routine for many large industries and corporations nowadays, but, it is still a big challenge for a small and medium companies. In context of end-of-life strategies implementation, there is a very little experience for smaller firms, and results are often controversial. This paper will touch material processing equipment end-of-life strategies combination perspectives, real-life implementation of them, benefits and consequences. The case study is made on a basis of a lorry that will be transferred into spoil mixing plant.

### **1. INTRODUCTION**

Without a fundamental rethinking of the structure and the reward system of commerce, narrowly focused eco-efficiency could be a disaster for the environment by overwhelming resource savings with even larger growth in production of the wrong materials, in the wrong place, at the wrong scale, and delivered using the wrong business models. Green or Environmental Conscious Manufacturing involves manufacturing products such that their overall negative environmental effects are minimized. Green Manufacturing (GM) also called Environmental Conscious Manufacturing (ECM) covers the whole life cycle of product, from requirements specification, design, manufacturing, and maintenance to final end-of-life [1,2].

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<sup>1</sup> Tallinn Technical University, Ehitajate tee 5, 19086, Tallinn, Estonia, [tatjana.karaulova@ttu.ee](mailto:tatjana.karaulova@ttu.ee)

Many modern industrial researches argued that as markets become more competitive, losing market share or stakeholder support can result from not establishing end-of-life treatment programs, concerning manufactured products. Not implementing end-of-life strategies viewed as missing a promising opportunity, which can be beneficial in the long term. That is why implementing ECM goals in real life is really important from the ecological and economical points. The two main objectives of this work are: 1) outline combination of end-of-life solutions suitable for industrial equipment life cycle extension and 2) show on practice how different end-of-life strategies combination within a frame of ECM principles could be applied. This will be applied a truck-based soil mixer, in order to prolong their life cycle and postpone their discarding. All this will be made within the guidelines of Green Manufacturing.

## 2. PRODUCT LIFE CYCLE ENGINEERING

Every product that has been manufactured by a company has a life cycle. Product's life cycle can be represented in the next way, through several stages (see Fig. 1). According to Gungor et al. the manufacturing of environmentally friendly products is crucial in order to minimize the use of virgin resources. This can be achieved by studying the life cycle of the product from its design stage to its retirement stage and incorporating this information into engineering design and production. [3] Very important tip is that producer should liquidate its product and promotion far before the cycle ends, approximately on the maximum point of the curve – at the end of maturity stage.

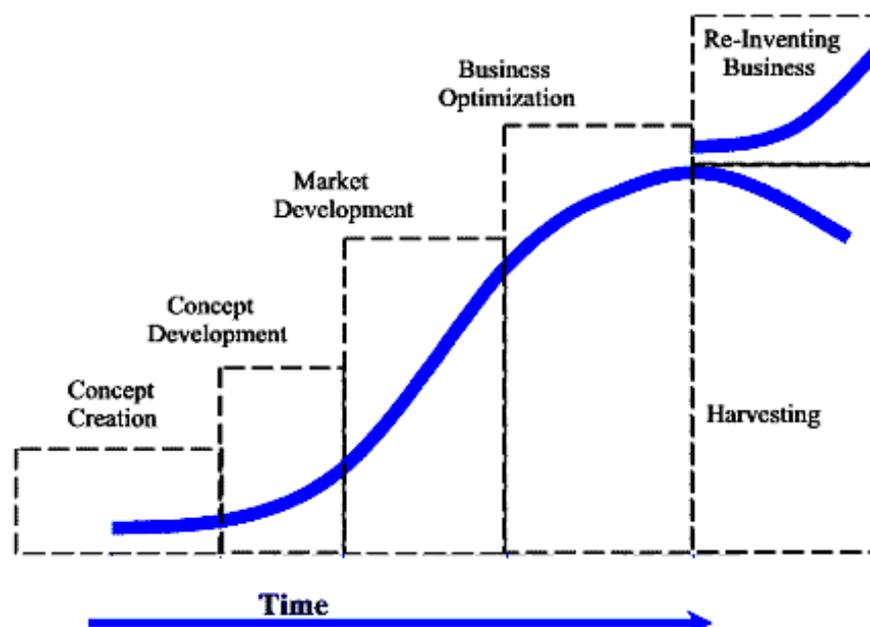


Fig. 1. Products life cycle can be also referred to service or business life cycle [4]

