Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 69 (2014) 526 – 535

Procedia Engineering

www.elsevier.com/locate/procedia

24th DAAAM International Symposium on Intelligent Manufacturing and Automation, 2013

Framework for Innovation-Oriented Product End-Of-Life Strategies Development

Viktoria Bashkite*, Tatyana Karaulova, Olesja Starodubtseva

Tallinn University of Technology, Ehitajate tee 5, Tallinn 19086, Estonia

Abstract

Nowadays it is absolutely clear all the enterprises are focused on cost reduction and resources efficiency to stabilize their position in competitive and economically variable market. Environmental policies and local authorities push manufacturing companies to produce in a clean and green way by using well-known philosophies like lean and green manufacturing, kaizen (continuous improvement) and etc. Everything mentioned above can help to overview and improve manufacturers' internal and external processes. Innovation is one effective approach to develop product life cycle and take control over internal issues concerning profitability of used industrial equipment. This paper is mostly focused on finding best standard or innovative end-of-life (EoL) solution for used industrial equipment life cycle extension by implementing Theory of Inventive Problem-Solving tools (TRIZ).

Keywords: Used industrial equipment; Green Manufacturing; EoL strategies; Remanufacturing; TRIZ tools

1. Introduction

Following EU Waste legislation and the regulations of WEEE (Waste Electrical and Electronic Equipment), RoHS (Restriction of Hazardous Substances), ELV (End-of life vehicle directives) and EPR (Extended Producers Responsibility) it is clear that there is no more opportunity to continue with traditional way of manufacturing [1]. The production process must be balanced from economic and social point of view by decreasing or holding at the same level the overall environmental impact. This is a key indicator in securing long-term sustainability as a main direction of manufacturing system development [2]. For instance, extended producer responsibility (EPR) legislation calls for producers to restore used products to decrease the amount of goods going to landfill [3]. Such tension, mixed with global market competition, defy companies to vary attitudes to product life cycle stages.

Corresponding author.. Tel.: +372 56 456 776 ; fax: +372 620 3480 .
E-mail address: viktoria.baskite@ttu.ee

doi:10.1016/j.proeng.2014.03.022

Manufacturers must forecast products life cycle for durability and simplicity of recovery at end-of-life stage, and must think about sustainable and innovative way of production to save resources and increase profitability of company [4,5].

1.1. Product recovery strategies

Every manufacturer takes the steps to become "environmentally friendly", "green", to be "zero-waste" and low emissions production.

The impact of using the remanufactured products gives effect almost in every aspect of the environmental development: from conserving resources and energy to reducing the amount of waste going to landfills [6]:

- Conserving Energy: Remanufacturing parts means new parts do not have to be produced. This saves the equivalent of millions of barrels of oil or its energy
- Resource Conservation: Remanufacturing existing parts means that the natural resources need to produce new parts can be conserved for later use
- Landfill Conservation: Any part that is reused is a part that does not go to the landfill reducing the need for landfills
- Air Pollution: Reusing parts keeps factories from polluting the air while producing new parts
- Fuel Economy: Economy and lower emissions are two great benefits to the environment

By convincing industries to choose remanufacturing as the best solution, it must be proved through the comparison of the existing strategy that implementing remanufacturing is economically and environmentally profitable. Conscious that remanufacturing cannot be a single end-of-life strategy (EoL), authors Gehin, Zwolinski, Brissaud, and Rose in their works [7,8] propose to consider a mix of recovery strategies: Reuse, Remanufacturing and Recycle (3R). Such end-of-life strategies as incineration and landfilling should be avoided as much as possible. Rose et al generally propose a classification of recovery options according to the environmental criteria and made out of some industrial cases as it is shown in Fig. 1.

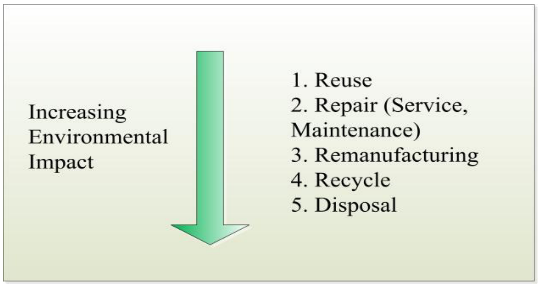

Fig. 1. Different EoL solutions and they influence on environment.

