ISSN 1392 - 1207. MECHANIKA. 2012 Volume 18(5): 561-568

Sustainable design of material handling equipment: a win-win approach for manufacturers and customers

E. Shevtshenko*, V. Bashkite, M. Maleki***, Yan Wang******

**Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia, E-mail: eduard@idssteam.com*

***UNIDEMI, Departamento de Engenharia Mecânica e Industrial, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal, E-mail: viktoria.bashkite@gmail.com*

****UNIDEMI, Departamento de Engenharia Mecânica e Industrial, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal, E-mail: maleki@fct.unl.pt*

*****The George W.Woodruff School of Mechanical Engineering , Georgia Institute of Technology, Atlanta, GA 30332-0405 USA, E-mail: yan.wang@me.gatech.edu*

crossref http://dx.doi.org/10.5755/j01.mech.18.5.2703

1. Introduction

Under the pressure from global economic crisis end users are becoming increasingly interested in sustainable and reconfigurable products in order to reduce their total lifetime cost of ownership. In the late 1980s, with the advent of consumer environmental awareness the number of questions about product environmental characteristics increased, which force enterprises to develop a recycling infrastructures. In the case of price sensitive market, governments can enforce market to use specific products containing recycled or recovered materials. The biggest issue in recycling anything is to get it back to the recycler [1]. In the USA, 95% of cars and trucks that are retired each year go to the recycler, and for each of those cars 75% by weight is recovered for reuse. In the European Union (EU) this percentage will reach 95% by the year 2015 [2]. Under certain conditions, manufacturing companies become more interested in the sustainability of products; one possible approach to make material handling equipment more sustainable is to make it reconfigurable, reusable and reliable. Those products are likely to be reused when customers' requirements change. More sustainable material handling equipment can be much easier sold in the future, due to the possibility to be reconfigured in accordance to the new customer requirements. In this case customers are mostly those companies, who are dealing with material handling such as logistic, production, and manufacturing companies.

After this section, sections two and three will cover brief literature reviews on sustainability and sustainable design (section 2) and reverse logistics framework for material handling equipment (section 3) to provide appropriate theoretical foundation for next sections. Section four is dedicated to comparison of conventional and more sustainable design for Material Handling Equipment. It is followed by section five where a case study put forward empirical evidences on advantages of employing more sustainable material handling equipments. And finally the research is finalized by conclusion given in section six.

This paper is focused on the development of a reverse logistics framework for more sustainable material handling equipment design. The novelty of the proposed reverse logistics framework is that it can reduce the backward flow of products to the manufacturer by enabling distributors to reconfigure products according to the renewed customer requirements.

2. Sustainable design and service oriented products

The objective of design for supply chain is to allow engineers to consider lifetime costs of products from production, distribution and maintenance, up to recycle during decision-makings at the product design phases [3]. Sustainability oriented approach assumes that natural resources are finite, and should be continuously re-used. In this approach designers are taking care of both responsibilities as to prevent environmental damage and the skills to move modern cultures into sustainable lifestyle [4]. The discussion on sustainability in scholar works may date back to early 1960s, when the product design impact on efficiency of working, re-collecting and recycling was emphasized. From that time on this trend continued and design became one of the most influential factors in the development of sustainable products and production systems [5]. The transition from „design for needs" to „design for environment" first began in the early 1970 [6]. In contrary to specialized industrial products with limited functionality and of short duration, postindustrial design goes for multifunctional products, repairable and durable, taking the form of a design that is socially responsive and eco-sustainable. The new requirements like energy efficiency, duration, and recyclability all appeal to consumer sensitivity to environmental issues [7].

Recent researches showed that there are difficulties and concerns for companies interested in practicing of sustainable design. Cerin and Karlson [8] showed new ideas, like sustainability, are viewed as financial risks and are not likely to be supported by companies. Smith and Weintraub [9] found that many companies see sustainable business as a waste of time. The California Waste Management Board [10] discovered that in the short term for some items sustainable product design is more expensive than unsustainable alternative. Merrick [11] discovered that consumers do not purchase sustainable goods because it is more complicated to choose sustainable alternatives over readily available products. Dermirbilek and Sener [12] identified that it is critical for companies to provide sustainable products that satisfy the quality, function and durability that consumers expect.

Sustainable design requires close link between consumers and distributors. The choices that designers make in materials, structures, and functions of a product can greatly affect sustainability of product. Designers opt for different sustainable design methodologies such as design for disassembly, design for remanufacturing, and design for recycling according to their industrial context. These methods often focus on optimizing the product's construction so that the product can be taken apart, either to be refurbished or broken down into its constituent components to refurbish the materials or be recycled [13, 14].