It is also vital for company to start new product development somewhere in the middle of the growth stage of the previous product. The typical problem seems to appear here is that companies do not think about what to do with unsold and returned products, their parts, which have left from production, old or obsolete products. Most managers consider it as wastes. But if a one business thinks in ‘Green’ way, there are several options to follow:

- First one, the smartest: develop or upgrade product with a possibility to use parts or subassemblies from previous product.
- Another option: collect and recycle products, parts, and material.
- Finally, worst and simple option is a landfill. Unfortunately it is the most widely used option nowadays.

Due to the price of industrial equipment is very high the product life cycle has to be as longer as possible. When the product has distinguished the end of its life cycle the proper solution has to be proposed. In fact, the end of product life cycle can be different. First and the most common, there is no need in this product on the market, the customers are not buying it because they have got better offer for updated version of the needed equipment. The second option it cannot be repaired or it is unprofitable procedure. The third possibility when the owner of the equipment cannot use that because the direction of business has been changed. The Re-Inventing Business graph on Fig. 1 is most interesting part of product end-of-life phase.

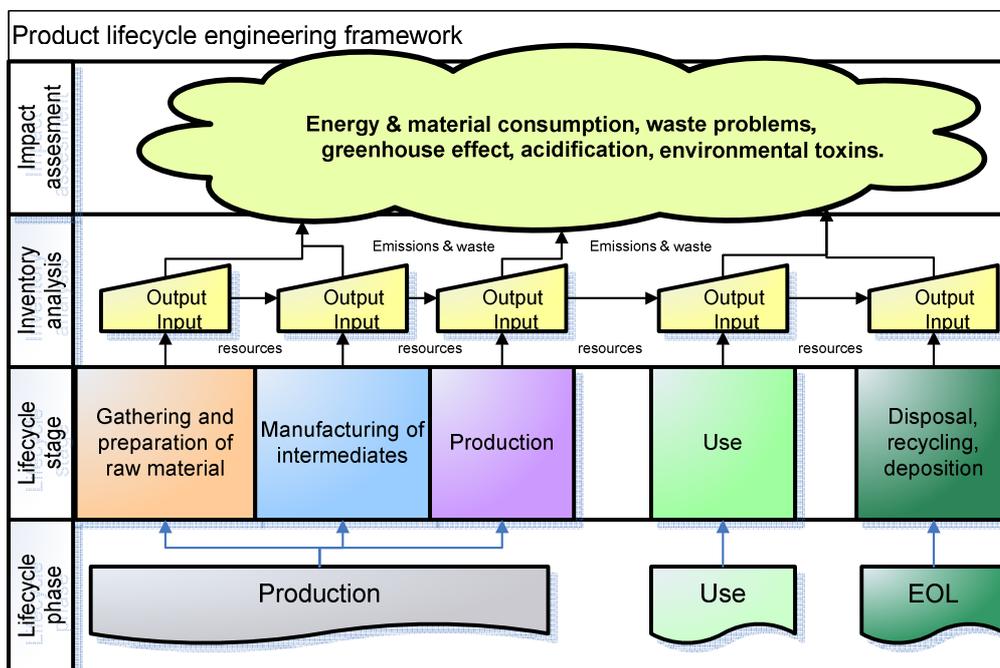


Fig. 2. Product life cycle engineering framework

Life cycle Engineering (LCE) is a process to develop specifications in order to meet a set of performance, cost, and environmental requirements and goals that span the product,

system, process, or facility life cycle. Engineering the product's life cycle activity is separated into three phases, according to product's life cycle phases: production phase, use phase and end-of-life phase. The LCE process is an ongoing, comprehensive examination with the goal of minimizing adverse environmental implications throughout the life cycle. As illustrated in Fig. 2, LCE offers a platform to apply improvement strategies and identify engineering activities in a manner more comprehensive than pollution prevention with respect to the life cycle. In order to obtain eco-efficiency, several Life cycle Engineering approaches can be applied, as for instance ecodesign (or Design for Environment or DFE), Life cycle Analysis (LCA - part of the ISO14000 environmental management standards: in ISO 14040:2006 and 14044:2006.), Cleaner Production, among others, Ten golden rules methodology [5,6].