In our research we will focus on remanufacturing as a main approach for life cycle extension of second-hand industrial equipment.

1.2. Remanufacturing as a step for environmental sustainability

According to Kerr and Ryan remanufacturing has a willingness to reduce environmental impacts and costs of manufacturing processes, while decreasing final disposal costs of products and components [9]. The same opinion is presented by Indians researchers in their paper about how to distinguish sustainability through remanufacturing [10]. Economically, remanufacturing is an interesting strategy since it preserves a product's value added during design and manufacturing processes. The environmental importance of remanufacturing lies on extending a product's lifetime by adding a second life, since if a product lasts longer through remanufacturing, less material is needed to meet customer needs [7]. The value added in a product, in the form of cost of materials, energy, labour and manufacturing operations, is preserved in reuse, repair and remanufacturing. However, only remanufacturing ensures that the product quality is as good as new [11].

Remanufacturing is one of the simplest ways to achieve environmental sustainability. It saves over 80% of the energy and raw material required to manufacture a new part and keeps used parts, otherwise known as "cores", out of landfills. Remanufacturing can often improve the original design by using re-engineering techniques to determine why a part failed prematurely. That ability to diagnose flaws, renew original cores and improve their performance is what differentiates remanufacturing from recycling, where used products are broken down to their raw form [12].

For instance, in the USA SMEs (20–499 workers) are appreciated to account for an important share of remanufacturing employment, production, and trade. SMEs have accounted for 36% (65,500 workers) of U.S. remanufacturing employment, 25% ($11.1 billion) of U.S. production of remanufactured goods, and 17% ($1.8 billion) of U.S. exports in 2011. U.S. remanufacturing investment is estimated to have nearly doubled during the study period, rising from $639 million in 2009 to $1.2 billion in 2011[13].

1.3. Objective of the research

One biggest issue is about prolonging industrial equipment life cycle, what is concentrated on two main questions: when the right time to remanufacture the core and how many times is it worth to remanufacture? The main objective of current research is to develop the mechanism for more accurate estimation of used industrial equipment life cycle and for its extension in order to increase the economic and ecological benefits in small and medium-sized enterprises (SMEs).

The flowchart of industrial equipment estimation is represented in the paper and shows the potential approach for combination of end-of-life solutions with innovative tools coming from Theory of Inventive Problem-Solving (TRIZ). Innovative tools are introduced to give an idea how the case study is analysed. Thereafter, the case study example and possible solutions present the benefits of proposed framework.

2. Theory of inventive problem-solving as a part of green manufacturing (GM)

As it was mentioned above, GM is the manufacturing approach what is seeking for innovation and new solutions. First of all, it is a great challenge for engineers to find these opportunities in long time existing and progressing manufacturing areas. Obviously, there is a severe need in innovative solutions. Innovation is not the flashing lamp in our heads; it is the possibility to create something new and great for future generations. One known approach to direct the innovation is Theory of Inventive Problems-Solving (TRIZ). TRIZ is a Russian acronym and was defined by Russian researchers from the 1940s. These researchers, pioneered by Genrich Altshuller looked for fundamental principles of inventive problem solving. Altshuller analysed a big number of Russian patents for generic principles how the patented solutions were arrived at. He identified the following laws of evolution of technical systems [14, 15]:

- Stepwise evolution of systems: systems evolve in discrete steps
- Increasing ideality: systems evolve towards ideality, characterized by supplying the technical function without causing any harmful effects (in terms of effort, resource consumption, etc.)
- Different evolution of system elements: system elements evolve on different levels
- Increase in dynamics and control: systems are dynamited, control increases over evolution
- Increase in complexity and decrease again: the complexity of a system increases and decreases again after reaching a certain level of complexity
- Increase of coordination: the rhythm of the different elements of a technical system becomes more and more coordinated
- Miniaturization: the system and its elements tend to become miniaturized
- Decrease in human interaction: Human interaction with the system decreases with evolution

During this research authors found that the eight TRIZ Principles show similarities and some correspondence to the strategies of GM. The same is mentioned by Johannes Fresner at al in their research, where cleaner production strategies are compared with the Laws of Evolution as defined by Genrich Altshuller [16].

