LogForum
> Scientific Journal of Logistics <
2020, 16 (1), 171-181
http://doi.org/10.17270/J.LOG.2020.386
http://www.logforum.net p-ISSN 1895-2038 e-ISSN 1734-459X
ORIGINAL PAPER

RECOVERY ALTERNATIVES DECISION BY USING FUZZY BASED PREFERENCE SELECTION INDEX METHOD

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ABSTRACT. **Background:** The electrical and electronics sector has become one of the rapidly developing and growing sectors, as a result of technological and economic developments. Rapid changes in consumer demands and needs have increased the use of electrical and electronic equipment and shortened product life cycle, resulting in an increase in equipment waste. Therefore, recovery alternatives for electrical and electronic equipment waste should be considered subject. The aim of this study is to evaluate the recovery alternatives of electrical and electronic wastes and to determine the best.

Methods: Multi-criteria decision-making techniques used to select the best among multiple alternatives have many application areas. The selection of recovery alternatives based on criteria includes some fuzzy topics. For this reason, the fuzzy logic approach was used to evaluate the answers of the decision makers and the fuzzy numbers obtained were analyzed by PSI method and criterion weights were determined and alternatives were listed.

Results: According to results of analysis, social responsibility and environmental awareness criteria have the highest values for selecting recovery alternatives. In addition, remanufacturing, regeneration and recycling take the first place among the alternatives.

Conclusions: Recovery of electrical and electronics waste is an important subject in current conditions. Alternative methods vary from reuse to incineration, but correct choice of recovery techniques rely on multi criteria and decision should be made adhering to them.

Key words: recovery, multi-criteria decision-making, fuzzy, preference selection index.

INTRODUCTION

As a result of technological and economic developments in recent years, the electricity and electronics sector has become one of the rapidly developing and growing sectors. This growth in the sector significantly changes people's lifestyles and consumption habits. On the one hand, more innovative, well designed and multifunctional electronic products are offered to the market at attractive prices in order to make consumers' lives better and more comfortable. Moreover, consumers' search for a better lifestyle shortens the lifecycle of these products, which leads to an increasing interest in waste electrical and electronic equipment (WEEE) worldwide.

With the efficient management of WEEE, products and materials can be recovered efficiently without being sent to landfills. Thus, it is possible to protect living health, improve environmental conditions and improve financial performance [Flygansvaer et al. 2018]. The process of reassessing electrical and electronic products is complex and focuses not only on reuse or recycling within the scope of reverse logistics, but also on the proper treatment or disposal of hazardous substances such as lead and mercury to eliminate or minimize the risks to human health and environment. [Yu, Solvang 2016].

Citation: Sari E.B., 2020. Recovery alternatives decision by using fuzzy based preference selection index method. LogForum 16 (1), 171-181, http://doi.org/10.17270/J.LOG.2020.386
Received: 23.09.2019, Accepted: 02.12.2019, on-line: 30.12.2019.

Due to the rapid development of technology, the continuity of innovations and the rapidly changing demands, the life of electronic products is shortened. Therefore, deprecated electronic products are quickly discarded or disposed. This results in a large amount of electronic waste [Zhao et al., 2018, Flygansvaer et al., 2018]. It is very important that the electronic products that are no longer used can be recovered without harming human health and the environment. Many factors such as regulations, corporate awareness and the increase in the number of conscious consumers have led electronic manufacturers to reverse logistics activities. Therefore, the electronics sector fulfills its responsibility for the re-evaluation and proper recovery of end-of-life products with regulations such as WEEE, RoHS (Restriction on Hazardous Substances) [Ravi et al., 2008].

Today, not only forward logistics from the manufacturer to the consumer, the concept of reverse logistics which takes into consideration the issues such as product recovery and re-evaluation also comes to the fore. Although it is thought to be the opposite of forward logistics, reverse logistics differs from in many decision points [Bilgin 2012]. Reverse logistics is aiming to recover value from end-of-life or obsolete products, that cannot be used in a suitable way by planning, operating, managing effective material, information and money flows. Reverse logistics obtain value from end-of-life or no-use products which is a process from consumer to raw material supplier [Yu, Solvang 2016].