By understanding the whole life cycle, the engineering team can often identify and realize additional benefits upstream in the supply chain and downstream in customer organizations or during end-of-life management. Many times these situations are positive both within the decision-making organization and outside of it. Many practitioners of LCE find that environmental impact reduction and cost savings are not mutually exclusive. Even when the benefits occur in supplier or customer organizations, it is possible to negotiate shared savings in the form of price reductions for raw materials or waste handling, as an example. In order to do this, it may be necessary to catalogue the external benefits using measures other than monetary indicators [7].

### 3. END-OF-LIFE SOLUTIONS

The life cycle of product refers to the sequence of interrelated steps of a product from the acquisition of raw materials for manufacturing to the disposal of the used product, i.e. its end-of-life (here and further – EOL). At the end-of-life, the product can be either disposed off, or still used to extend its life cycle. According to our previous researches after product reaches its end-of-life stage, it should not be wasted, but one of the next options should be applied to it, see table 1 (in order of preference and importance).

Table 1. Different EOL strategies and approaches.

<b>Preference</b>	<b>EOL strategy</b>	<b>EOL approach</b>
I	Reuse	Direct reuse, indirect reuse, reuse after minor repairs
II	Servicing	Reconditioning, repairing, product/service systems
III	Remanufacturing	Remanufacturing of product, components, demanufacturing [parts reuse or "cannibalization"]
IV	Recycling	Recycling with and without disassembly
V	Disposal	Incineration, landfill

From the Table 1 it is seen that EOL approaches here and further will be presented as a subcategory of five main EOL strategies. According to most recent researches, the best EOL strategy for industrial equipment to prolong its life cycle is a corporation of take-back approach with remanufacturing concept. This method is widely used in industries all over the world. A research finding has reported that companies that make use of remanufacturing and take-back in the product recovery are estimated to save 40–60% of the costs compared to manufacturing a completely new product [8] while requiring only 20% of the effort [9]. All the EOL strategies described above, aim at a reduction of the ecological impact of discarded products, a reduction of the use of virgin materials and a decrease of the total amount of waste.

In this research everything is focused on the used product without taking under consideration the possibility to reconfigure one used product into another one with absolutely different purpose. Reconfiguration as combination of different EOL strategies is a very interesting look at product life cycle. The product is in good technical condition, but it makes no sense to use it anymore. According to Green thinking it cannot be recycled or landfilled. The idea is to create the new product with different more complicated application on the base of this used product. In fact, the reuse, reconditioning and remanufacturing EOL strategies will have place during the procedure. This EOL strategy is missed in the row of different EOL solutions. Of course, reconfiguration as combination of different EOL strategies can be implemented under clear conditions with certain products. It cannot be done with copying machine or toaster, due to the product is cheap and narrowly oriented. This opportunity has to be taken into account by industrial products designers and developers. The case study with material processing equipment is the real example of reconfiguration possibility.

#### 4. INDUSTRIAL EQUIPMENT RECONFIGURATION

Product life prolonging activity does not only increase useful life of the product, but also in pair with product reconfiguration can result in totally new product for lower cost and lower working hours spent. By reconfiguring an existing used product into product with absolutely different purpose can save resources, money and time. This case study is made in order to show an example of how to apply efficiently the combination of EOL strategies. The result of this project is the reconfigured special purpose truck-based mixing plant.