There are a number of different TRIZ tools what can be helpful to engineers to overcome the psychological inertia. It is clear there is no possibility to create something just based on previous experience. Innovation needs strong knowledge of the area engineer is working in and a will to think out-of-the-box. This can be easily handled by TRIZ tools, such as 40 Principles, Contradiction Matrix, ARIZ - Algorithm for Inventive Problem Solving, Ideal Final Result (IFR) and Ideality, 4 separation rules and etc.

TRIZ was applied in a number of companies in the last 20 years to solve different problems (among them Procter & Gamble, Ford Motor Company, Boeing, Philips Semiconductors, Samsung, LG Electronics). TRIZ applications to the design of products in cooperating sustainability and eco-efficiency related problems are documented in the literature, however rare [17–21]. Explicit use of TRIZ within CP is not documented until today, according to the knowledge of the authors. TRIZ, however, has been used within six sigma projects effectively [22].
Just some of the tools are used for the current case study. These tools are particularly described in case study section. TRIZ is a powerful methodology what has a lot of followers, but it is not easy to implement.

3. General framework development for industrial equipment assessment

Nowadays many companies start to use electronic databases and store all possible data there. Unfortunately, there is not so much information in electronic view about old used industrial machines, such as forklift trucks and their service history, machinery with 50-60 years of exploitation data. This information is stored in handwritten books and sheets. That's why it is important to have some basic data to start the analysis.

The general framework is divided into 4 parts and presented in Fig. 2. It is called CAIS (Calculate Analyze Innovate Simulate) and can be taken as the basis for different GM projects integration in enterprises. This time it is a part of used equipment life cycle analysis. Mainly, it is focused on idea to extend used industrial equipment life cycle and improve the influence to environment by reducing it.

This framework can recall well-known methodologies or frameworks from Six Sigma and Lean philosophies, such as PDCA (Plan Do Check Act), DMAIC (Define Measure Analyze Improve Control), DFSS (Design for Six Sigma), and DMADV (Define Measure Analyze Design Verify), but CAIS is more specific mechanism. It is developed for everyday usage and has simple mechanism inside with integrated innovation module. It must help to get the answers quickly and give the overview about actual state of used industrial equipment. It is significant to mention the approach is centered on finding non-standard solution and think out-of-the-box. The assessment of equipment according to proposed framework must be done at least once per year to have an overview about current situation; therefore it is not complicated to use it.

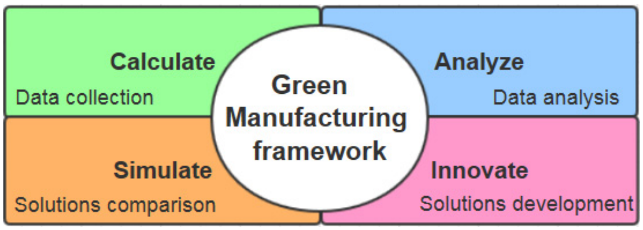

Fig. 2. The general framework for GM projects integration.

The proposed framework has mainly 4 different scopes. The first one is "data collection". The second one is "data analysis". Normally, after the second part all analysis are finished and decision is taken. Nowadays, such decisions cost a lot of re-work and definitely other resources. Thus, there is a strong need to finalize the analysis with the third and the forth parts. The third section is concentrated on ideas generation. The point is not to stop on some well-known option, but to try to get a little bit bigger picture. It does not mean the standard solution is not good, but the result must be the best possible. There is no more space for compromises; the manufacturing world is seeking for innovative and new solutions. It is always good to have two or three different options for further simulation if possible. The current research is focused mostly on the second and third part of general framework. The forth section is dedicated to simulation options. Evidently, it is cheaper to play a couple of various end-of-life scenarios in computer and then to choose the best one based on results. The insufficient approach called trial and error method is still widely used, but there is no more capacity from efficiency point of view to use this method.