With the effect of the increasing importance of environmental and waste disposal issues, mandatory legislation and corporate social concerns, businesses are awareness to focus on reverse logistics activities under conditions of intense competition [Prakash, Barua 2016]. For this reason, in this study, it is aimed to determine the recovery alternatives of the companies operating in the electronics sector in the Aegean Region within the scope of reverse logistics and focusing on reverse logistics activities for the returning products for different reasons. To this end, a focus group consisting of academicians and experts who are knowledgeable about the subject of the study was formed. And Delphi method was applied to determine the dimensions and criteria of the subject. After determining the criteria, PSI (Preference Selection Index) method was used to select the most suitable alternative for remanufacturing, recycling, cannibalizing, repairing, direct reuse and incineration / burying alternatives for electronic products.

In the second part of this study, some studies from the academic literature on reverse logistics and recovery are examined. In the third chapter, the method used in the study is explained briefly and in the fourth chapter the application stages and findings are presented. In the last section, a general evaluation is made in which the results of the study are interpreted.

LITERATURE RESEARCH

Nowadays, technological developments are rapidly increasing and product life cycle is shortened, customers are constantly demanding new products, and all these products are turned into waste even before the end of their service life. These facts are forcing the companies to an effective reverse logistics management. Reverse logistics in a narrow sense refers to all activities related to the collection, recovery or disposal of used products; in broader manner, cooperation between the producer and the consumer in order to minimize the generation of waste by re-use, re-production, recycling or safe disposal of products that are no longer used in order to increase renewable energy sources [Bouzon et al., 2016].

The responsibilities imposed on the producers and the legislation on waste put pressure on the producers to take back the products that have reached the end of their life and dispose of these products in an appropriate way. Studies have shown that the rate of return is high especially for electronics, computers, cameras, mobile phones, automobiles, chemical and medical products [Prakash, Barua 2016]. For the recovery of the products returning to the enterprise, it is important to classify and evaluate the products and apply the most appropriate recovery alternative.

Recovery alternatives of products depending on the degree of remanufacturing; modernization, cannibalization, repair, direct reuse, recycling and incineration. Remanufacturing; the products are completely dismantled according to the component levels and brought to the quality standards applicable to new products, comprehensive inspection and replacement of broken / old parts [Bilgin, 2012]. Regeneration; the quality of used products is to raise to higher level by disassembly, to check and to replace the broken components. The upgrade can also be accomplished by replacing outdated modules or components with technologically superior ones. Cannibalization; recovering a small number of items returned for use in any of the aforementioned recovery alternatives for reuse. Repairing; returning products to work again. The quality of repaired products may be lower than that of new products. Recycle; It refers to the re-use of the material obtained by destroying the original features and functions of the products and parts as a result of subjecting them to various separation processes [Wadhwa et al., 2009]. Direct reuse; in the process of returning pallets, containers without any changes on materials such as cleaning or cleaning and so on. Small operations are directly involved in the process. The alternative to incineration / burying is the destruction of the product by the enterprises when they no longer have any other options. Instead of disposing of the returned products, the company determines the most suitable recovery alternative for the processes and reduces the consumption of new materials by using the materials evaluated from these products, thus producing many additional values, especially economic [Bilgin 2012].

In this study, selection of the most suitable recovery alternative for an enterprise producing electronic products is discussed by using multi - criteria decision making approach. Firstly, the criteria are determined by using Delphi method, and in the next stage, the most suitable recovery alternative was selected by using the PSI method. Since there are many criteria affecting the alternatives, multi-criteria decision-making methods can be used to selection of alternatives. The Preference Selection Index (PSI) is a multi-criteria decision-making method used by firstly Maniya and Bhatt [2010]. PSI provides systematic evaluation without the need for additional weighting of the criteria.