Design for reuse and recycling is one of the principles of sustainable design where products, processes, and systems are designed for performance in a commercial „after life". In the context of automotive industry, one of the major barriers is lack of research and development in the design for reuse [15]. Remanufacturing of some components requires significant change in design, operation, and probably industry structure, and as a consequence automotive manufacturers are not designing vehicles to facilitate reuse and remanufacture. Therefore more efforts on research and development in design for reuse have to be conducted in order to develop the optimum automotive component for reuse [2].

Sustainable design has also common features with design for remanufacturing. Accordingly to Hammond et al. [15] durable cores are the key to the remanufacturing process, and the top three factors that make an automotive component difficult to remanufacture are: core availability, assembly/disassembly, and design simplicity. Parametric components can be easily adapted to suit to different customer's needs which are consistent with the features of service oriented products [16]. Eco-product design for remanufacturing is a combination of ecological, economic and customer considerations are also consistent with sustainable product. Eco-designed product for remanufacturing has a positive impact on the decision to remanufacturing a service/aftermarket part [17-19]. Eco-product can be defined as service-oriented product. Service Oriented Products is a well-known sustainable design paradigm that requires reverse logistics. One promising approach is to shift the source of value from the amount of sold products to the quality of services the product provides. Jun Fujimoto et al. [20] described the need for redesigning recycling systems from a manufacturing perspective and then discusses the possibility of products servicification. There are emerging trends of "servicizing" business models that create the demand pull for remanufactured products. In such models end consumers avoid risk of ownership, expect better product upgrades at low cost, wish to have increased flexibility and are more environmentally conscious [21].

3. Reverse logistics framework for material handling equipment

The attention to reverse logistics has increased as Stock et al. reported that the total value of products returned in the U.S. is estimated to be $100 billion annually [22]. Therefore, reverse logistics is one of the essential components to have sustainable products. Its impacts on product lifecycle, information sharing, and decision support should be studied for sustainable product development.

Murphy [23] studied the reverse distribution of products from product recalls. Thierry et al. [24] formulized product recovery management by checking over the recovery options, from direct re-use to disposal, and by placing the options into the supply chain. Carter and Ellram [25] reviewed some early work on reverse logistics and subdivided the literature of reverse logistics into transportation, packaging, and purchasing. Besides, there have been studies of how reverse logistics is impacted by product life cycle management, including opportunities to reuse and recycle, as well as the processes, actors, types of recovery in reverse logistics and the models to support reverse logistics from the business perspective [15, 26]. Most of the existing researches on reverse logistics are more interpretive than quantitative in nature [17]. Some authors increase the attention placed on direct observation methods [27]. The trend in survey research is moving from being exploratory in nature to building and testing models.

Design for reverse logistics is consistent with sustainable design for the case of service-oriented products, which are an excellent pathway to sustainability – for products with intensive manufacturing environmental impacts. Reverse logistics is the process of returning new or used products from their initial point in a supply chain, and it may include returns from consumers, retailers or distributors because products are unsatisfactory, outdated, recalled or overstocked. The Council of Logistics Management (CLM) published the first known definition of reverse logistics in the early 1990s as: "the role of logistics in recycling, waste disposal, and management of hazardous materials; a broader perspective includes all related to logistics activities carried out in source reduction, recycling, substitution, reuse of materials and disposal" [28]. Reverse logistics consists of planning, implementing and controlling the reverse flow of materials as well as management of related downstream information within the supply chain with the primary purpose of recapturing value. Today customers are looking for product features that include reusability, multi-functionality and reconfigurability [29].

4. Comparison of conventional and more sustainable design for material handling equipment

The strong development of well-known today material handling equipment manufactures, such as Jungheinrich, BT, Toyota, Hyster, Linde, Yale, was initiated in the late 1940s. In 1946 Hyster Company's first plant devoted exclusively to the mass production of lift trucks opens in Danville, Illinois (USA). In 1948 BT manufactured the first hand pallet truck. In 1956 Jungheinrich developed the first reach truck "Retrak®" as a milestone for space-saving storage. In the same time they started to produce own electric motors. In 1952 Hyster opened its first plant outside the US, in Nijmegen, the Netherlands. The Hyster 40" and Karry Kranes were the first machines to be assembled there. In 1955 Linde company produced the first hydrostatically driven vehicle, the so-called Hydrocar. In 1956 Toyota produced the first counterbalanced forklift truck. Today all material handling manufacturing companies are devoted to sustainable development of their production plants and products.