Proposed approach must help to improve the efficiency of utilized resources, solve environmental issues and control safety problems by prolonging used machinery life cycle for next 5-10 years and even more. The concept is to take overall control over used old equipment and monitor it year-by-year at least on company level. Definitely, it is a big challenge for the engineers in case of new concepts and solutions generation. GM end-of-life solutions such as remanufacturing, reuse or recycle, or maybe there is a point to think about some new, more innovative decisions?

The main framework of our research is shown in Fig. 3 and it is dedicated to the second “Analyze” and third part “Innovate” of the general CAIS framework. It is divided into two parts: “Used equipment state analysis” and “Innovative solution TRIZ”. Second part must be used if right solution could not be found in first part or as alternative solution. Analysis methods used in the first part may be several. This time next tools were used for the case study:

- Overall Equipment Effectiveness calculation
- Analysis of used equipment age, type of faults, and Mean Time To Repair (MTTR)
- Cost analysis

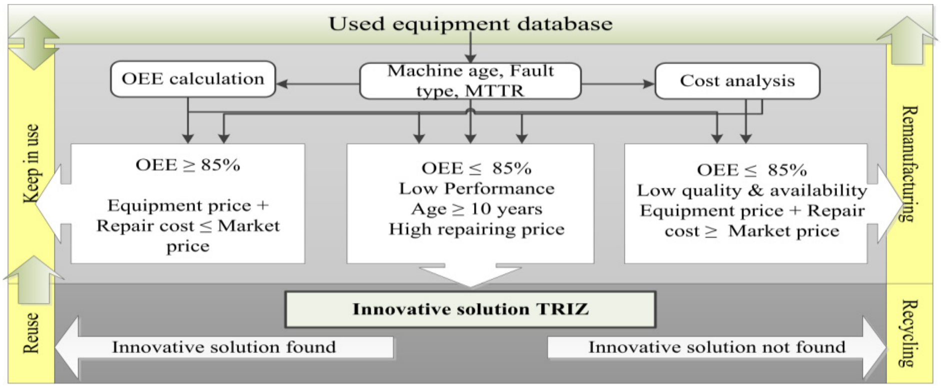

Fig. 3. The main framework for used industrial equipment life cycle extension.

3.1. Used equipment state analysis

Overall Equipment Effectiveness (OEE) is a "best practices" way to monitor and improve the efficiency of the manufacturing processes. OEE is simple and practical. It takes the most common and important sources of manufacturing productivity loss, places them into three primary categories and distils them into metrics that provide an excellent gauge for measuring where you are - and how you can improve. OEE is frequently used as a key metric in TPM (Total Productive Maintenance) and Lean Manufacturing programs and gives you a consistent way to measure the effectiveness of TPM and other initiatives by providing an overall framework for measuring production efficiency.

OEE is calculated as the product of its three contributing factors: OEE = Availability x Performance x Quality. The generally accepted World-Class goals for each factor are quite different from each other, as is shown in the Table 1 below. Of course, every manufacturing plant is different. Worldwide studies indicate that the average OEE rate in manufacturing plants is 60%. As you can see from the above table 1, a World Class OEE is considered to be 85% or better [23]. In main framework OEE value 85% is taken as critical for decision making. When the OEE is calculated and less than 85%, the next step is to find out all problems connected to faulty equipment. It is important to have quiet precise calculation about needed repairs and future maintenance. Due to the owner is dealing with used equipment, it is vital to know the market price of the machine. This is another important decision point. If the price of the used machinery exceeds the market price, there is no more point to repair, remanufacture or reuse it.

Table 1. World Class OEE.

OEE Factor	World Class
Availability	90.0%
Performance	95.0%
Quality	99.9%
Overall OEE	85.0%

Equipment repairing cost calculation is not given in this paper; it is possible to find it in several sources. In the current case study we used statistics data of the enterprise for equipment repairing cost and also for mean time equipment repairing (MTTR). Mean time to repair (MTTR) represents the average time required to repair a failed component or device. Expressed mathematically, it is the total corrective maintenance time divided by the total number of corrective maintenance actions during a given period of time [24].