Some of the studies conducted in the literature to evaluate recovery alternatives are as follows: Wang et al. [2018] used interval-valued Fuzzy DEMATEL and interval-valued fuzzy Gray Relational Analysis methods in order to determine the best scenario among alternatives for the evaluation of urban solid wastes. Agrawal et al. [2016] preferred to use AHP and Fuzzy TOPSIS methods in order to determine the best alternative for disposing the product for an Indian electronics company producing mobile phones. Jindal and Sangwan [2016] used AHP and TOPSIS methods in a fuzzy environment to evaluate the product recovery processes. Samantra et al. [2013] used fuzzy cluster and VIKOR methods together to determine the optimum recovery alternative for the product. Mahapatara et al. [2013] made the selection of reverse production alternatives by TOPSIS method. Ravi and Shankar [2012] used the ANP method to evaluate recovery alternatives in the automobile industry. Wadhwa et al. [2009] evaluated the recovery alternatives of returned brown goods with fuzzy TOPSIS. Ravi et al. [2005] ANP and balanced scorecard methods using the combination of end-of-life computers to model the selection of the most appropriate among the recovery alternatives.

One of the most important issues to be considered in the recovery of electronic wastes is the efforts to recover the precious and scarce resources in the electrical and electronic products such as gold, silver, zirconium and palladium. In this respect, Sun et al. [2017], a mathematical formulation has been developed to determine how much of these metals in electronic waste will be recovered. In the same study, the scarcity of the precious metals in electronic products on the basis of resources was determined and it was clearly revealed which kind of metals should be evaluated with priority recovery alternatives.

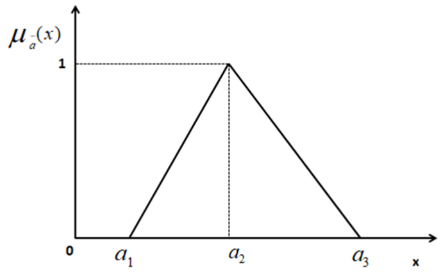
METHOD

In particular, the fact that the relative weight of the occurrence factors is not taken into account and that the uncertainty of information does not allow for the calculation of the exact values and computations is a common point of these criticisms. In order to overcome these deficiencies of the classical method, fuzzy logic approach and factor weighting methods are assumed to be more effective than the model proposed.

Fuzzy set theory is a tool that was developed by Zadeh [1965] and can be used to describe mathematically complex and ambiguous systems that have difficulty in expressing exact numbers [Yadav, et al., 2003]. The application of fuzzy set theory in risk assessment problems of FMEA has several advantages over deterministic models such as the use both quantitative and qualitative data together to obtain consistent results, the direct interpretation of failure modes using linguistic variables. In addition, fuzzy logic is considering the uncertainty of a system affected by many factors [Liu 2016].

The fuzzy set is a set of elements that do not have definite boundaries, have gradual transitions, and have certain membership degrees. This cluster describes a convex structure of fuzzy numbers, each with a membership degree between 0 and 1 [Hu, et al., 2009]. Certain membership degrees are determined using membership functions rather than definitive expressions, such as members or members in determining the membership of this cluster [Zadeh 1975]. In the definition of membership functions, the proximity of the numbers is used, and the membership functions are usually represented by triangular membership functions and trapezoidal membership functions according to the situation of this neighbourhood [Sanayei et al., 2010]. In applications, triangular membership functions are preferred mostly for ease of calculation. In this study, triangular membership function is used.

Triangle membership function is defined by three parameters a1, a2 and a3. Here, a1 and a3 respectively, the lower and upper limit values of the number of fuzzy a2 is the mean value of the middle [Salehi, Tavakkoli-Moghaddam 2008]. Triangle membership function is defined in equation 1 and the triangular form is shown in the Figure 1.



$$\mu_{\tilde{a}}(x)=\begin{cases}\dfrac{x-a_1}{a_2-a_1}, & a_1\le x\le a_2\\ \dfrac{a_3-x}{a_3-a_2}, & a_2\le x\le a_3\\ 0, & otherwise\end{cases} \qquad (1)$$

Source: Salehi, Tavakkoli-Moghaddam, 2008

Fig. 1. Triangle membership function

Another important feature of the fuzzy logic approach is that it allows to give meaning to difficult situations with quantitative values. The concept of linguistic variable is very practical in dealing with situations that are too complex to be reasonably defined by traditional quantitative expressions [Zadeh, 1975]. A linguistic variable is a factor whose values are words in language and fuzzy numbers are used for expressing these linguistic variable values. Linguistic variables and the conversion the fuzzy numbers are explained in Table 1.