The idea behind more sustainable design is to have material handling product modularity. Due to this reason the technical condition control step is added to the new reverse logistics framework for more sustainable material handling equipment. Returned equipment is normally used product, and the general condition of the parts should be assessed before they can be reused in the reconfiguration process. The reconfigured equipment should be reliable and fulfill customer expectations. The differences between more sustainable and conventional design for material handling equipment are summarized by authors in Table 1. In more sustainable design the future requirements of customers are predicted. To satisfy this requirement the resulted products should be reconfigurable without considerable investments. Returned material handling equipment will be reconfigured later and reused which makes such equipment more sustainable.

Table 1

Assumption of differences between conventional and more sustainable design for material handling equipment

Conventional design	More Sustainable design
Product design is fixed	Product design is dynamic in the frames of given product portfolio
Product disposed when customer requirements are changed	Product reconfigured when customer requirements are changed
Product features should be selected at the moment of the product purchase	New features can be added to the product when required
Product life cycle is fixed	Product life cycle has the potential to get increased

Authors of the current research propose a framework for reverse material flow for more sustainable material handling equipment as illustrated in Fig. 1. In the forward material flow, products, accessories, and materials are moving from suppliers and manufacturers to distributors. Distributors are selling more sustainable products to the customers. The reverse material flow of products to the manufacturers is reduced, because when the customer requirements are changed, the information will be provided through distributor to manufacturer.

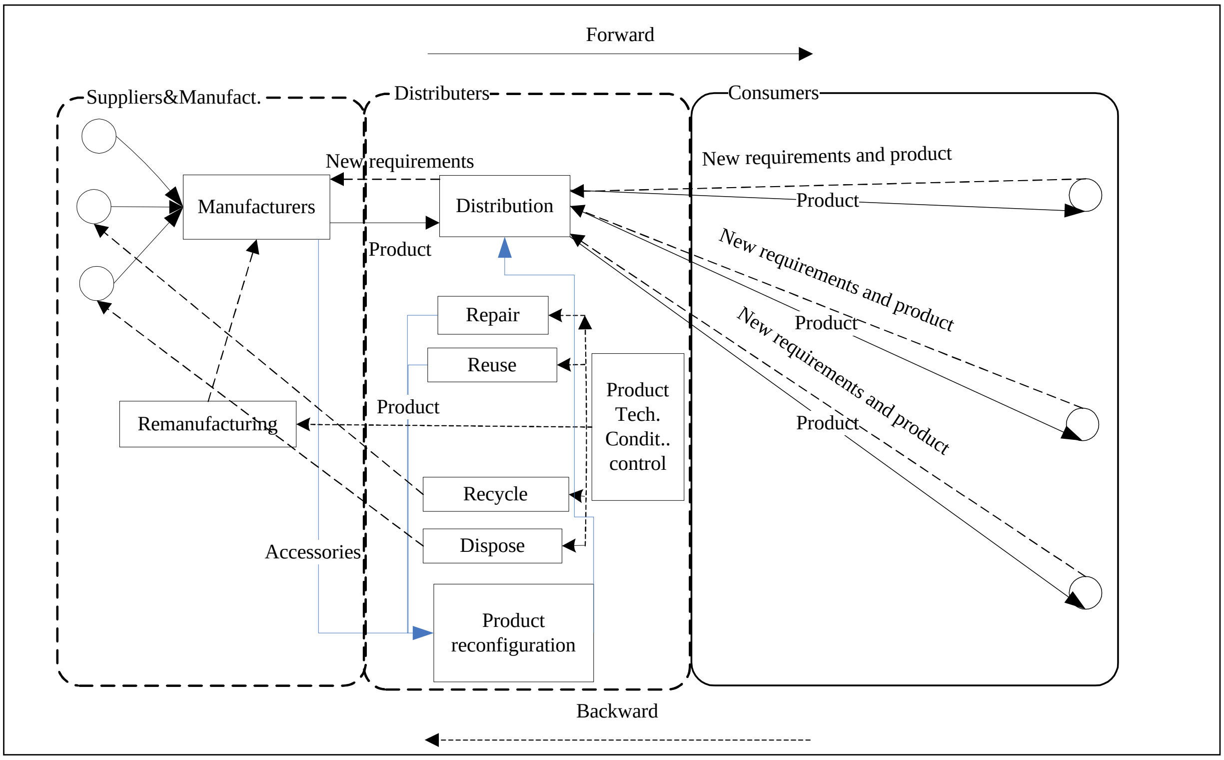

Fig. 1 The proposed framework for the more sustainable design product reverse logistics flow

When customer decides to upgrade material handling equipment the accessory is received from distributor and can be easily installed by customer. In case, customer returns material handling equipment to distributor, the product will be reconfigured accordingly to the requirements of the next customer. There is no need to return the product to the manufacturer. More sustainable design also changes the partner's roles in the supply chain [30] as presented in Fig 1. Manufacturing enterprises or suppliers, distributors and customers have additional responsibilities on sustainable products.