Equipment repairing cost grows with the age of it. If the own cost is higher than market equipment cost then makes more sense to think about buying new equipment with better performance. Definition of critical point when is reasonable to use TRIZ is shown in Fig. 4.

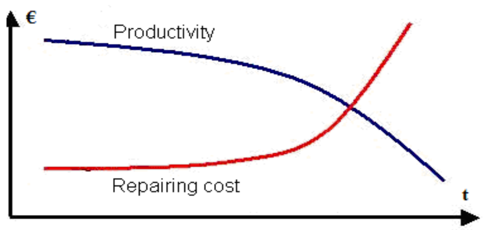

Fig. 4. Interrelation between equipment productivity and repairing cost.

4. Case study

4.1. Used equipment data collection and analysis

The current case study is based on one big Estonian machinery company database. This company has a great park of different machineries. The problem is how to define when it is time to take decision about the old ones. First step is data collection. Company has different types of machines, but mostly and commonly used are lathes and milling machines. In this section next data is collected: number of machines, age shown in Table 2, and faults with time spent on repairs for two periods: 2007 – 2009 and 2010 – 2012, explained in Tables 3-4.

Table 2. Machinery types and condition.

Nr	Machinery types	Newest, year	Oldest, year	Number of machines in expluatation
1	Lathe	2003	1966	13
2	Milling machine	2001	1963	8

Machinery useful life cycle is 15-20 years. As it is seen from Table 2, used equipment has a great difference. Of course, the oldest equipment is already remanufactured many times and has almost all new components. The average age for lathes is 26 years and 33 years for the milling machines respectively.

Table 3. Lathe machines faults for both periods 2007-2009 and 2010 – 2012.

Fault type	Average nr of faults for one bench for the certain period of time	MTTR *(min)*
Component weared	60	13 299
Component damaged	58	4 271
Electrical fault	44	27 150
Program & Machine setup	52	43 156

Table 4. Milling machines faults for both periods 2007-2009 and 2010 – 2012.

Fault type	Average nr of faults for one bench for the certain period of time	MTTR*(min)*
Component weared	44	8 390
Component damaged	45	25 390
Electrical fault	221	43 640
Program & Machine setup	126	28 790

It is necessary to point out the most frequently appeared faults for both types of machinery in this case study. Both periods for lathes show that the main time consuming operation is setup of machine and program. The second serious fault is electrical problem. It is necessary to mention that the analysis is based on time spent for repairs. Time is directly connected to money and summed up in Table 5. The recurrence of faults is also important, but time is more important in current case.

Tabel 5. Repairing cost of equipment.

	Average repairing cost of a machine tool *(€)*					
	First period (2007 – 2009)			Second period (2010 – 2012)		
	2007	2008	2009	2010	2011	2012
Lather machine	2 980	3 015	3 030	3 080	3 140	3 190
Total cost during period			**9 025**			**9 410**
Milling machine	3 350	3 400	3 410	3 460	3 530	3 580
Total cost during period			**10 160**			**10 570**

Both periods for lathes show that the main time consuming operation is setup of machine and program. The second serious fault is electrical problem. The same analysis was prepared for milling machines and as a result the main time consuming fault is electrical one. The second serious fault is setup. The data indicate that the machines useful time is going on setups and electrical faults. It is not a secret that electrical faults can be very complicated and it is not easy to find out the problems quickly. The overall tendency is seen in Table 5. Since 2007 the downtime recurrence and time spent on repairs is just growing. In 6 years it is almost doubled for both types of machines.

4.2. Solution developing using TRIZ tools

This section is dedicated to the most important part of our research – innovation. TRIZ is a very complicated methodology, thus it is not popular among researchers and engineers. Darrell Mann systemazed TRIZ into overall procedure Fig. 5. [25], what can be summarized as:

- Problem Definition Stage: Three methods (i.e. Problem explorer, Function/attribute analysis, and S-curve analysis) are mandatory, and IFR is highly recommended. The 9-Windows Method is most relevant to this stage but works all through the procedures.
- Second Tool Selection Stage: Corresponding to the problem situations, a special table recommends the user a few appropriate solution-generation tools. For each of 19 cases of situations, up-to-four tools are recommended with priority order.
- Solution Generation Stage: There are 11 individual tools for solution generation. Mann advises to learn these tools one by one when they become necessary to apply to your own case.