Table 1. Linguistic variables and triangular fuzzy numbers

Linguistic Variables	Triangular Fuzzy Numbers
Very Low	(0,0,1)
Low	(0,1,3)
Medium Low	(1,3,5)
Medium	(3,5,7)
Medium High	(5,7,9)
High	(7,9,10)
Very High	(9,10,10)

Source: Zadeh, 1975, cited in: Liu, et al., 2015

One of the most important steps of fuzzy logic approach is the process of defuzzication. Defuzzification is performed to obtain a best non-fuzzy performance (BPN) value. Between the techniques like as center of area (COA), mean of maximal (MOM), and a-cut; the COA has practical process and is calculated with equation 2 [Alcan, et al., 2013].

$$x_0(a) = a_1 + [(a_3 - a_1) + (a_2 - a_1)]/3 \qquad (2)$$

Following the defuzzication process, The Preference Selection Index (PSI) is used for selection, PSI is developed by Maniya and Bhatt [2010] and is used for multi-criteria decision making (MCDM) problems. The PSI is explained as a method that stands out due to its feature that determines the weight of the criteria and which does not require relative weighting.

In the PSI method, the overall preference value calculated for each criteria and the preference index (I_j) are calculated for each alternative, and the height of the preference index value allows the alternative to be determined as the best alternative [Maniya, Bhatt 2010]. The use of the PSI method arises in situations where it is difficult to decide the criteria weight [Attri, Grover 2015].

In the literature, the PSI method is used for ranking or selection of alternatives, and the validity of the method is compared with the other commonly used methods. Firstly, Maniya and Bhatt [2010] applied the PSI for material selection problem and the results were compared with the outputs obtained by TOPSIS and GTMA methods. Sawant, et al., [2011] in their study used the PSI method for the problem of automatic-oriented vehicle selection, sixteen different models were ranked based on nine criteria. In the study, for used criteria were desired the maximum and minimum values and the results were compared with the TOPSIS method. Mufazzal and Muzakkir [2018] and Noryani et al., [2018], in their researches; PSI was discussed with AHP, ANP, DEA, ELECTRE, GRA, GTMA, MAUT, PROMETHEE, SAW, TOPSIS, VIKOR.

Advantage of the PSI method; it is the direct implementation of the alternative to assess the performance of the alternative and to calculate the rating score. On the other hand, the disadvantage is the method that does not allow the user to consider the qualitative factors [Noryani et al., 2018]. This is related to the method based on calculations that determine the weight of criteria within its own systematic.

The steps taken by the PSI method in Maniya and Bhatt [2010] are as follows:

Step - 1: Defining the problem and determining the criteria.

Step - 2: Rows are the alternatives A=[A_i, i=1, 2, … , n], columns are the set of criteria C=[Cj, j=1, 2, … ,m], and the value of cells X_{ij}, represent the decision matrix.

Step - 3: Normalization of the decision matrix is the standardization of the criteria measured by different units.

The normalization of the criteria in different units is 0 - 1, and the reinterpretation of the data to show if the maximum value of the criterion is better, 1 is the best, 0 is the worst, if the minimum value of the criterion is better, 0 is the best, 1 is the worst.

$N_{ij} = \frac{X_{ij}}{X_{ij\ \max}}$; $\forall$ i,j $\rightarrow$ if the great value represents better (3)

$N_{ij} = 1 - \frac{X_{ij}}{X_{ij\ \max}}$; $\forall$ i,j $\rightarrow$ If the small value represents better (4)

Step - 4: Calculating preference variation value (PV_j).

$$PV_j = \sum_{i=1}^{n}[N_{ij} - \overline{N_j}]^2 \quad (5)$$

$\overline{N_j}$: is the average of the normalized values of the alternative j

$$\overline{N_j} = \frac{1}{n}\sum_{i=1}^{n} N_{ij} \quad (6)$$

Step - 5: Determining the overall preference value ψ_j for each criteria. For each criteria, the overall preference value deviation θ_j is found. (Quantitative Weighting).