The brief idea of the project (BX-69) was to construct mixing unit BELMIX EB50 on the base of average lorry, able to handle up to 50 tones per hour of excavated spoil. It was decided to place modified EB50 mixer on the used lorry chassis. For this reason a used Iveco truck with grab crane was ordered. Trucks had next technical specifications: own weight – 26 tons, manufacturer – Iveco, year of construction – 2001, condition – used, estimate value – 20,000.00 GBP. Before the Iveco lorry was used to load and transport a free-flowing soil.

Main criteria for ordering the lorry chassis for this project was not its age, but condition (as better condition would reflect in less work and less expenditures) and presence

of grab crane, because this part was impossible to manufacture domestically. The main advantage of applying a used truck for this kind of industrial mixer was the interesting opportunity itself. It is estimated that similar truck based mixers spend only one fourth of its life cycle driving, compared to average truck's life cycle. Three fourth of its life this unit is going to mix and crush different types of spoil, rubble and small rocks, staying at one place. Evidently the main idea of this project was to make a truck based plant that will answer all terms required to both truck and mixing plant. As ordered truck was missing a platform it was decided to build one for this truck. The platform has to be able to hold a hopper, loading strip, crusher, generator and other mixer's components as well as hydraulic stabilizers under it. The mixing plant has been designed to fix to the lorry chassis permanently. The lorry bed was not designed to carry materials other than the tools and equipment required for normal operation of the mixing plant.

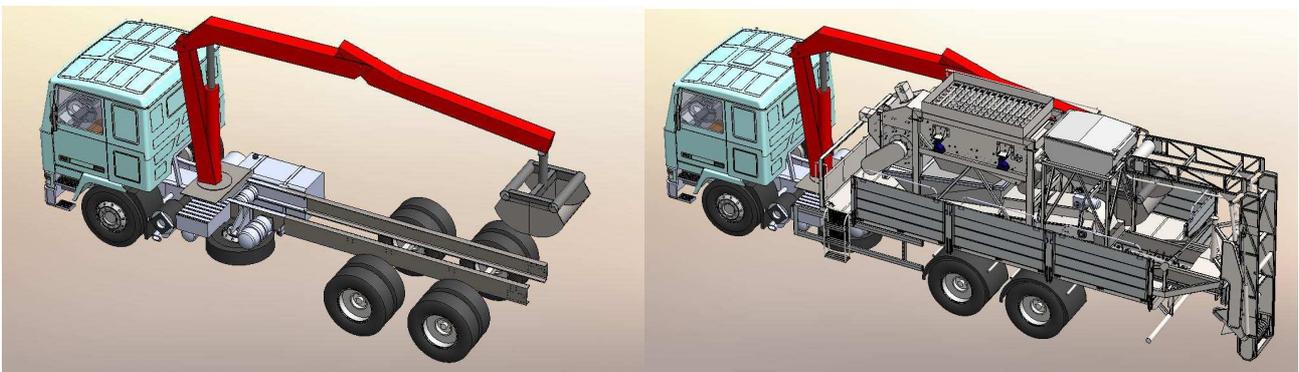


Fig. 3. Used Iveco lorry on the left and EB50 mixer mounted on the Iveco truck on the right

EB50 mixer reconfiguration started from making a scale models and drawings in SolidWorks (see figure 3), checking the possibility of manufacturing, making changes. The load on the flatbed was calculated. Engineering team designed a flatbed and a mixer using as much standard parts and profiles as possible. During the BX-69 manufacturing, parallel with flatbed construction the process of bringing Iveco truck to new life happened. As this truck was used previously for spoil and garbage transportation, it had an ordinary chassis, frame and a grab. All the components were functioning at satisfactory level, except the rear view video camera, rear lights, and minor hoses and cables. The condition of many parts, at the level of wheels was terrible – many steel parts were covered with rust; two platform frame profiles were totally rust and rotten. These elements were replaced. It was decided to replace all the parts that were in unsatisfactory condition and all minor parts, showing moderate wear-out. For those parts that were left as-is, a cleaning and painting processes were applied.