- Solution Evaluation Stage: Determine which is the best among the generated solutions and decide whether the solution is good enough. If not satisfactory, go back to the tool selection stage or to the top of the whole procedure for re-defining the problem.

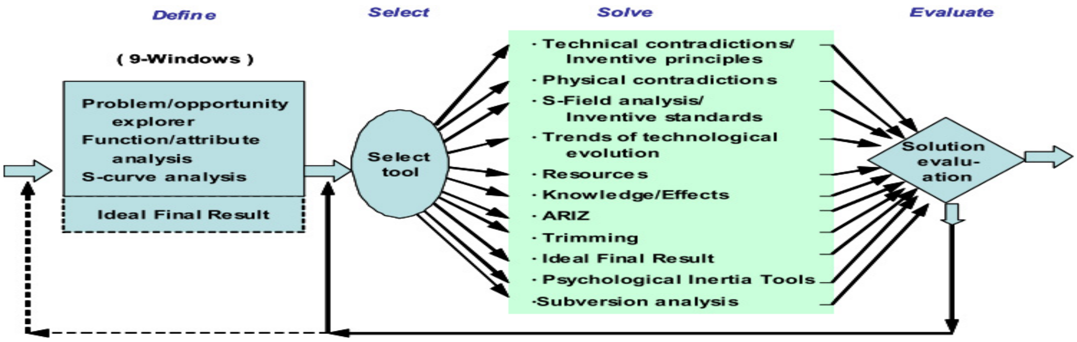

Fig. 5. TRIZ into overall procedure by D.Mann [25].

This time two different TRIZ tools are selected for alternative option development. One is IFR tool in Define phase and another one is 40 Inventive Principles in Solve phase. The last is used to solve technical contradiction between two factors. Normally, contradiction appears when one factor improves and another one worsens at the same time. When these two factors are set, the TRIZ Matrix shows possible principles what can solve the contradiction. The most important is to figure out what is the best possible EoL scenario for the company for present used industrial equipment and actual state.

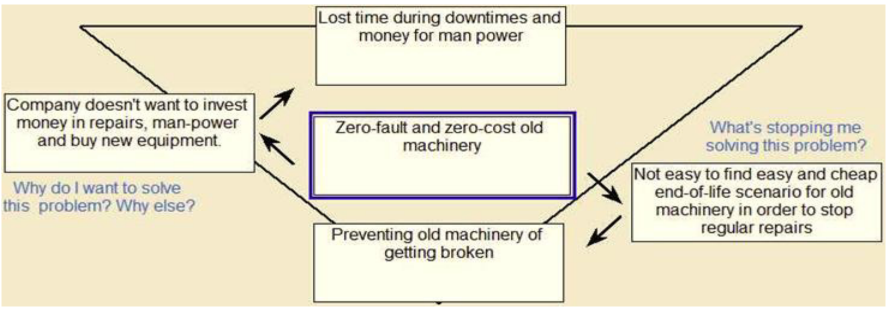

Fig. 6. IFR for current research.

In current situation the IFR can be named „Zero-fault and zero-cost“ Fig. 6. The biggest fault for lathes is setup. The milling machines are suffering mostly from electric faults and the second one is again setup. In the section of decision searching process, the main focus is on setup fault by solving defined technical contradiction between improving factors “ease of operation” and worsening “adaptability or versatility”. The solution can help to prolong useful life span of lathes and milling machines. It will be the alternative option what can be also taken into account during decision making procedure or somehow combined with the main proposal. According to Creax Innovation Suite 2.0 toolbox the following technical contradiction can be solved by using 4 different principles from 40 Principles of TRIZ. Matrix is giving principles: 15, 34, 1 and 16 shown in Fig. 7.

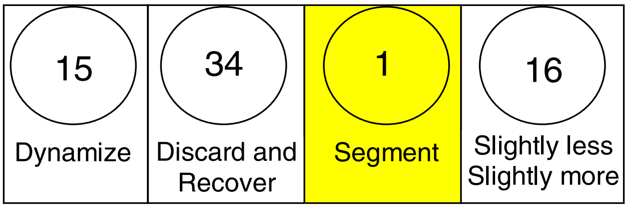

Fig. 7. Technical contradiction solution for "setup" fault by using TRIZ Matrix.

