DECISION TREE AS A TOOL FOR DECISION MAKING IN RETREADING TIRE TECHNOLOGY

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Abstract: In modern business, more and more production companies are taking responsibility for the products at the end of their exploitation. For this reason, in the realization of all logistics activities, the emphasis is placed on increasing the degree of reusing products. Among such products are tires. They belong to the category of expensive vehicle parts that are usually changed several times during the lifetime of vehicles. The most popular and increasingly implemented treatment of used tires is retreading. It is the procedure of replacing the spent tire tread with new ones. Tire retreading is an economically attractive and environmentally beneficial process for extending the lifetime of used tires. Research has shown that the efficiency of retreaded tires depends on the type of tires, type of vehicle, tire manufacturers, but also on retreading technologies implemented. The aim of this paper is to provide support in decision making when retreading tires for commercial vehicles, from the aspect of selecting the retreading technology (brand). Applied technology of retreading tires can have a significant impact on the business effects of large transport companies; thus, the paper analyzes some exploitation parameters related to the economic aspect of this process - costs of labor and energy consumed for retreading. Using tools based on the decision tree, the paper has created a basis for making the decision on selecting the retreading technology, with the respect of retreading technology capacity, as well as investment costs, which are important for a company introducing an additional activity related to the regular maintenance of its vehicles in the business. For that reason, respecting economical and ecological sustainability leads to selecting the technology that requires lower energy consumption as well as an increasing degree of humanity processes.

Keywords: used tires, retreading, technology, decision tree

1. INTRODUCTION

In modern business, the imperative for the survival of every business entity is focused on respecting the ecological, economic and social sustainability in all segments of the supply chain. The main objective is that each product has a possibility of further exploitation at the end of its life cycle, with the emphasis on increasing its level of reproducibility. The result of this demand is that an increasing number of manufacturers have an additional activity related to extending the responsibility for their products. Manufacturers have an obligation to take responsibility for their products by
implementing an appropriate treatment at the end of their service life, which is in accordance with the laws of the European Union (EU). In the Extended Producer Responsibility (ERP) program, at first, there were only the ones who manufactured multicomponent and expensive products, and then they were followed by those with the possibility of extending their exploitation period.

Among the products that are designed to be repaired, with some of their parts that can be renewed in order to prolong the life of their exploitation, are vehicles. Vehicles are complex products, made of different materials, with a large number of components and parts. Components of vehicles with a significant economical and ecological influence at the end of their working life are tires. In the past few decades, the emphasis has been on their further use. During the exploitation, a tire with a worn tread can be processed in a certain manner to allow its reuse; that process is called retreading.

When the tire for some reason has to be replaced, there are various types of treatments. The legislation prohibited the permanent disposal of tires to a landfill because the period of their decomposition is over 150 years long (Dabić-Miletić and Miljus, 2018). For this reason, it is necessary to apply one of the following types of appropriate treatment: regrooving (which deepens the tire tread, unless it is completely worn-out; this procedure is performed only once in the commercial vehicle tires, using the appropriate tools), retreading, recycling, pyrolysis, and burning (as a heat source usually found in cement kilns). Retreading represents one of tire treatments whose aim is to extend the lifetime of their exploitation (Dabić-Ostojić, 2014). This process reduces the negative influence of used tires on the environment as well as natural resources exploitation.

Tire retreading is an economically attractive and environmentally beneficial process for extending the lifetime of used tires. It reduces the negative influence of used tires on the environment as well as natural resources exploitation. The decision to retread tires is affected by a relatively large number of parameters. Although it has already been theoretically and practically proven that retrieval is justified, both from the economic and environmental point of view, there are numerous questions related to this procedure: which types of tires to protect, which technology to use, which parameters to consider, etc. When a company that has a significant number of commercial vehicles in its fleet makes a decision to protect tires, there is often a very important next decision related to selecting the appropriate retreading technology. Using the approach based on a tool called the decision tree, this paper presents the analysis for the selection of one of two retreading technologies. For decision making on retreading technology, the analysis is based on labor costs and consumed electric energy, respecting the capacities of the retreads, as well as the investment costs for the retreading plant.