5. Case study: potential advantages of sustainable material handling equipment for customers

In this section, the authors demonstrate the effectiveness of new reverse logistics framework for sustainable products with an application of materials handling equipment. This application study shows how changes in a customer's attitude can force a manufacturer to redesign products in a sustainable way in order to satisfy the future needs.

In this case study it is examined what can be done in the design of material handling equipment to meet the customers' potential needs in the future. The case study is divided into two parts. First, the advantages that sustainable products can provide to customers will be discussed.

Fig. 2 Conventional and sustainable design

The reach truck model used in this application study has the highest demand in the material handling equipment market. There are two different types of reach trucks in the conventional design. One is equipped with the standard "vulkollan" load wheels that can only be used for indoor purposes, as these wheels will be worn-out very fast if used outdoors. The second type of reach truck is equipped with outdoor wheels. In order to meet the customers' expectations of being able to work both indoors and outdoors, the more sustainable design allows trucks to be used in both scenarios. The reach truck with super elastic tires has been designed to combine the functionalities of both the counter-balanced truck and the conventional reach truck, as shown in Fig. 2.

This new reach truck can work as a conventional reach truck without any space loss inside the warehouse and also can be used as a counter-balanced forklift truck for outdoor purposes. This is enabled by the redesigned chassis that can be used with the high load wheels. Customers may have additional requirements in the next ten years after a truck is purchased which is supported by collected statistics given in Table 2. The average lifetime cost of conventional design reach truck is 3695 EUR.

Table 2

Lifetime cost of conventional design forklift trucks with configuration changes

	Forklift type	Model Year of purchase	Year of reconfi-guration	Reconfiguration details	Price + spare parts prices EUR	labour + distribution days + replacement truck rental cost	Average lifetime cost per year period
1.	IC counter-balanced (LPG)	Toyota (Cesab) CBG25 2004	2008	Installation of new distributor for 4 hydraulic. Installation of new clamp for pallets carrying.	~19200 (truck itself) + 1700 (valve) + 8544 (clamp) EUR = 30244 EUR	10×100 (distributor)+4×100 (clamp) 14 × 700 (rental) = 10900	41444/10= 4144
2.	Electric counter-balanced	Yale ERP15 2004	2006	Installation of new distributor for 4 hydraulic valve instead of standard 3. Installation of new joystick for the special clamp with rotation.	~19200 EUR + 1700 (clamp) + 2300 EUR (joystick) = 20900 EUR	8×100 (joystick)+4×100 (clamp) + 12×700 (rental) = 11000	31900/10=3190
3.	Electric reach stacker	BT RR M14 2008	2010	Installation of cold package on reach stacker. Installation of cabin for usage in refrigerator.	~26000 EUR+ 300 EUR + 5200 EUR = 31500 EUR	6 × 100 (package)+3×100+ 10×700 (rental) = 7900	39400/10=3940
4.	IC counter-balanced (LPG)	GT45 2003	2007	Installation of new steel cabin for usage outside the warehouse. Cold package.	~22000EUR 3500 EUR + 300 EUR=25800	6×100 (package) + 3 × 100 (cabin) +10×700 (rental) = 7900	33700/10=3370
5.	Electric counter-balanced	XE18ac	2007	Activation of 4 hydraulic function. Installation of special rotating device.	~19200EUR 1700(clamp) + 6500 EUR=27400	6×100 (rotator) + 4×100 (clamp) 14×700 (rental) = 10900	38300/10=3830
							Average lifetime cost/year 3695

As it could be considered from collected statistics the reconfiguration of existing reach truck today is a very expensive and time consuming process, in addition the another truck should be rented if the existing truck is sent for reconfiguration to distributor. The most common reconfiguration activities in forklift truck are: activation of additional hydraulic function, installation of special additional equipment or adaption of it. Based on collected statistics for more sustainable design of reach truck the prerequisites for those most popular extras will be preinstalled during the manufacturing process in current case study and the lifecycle analysis will be completed. Therefore, in this case study the more sustainable design of reach truck will enable to add the following three different accessories easily without substantial additional costs:

1. Installation of maximum quantity of hydraulic functions if the user requires new additional equipment for the new needs.