$$\theta_j = 1 - PV_j \quad (7)$$

$\psi_j = \frac{\theta_j}{\sum_{j=1}^{m}\theta_j}$ $\rightarrow$ Sum of the overall preference values of the criteria equals the one ($\sum \psi_j = 1$) (8)

Step-6: Calculating the index value.

$$I_i = \sum_{j=1}^{m}(N_{ij}\ x\ \psi_j) \quad (9)$$

The results are accepted as Preferred Selection Index (PSI) and are shown as I_i. PSI values are used for alternative selecting, sorting, and comparing, with the highest value showing better.

COMPUTATIONAL EXPERIMENTS

The recovery alternatives of the products are affected by many factors like environmental, social, technical, economic and so on. When determining these factors, the opinions and interests of the stakeholders must be taken into consideration. A crucial factor for one stakeholder may conflict with the interests of another stakeholder. Therefore, it is necessary to determine the product recovery option with a method that covers all stakeholders involved in the process.

This provides a method to guide the decision-making process on the recovery option of electronic products that have completed their working life.

Within the scope of reverse logistics, a project group consisting of academicians and experts working in the reverse logistics process has been formed in this study, in which the evaluation options of the electronic manufacturers operating in Aegean Region are evaluated. As a result of the interviews and literature review on the subject, Cost, Duration, Economic Gain, Product Quality, Environmental Awareness, Legal Regulations, Pollution and Social Responsibility was selected as the criteria of the study; Remanufacturing (A1), Regeneration (A2), Recycling (A3), Cannibalization (A4), Repair (A5), Direct Reuse (A6) and Incineration / Burying (A7) were identified as alternatives [Sharma et., al. 2016, Lou, Wang 2009].

Based on the project group consisting of 5 people and the information obtained from the literature, seven alternatives determined for the recovery of electronic wastes were evaluated by the expert group within the framework of eight criteria. Decision-makers evaluated the significance of the criteria and each alternative according to these criteria. The Fuzzy Decision Matrix obtained with the help of equations (1) and (2) is shown in Table 2.

Table 2. Fuzzy decision matrix

	Cost	Process Length	Economic Gain	Product Quality	Environmental Awareness	Legal Regulation	Pollution	Social Responsibility
Remanufacturing	(0,1.4,5)	(0,2.4,5)	(3,7.4,10)	(3,5.8,10)	(5,8.4,10)	(1,4.2,9)	(3,7.4,10)	(5,8.4,10)
Regeneration	(1,5,9)	(0,1.8,5)	(5,8.4,10)	(3,7,10)	(3,7,6,10)	(1,4.6,9)	(3,6.6,10)	(5,8.4,10)
Recycling	(0,2.4,5)	(1,5.4,9)	(5,7.8,10)	(3,7.4,10)	(3,7.4,10)	(3,7.4,10)	(5,7.4,10)	(3,7.4,10)
Cannibalization	(3,7.4,10)	(5,8.2,10)	(3,7.4,10)	(1,5,9)	(5,8.2,10)	(1,5,9)	(3,6.2,9)	(3,7.4,10)
Repairing	(1,4.6,9)	(1,5,9)	(5,8,10)	(3,7.4,10)	(3,8,10)	(0,2,5)	(3,7,10)	(5,8.2,10)
Direct Reuse	(3,7.4,10)	(5,8.2,10)	(5,7.8,10)	(3,7.4,10)	(5,8.4,10)	(1,5.4,9)	(3,6.2,9)	(3,7.4,10)
Incineration / Burying	(0,1.8,5)	(3,7.4,10)	(0,1.4,5)	(0,2,5)	(0,2.6,5)	(0,2.2,5)	(0,2.6,5)	(1,4.6,9)

Source: own work

Table 3. Decision matrix

	C1	C2	C3	C4	C5	C6	C7	C8
A1	2,13	2,47	6,80	6,27	7,80	4,73	6,80	7,80
A2	5,00	2,27	7,80	6,67	6,87	4,87	6,53	7,80
A3	2,47	5,13	7,60	6,80	6,80	6,80	7,47	6,80
A4	6,80	7,73	6,80	5,00	7,73	5,00	6,07	6,80
A5	4,87	5,00	7,67	6,80	7,00	2,33	6,67	7,73
A6	6,80	7,73	7,60	6,80	7,80	5,13	6,07	6,80
A7	2,27	6,80	2,13	2,33	2,53	2,40	2,53	4,87

Source: own work

In order to defuzzy the total fuzzy matrix, the Center of Area (COA) method was used as described in the methodology section, and the decision matrix was reached shown as Table 3.