The paper is divided into several parts. After the introduction, a brief overview of the literature related to research in the field of treatment of used tires is presented, with the emphasis on retreading. The literature that uses the Decision Tree (DT) as one of the methods in making business decisions is particularly analyzed. After that, the characteristics of the retreading tires process are depicted through analyzing some parameters related to the increase in the number of tires in exploitation, respecting a growing emphasis on the reproducibility of used products (here retreading commercial vehicle tires). The fourth part of the paper is the main one and consists of several sections. First, the retreading technology is briefly explained. In a special section, the
basis for the choice of the retreading technology by using the DT is established. At the end, the obtained results are discussed. In conclusion, concrete and final considerations related to the problem of elective technology are provided, with a particular emphasis on the directions for future research.

2. LITERATURE REVIEW

The literature analysis demonstrates that many authors have dealt with the problems related to the logistics activities in the field of used tires management. The treatment of used tires is becoming a higher challenge for experts in this area. A significant number of authors analyze problems in the domain of treatment of used tires, with special emphasis on retreading. This form of treatment allows for an extension of their exploitation period, which is of relatively high importance from the economic and ecological point of view.

The used literature review is generally systematized in two parts. The first part considers the problems in the field of management of used tires. The second part explains the DT approach and its use, place and role in decision making in retreading tires management.

Considering the research in the domain of the treatment of used tires, including retreading, it can be concluded that these issues have become very contemporary in recent decades. Among numerous researches, only some of the publications that have been published so far are presented here. In this context, it is necessary to point out that Ferrer (1997) assumes that the lifetime of the tire does not depend on the number of the retreading operations; the number of retreading tires for commercial vehicles is unlimited. Beukering and Janssen (2001) assume that retreaded tires travel the same distance as the new ones. The complexity of the problems in the field of used tires has led to the publication of a significant number of studies in it. Two review papers were also published (Dabić-Ostojić et al., 2017 and Simić and Dabić-Ostojić, 2017). In these studies, 72 peer-reviewed international journals published in the period between 2006 and 2017 were categorized, analyzed and interpreted. The stated number of journals clearly indicates the great relevance and importance of the explored research area.

Problems in the retreading area are numerous, so different systems, tools, and methods of Decision Support Systems (DSS) are used in all segments in this field. One of the developed models uses conditional probabilities as input parameters in order to solve the problem of decision making on the number of cost-effective retreadings. The obtained results show that the retreading is economically efficient up to the traveled distance of the retreaded tire, in which the cost per km is lower than the one when the new pneumatic is used (Dabić-Ostojić et al., 2014; Dabić-Miletić and Miljuš, 2018). Conventional approaches are based on the fact that every tire can be potentially protected. The modern approach is based on formulation models that have the ability to include a significant number of parameters characterized by uncertainty in decision making. Simić and Dabić-Ostojić (2017) developed a model that has the ability to examine different permissible levels of risks related to the capacity of the retreading plants. Continuing the previously described research, the challenge is to develop a model that has the ability to consider the effects of external influencing factors that relate to complex economic, environmental and social aspects of systems for the used tires.
management (Simić et al., 2017). Many authors use a combination of different approaches for making a decision on retreading. The aim is to develop models that include greater number of parameters that are characterized by the uncertainty in the decision making related to retreading, so that the treatment could be justified from different and numerous aspects.

When a company decides to protect the tires of its vehicles, it is necessary to select a retreading technology. Assuming that every technology is certified, there are numerous influential factors that determine the company's choice of the technology: investment costs, implementation period, retreading capacity, the degree of utilization, the level of implemented technology, etc. This paper presents the initial research related to the selection of the retreading technology. For the purpose of the research in this paper, the costs of labor and the consumption of (electric) energy were analyzed when deciding between one of two analyzed retreading technologies. One of the many methods that were used for this study was based on the application of the DT approach.

DTs find use in many different disciplines, including medical diagnosis, cognitive science, artificial intelligence, game theory, engineering, and data mining. Many authors deal with its structure analyses, forming methods and techniques applied in structuring; between them are Olaru and Wehenkel (2003) who present and analyze the possibility of fuzzy DT use, as well as Olivas (2007) who deals with the methods of the tree forming in general. Cho et al. (2002) suggest the methodology that is based on a variety of data mining techniques such as web usage mining, DT induction, association rule mining, and the product taxonomy. Huercio et al. (2003) developed an algorithm based on a DT analysis for production control. In this paper, a reactive scheduling algorithm is presented, which adapts the current schedule to real-time disturbances, integrated to a supervisory system capable of handling the new schedule generated, thus filling the existing gap between high production scheduling and low sequential control levels in the Chemical Process Industries. Boustani et al. (2010) use the DT approach in order to decide whether to buy new tires or to treat the old ones. They illustrate the DT for evaluating the energy benefits of retreading. Sheu et al. (2008) use DT for online group buying consumers' behavior. Starr (2002) uses DT methodology successfully to capture elements using data from a larger study of product development in the world auto industry. Kim et al. (2011) use DT for data evaluation using the number of decisions that are different from the optimal solutions of the slower dynamic programming solution method. It can be pointed out that decision making in the area of tires retreading is poorly treated in the literature. This tool was successfully used by Dabić et al. (2012) to make a decision on selecting the tire manufacturers. The analysis is performed on the concrete sample of tires for commercial vehicles of one of the largest companies for public city passenger transportation in Serbia, “JKP GSP Beograd”.

