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State of the Art in the End-of-Life Vehicle Recycling

Radim Lenort[*]
ŠKODA AUTO University, Czech Republic
https://orcid.org/0000-0001-6194-5364

David Staš
ŠKODA AUTO University, Czech Republic
https://orcid.org/0000-0002-6089-3037

Pavel Wicher
ŠKODA AUTO University, Czech Republic
https://orcid.org/0000-0002-0393-2351

Martin Straka
Technical University of Košice, Slovakia
https://orcid.org/0000-0002-2207-0160

[*]*corresponding author's e-mail: radim.lenort@savs.cz*

Abstract: Growing ecological awareness in society and legal regulations aimed at reducing the negative impact of used products on the environment means that waste management begins to play a significant role in the modern world. Therefore, it is necessary to conduct research towards the organization and implementation of waste management. It has been noticed that an important link in the economy is the recycling of used products. Thus, numerous studies are undertaken in the direction of organization, improvement, automation and computerization of the product and material recycling process. The article presents the results of literature research in terms of the implementation of the end-of-life vehicle recycling process.

Keywords: waste management, reuse, recovery, recycling, end-of-life vehicle (ELV), recycling network, recycling system, disassembly

1. Introduction

Efficient waste management is a challenge to be faced by today's society. Waste generated at the stage of production is being called post-production waste, it results from production technology and defective products (Woźniak et al. 2017, Nawrocki et al. 2018, Kielec et al. 2018). In the area of production, measures are taken, environmental research is carried out (Lenort et al. 2019), the aim of which is to reduce the amount of waste generated by this sector. One of such activities is the use of 3D scanning and 3D printing technology in the production process

(Jakubowski et al. 2016, Jakubowski et al. 2017, Jakubowski et al. 2018, Królikowski et al. 2019, Królikowski et al. 2019a, Pałka et al. al. 2020). The reduction of post-production waste is in line with the implemented concept of Industry 4.0 (Kostrzewski et al. 2020, Królikowski et al. 2021). Waste generation can also be counteracted by modern technologies (Szajna et al. 2020, Zwolińska et al. 2020, Szajna et al. 2020a, Szajna et al. 2019) implemented in the industry, which are also part of the Industry 4.0 concept.

However, an important element in waste management are urban areas, which have to cope with a significant amount of waste generated by city dwellers (Zajac et al. 2019, Zajac et al. 2019a, Zajac et al. 2020, Zatrochova et al. 2020). The waste generated in this way should be collected and transported (Izdebski & Jacyna 2018), with minimized amount of partially filled transports (Wozniak et al. 2016, Wozniak et al. 2018) and an environmentally friendly transport system (Jacyna et al. 2018) in the scope of the implemented concept of sustainable transport (Chamier-Gliszczyński 2011, Chamier-Gliszczyński & Bohdal 2016, Chamier-Gliszczynski 2016a).

Pursuant to Directive 2008/98/EC, waste management refers to the implementation of processes related to the collection, accumulation, transport and processing of waste. Taking into account the provisions of the directive, waste management covers a number of processes, i.e. segregation $\boldsymbol{SE}$, collection $\boldsymbol{ZB}$, transport $\boldsymbol{TR}$, storage $\boldsymbol{MA}$, recovery $\boldsymbol{OD}$, disposal $\boldsymbol{UN}$, supervision $\boldsymbol{NA}$, which are necessary for the implementation of waste management. Thus, we can write $\boldsymbol{MWM}$ waste management in the form of an ordered set of seven:

$$\boldsymbol{MWM} = \langle \boldsymbol{SE}, \boldsymbol{ZB}, \boldsymbol{TR}, \boldsymbol{MA}, \boldsymbol{OD}, \boldsymbol{UN}, \boldsymbol{NA} \rangle \tag{1}$$

The article focuses on the recovery process, which includes all activities leading to the reclamation of waste in whole or in part, leading to obtaining substances, materials or energy. Pursuant to EU legislation, a recovery process is any activity which does not pose a threat to life, human health or the environment, which leads to the use of waste in whole or in part, recovery of substances, materials or energy from waste and their use. Thus, recovery can be written as a two-element set of processes, i.e.:

$$\boldsymbol{OD} = \{\boldsymbol{OE}, \boldsymbol{R}\} \tag{2}$$

The elements in such a set are the energy recovery process $\boldsymbol{OE}$ and the recycling process $\boldsymbol{R}$.

The article presents analysis of the recycling process, which means the re-processing of waste in the production process in order to obtain substances or materials for primary or other purposes.