2. Installation of "cold storage package" if there is a need to work in refrigerator storage type.

3. Installation of protective features such as non-marking super elastic tires, lifting height indicator and weight on forks required for indoor warehouses or refrigerator conditions.

Those options might not be added when customers first purchase trucks. The more sustainable design needs to provide the flexibility to allow customers to add options later when they are required. The three scenarios are considered. In the first accessory scenario, the sustainable design requires that the truck should support the installation of all possible hydraulic functions. This option is very important for the major forklift function to be further reconfigurable.

It is important to explain why the sustainable product, with preinstalled empty hydraulic channels, should be preferred by the customer. For example, consider the case where the customer has received an order for a new product type that should be rotated during handling operations. The reach truck can rotate the pallet, after a special clamp is added to the forklift to provide 180 or 360 degrees rotation. Sustainable products have free hydraulic channels and the special clamp installation process will take less than half an hour. However, if a non-sustainable reach truck has been previously selected, there will be no empty hydraulic channels. In either case, the reach truck's hydraulic system should be rebuilt by the distributor's technician before the special clamp can be added. For this procedure the reach truck should be taken out of use for a two-week period. For this period the customer will need to rent another reach truck. Otherwise the sales orders will be lost. Other negative consequences include the loss of hydraulic system factory warranty if this system was rebuilt and the increased cost because the reconfiguration process is much more complicated. To summarize, the advantage of the sustainable product is that additional functions could be easily added when required. Besides, the reach truck offline time is reasonable and the hydraulic system remains under warranty.

The second accessory scenario involves enabling the reach truck to work in different storage environments. For example, if the customer receives an order for products that require refrigeration, it is possible to use the sustainable reach truck in the refrigerated areas. When the reach truck is moving between different temperature storages, it will encounter high levels of condensation. For this purpose a sustainable reach truck should include additional protection for electronic components. This option is useful because usually the reach truck is used in different storages or indoor / outdoor conditions. Usually when operators transport products from cold storage to warm or vice versa, temperature fluctuation increases the condensation, which can cause malfunctions in the reach truck's electronic system. If additional protection was installed previously, the "cold storage package" can be easily added when required. This package includes cabin, seat heating, and special hydraulic oil for cold stores. Oil can be changed before the truck will be used in the cold store. To summarize, the selection of sustainable product with additional protection for electronic components will protect the reach truck from condensation and the cold storage "package" can be easily added later when required.

The third accessory scenario is the installation of very important optional equipment for the reach truck operator. During operation the reach trucks often lift loads to the maximum height. This is not allowed by the safety regulations and residual capacity tables prepared by the manufacturers. However it is difficult to control those parameters during reach truck operating process. If those parameters are exceeded, the hydraulic, lifting and driving systems can be damaged. Also the useful lifecycle of the reach truck is reduced and operation is not safe. The sustainable reach truck includes an optional height indicator to protect the reach truck under operating conditions when the height of the racking systems used in the warehouse is known. In addition the lifting height indicator increases the operation's speed several times. Another important feature of sustainable reach truck is a lifting indicator. It enables the operator to monitor the lifting operation when the lifting height is about 10 meters. With this option the load is safe and the amount of operator errors is decreased. The next option is weight on the forks, which can be installed by the manufacturer, by the distributor or by a third company, which specialize in the installation of optional equipment. This option will prevent the lifting of loads if the maximum weight is exceeded. This option enables users to reduce number of repairs and maintenance costs needed for sustainable reach truck and well as it also increase the product lifecycle. The last important option is non-marking wheels, which protect warehouse floors from the black marks left on the floor when conventional wheels are used.

When customer needs to add any of those new functionalities today, the reconfiguration of conventional reach truck is not supported by original equipment manufacturer. The reason is that conventional design, which does not support reconfiguration. Today the customer should buy two conventional products to be able to work inside and outside of the warehouse. Due to aforementioned reasons customers prefer to purchase the sustainable design reach truck which is 41% cheaper than the purchase of conventional reach and counterbalanced trucks. Calculations of sustainable reach truck cost and analogue combination of conventional reach truck as well as counterbalanced forklift truck are given in the Table 3 below.