PSI Calculations

After the decision matrix is formed in the PSI method, a normalized decision matrix is formed to standardize the values. Table 4 shows the normalized decision matrix and shows the $\overline{N_j}$ values.

Table 4. Normalized decision matrix

	C1	C2	C3	C4	C5	C6	C7	C8
A1	0,686	0,681	0,872	0,922	1,000	0,696	0,089	1,000
A2	0,265	0,707	1,000	0,980	0,880	0,716	0,125	1,000
A3	0,637	0,336	0,974	1,000	0,872	1,000	0,000	0,872
A4	0,000	0,000	0,872	0,735	0,991	0,735	0,188	0,872
A5	0,284	0,353	0,983	1,000	0,897	0,343	0,107	0,991
A6	0,000	0,000	0,974	1,000	1,000	0,755	0,188	0,872
A7	0,667	0,121	0,274	0,343	0,325	0,353	0,661	0,624
$\overline{N_j}$	**0,363**	**0,314**	**0,850**	**0,854**	**0,852**	**0,657**	**0,194**	**0,890**

Source: own work

Table 5. Overall preference value

	C1	C2	C3	C4	C5	C6	C7	C8
A1	0,105	0,135	0,000	0,005	0,022	0,002	0,011	0,012
A2	0,010	0,154	0,023	0,016	0,001	0,003	0,005	0,012
A3	0,075	0,000	0,016	0,021	0,000	0,118	0,038	0,000
A4	0,132	0,099	0,000	0,014	0,019	0,006	0,000	0,000
A5	0,006	0,002	0,018	0,021	0,002	0,098	0,008	0,010
A6	0,132	0,099	0,016	0,021	0,022	0,010	0,000	0,000
A7	0,092	0,037	0,332	0,261	0,278	0,092	0,218	0,071
PV_j	0,551	0,526	0,404	0,360	0,344	0,329	0,279	0,106
Q_j	0,449	0,474	0,596	0,640	0,656	0,671	0,721	0,894
W_j	**0,088**	**0,093**	**0,117**	**0,126**	**0,129**	**0,132**	**0,141**	**0,175**

Source: own work

Following the creation of a normalized decision matrix, it is necessary to find the preference variance and to determine the overall preference value. Overall preference value can be considered as benchmark weights. Table 5 shows the overall preference value calculation step.

When the overall preference values that determined for each criteria, were examined, the highest weight was given to the Quality indicator with a value of 0.222. The second most significant weight is given to the Performance indicator with a value of 0.207. These two criteria with the highest weight are the values used for the OEE calculation. As a result of the overall preference value for each criterion, the values accepted as the PSI for each alternative are calculated. Table 6 shows the calculation of PSI values.

Table 6. Calculation of PSI values

	C1	C2	C3	C4	C5	C6	C7	C8	**PSI**
A1	0,060	0,063	0,102	0,116	0,129	0,092	0,013	0,175	**0,749**
A2	0,023	0,066	0,117	0,123	0,113	0,094	0,018	0,175	**0,729**
A3	0,056	0,031	0,114	0,126	0,112	0,132	0,000	0,153	**0,723**
A4	0,000	0,000	0,102	0,092	0,127	0,097	0,027	0,153	**0,598**
A5	0,025	0,033	0,115	0,126	0,115	0,045	0,015	0,174	**0,648**
A6	0,000	0,000	0,114	0,126	0,129	0,099	0,027	0,153	**0,646**
A7	0,059	0,011	0,032	0,043	0,042	0,046	0,093	0,109	**0,436**

Source: own work

When the preference index values calculated by PSI method are examined, it is seen that A1 has the highest value and it is followed by M2 and M3 recovery alternatives. They are remanufacturing, regeneration and recycling which are the value adding activities are more than others. And the last chosen alternative is A7 and it is incineration / burying which is the destruction operation and there is no gain.