This time all options can be used and explained. The third option "Segment" looks good due to it is not showing direction to EoL strategies, such as 3R. For example, next possible extra options can be added to general decision, such as the manufacturing process can be divided (separated) among different machines. This will reduces the number of operations for one machine. In addition machines will be used less and the problematic spare parts will have less stress during setups. Another option is to group machines according to their specification and technical problems and tries to separate products according to that in order to keep the quality level and decrease the number of setups.

The collected data is analysed and summed up. Next results are represented in Table 6 without using any innovative techniques and tools of TRIZ. If the company takes into consideration next proposal, it will save 27600€/year for lathes and 20700€/year for milling machines. Such savings will give the opportunity to purchase new equipment with better quality. The results are good, but it is always important to have an alternative option.

Table 6. Used equipment end-of-life possible scenarios according to cost efficiency.

Used equipment description	Year	End-of-life scenario	Used equipment description	Year	End-of-life scenario
Lathe Rafmet	1966	Recycle	Milling machine KC 02 1110	1963	Recycle
Lathe 1341	1973	Recycle	Horizontal milling machine 6N8	1964	Recycle
Revolver lathe 1341	1973	Recycle	Milling machine 5342	1965	Recycle
Lathe 16K25	1978	Remanufacturing	Milling machine NGZ110=3	1972	Recycle
Lathe 16K20	1980	Remanufacturing	Vertical milling machine 6R12	1982	Remanufacturing
Lathe 16K20M	1983	Remanufacturing	Vertical milling machine 6T12R	1991	Remanufacturing
Lathe 16A2003S3	1984	Remanufacturing			
Lathe 1L532	1989	Remanufacturing			
Lathe 16K30FZ	1991	Reuse			

5. Conclusion

Today all industrial companies are trying to find best solutions to rationally manage own resources. The approach towards the maximum utilization of existing equipment for different manufacturing enterprises was developed in this paper. Proposed framework must be used for industrial equipment assessment and improvement of the company inventory controllability and utilization. It will minimize environmental impact and resource consumption during the entire life cycle of equipment.

The general framework defines conditions for finding a more suitable way for used industrial equipment life cycle management. In the first stage it is possible to evaluate the remanufacturability of old equipment through the technology and economic feasibility. At the second stage equipment evaluation is needed when index of equipment efficiency and economic feasibility is low, and question is in finding more suitable ways for using it (reuse) or recycling. In this case for decision making we propose the use of innovation solution TRIZ.

The principles of TRIZ are explored of its applicability to provide an eco-centred solution. Suggested approach must help entrepreneurs to improve the efficiency of utilized resources and upvalue environmental issues by prolonging used machinery life cycle. The idea is to develop the engine based on offered flow chart to simulate found solutions and help company management make fast and right decisions.

Acknowledgements

The research was supported by Estonian Ministry of Education and Research for targeted financing scheme SF0140035s12, grant ETF9460 and the DoRa programme Activity 6 and 8 stipends.

References

[1]Municipal Waste Europe 2013. Summary of the current EU waste legislation, Available from: http://www.municipalwasteeurope.eu/summary-current-eu-waste-legislation Accessed: 2013-06-02.

[2] Wie M. V., Stone R. B., McAdams D. A.. Sustainable design through flexible product evolution. ASME Conference Proceedings, 2004, Vol.1: pp. 187-196.

[3] G. Donatello, S., Tyrer, M., Cheeseman, C.R., 2010. EU landfill waste acceptance criteria and EU Hazardous Waste Directive compliance testing of incinerated sewage sludge ash. Waste Management 30 (1), pp. 63–71.

[4] Shevtshenko, E.; Bashkite, V; Maleki, M.; Wang, Y. (2012). Sustainable Design of Material Handling Equipment: A win-win approach for manufacturers and customers. Mechanika, 18(5), pp. 561 - 568.