Table 3

Calculations of conventional and more sustainable reach trucks

Reach truck with standard "vullkolan" wheels + counterbalanced forklift truck (conventional way) cost EUR	Reach truck with superelastic wheels in more sustainable way (cold package, and 4 hydraulic function included
Reach truck with standard "vullkolan" wheels 23000 EUR	Reach truck with standard SE wheels 26000 EUR
Counterbalanced forklift truck 19200 EUR	Superelastic wheels 5500
	4 hydraulic function additional cost 800EUR
	Cold package 300 EUR
Total cost 41200 EUR	Total cost 32600

Table 4

More sustainable Forklift trucks with configuration changes

	Forklift type	Model Year of purchase	Year of reconfig-uration	Reconfiguration details for the more sustainable reach truck	Price + spare parts prices EUR	Installation cost	Average lifetime cost per year period
1.	IC counter balanced (LPG)	Toyota (Cesab) CBG25 2004	2008	Installation of new clamp for pallets carrying	~32000 (truck itself) + 8544 (clamp) EUR=40544 EUR	4x100 (clamp)	40944/10= 4094
2.	Electric counterb alanced	Yale ERP15 2004	2006	Installation of new joystick for the special clamp with rota-tion.	~32000 (truck itself) + 2300 EUR (joystick) = 34300 EUR	8x100 (joy-stick)	35100/10=3510
3.	Electric reach stacker	BT RR M14 2008	2010	Installation of cabin for usage in refrigerator.	~32000 (truck itself) + 5200 EUR = 37200 EUR	3x100=300	37500/10=3750
4.	IC counterb alanced (LPG)	GT45 2003	2007	Installation of new steel cabin for usage outside the ware-house. Cold package.	~32000 (truck itself) EUR + 3500 EUR=35500	3x100(cabin)= 300	35800/10=3580
5.	Electric counter-balanced	XE18ac	2007	Activation of 4 hydraulic function. Installation of special rotating device.	~32000 (truck itself) + 6500 EUR=38500	6x100 (rota-tor) = 600	39100/10=3910
							Average lifetime cost per year 3768,8

It is calculated that the average lifetime cost for proposed sustainable reach truck based on the statistical data from table 4 is 3768,8 EUR The lifetime cost per year for the more sustainable product is only 3% higher. Based on available customers' reconfiguration orders and lifetime cost analysis we can conclude that sustainable design will be more attractive to customers, especially in the global market where customers are more cost conscious and need combination of functionalities. There are also additional advantages when sustainable design reach truck is used, which are described in Table 4. In a nut shell, sustainable design reach truck makes the operation process faster (no reloading operation from reach truck to counterbalanced forklift is required) and cheaper (we don´t need to have additional driver, storage and maintenance cost for the second counterbalanced truck).

Table 5

Comparison of advantages and disadvantages between conventional and more sustainable reach truck design

	Reach truck + Counterbalanced	More sustainable reach truck
Price	More expensive	Cheaper, ~41%
Fail risk	More	Less
Human resources	2 operators	1 operator
Loading/unloading procedure		Faster
Realization possibility	It is more complicated to realize 2 standard trucks	More chances to sell the truck after the exploitation period
Reconfiguration	Complicated and big risks	Easy and fast

6. Conclusions

Today with the advancement of information system a manufacturers are able to store data of a sustainably designed product, monitor the product condition and customer requirements, support product reconfiguration at the distributor facility. The distributor is also able to inform the manufacturer about the changes made to the product and to replenish the accessories. Thus sustainable design with the reverse logistics consideration is ready to be used. The main problem for distributors of material handling equipment is that the customers prefer to work on long-term-rental (LTR) conditions, which is beneficial for the big companies. There are certain advantages if needed warehouse equipment is ordered and an LTR agreement is signed. First, there are no relations with Banks or other leasing companies. Companies rent directly from the distributor. This means that after five years the company can return the used reach truck and order a new one. The higher monthly payments compensate for the risk related with Bank loans. Due to the unstable economical situation, distributors face the problem of customer companies liquidating. It is more profitable for the customer to pay a penalty and return the reach truck, than to cancel the bank loan.

Selling sustainable reach trucks decreases the number of returns. A sustainably designed reach truck is a product with the potential for successful reuse. If a designed for sustainability reach truck is returned, it could be easily reconfigured according to the new customer's requirements.

The limitation authors see is that quality of reconfigured product is the subjects to uncertainty due to the fact that new, reused, repaired and remanufactured parts are used for product reconfiguration.

In this paper was presented a new framework for the reverse logistics for sustainably designed products. In the presented case study, benefits of employing sustainable reach truck were investigated. As a result, using sustainable product provides cost and flexibility advantages for both manufacturer and customer.