CONCLUSIVE REMARKS

The subject of recovery activities in order to create value and use effective resources is becoming increasingly important for products that have reached the end of their useful lives be. Recovery activities represent an important area within the development policy of many countries where projects are prepared. Recovery operations, micro-scale firm, macro-scale, as well as the economic contribution to the national economy; social responsibility awareness and production systems are becoming more environmentally friendly. Within the scope of the study, the recycling of electrical and electronic wastes has been covered in the scope of this important waste recovery. PSI method has been used within the framework of fuzzy approach, since it will be difficult to make certain decisions about the selection of recovery alternatives.

As a result of the interviews with the decision-making expert group, the most important criterion is social responsibility and environmental awareness criteria and the cost criterion takes the last place in determining the weights of the PSI method with the evaluations taken on the choice of recovery alternatives; it is a reflection of the consciousness that occurs on this subject. As a result of the analyzes, remanufacturing, regeneration and recycling take the first place among the alternatives, this is again an indication of the growing awareness in this regard.

In this study, conversely with other studies in the literature, fuzzy based PSI method was used. Although remanufacturing is seen as the best alternative in the literature, it is an innovative approach to support this result with the PSI method. In future studies, it may be suggested to create more specific research results on the basis of products by making evaluations for each product group by acting on electronic product groups. The study can also be expanded by comparing the results with other multi-criteria decision-making methods.

ACKNOWLEDGMENTS AND FUNDING SOURCE DECLARATION

Statutory fund of Dokuz Eylul University.

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PODEJMOWANIE DECYZJI RECYCKLINGOWYCH PRZY ZASTOSOWANIU METODY WSKAŹNIKOWEJ WYBORU PREFERENCJI

STRESZCZENIE. Wstęp: Przemysł elektryczny i elektroniczny to gałęzie przemysłu o dużej dynamice wzrostu i rozwoju, będącej wynikiem rozwoju technologicznego i ekonomicznego. Gwałtowne zmiany popytu i potrzeb konsumentów wpłynęły na wzrost zapotrzebowania na sprzęt elektroniczny oraz skróciły cykl życia produktu, co w efekcie doprowadziło do zwiększenia ilości odpadów sprzętowych. Dlatego też istotnie jest zajęcia się tematyką odzyskiwania części ze zużytego sprzętu elektrycznego i elektronicznego. Celem pracy jest ocenienie metod odzyskiwania elementów ze zużytych sprzętów oraz wybór najlepszej z tych metod.

Metody: W wielu obszarach stosuje się techniki wielokryterialne podejmowania decyzji w celu dokonania wyborów pomiędzy różnymi alternatywami. Wybór metody odzyskiwania w oparciu o kryteria obejmuje zagadnienia modeli rozmytych. Z tego też powodu, zastosowano logikę rozmytą do oceny odpowiedzi osób decyzyjnych a uzyskanie liczby rozmyte zostały poddane metodzie PSI, w wyniku której uzyskano kryteria ważone jak i listę alternatyw.

Wyniki: Na podstawie uzyskanych wyników stwierdzono, że kryteria odpowiedzialności i świadomości ekologicznej mają najwyższą wartość przy selekcji metod odzyskiwania. Dodatkowo, najczęściej wybieranymi metodami były: przerób, regeneracja oraz recykling.
Wnioski: W istniejących obecnie uwarunkowaniach, odzyskiwanie elementów ze zużytego sprzętu elektrycznego i elektronicznego jest bardzo ważne. Metody alternatywne obejmują całą paletę od ponownego użycia do spalenia, jednakże prawidłowy wybór stosowanej techniki odzysku powinien opierać się na wielokryterialnym procesie decyzyjnym.

Słowa kluczowe: odzyskiwanie, wielokryterialne podejmowanie decyzji, wskaźnik preferencji wyboru

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