The aim of the article is to present selected activities and research that are undertaken towards the implementation of the recycling process in the area of

transport with special focus on the end-of-life vehicle recycling process. The implementation of the goal will be based on the literature analysis of the issue. The research process will use data available on the Scopus and Web of Science platforms.

2. Recycling in transportation

Waste management in transportation is an important element of activities, here – recycling is the most common process. Recycling is a component of two forms of recycling, i.e. product recycling $\boldsymbol{RP}$ and material recycling $\boldsymbol{RM}$, i.e.:

$$\boldsymbol{R} = \{\boldsymbol{RP}, \boldsymbol{RM}\} \tag{3}$$

Product recycling $\boldsymbol{RP}$ consists of recovering parts and components in good technical condition from used products (e.g. end-of life vehicles (ELV)). The elements recovered in such a way become spare parts that can be successfully reused. The recycling defined in this way can be divided into two forms of recovery, i.e.:

$$\boldsymbol{RP} = \{\boldsymbol{RP_B}, \boldsymbol{RP_R}\} \tag{4}$$

The first form is direct product recycling $\boldsymbol{RP_B}$, that is disassembly of parts and subassemblies that can be directly reused. The second form is product recycling in the form of $\boldsymbol{RP_R}$ regeneration, which consists in restoring the functional properties of the recovered part through the regeneration process. It is important that regeneration requires additional expenditure in the form of manpower, the use of appropriate technology and raw materials, as opposed to direct product recycling.

On the other hand, material recycling consists in processing the parts recovered from used products into raw materials. Regarding end-of life vehicles, the set $\boldsymbol{RM}$ can be written as (Chamier-Gliszczyński 2011a):

$$\boldsymbol{RM} = \boldsymbol{MS} \cup \boldsymbol{MN} \cup \boldsymbol{MT} \cup \ldots \cup \boldsymbol{MP} \tag{5}$$

The elements of the $\boldsymbol{RM}$ collection are recovered raw materials, i.e. $\boldsymbol{MS}$ – steel scrap, $\boldsymbol{MN}$ – non-ferrous scrap, $\boldsymbol{MT}$ – plastics, $\boldsymbol{MP}$ – liquid raw materials (fuel, oils, operating fluids), etc.

The implementation of a complex recycling process in waste management allows not only material and energy savings but is also a necessity resulting from the recommendations relating to waste management. The recommendations state that waste generation should be avoided, and if it cannot be avoided, it should be reused for the same or a different purpose. If this is not possible, it should be stored or disposed in an environmentally safe way.

3. Research project

The research project concerns a literature review on the implementation of research in the field of vehicle recycling. The research will be based on the Web of Science and Scopus databases. For the purposes of the research, the end-of life vehicles $\boldsymbol{MRELV}$ model was defined in the form of an ordered five, i.e.:

$$\boldsymbol{MRELV} = \langle \boldsymbol{RS}, \boldsymbol{NS}, \boldsymbol{DP}, \boldsymbol{RR} \rangle \tag{6}$$

The first element of the model is $\boldsymbol{RS}$ research on the treatment of ELV recycling in system categories. Interpreted ELV recycling system is an interrelated system of technical, organizational and human measures, the aim of which is to implement the process of recycling used vehicles.

Another element is research on the construction and organization of the ELV $\boldsymbol{NS}$ recycling network. The ELV recycling network consists of entities that participate in the process of waste vehicle management and a set of characteristics described on the network connections (e.g. financial, material, information characteristics). The purpose of creating the system and network is to minimize the negative impact of used vehicles on the environment and to obtain raw materials for production. The research area related to the ELV recycling system is presented in Table 1, and to the ELV recycling network in Table 2.

Table 1. Research areas for the ELV recycling system

Research area	Source
Development of assumptions for the construction of the ELV recycling system. Interpretation of the system in a block layout.	Chamier-Gliszczyński 2011b
Comparative studies of ELV recycling systems operating in the EU, Japan, Korea, China and the USA	Sakai et al. 2014
Optimization research of the ELV recycling system based on ExtendSim software	Deng et al. 2018
A conceptual approach to the problem of vehicle recycling in China	Yu et al. 2019
Research integrating the ELV recycling system in China in terms of material flow and LCA life cycle assessment	Liu et al. 2020
Research on the ELV recycling process in a systemic perspective	Li et al. 2021
SWOT analysis for the ELV recycling system	Numfor et al. 2021
Analysis of activities in the area of the ELV recycling system in the aspect of extended responsibility of the vehicle manufacturer	Khan et al. 2021