Acknowledgements

E. Shevshenko would like to thank the Estonian Science Foundation for the targeted financing scheme SF0140113Bs08, grant ETF9460 and the U.S. Department of States Bureau of Educational and Cultural Affairs for the Fulbright grant that enabled us to carry out this work. Besides, M. Maleki would like to appreciate financial funding for doctoral study from MIT-Pt/EDAM-IASC/0033/2008 project.

References

1. **Sharfman, M.; Ellington, R.; Meo, M.** 2001. The introduction of postconsumer recycled material into TYVEK, Journal of Inductrial Ecology 5(1): 127-146. http://dx.doi.org/10.1162/108819801753358544.
2. **Lily, A.; Dzuraidah, A.W.; Che Hassan, C.H.; Che Husna, A**. 2009. Development of an optimization mode for automotive component reuse, Journal on Advanced Manufacturing Technology 3(1):87-96.
3. **Shevtshenko, E.; Wang, Y.** 2009. Decision support under uncertainties based on robust Bayesian networks in reverse logistics management, International Journal of Computer Applications in Technology Vol. 36(3-4): 247-258. http://dx.doi.org/10.1504/IJCAT.2009.028047.
4. **Wie, M.V., Stone, R.B., McAdams, D.A.** 2004. Sustainable design through flexible product evolution, ASME Conference Proceedings 1: 187-196.
5. **Asimow, M.** 1962. Introduction to Design, Prentice Hall, Englewood Cliffs, NJ, 135 p.
6. **Madge, P.** 1993. Design, ecology, technology: A historiographical review, Journal of Design History 6(3): 149-166. http://dx.doi.org/10.1093/jdh/6.3.149.
7. **Elkington, J.; Burke, T.; Hailes, J.** 1988. Green Pages: The Business of Saving the World, Routledge, London.
8. **Cerin, P.; Karlson, L.** 2002. Business incentives for sustainability: A property rights approach, Ecological Economics 40(1): 13-22. http://dx.doi.org/10.1016/S0921-8009(01)00275-0.
9. **Smith, M.; Weintraub, D.** 1998. Breaking Ground: Environmental Practices and Big Developers. Home Energy Magazine Online. Retrieved March 25, 2006, from: http://www.homeenergy.org/archive/hem.dis.anl.gov/eehem/98/980910.html.
10. **California Integrated Waste Management Board**. (2005) Sustainable Materials Selection.
11. **Merrick, J.** 2005. Eco-Cool Moves in, in The Independent, 2005: London.
12. **Dermirbilek, O.; Sener, B.** 2003. Product design, semantics, and emotional response, Ergonomics 46(13/14): 1346-1360. http://dx.doi.org/10.1080/00140130310001610874.
13. **Schiller, A.; Hunsaker, C.T.; Kane, M.A.; Wolfe, A.K., Dale, V.H.; Suter, G.W.; Russell, C.S.; Pion, G.; Jensen, M.H.; Konar, V.C.** Guide to sustainable community indicators, Ipswich, MA:Quebec-Labrador Foundation/Atlantic Center for the Environment.
14. **Harker, D.F.; Natter, E.U**. 1995. Where we live: A citizen's guide to conducting a community environmental inventory, Washington, DC: Island Press.
15. **Tibben-Limbke, R**. 1998. Life after death: reverse logistics and the product life cycle, International Journal of Physical Distribution and Logistics 132(3): 223-244.
16. **Hammond, R; Amezquita, T; Bras, B**. 1998. Issues in the automotive parts remanufacturingindustry – a discussion of results from surveys performed among remanufacturers, International Journal of Engineering Design and Automation 4(1): 27-46.
17. **Sachan, A.; Datta, A**. 2005. Review of supply chain management and logistics research, International Journal of Physical Distribution & Logistics Management 35(9): 664-705. http://dx.doi.org/10.1108/09600030510632032.
18. **Moseichuk, V.; Bashkite, V.; Karaulova, T.** 2010. Combination of end-of-life strategies for extension of industrial equipment life cycle, Journal of Machine Engineering 10(4): 76-88.
19. **Bjorklund, T.; Pribytkova, M.; Karaulova, T.** 2010. Development the maintenance plan: maintenance activities on operational level, Proceedings of the 7th International Conference of DAAAM Baltic Industrial Engineering 1-2: 286-291.
20. **Fujumoto, J.; Umeda, Y.; Tamura, T.; Tomiyama, T.; Kimura, F**. 2003. Development of service-oriented products based on the inverse manufacturing concept, Environmental Science Technologies 37: 5398-5406. http://dx.doi.org/10.1021/es034439d.
21. **Subramoniam, R.; Huisingh, D.; Chinnam, R.B.** 2009. Remanufacturing for the automotive aftermarket-strategic factors: literature review and future research needs, Journal of Cleaner Production 17: 1163-1174. http://dx.doi.org/10.1016/j.jclepro.2009.03.004.
22. **Stock, J.; Speh, T.; Shear, H**. 2002. Many happy (product) returns, Harvard business review 80(7): 16-17.
23. **Murphy, P.A**. 1986. Preliminary study of transportation and warehousing aspects of reverse distribution, Transportation Journal 25(4): 12-21.
24. **Thierry, M.; Salomon, M.; Nunen, J.; Wassenhove, L**. 1995. Strategic issues in product recovery management, California Management 37(2): 114-135. http://dx.doi.org/10.2307/41165792.
25. **Carter, C.R.; Ellram, L.M.** 1998. Reverse logistics: a review of the literature and framework for future investigation, Journal of business logistics 19(1): 85-102.

