USED TIRE MANAGEMENT: AN OVERVIEW, PART II

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Abstract: *This paper is the second and the final part of the review paper, which investigates the used tires management research area. The available system analysis models for the used tires management as well as existing treatment options are reviewed in detail. The distribution list of journal papers published in the period 2006-2017. in peer-reviewed international journals is created to identify primary and secondary publication outlets. Finally, on the basis of the performed review, several important recommendations for the future research are highlighted and briefly discussed.*

Keywords*: review, content analysis, used tires, modeling approach, treatment options.*

1. INTRODUCTION

Rapid social, economic, environmental and technological changes brought human society in front of unprecedented challenges and the need for waste valorization. The problem of managing used tires has become very serious and wide-ranging scientific research efforts are made to reduce their negative impact on the environment. In fact, an effective used tires management is considered vital for mitigating the effect of the continuously growing number of used tires.

This paper is the second and the final part of the review paper, which investigates the used tires management research area. In this part, the available system analysis models for the used tires management as well as existing treatment options are reviewed using the content analysis method. On the other side, in the preceding paper named Used tire management: An overview, part I, legislation-oriented research, industrially tested application alternatives and previous review papers, are identified and systematically analyzed. On the basis of the performed review, several important recommendations for the future research are highlighted and discussed.

2. RESULTS

2.1 Modeling approach

The increased environmental awareness has raised the investigation for economically attractive and environmentally responsive approach to management of used tires. However, the operational research of used tires management systems is still in its infancy and the literature provides only few advanced mathematical models.

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Lebreton and Tuma (2006) developed a linear programming model to assess the profitability of car and truck tire retreading process in Germany. Having in mind that LCA models are becoming important decision support tools of waste management systems, Christensen et al. (2007) created LCA-based model for integrated waste management (including used tires).

Pehlken and Müller (2009) analyzed the separation process of recycling end-of-life (EoL) tires and concluded that modeling such a process is a challenging task, because there are many uncertainties to identify. They highlighted that more research of this matter is needed. Dehghanian and Mansour (2009) proposed a three-objective linear programming model, which is able to simultaneously maximize economic and social benefits as well as minimize environmental impacts, in order to design a network of recycling plants for used tires in Iran. Kannan et al. (2009) formulated a linear programming model for minimizing the costs of a multi-echelon closed-loop supply chain for a tire manufacturer.

Sasikumar et al. (2010) developed a mixed-integer nonlinear programming model for maximizing the profit of a multi-echelon reverse logistics network for truck tire retreading. However, many modeling parameters (e.g. cost parameters) had been identified as deterministic, which limits real-world applicability of this model. Abdul-Kader and Haque (2011) had identified a tire, collection center, recycling plant and retreading plant as "agents" involved in the management of used tires and applied an agent-based simulation approach to tackle the used passenger car tire retreading problem.

Mondaln and Mukherjee (2012) used a simulation approach to plan manpower deployment for labor intensive operations of the tire retreading process. Creazza et al. (2012) formulated a mixed integer linear programming model to optimize logistics network of the tire manufacturer Pirelli. Kop et al. (2012) used the fuzzy Analytic hierarchy process to identify the most efficient EoL tire management option in a Turkish context.

Vinodh and Jayakrishna (2013) applied the fuzzy Analytic hierarchy process for weighting criteria and VIKOR for selecting the best tire retreading process for an Indian manufacturing organization. De Souza and D'Agosto (2013) proposed a conceptual model of the reverse logistics chain of EoL tires and explored financial benefits of their sending to the cement industry.

Pirachicán-Mayorga et al. (2014) analyzed reverse logistics practices in Colombia and proposed a conceptual model of the used tire reverse logistics chain. Dhouib (2014) used the fuzzy MACBETH to assess alternatives in reverse logistics for used tires. Kannan et al. (2014) presented a framework to analyze the motivating factors of EoL tire management in an Indian context and validated it with the assistance of the Interpretive structural modeling. Pehlken et al. (2014) provided a concept for developing a model of EoL tire recycling plant based on Petri nets and neural networks. Dabic-Ostojic et al. (2014) presented a tool based on Bayesian networks for making decisions whether to retread used tires or not.

Subulan et al. (2015) proposed a mixed integer linear programming model for tire closed-loop supply chain and suggested that uncertainty analysis related to various modeling parameters definitely deserves future research efforts. Bazan et al. (2015) presented a reverse logistics mixed-integer linear programming model for minimizing the costs of the tire retreading industry in Canada, which captured the costs for greenhouse-gas emissions and energy usage.

Vorasayan (2016) used the two-player game theory approach to determine prices of a certified retreaded tire with warrantee and a noncertified retreaded tire under cooperative and non-cooperative schemes. Chang and Gronwald (2016) applied four different multi-criteria decision making methods to rank numerous used tires management alternatives and identified retreading as the best option.