[5] Loun, K., Riives, J., Otto, T., (2011) "Evaluation of the operation expedience of technological resources in a manufacturing network", Estonian Journal of Engineering, Vol. 17, No. 1, pp.51–65.

[6] Baileys' Diesel Group, 2013. Remanufacturing is Green Manufacturing. Available from: http://www.baileysdiesel.com/on-highway/remanufacturing-is-green-manufacturing/ Accessed: 2013-06-29.

[7] Gehin, A.; Zwolinski, P.; Brissaud, D. A tool to implement sustainable end-of-life strategies in the product development phase. Journal of Cleaner Production, Volume 16 (5) Elsevier – Mar 1, 2008.

[8] C. Rose. Design for environment: a method for formulating products end-of -life strategies, Stanford University, Ph.D. Thesis, 2000.

[9] W. Kerr, C. Ryan Eco-efficiency gains from remanufacturing: a case study of photocopier remanufacturing at Fuji Xerox Australia Journal of Cleaner Production, 9 (1) (2003), pp. 75–81.

[10] P. Rathore, S. Kota, A. Chakrabarti. Sustainability through remanufacturing in India: a case study on mobile handsets. Journal of Cleaner Production. Volume 19, Issue 15, October 2011, pp. 1709–1722.

[11] M.K. Andrew, S. Burges, W. Ijomah, C. McMahon. Reducing waste: repair, Recondition, remanufacture or Recycle? Sustainable Development, 14 (4) (2006), pp. 257–267.

[12] Cardone Industries Ltd. Saving the environment one core at a time...Available from: http://www.cardone.com/about-us/environmental-commitment Accessed: 2013-06-15.

[13] United States International Trade Commission: Irving A. Williamson, Daniel R. Pearson, Shara L. Aranoff, Dean A. Pinkert, David S. Johanson, Meredith M. Broadbent. Remanufactured Goods: An Overview of the U.S. and Global Industries, Markets, and Trade. Investigation No. 332-525. USITC staff calculations of weighted responses to the Commission questionnaire, October 2012.

[14] Altshuller Genrich Saulowitsch. Erfinden – Wege zur Lo Probleme. PI Verlag; Ösung technischer, 1998.

[15] Bashkite, V.; Karaulova, T (2012). Integration of Green thinking into Lean fundamentals by Theory of Inventive Problems-Solving tools. DAAAM International, Vienna, Austria, EU, pp. 345 – 350, 2012.

[16] J. Fresner, J. Jantschgi, S. Birkel, J. Bärnthaler, C. Krenn. The theory of inventive problem solving (TRIZ) as option generation tool within cleaner production projects. Journal of Cleaner Production 18, 2010, pp. 128–136.

[17] Hockerts K. Eco-efficient service innovation: increasing business - ecological efficiency of products and services', in charter. In: Greener M, editor. Marketing: a global perspective on greener marketing practice. Sheffield, UK: Greenleaf Publishing; 1999. pp. 95–108.

[18] Jones E, Mann D. An eco-innovation case study of domestic dishwashing through the application of TRIZ tools. Creativity and Innovation Management March 2001;10(1):3–14.

[19] Chen JL, Liu C. An eco-innovative design approach incorporating the TRIZ method without contratiction analysis. The Journal of Sustainable Product Design December 2001;1(4):263–72.

[20] Kobayashi H. A systematic approach to eco-innovative product design based on life cycle planning.Advanced Engineering Informatics April 2006;20(2):113–25.

[21] Six Sigma TRIZ. Successful Inventive Problem Solving. Available from: http://www.sixsigmatriz.com Accessed: 2013-06-22.

[22] Ericson A, Bertoni M, Larsson T. Needs and requirements – how TRIZ may be applied in product-service development. In: Second Nordic conference on product life cycle management – NordPLM'09, Göteborg; January 28–29 2009.

[23] Vorne Industries Inc. The Fast Guide to OEE™, 2002 – 2008.

[24] Military Handbook, MIL-HDBK-338B, Electronic Reliability Design Handbook, 1998.

[25] D. Mann. Hands-On Systematic Innovation, CREAX Press, Ieper, Belgium, 2002 (E); Principal stages of Overall Procedure.