3. CHARACTERISTICS OF THE RETREADING PROCESS

The analysis of numerous studies in the field of car industry demonstrates that vehicles have a large negative environmental impact on our everyday lives, as well as significant participation of the world's capital in the vehicle industry. The total number of vehicles at the world level has been over one billion units for a long time. The first time this number was mentioned was in 2010, which is, compared to 2009, an increase of 3.6%, or the highest annual increase in this century (Dabić-Ostojić, 2014). It can be concluded
that the increase in the number of manufactured vehicles influences the increase in the number of tires in use. At the same time, the number of tires that have to be removed from the vehicle during its exploitation has increased.

Tires have an important share in the exploitation costs of commercial vehicles, and particularly in fleets of companies transporting passengers and goods. The tire usage time is significantly shorter than the period of the vehicle’s exploitation. When the tire tread is worn-out to a certain depth defined by legislation (1.6 mm), it is necessary to replace it. This procedure belongs to the category of regular vehicle maintenance (Dabić-Miletić and Miljuš, 2018). According to the latest data, the world annually generates approximately 1.8 billion used tires, indicating their growing influence on environmental sustainability as one of the key imperatives of successful business operations (Dabić-Miletić, 2018; www.maschinenmarkt.vogel.de/recycling/articles/, accessed 12/01/2018).

Management of used tires is globally a crucial environmental problem (Labaki and Jeguirim, 2017; Hashemi et al., 2014; Oikonomou and Mavridou, 2009). There is a strong motivation to successfully manage this fast-growing waste flow since used tires are not biodegradable. One of the most popular approaches for sustainable environmental stewardship of used tires is retreading.

Retreading is one of the most popular ways in ecologically sustainable management of used tires (Simić et al., 2017). Retreaded tires are used tires that have undergone a process designed to extend their service life (Boustani et al., 2010). At an acceptable processing cost, tire retreading successfully takes full advantage of the value that remains in the used tires. In this process, used tires are subjected to a sequence of value additive operations and are converted to reusable ones (Mondaln and Mukherjee, 2012).

Retreading represents a group of activities performed in order to apply a new tread in the pneumatic prepared, and to prolong its exploitation period. Two technologies of retreading – setting up a new tread on a prepared tire – are being applied, namely, cold cure and hot cure retreading. Cold cure retreading is the process used for tires of commercial vehicles. This process can be repeated several times since it does not influence the structure of a tire. It is performed by applying a new tread on a tire in the form of a ring (Figure 1a) or strip (Figure 1b), and then such a tire is placed in special chambers where the pasting procedure of a new tread is completed. In commercial vehicle tires, cold retreading involves the application of a new tread on the tire at temperatures below 100°C, which is accomplished in special chambers (autoclaves). The methods of applying the tread on the tire depend on the retreading technology and have no impact on the quality of the tire.

![Figure 1. Types of treads (Dabić-Ostojić, 2014)](a) Ring shape  (b) Strip shape
In practice, it has been demonstrated that 60 to 70% of used tires with a worn tread are retreadable (Dabić-Ostojić, 2014). It is important to point out that the retreaded tires, according to their techno-exploitation characteristics, can be compared to the new ones, with special attention being paid to the safety in exploitation, which has been particularly emphasized in previous studies (Dabić-Miletić, 2018). Therefore, it is increasingly insisted on the implementation of this treatment in companies with a significant number of commercial vehicles, as well as in the increase in the number of retreaded tires in exploitation.

In a number of studies, it has been argued that after each retreading, the traveled distance is reduced. The key parameters that are usually analyzed when making a tire retreading decision are: traveled distance of a tire (the new one, after the first retreading, total traveled distance...) and retreading number. In addition to these parameters, the conditions of exploitation (driving mode, vehicle load, road type...), information on the tire manufacturer and others are very important.