According to Tanskanen et al. the typical EOL process consists of end-of-use phase, take-back, sorting, disassembly, separation and one of two options: sale or dispose [10]. The whole process is the combination of different of EOL strategies by developing the new EOL strategy – reconfiguration. Making a comparative sketch it is not difficult to see that in case

of reconfiguring a lorry in our example process diagram is very near to Tanskanen's proposal. As in real life this process is different for small quantity take-backs and projects, such as reconfiguring a whole lorry for BX-69, the theory can be applied for both of them. The most considerable difference is the take-back volume, resulting in economies of scale. This approach can be applied mostly for industrial equipment; due to the price of these products is high and customer's oriented.

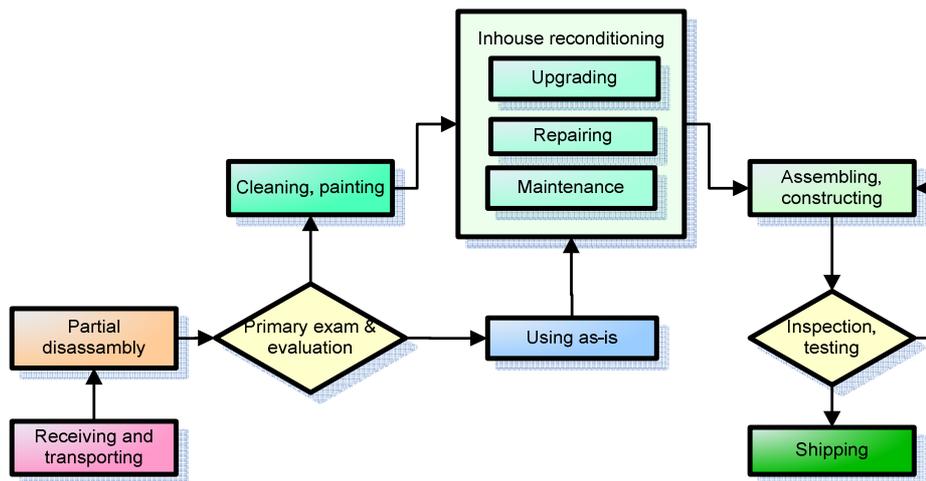


Fig. 4. The process of bringing used Iveco lorry to new life

On Fig. 4 it is clear that much work has been applied to renew used equipment. In-house production was enlarged with reconditioning activities of the Iveco truck. According to calculations gained in the end, implementation of equipment remanufacturing, domestic labour and materials are cheaper than paying for new equipment.

#### 4.1. LIFETIME OF PRODUCT

Table 2 represents several examples of typical product lifetimes. As there were no comparative table for spoil and rubble mixing equipment, the nearest example in this table is long-haul truck from the second row. Both BX-69 truck and long-haul logger truck have something in common: they both used for special purposes, both have grab crane, hydraulic stabilizers, etc. It is shown on the table that similar equipment has a spare/ service commitment of up to 10 years and product market life cycle up to 4 years. An estimated spare/ service commitment for BX-69 is less than 10 years because the mixer has a comparatively big number of parts, which wears-out quite soon. Those they required to be replaced.

It was mentioned earlier that there were a combination of the two different units used in the BX-69 mixing plant: used old lorry with a grab, in satisfactory condition and newly

constructed flatbed with mixer. It was also mentioned that lorry’s life cycle was near the end when it was brought by remanufacturer, reconditioned and used for BX-69 mixing plant. Here, a new life cycle for Iveco lorry begun. Unfortunately it has been forecasted to be not exactly the same as for EB50 mixer. That is because lorry had already been used for specific purposes, and even deep reconditioning, replacement of worn-out parts and repairing could not prolong lorry’s life for a long period of time. On the other hand, EB50 is made from new steel profiles, sheets, plates, parts and subassemblies, which could work for a comparatively long time.