26. **Karaulova, T.; Bashkite, V.; Moseichuk, V.** 2010. Lifecycle extension for industrial equipment, Proceedings of the 7th International Conference of DAAAM Baltic Industrial Engineering 1-2: 364-369.
27. **Chouinard, M.; D'Amours, S.; Aït-Kadi, D**. 2005. Integration of reverse logistics activities within a supply chain information system, Computers in Industry 56(1): 105-124. http://dx.doi.org/10.1016/j.compind.2004.07.005.
28. **Stock, J.R**. 1992. Reverse Logistics. Council of Logistics Management, Oak Brook, IL.
29. **Kangilaski, T.** 2005. Virtual organisation and supply chain management, ETFA 2005: 10th IEEE International Conference on Emerging Technologies and Factory Automation 1(1, 2): 705-712.
30. **Kangilaski, T.** 2010. Challenges for SMEs entering into the virtual organization partner network, Proceedings of the 7th International Conference of DAAAM Baltic Industrial Engineering 1-2: 352-357.

E. Shevshenko, V. Bashkite, M. Maleki, Yan Wang

REKONFIGŪRUOJAMŲ KROVIMO ĮRENGINIŲ PROJEKTAVIMAS: WIN-WIN PRIEGA VARTOTOJUI IR KLIENTUI

R e z i u m ė

Krovimo įrenginių gamintojai suinteresuoti savo gaminių stabilumu. Norint padidinti krovimo mechanizmų stabilumą, reikia daryti juos rekonfigūruojamus, patikimus, daugkartinio naudojimo. Tai leidžia naudoti gaminį pakartotinai net pasikeitus pirkėjo poreikiams. Gaminį, kurį galima keisti pagal naujo kliento pageidavimus, bus lengviau perparduoti ateityje.

Straipsnyje daugiausia dėmesio skiriama reversinės logistikos struktūros plėtrai projektuojant tinkamus ilgiau naudoti krovimo įrenginius. Siūlomos reversinės logistikos struktūros naujumas pasireiškia tuo, kad leidžia sumažinti gaminių grįžtamumą gamintojui, skirstytojui ją perkonfigūruoti pagal naujus užsakovo reikalavimus. Pateiktame pavyzdyje parodyti rekonfigūruojamo krovimo įrenginio naudojimo privalumai: sumažėja jo eksploatacijos išlaidos, užtikrinamas panaudos lankstumas gamintojui ir pirkėjui.

E. Shevshenko, V. Bashkite, M. Maleki, Yan Wang

SUSTAINABLE DESIGN OF MATERIAL HANDLING EQUIPMENT: A WIN-WIN APPROACH FOR MANUFACTURERS AND CUSTOMERS

S u m m a r y

Manufacturing of material handling equipment companies become more interested in the sustainability of their products. One possible approach to make material handling equipment more sustainable is to make it reconfigurable, reusable and reliable. Those products are likely to be reused when customers' requirements change. More sustainable material handling equipment can be much easier кysold in the future, due to the possibility to be reconfigured in accordance to the new customer requirements is high.

This paper is focused on the development of a reverse logistics framework for more sustainable material handling equipment design. The novelty of the proposed reverse logistics framework is that it can reduce the backward flow of products to the manufacturer by enabling distributors to reconfigure products according to the renewed customer requirements. In the presented case study the benefits of employing sustainable reach truck were investigated. As a result, using sustainable product provides cost and flexibility advantages for both manufacturer and customer.

Keywords: sustainable design, material handling equipment, win-win approach.

Received June 16, 2011
Accepted October 12, 2012