It can be assumed that two key parameters are random values, since they depend on a number of factors (manufacturer, driving conditions, road quality, type/load of the vehicle, mode of driving...). In order to verify this assumption, a detailed analysis of a significant sample of written-off bus tires in one of the facilities of the company “GSP Beograd” has been performed for two manufacturers—“Sava” (506 tires) and “Kormoran” (547 tires).

Based on the values from Figure 2a, it can be noted that the number of retreadings of “Sava” tires is a random value with the mean $\mu_{\text{Sava}} = 1.59$ (retread/tire). The hypothesis on the accordance of the described empirical distribution with the Poisson probability distribution law is confirmed by the Chi-squared test ($\chi^2 = 2.227$).

For “Kormoran” tires, a significantly different distribution of retreadings per tire is noted (Figure 2b). The mean value is $\mu_{\text{Kormoran}} = 0.63$ (retread/tire), while the hypothesis on the accordance of the described empirical distribution with Poisson probability distribution law has not been confirmed. This demonstrates a significant difference between the exploitation parameters of those two manufacturers. Also, it is necessary to point that there are cases where a new tire, due to some damages, cannot be retreaded (in Figure 2 these are the frequencies for values of the random variable equal to 0). For “Sava” tires this probability is $p_{0,\text{Sava}} = 104/506 = 0.206$, and for “Kormoran” tires $p_{0,\text{Kormoran}} = 249/547 = 0.455$ (Dabić and Mijuš, 2013).
Analyzing the results obtained on a realistic sample from two manufacturers, it can be clearly seen that the number of economically justified retreading of "Sava" tires is higher than that of "Kormoran". If only the number of cost-effective retreadings were considered when selecting the type (brand) or tire manufacturer, it is clear that the company would decide to acquire "Sava" tires because they can be protected as many as 5 times, while the pneumatic producer "Kormoran" can be retreaded not more than 3 times. The analysis displays a drastic reduction in the number of tires that can be retreaded.

When the company decides to retread the tires of their vehicles in order to achieve economic savings, there are numerous questions. One of many is related to the selection of technology that will be implemented in this process. Therefore, in the following parts of the paper, the emphasis will be on the selection of an appropriate retreading technology.

4. MAKING DECISIONS ON TIRE RETREADING TECHNOLOGY

For the purposes of business decision making, a significant number of methods, techniques, and tools have been developed so far. In order to solve various and increasingly numerous problems in the domain of managing the used products and/or their parts, quantitative methods are being developed, and they are generally divided into single-criterion and multi-criteria ones. Logically, every decision is better if a multi-criteria approach is applied. One of the most commonly used approaches is based on the application of a tool called the DT (explained in Section 4.2).

This part of the paper is organized in several sections. The first of them briefly explains one of the most commonly used retreading technologies, "Bandag". For the purposes of research in the paper, every activity taken in this technology is explained. The problem solved in this paper is related to the choice of retreading technology from the aspect of some groups of costs (labor and consumed energy). In order to choose the retreading technologies, the cost of retreading plants (including equipment: machines, tools, energy consumption, etc.) and their capacity have been respected, and analyzed in detail in the second part of this paper. At the end of this part, the obtained results are discussed. These results are the basis for the main conclusions related to decision making in the tire retreading technology.

4.1 The technology of retreading tires

The tire's life is usually shorter than the vehicle's exploitation period. When the tire lifespan is over, its replacement is necessary. On a question that has been asked (for a long time) - "What to do with tires that have been removed from the vehicle?" - the answer has long been provided (see Introduction). According to the classification of used products, parts, and materials, tires belong to the category of hazardous waste, and they have a (unique) catalog number 16 01 03, defined by the Catalog of Waste by the Ministry of Environment and Spatial Planning and the Environmental Agency (http://www.sepa.gov.rs/download/Otpad/OtpadKatalogOtpada.pdf, accessed 11/01/2019.). Therefore, when used tires are for some reason found to be removed from the vehicle, they have to be treated (in some way). In practice, there are various kinds/forms/types of treatment: regrooving, retreading, recycling, pyrolysis, and
burning. The explanations of these treatments are not the focus of this paper, and a more detailed analysis of every treatment can be found in previous studies investigated by the authors (Dabić-Miletić and Miljus, 2018; Simić et al., 2017; Dabić-Ostojić, 2014, etc).