Table 2. Typical Product Lifetimes

	Typical Product Life		Market Inertia		Comment
	Spares/ Service Commitment	Product Market Life Lifecycle	Months for external approvals	Months to reach Full Sales Rate	
Machine Tool Controller	10 years	15 years	1	36	Tools are often purchased as part of a multi-year long program. Market slow to adapt
Long-Haul Truck AVL/Data-Logger	10 years	4 years	1	12	Fleets are developed over decades. Fleet compatibility important
Farm Equipment Precision Farming System	15 years	10 years	1	24	Biggest single investment on the farm expected to last
Medical Device For Patient Care	5 years	10 years	24	24	Approval cycles, for finished device, can take 2 years
Industrial Controller For PLC or Similar Applications	10 years	20 years	4	36	Controllers are often purchased as part of a multi-year long program. Market slow to adapt
PDA	1 year	6 months	1	1	Rapid development, approvals often in-house
Cell Phone	2 years	3 months	1	1	These are becoming a fashion item. Marketable lifetime is measured in seasons or weeks.

Heinz’s proposed a calculation method to estimate a life cycle until failure, applied for industrial equipment, consisting of several subunits. The life cycle until failure of the BX-69 unit could be estimate by using a Heinz’s Formula:

$$MTBF = \frac{1}{\left[ \left( \frac{1}{L_1} \right)^2 + \left( \frac{1}{L_2} \right)^2 + \left( \frac{1}{L_3} \right)^2 + \left( \frac{1}{L_4} \right)^2 \right]^{0.5}} \tag{1}$$

where  $L_N$  is estimated lifetime of the component subject  $N$ , in years [11].

Formula requires to have already estimated life cycles until major repair or service for every subcomponent used, e.g. electromotor, bearing, pump. The estimated lifetime for the Iveco lorry with minor repairs is  $N_l = 5$  years. Estimated lifetime for EB50 also with minor

repairs, appropriate care and full working load is  $N_2 = 10$  years. Estimated lifetime between failure for electro-motors used in this mixing plant considered  $N_3 = 4$  years. A summary MTBF will be three years. Thus it is crucial to supply a customer with appropriate technical help and maintenance to avoid earlier failures happening. It is important to mention that during this estimation mixers blades were not considered even though they are the fastest wearing-out parts. They are replaced according to specific requirements, considering how frequently mixer is used and what sort of spoil or rubble is mixed.

#### 4.2. LIFECYCLE ANALYSIS

A life cycle analysis (LCA) can help in measuring and comparing environmental impacts of various alternatives. This will aid decision-making process, and yield better products with less cost over their lifetimes. Life Cycle Analysis is as much a way of thinking as a specific tool. It is a methodology for identifying and quantifying the impact a product has on the environment throughout its lifespan, from procurement of raw materials, production, use through end-of life disposal and transportation.

In this work a simplified LCA BX-69 was executed with a help of SimaPro software.