Table 2. Research areas for the ELV recycling network

Research area	Source
Identification of the recycling network in a three-stage system of collection and recycling of used vehicles	Chamier-Gliszczyński 2005
Optimization of the location of enterprises operating within the ELV recycling network with the criterion of total network operating costs	Merkisz-Guranowska 2010
Identification of a two-criteria model for the location of recycling companies, taking into account the preferences of vehicle owners and enterprises	Merkisz-Guranowska 2013
Optimization studies of the location of disassembly stations in the ELV recycling network	Gołębiewski et al. 2013
Research on the business model of SMEs participating and cooperating in the ELV recycling network	Hovest et al. 2016
Optimization research of the recycling network in terms of CO_2 emissions	Xiao et al. 2019
Optimization research on the example of the recycling network operating in Istanbul	Kusakci et al. 2019
Research in the area of ELV recycling network design	Merkisz-Guranowska 2020

The core element of the ELV recycling system and network is the ***DP*** disassembly process, which is the basis for the idea of recovering components and materials from used vehicles. It is the disassembly process that enables product and material recycling. This process is another element of the end-of life vehicles ***MRELV*** model, and the research in this area is presented in Table 3.

Table 3. Research areas for ELV disassembly

Research area	Source
Description and identification of the elements of the disassembly process	Chamier-Gliszczyński 2010
Optimization of the recovery of elements and materials from ELV based on the implementation of the disassembly process	Chamier-Gliszczyński 2011c
Optimization of the disassembly process using the PSO (particle swarm optimization) algorithm	Zhou et al. 2016
Analysis of the storage process as one of the elements in the ELV disassembly station	Kudelska et al. 2017

Table 3. cont.

Research area	Source
Implementation of the method of sustainable resource management at the ELV disassembly station	Kosacka et al. 2017
Research on the disassembly process in the aspect of the concept of sustainable development and analytical evaluation of the process using the AHP method	Zhang & Chen 2018
Research on the development of a line for disassembly of vehicles	Zhang & Chen 2018a
Automation of the ELV disassembly process, implementation of RFID technology	Dia & Zhou 2018
Multi-criteria assessment of the disassembly process as a support for the ELV recycling process	Li et al. 2019
Research on the development of decision-making processes at the stage of disassembly implementation in ELV recycling companies	Czajda et al. 2019
Description of the waste management method in the ELV dismantling process	Kosacka-Olejnik 2019
Sustainable design of a plant with an ELV dismantling line	Li et al. 2021
Optimization of the ELV disassembly process with a description of the individual process steps	Zhang & Liu 2021

Research in the field of ELV recycling is also carried out in relation to individual parts, subassemblies and given materials. Research is also carried out on the development of indicators for assessing the recycling process. In the end-of life vehicles ***MRELV*** recycling model, these studies are identified as other studies relevant to the implementation of ELV recycling. Study identifications in the area of other ***RR*** studies are presented in Table 4.

Tabele 4. Research areas in the category of other ELV recycling studies

Research area	Source
Research on the development of energy storage with the use of ELV batteries	Jajczyk & Słomczyński 2019, Filipiak et al. 2019, Jajczyk & Lorkiewicz 2018
Planning and Management of the Mechanical Assembly Sequences	Sąsiadek et al. 2018

Tabele 4. cont.

Research area	Source
End-of-life vehicle management: a comprehensive review	Karagoz et al. 2019
Optimizing energy consumption in the ELV recycling process	Petronijevic et al. 2020
The State of the Air Quality in Poland	Gabryelewicz et al. 2020
Raw material and environmental safety of industrial processes	Gabryelewicz et al. 2021
Research on the use of robots in the process of recycling batteries from vehicles	Zhou et al. 2021
Modeling the market for ELV recycling	Mohan & Amit 2021
Application of the Deep CNN-Based Method in Industrial System for Wire Marking Identification	Szajna et al. 2021
Research on the implementation of a unique recycling strategy aimed at the simultaneous use of the cathode and anode from waste batteries	Meng et al. 2022

4. Summary

The problem of managing used products with an indication of used vehicles has long been a subject of discussion. It was the European Union that was one of the first to take steps to regulate this issue. The activities focused on regulating the issue of waste collection and its processing in a manner that does not endanger the environment. An important element in these activities is the process of developing end-of-life vehicles. For this purpose, the recovery process has been defined and its components in the form of product and material recycling have been specified. It was also emphasized that the disassembly process is the basic element of recycling. The research process, the results of which are presented in the article, showed that one of the important issues in this regard is the systemic approach to the end-of life vehicle recycling process, the organization of a recycling network and research to improve the ELV disassembly process.

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