A retreaded tire has the same features as the new one, regarding the aspect of reliability, safety, durability, capacity, and vehicle load. The only condition that has to be respected for retreaded tires is their use and treatment, the same as for the new ones (regular maintenance, tire pressure check, load-bearing constraints, driving and road conditions). Retreading technology has improved over time, so that the retreaded tires are hardly recognizable when compared with the new ones, except for a label that is printed on the outside - the basis of the tire (stating it has been protected, the date, the country in which the retreading was carried out, the technology type, the number of previous retreadings, etc).

Tire retreading is performed by certified technology. Every technology is characterized by a significant number of control activities (after almost every operation). However, the main problem that may cause prudence in the purchase of tires is the lack of users' confidence, or insufficient information on the retreading technology and the quality of the retreaded tires, which is a consequence of the relatively poor market promotion. The motive for improving the field of market activities can be found in the fact that the guarantee for the retreaded tires is the same as for the new ones (according to all criteria).

For the purposes of this research paper, it is necessary to know the basic steps in retreading technology. One of the very famous retreading technologies is "Bandag", and it is also used for bus tires in one of the facilities of "GSP Beograd". Some of the basic activities of this technology (Figure 3, Dabić-Miletić and Miljuš, 2018) are briefly explained (https://www.bandag.com/en-ca/why-retread, accessed 12/01/2019):

1 - Initial inspection: when used tires arrive in the tire retreading plant, they are unloaded from large trailer trucks and sent for storage; every used tire planned for retreading is initially inspected to determine whether it is reusable, retreadable, as is or EoL (End of Life) (e.g. tread depth is too low, tire is significantly damaged, etc);

2 - Visual inspection: retreadable tires are visually inspected by the trained specialists using proper equipment, thus trying to identify any damage missed during the initial inspection; only tires that pass this activity are forwarded to next inspection;

3 - Shearography inspection: this is an advanced nondestructive inspection procedure based upon shearography cameras; in this way, it is possible to determine even the smallest anomalies in tire structure under forced conditions of exploitation (e.g. holes, stitches, etc.);

4 - Buffing: this procedure mechanically removes the tread and corrects deviations in the circumference of the tire;

5 - Filling repair: buffed retreadable tires are sent to the filling repair activity to clean them off, to fill their remaining minor damage, and eventually restore the original strength of their casing;

6 - Final preparation: applying the thin layer of adhesive mass around cleaned tire casing;
7 - Building: retreadable tire prepared for the building is mounted on a machine that rotates at a certain speed and applies pressured tread rubber around the circumference of its casing accurately and consistently;

8 - Enveloping: retreadable tire with new tread is firstly placed inside the outer envelope before the inner envelope is fitted into it; (clearly: to serve as a wrapping or covering for...; to surround entirely);

9 - Curing (for this type of technology, capacity is 22 tires/300min): enveloped tires are vacuumed out and sent to curing at a moderate temperature and pressure that adheres new treads to them;

10 - Marking tires: putting the mark on the retreaded tire;

11 - Final inspection: the last activity of the tire retreading process; it assures that only the labeled retreaded tires that meet rigorous industry quality standards and customer demands are allowed to leave the tire retreading plant.

Figure 3. Basic steps in retreading tires, "Bandag" technology
(Dabić-Miletić and Miljuš, 2018)

Based on the analysis of activities in the "Bandag" retreading technology, general conclusions and assumptions that characterize every retreading technology can be made with:

- line production/processing, with the tire successively moving from one workplace to another;
- a high degree of stochasticity at all levels and in every segment of all retreading technologies;
- a significant number of control activities in order to register any deficiencies due to the retreading process as soon as possible; although it is permanently insisted
on the automation of industrial processes and the human aspect of the realization of every modern business branch (related to Industry 4.0), it is necessary to secure the presence of an operator in retreading plants, mainly for the control activities of both the machine operations and the tires in the retreading process.