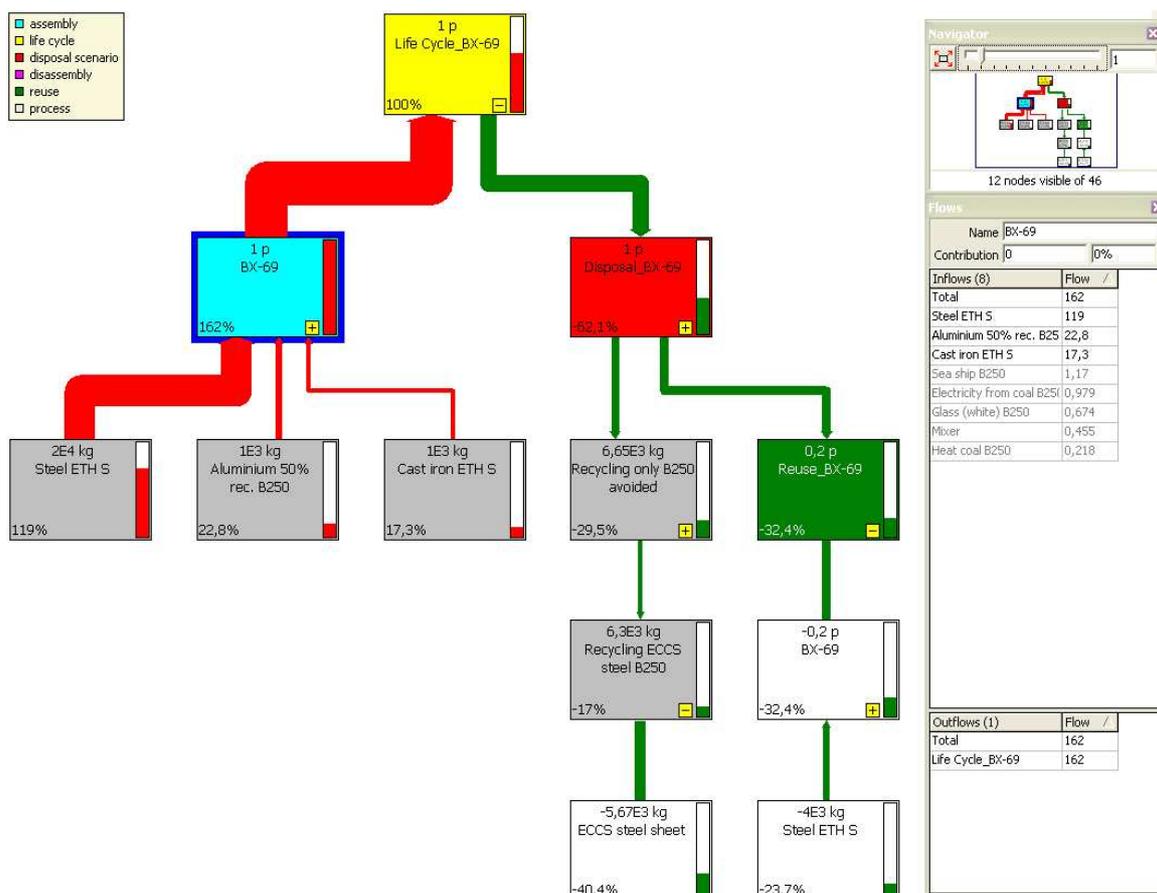


Fig. 5. BX-69 unit LCA result in SimaPro software

Modelling approximate life cycle of product in SimaPro requires knowing which materials, energy sources and methods were used during the manufacturing process (input). The main material for the lorry-based mixing plant is steel. Also aluminium and different plastic spares are used. Other materials do not affect life cycle impact, because most of them are non-toxic and use in small amounts. Figure 5 indicates that potential of BX-69 for reuse is medium after reaching its end-of-life. That is because product consists of two general modules, produced separately, in different time and used for a different period of time, and because the lorry has been used for a period of time. Mixing unit separately has a better opportunity for being disassembled and recycled because it consists mainly of the same material. Life cycles (yellow) can include additional life cycles for minor subassemblies, such as motors, filters etc. Additional life cycles include production and disposal – not showed here. Small bar charts on the right side of each rectangle indicate contribution to the selected indicator. For example steel production used in manufacturing contributes the most to the indicator. And this material also has a great potential for recycling as well as aluminium. Although aluminium is used in this equipment in smaller quantity (less than 700 kg) compared to steel alloys (more than 20 tons), the resource savings of recycling aluminium is quite high – 95% compared to steel – 61%.

#### 4.3. COST CALCULATION

To calculate a production costs for BX-69, formulas from the publication “Modular design to support green life cycle engineering” by Tseng et al, were used. [12] The total cost or TC for manufacturing the BX-69 mixer, excluding the lorry is next:

$$TC = C_m + C_{mpc} + C_a, \quad (2)$$

where  $TC$  represents the total cost,  $C_m$  is the cost of material,  $C_{mpc}$  is the cost of manufacturing,  $C_a$  is the cost of assembly.