Amin et al. (2017) proposed a mixed-integer linear programming model for maximizing the profit of a tire remanufacturing closed-loop supply chain network in Toronto, Canada. They used

a simplistic graphical tool to assess decisions under uncertain demand and returns. Pedram et al. (2017) presented a mixed integer linear programming model for maximizing the profit of a multi-echelon closed-loop supply chain of the tire industry in Tehran, Iran. They used a simple scenario-based approach to represent uncertainties in demand, return rate and quality of used tires. Afrinaldi et al. (2017) proposed a two-objective nonlinear programming model for creating an optimal preventive replacement schedule of a bus tire through minimization of its economic and environmental impacts. Simic and Dabic-Ostojic (2017) developed an interval-parameter chance-constrained programming (IPCCP) model for uncertainty-based decision making in tire retreading industry. The proposed model can examine various admissible risk levels of violating retreading capacities. Compared with the available system analysis models, IPCCP model can incorporate much more uncertain information thus avoiding inferior decisions.

2.2 Treatment options

The primary aim of used tires treatment options is to reduce their negative impact on the environment.

The present rate of economic growth is unimaginable without saving of fossil energy like crude oil, natural gas or coal. If recycling of used tires can be made to function effectively, it represents the most desirable approach. Abdul-Raouf et al. (2009) outlined that recycling of used tires has received much attention in recent years. Wang et al. (2009) presented the current situation on end-of-life tires generation and recycling in China. They analysed the existing industry problems and proposed efficient countermeasures.

Silvestravičiūtė and Karaliūnaitė (2006) analysed the following end-of-life tire treatment technologies: co-incineration in cement kiln, thermolysis, conventional mechanical recycling, baro-destructive mechanical recycling and ultrasound mechanical recycling. Gehin et al. (2008) presented a tool for implementing sustainable end-of-life strategies in the tire development phase. Li et al. (2010) compared four different end-of-life tire treatment technologies in China from environmental and economic perspectives. The following treatment options were evaluated: ambient grinding, devulcanization, pyrolysis and tire oil extraction. Kardos and Durham (2015) outlined the need for discovering additional utilization options for used tires, since stockpiles of used tire in the United States are growing fast. Hita et al. (2016) claimed that pyrolysis of used tires is the most respectful environmental option for treatment of used tires.

One of the most popular approaches for sustainable environmental stewardship of used tires is their retreading. Retreading is especially beneficial for used truck tires, since they could be processed from three to four times. Sharma (2013) described in detail two retreading process, hot and cold, and stated that used tires retreading is profitable business in India. Bazan et al. (2015) found that retreading offers the most resource-efficient strategy for used tires, because it provides the possibility to save both material and energy.

3. DISCUSSION

The distribution list of peer-reviewed international journal papers published in the period 2006-2017 is presented in Table 1.

From the distribution list of journal papers (Table 1) it can be concluded that the primary publication outlets for the used tires management research area are: Waste Management (13.9% share), Journal of Cleaner Production (9.7% share) and Resources, Conservation and Recycling (8.3% share), jointly publishing 31.9% of the total number of identified peer-reviewed international journal papers printed in the period 2006-2017. The secondary publication outlets for the explored research area are: Renewable and Sustainable Energy Reviews (5.6% share) and Construction and Building Materials (5.6% share). From Table 1 it is evident that scientific contribution on the used tires management is increasing, particularly in the last few years. In

fact, approximately two-thirds of all collected research papers are published after 2012. Therefore, the emergence of the explored research area is more than obvious. Finally, in the past several years, numerous top-tier scientific journals have extended their aims and scopes to welcome papers from this research area, like: Progress in Materials Science (IF 2015=31.083), Omega, Expert Systems with Applications, Computers & Industrial Engineering, Applied Mathematical Modelling, Energies.

Table 1. Distribution of journal papers published in the period 2006-2017†.

Journal	Year of publication												Total
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	
Waste Management	–	–	1	–	2	1	1	2	–	2	–	1	10
Journal of Cleaner Production	1	–	1	1	–	–	1	–	–	1	–	2	7
Resources, Conservation and Recycling	–	–	2	2	–	–	–	1	1	–	–	–	6
Renewable and Sustainable Energy Reviews	–	–	–	–	–	–	–	2	–	–	1	1	4
Construction and Building Materials	–	1	–	–	–	–	1	–	–	1	1	–	4
Other (37 journals)	3	2	0	3	2	2	6	1	9	4	7	2	41
Total (42 journals)	4	3	4	6	4	3	9	6	10	8	9	6	72

4. CONCLUSION

In this research (parts I and II of the presented review paper), 72 peer-reviewed international journals papers have been categorized, analyzed and interpreted. Previous figure clearly indicates great relevance and importance of the explored research area.

On the basis of the performed review, the following recommendations for future research are provided:

- The research on *more profitable and ecologically efficient treatment options* represents interesting avenue for further research.
- Uncertainty is the key factor influencing the management of used tires. However, uncertainty analysis is mainly ignored in available research studies. It is strongly recommended to *incorporate uncertainty analysis methods into modeling frameworks*. Only in this way avoidance of erroneous decisions is secured.
- The available system analysis models based on risk-neutral approaches are unsuitable for non-repetitive decision-making problems. Effective *risk measures should be applied* to generate more reliable decision outputs.

Finally, we acknowledge that this review cannot be claimed to be exhaustive due to enacted limit in paper's length, but it does provide comprehensive insight into the state-of-the-art literature on the used tires management. Therefore, this review could provide valuable source of references for other researchers as well as extensive content analysis overview for readers interested in the highlighted research area.

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† All reviewed papers (parts I and II of the review paper) are included in the presented distribution list.

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