When a company that has a significant number of commercial vehicles in its fleet makes a decision to retread tires, the next step is to select a tire manufacturer and the type of retreading technology. The choice of the manufacturer has already been discussed. However, the question that very often arouses is the one about the selection of a retreading technology. Based on the survey conducted among the employees in the company GSP Beograd, the choice of "Bandag" technology is randomly made. The selection criteria has been primarily related to the positive experiences in the application of this technology, but also to the number of vehicles, i.e. the number of retreaded tires. A description of the activities in the "Bandag" technology is presented in Table 1.

| ORDINAL NUMBER OF THE PROCESSES (i) | PROCESSES (short explanation) | DESCRIPTION PROCESS (necessary elements/entities for the process) | MEAN VALUE OF THE CAPACITY PER PROCESS \(m_i\) (TONES/H) | \(P_i\) (PROCESS PROBABILITY) |
|-----------------------------------|-------------------------------|---------------------------------------------------------------|-------------------------------------------------|--------------------------------|
| 0                                 | Storages                      | /                                                             | /                                              | /                              |
| 1                                 | Initial inspection            | 1 worker                                                      | 1.67                                           | 0.50                           |
| 2                                 | Visual inspection             | 1 worker, machine, energy                                     | 2.08                                           | 0.75                           |
| 3                                 | Shearography inspection       | 2 workers, machine, energy (x5)                               | 5.00                                           | 0.65                           |
| 4                                 | Buffing                       | 1 worker, machine, energy (x2)                                | 3.33                                           | 0.75                           |
| 5                                 | Filling repair                | 1 worker, machine, energy, material (old and thin rubber)     | 2.50                                           | 0.85                           |
| 6                                 | Final preparation             | 1 worker, machine, energy, material (adhesive)               | 1.25                                           | 1                              |
| 7                                 | Building                      | 1 worker, machine, energy (x4), material (rubber)            | 2.50                                           | 1                              |
| 8                                 | Enveloping                    | 1 worker, machine, energy                                    | 1.67                                           | 1                              |
| 9                                 | Curing (300min/22 tires)      | 3 workers, oven, energy (x10), 5 hrs                         | 1.14                                           | 0.95                           |
| 10                                | Marking tires                 | 1 worker, tool(s)                                             | 1.14                                           | 1                              |
| 11                                | Final inspection              | 1 worker                                                      | 1.14                                           | 1                              |

4.2 Selecting the retreading technology using the DT approach

Nowadays, there are numerous certified retreading technologies on the market. The differences in technologies are related to the volume of initial investments in them, following the number of activities that every machine can perform in the process (more modern machines perform more activities, though they are also more expensive).
Significant differences are also found in the capacity of the represented technologies (a number of retreaded tires per time unit).

This paper is the initial research related to the selection of the tire retreading technology. For this purpose, a model based on DT has been developed. A decision tree is a diagram used to describe decision alternatives and chance events. A decision strategy is a particular branch path in a DT and includes all the decisions and chance events along that branch path. DT generally includes two or more possible decision strategies. One decision strategy is generally found to be the “preferred decision strategy”, since decision strategies can be compared by computing their respective Expected Values (EV). Decision tree analysis is the process of evaluating decision alternatives emanating from the root node. The analysis requires calculating and then comparing the expected values. The analysis can also involve making adjustments to probabilities and payoff values to determine how changes to those values may affect the expected values.

In this paper, the developed model testing was performed with respect to real conditions and parameters related to two cost groups in the retreading technology. It was necessary to calculate the EV for any chance node by summing together all the EVs for each branch connected to the node. In order to count EVs and to decide accordingly, the following input data are required:

- The weight of a single tire is 40kg; for the purposes of calculation and due to the shape of the tire, the capacities are presented in tons/hour
- The mean value of the capacity of each workplace - \( m_i \) (tons/hour) (“Bandag” retreading technology, Section 4.1, Table 1) and \( m_j \) (“Marangoni” retreading technology, Section 4.2, Table 2)
- The probability that after the i-process the tire will be retreadable (\( P_i \)) (the probability that after the i-process the tire can be sent to the next one \( (i+1) \), because there were no defects, errors, deformities, etc. identified, which would exclude the tire from the retreading process) (Section 4.1, Table 1 and Section 4.2, Table 2);
- Retreading is a complex waste management system with many of its components being uncertain. Fluctuations in time of operational capacities of all retreading entities (i.e. initial inspection, visual inspection, shearography inspection, buffing, filling repair, final preparation, building, enveloping, curing, labeling and final inspection) are caused by the variations of used tire type and shape as well as equipment and labor conditions. Actually, the operational capacities of retreading entities, observed as random uncertainties, are fixed with a level of probability that reflects the risk of violating the uncertain retreading capacity constraints (Simić at al., 2017); for these reasons, probability values were adopted based on empirical research and analysis of all activities in the retreading process.