The material cost  $C_m$  can be defined by Formula (3):

$$C_m = C_{mu} \times W_m, \quad (3)$$

where  $C_{mu}$  indicates the unit cost of material (EEK/kg); and  $W_m$  indicates the material weight (kg). If the price for material is in EEK per m than  $L_m$  instead of  $W_m$  will be used.

The manufacturing cost  $C_{mpc}$  can be computed based on the feature methodology developed by Shehab and Abdalla. [13] In their methodology, a feature is defined as a generic shape carrying product information from computer aided design, or communication between manufacturing and design. The manufacturing cost  $C_{mpc}$  can be decided by Formula (4):

$$C_{mpc} = C_{pcu} \times T_{pcw} \quad (4)$$

where  $C_{pcu}$  means the unit cost of manufacturing (\$/s);  $T_{pcu}$  indicates the time for manufacturing (s). The assembly cost  $C_a$  can be decided by Formula (5):

$$C_a = C_{au} \times T_{au}, \quad (5)$$

where  $C_{au}$  represents the unit assembly cost (\$/s), and  $T_{au}$  refers to the assembly time (s). In case of BX-69 unique lorry based mixing plant it makes no sense to represent a unit assembly in seconds, as it is a complicated and time taking process. Therefore  $C_{pcu}$  and  $C_{au}$  will be denoted in EEK per hour and assembly time  $T_{pcu}$  and  $T_{au}$  will be presented in hours.

To calculate manufacturing cost of the EB50 mixer and flatbed platform, assembly costs for every main subassembly of the BX-69 were calculated firstly. Table 3 represents all major subassemblies of BX-69, divided by future operation orientation, including lorry itself. According to plant's working process, those are: lorry, grab, hopper, breaker, feeder, powder hopper, and mixer and delivery conveyor.

Table 3. Subunits of the EB50 mixer.

	<i>Subunit</i>	<i>Purpose of the subunit</i>
Purchase Used	Lorry	Transportation
	Grab	Loading input
Build domestically	Flatbed platform	Basement for EB50 mixer and generator
	Hopper	Temporary collection and screening
	Breaker	Breaking bigger pieces
	Feeder	Delivering crushed pieces further
	Powder hopper	Storing and adding powder
	Mixer	Mixing spoil with powder
	Delivery conveyor	Delivering output

Table 4. Production costs BX-69 projects (in EEK)

Module	Description	Cost
Lorry	Lorry estimated price	340,000 (Used)
	Reconditioning and repair costs	10,000
	Logistics costs for transporting the lorry to and from Estonia	35,000
Flatbed & Mixer	Production cost of the flatbed platform for the lorry	218,700
	Materials, profiles and standard parts used for the flatbed	
	Production cost for Exomixer, based on the lorry chassis	
	Additional material, elements and painting costs for mixer	25,000
	Summary cost of the all equipment, labour, production, material embedded in equipment	628,700

For several subunits it is important to calculate the assembly cost and assembly time, because several subunits were produced by local company and are standard ones, because they are used on various versions of the mixers. This will help company to develop and optimize further assembly techniques. The approximate costs analysis is represented in the Table 4.

## 5. CONCLUSIONS

The objective of this paper was to review, describe and evaluate possible product's end-of-life strategies and approaches combination on the basis of real life case study. The result of the work was a development a comprehensive EOL guideline for single or small quantity products to be adopted in SME, and its real life implementation, described in the case study.

The industrial equipment, analyzed in the case study, has proven that there is not only environmental benefit, but also the economical one. All in all the combination of different EOL treatment strategies implementation resulted the new business opportunities.

Although term 'Green' is vital important in modern industry, functionality and economy normally have the highest business priority. Environmental matters must be balanced against all other requirements for the product. Without customers prepared to pay for the function and if companies cannot make a profit, there will be no market for such product; no matter how well the environmental issues have been addressed.

## ACKNOWLEDGEMENTS

*Hereby we would like to thank the Doctoral school of energy and geotechnology II, The Archimedes foundation and Estonian Science Foundation Grant 7852 that enabled us to carry out this work.*

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