The general formula for calculating \( EV \) at any chance nodes is given as:

\[
EV_{\text{chance node}} = EV_{\text{branch 1}} + EV_{\text{branch 2}} + \ldots + EV_{\text{branch N}} = (1)
\]

There are several key facts that are respected for calculating EVs, and they are:

- Labor costs in the waste management sector - independent variable of retreading technology, constant \( \text{(26.7} \text{ €/hour)} \) (Eurostat, 2018a,
http://epp.eurostat.ec.europa.eu
(http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=lc_lci_lev&lang=en, accessed 17/03/2019) (A – in formulas (2) and (3));

- Costs of consumed energy at every step of the process (0.1€/tire; they depend on the type and device capacity (the number of tires being processed in time) at a particular workplace (Table 1 and Table 2 show the level of multiplication, e.g. Table 1, Shearography inspection, energy (x5)) (Eurostat, 2018b. https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics, accessed 20/03/2019) (B - in formulas (2) and (3));

- Material costs, or costs of a new tread 14 €/tire (Bandag technology), 11 €/tire (“Marangoni” technology) (C - in formulas (2) and (3));

- Retreading technologies differ in the number of logistics activities, the method of the process development, the machines that are used for certain operations (e.g., at some workplaces/machines several operations can be performed);

- The basic differences in these technologies are: the number of simultaneously vulcanized tires (the autoclaves capacity), as well as the separation and/or unification of the operations carried out between two basic steps (shearography inspection and vulcanization/curing), which are usually completed by the machines that require the largest investment.

The paper analyzes the choice of one of the two proposed retreading technologies. A description of the activities in the other one is provided in Table 2. Respecting the mentioned facts, the sum of all EVs for each activity gives the total cost value achieved by applying the appropriate retreading technology:

- Labor costs, prices of energy and materials used for retreading (the new tread per tire, the additional material) are fixed, regardless the technology;

- According to the result (cost values), a decision is made to choose the technology with lower operating costs (labor and energy consumption).

Based on the information available and relating to the characteristics of the Bandag technology (Table 1), the formula for calculating EV is:

\[ EV_{\text{Bandag}} = \sum_{i=1}^{n} P_i \cdot (A + B(\text{material}) + C) = \]
\[ 22.30€ + 42.55€ + ... + 30.44€ = 882.52€ \]

The same procedure for ”Marangoni” retreading technology tires results with the following formula:

\[ EV_{\text{Marangoni}} = \sum_{j=1}^{n} P_j \cdot (A + B(\text{material}) + C) = 708.38€ \]

Some important assumptions for making a decision include the following:

- The result with the lower costs, i.e. the lower total value of EVs points to the retreading technology which should be selected for the tire supply chain management;

- The analyses include only a part of the total costs that appear in the retreading plant activities, and they are related to labor costs (in this kind/type of process) and energy spent in the retreading process.
### Table 2. The description of the “Marangoni” retreading technology process²

| ORDINAL NUMBER OF THE PROCESSES (j) | PROCESSES (short explanation) | DESCRIPTION PROCESS (necessary elements/entities for the process) | MEAN VALUE OF THE CAPACITY PER PROCESS \(m_j\) (TONES/H) | \(P_j\) (PROCESS PROBABILITY) |
|-------------------------------------|-------------------------------|---------------------------------------------------------------|-----------------------------------------------|---------------------|
| 0                                  | Storages                      | /                                                             | /                                             | /                   |
| 1                                  | Initial inspection            | 1 worker, machine, energy                                     | 5.00                                          | 0.60                |
| 2                                  | Shearography inspection       | 2 workers, machine, energy (x5)                              | 3.13                                          | 0.50                |
| 3                                  | Buffing                       | 1 worker, machine, energy (x2)                               | 2.50                                          | 0.75                |
| 4                                  | Repairing                     | 1 worker, machine, energy, material (old and thin rubber + adhesive) | 2.08                                          | 0.90                |
| 5                                  | Building                      | 1 worker, machine, energy (x4), material (rubber)            | 2.50                                          | 1                   |
| 6                                  | Monorailing³                  | 1 worker, machine, energy                                    | 1.67                                          | 1                   |
| 7                                  | Curing (300min/15 tires)      | 3 workers, oven, energy (x10), 5 hrs                         | 1.67                                          | 0.95                |
| 8                                  | Labeling/marketing tires      | 1 worker, tool                                                | 1.67                                          | 1                   |
| 9                                  | Final inspection              | 1 worker                                                     | 1.67                                          | 1                   |

The results obtained by using the DT approach to select the retreading technology are presented in Figure 4. It can be concluded that the "Marangoni" retreading technology is more economically suitable in comparison to "Bandag".

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² The casings (basic tire structure) are handled in such a way as to prevent any contact with impurities and debris, using a made-to-measure monorail that, exploiting a double envelope system, ensures maximum adhesion of new parts to the casing.
4.3 The analysis and discussion of final results

In this paper, one of the ways for selecting the retreading technology has been shown (using the methods based on DT). The aim is related to selecting one of the two proposed technologies. The operating costs of the "Bandag" and "Marangoni" technologies have been analyzed in detail. Capacities, as well as the investment costs (for introducing the new technology), have been taken into consideration.

Capacities are significantly different; thus, by using the Bandag technology, 22 tires can be protected simultaneously, while by the "Marangoni" technology, the number reaches 15 tires (the duration of the new tread adhesion process on the prepared tire is the same for both technologies and lasts for 5hrs). If another technology was used, the capacity (and the time of vulcanization) would differ in comparison to the analyzed two (Simić and Dabić-Ostojić, 2017). Having in mind this fact, two technologies that require the same time of vulcanization have been analyzed in this paper. The operating costs of...
each technology are expressed in accordance with the mean capacity value of every machine/process per ton of tires.

The results of the research exhibit the following: when applying the "Bandag" technology, the labor costs and the energy consumed for retreading 1 ton of tires (cca 25 tires) are estimated at € 822.52, while with the use of the "Marangoni" technology, the costs are estimated at € 708.38. The difference in costs shows that the retreading according to the "Marangoni" technology is more than 15% cheaper when compared to the one according to the "Bandag" technology. Of course, this only refers to reducing labor costs and consumed energy in the process (per ton of tires). However, from the capacity aspect, the "Marangoni" technology simultaneously vulcanized 15 tires, as opposed to the "Bandag" technology that can perform a simultaneous retreading process for up to 30% more tires (22 tires). The conclusion is that the technology with greater retreading capacity is more expensive. Considering other factors, such as the number of activities included in the retreading process ("Bandag" 11 activities, "Marangoni" 9 of them), and the cost of a new tread ("Bandag" 14€/tire, "Marangoni" 11€/tire), the preference is for the "Marangoni" technology.

In this paper, the choice of retreading technology is considered only from the aspect of two mentioned parameters. However, some of the parameters could be considered in relation to the need for retreading, as well as the size of the company that introduces the retreading process (the number of commercial vehicles), the type of the logistics activities, etc. Those parameters need to be included in future studies.

5. CONCLUSION

This paper represents the initial research in the field of selecting the optimal retreading tire technology. The problem of decision making on one of the two analyzed retreading technologies, which are most often applied in practice, was solved. As the input data, the capacities of every machine/activity were used, but also the probability that after a certain activity, the tire would be sent to the next activity if there are no damages that would exclude the tire from entering the retreading process. It is necessary to emphasize that this is a certified technology, which indicates that the retreaded tire guarantee is the same as for the new ones and that this process can generate significant savings in a transport company. The implementation of another activity (retreading: space, equipment, etc.) requires a notable investment, which is also discussed in the paper. The size/volume of the investment depends on the price of the machine (stochasticity), which means that some of the existing machines in the retreading plant can be exchanged for the new, more productive ones. Every machine requires significant energy consumption, and the presence of workers in the retreading process is inevitable, bearing in mind the fact that during and after any operation, a detailed inspection of the processed tires is performed. Therefore, the selection of the technology is based on the operating cost of the retreading plant, respecting two parameters: labor costs in the waste management sector (26.7 €/workhour) and energy price unit (0.1 €/tires). Logically, the energy consumption for every process/machine is not the same, and there is also a variation in the number of workers engaged in analyzed technologies.

Considering the obtained results, and according to the currently available data, the decision is to introduce the "Marangoni" retreading technology as the new one. Of
course, this decision may be influenced by other numerous parameters that have not been considered in this paper: the needs and capabilities of the company implementing retreading, available resources, the benefits and costs ratio, etc. Bearing in mind the rapid development of science and technology, the future studies should focus on considering some newer retreading technologies, the degree of their presence, and the possibility of extending and upgrading every operational activity in the retreading plants, etc., which involves analyzing other parameters with a significant degree of stochasticity.

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