International Journal of Engineering

TECHNICAL NOTE

Comprehensive Decision Modeling of Reverse Logistics System: A Multi-criteria Decision Making Model Using Hybrid Evidential Reasoning Approach and TOPSIS

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A B S T R A C T

In the last two decades, product recovery systems have received increasing attention due to several reasons such as new governmental regulations and economic advantages. One of the most important activities of these systems is to assign returned products to suitable reverse manufacturing alternatives. In this study, a new approach based on the Evidential Reasoning Approach (ERA) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is proposed to deal with alternative (recovery system) selectionvia considering a comprehensive model in reverse logistics. This study contributes to the literature with not only a novel reverse logistics decision modeling framework, but also a pragmatic data transformation technique which can comfort the combination of quantitative data and qualitative opinions using the evidential reasoning approach and TOPSIS. Finally, a case studyin the automotive industry is used to demonstrate the efficiency of the proposed method in selecting suitable reverse manufacturing alternatives. The company has to deal with the return products and make appropriate decision with respect to various criteria such cost, quality, and available resource. Uncertainty of returned products in terms of quantity, quality, and time complicates the decision making process. The obtained results indicate a good compliance with experts' opinions and efficiency of the proposed hybrid decision making method (i.e., ER-TOPSIS) to offer a complete ranking.

doi: 10.5829/idosi.ije.2015.28.06c.13

1. INTRODUCTION

In the literature of supply chain, ausual approach recognizes flow in forward direction to end customer. However, there are some conditions in a supply chain that we have some materials flowing backward from customer (even end customer) to assemblers or manufacturers [1]. In literatures, management of the backward flow is known as reverse supply chain, recovery system or reverse logistic. Roger and Tibben-Lembke [2] have defined reverse logistic as flows;"the process of planning, implementingand controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing or creating

value, or for proper disposal."In the recent years, reverse logistic has been remarkably recognized by industrial and academic perspectives. We can point to following reasons behind the increase in the utilization of reverse logistics: 1) organizations obligation for product recovery and their rising sensitivity to environmental laws, 2) economical advantages of using returned products and parts, 3) customer's rising knowledge about environment. Nowadays, manufacturing environmentally friendly products is being a competitive tool for all organizations across the world. This impressive impact on strategies of organizations has been addressed to application of the new term "green supply chain" in literatures. Reverse logistics is considered as a part of this new field. Principalactivities of recovery systems which reverse logistic attempts to manage them are as follows [3]: 1) collection of used products from product holders, 2) determining the condition of the returns by inspection

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and/or separation to find out whether they are recoverable or not, 3) reprocessing or reconditioning the returns to capture their remaining value, 4) disposal of the returns which are found to be unrecoverable economically and/or technologically and (5) redistribution of the recovered products. The second step of recovering system's activities is to determine returned product's condition and recovery capability assessment. After distinguishing the recoverable items, they are separated from the unrecoverable ones. Then in the third step,the recoverableitems will be processed under the recovery system processing. There is a variety of typical classifications used to describe recovery processes in literatures. Srivastava [4] classified them to: repairing, refurbishing, remanufacturing and recycling. Another classification based on degree of disassembling and returned product quality has been done by Wadhwaet al., [5] as follows: 1) repair and reuse is to return used products in working order. The quality of the repaired products could be less than that of the new products, 2) refurbishing is to bring the quality of used products up to a specified level by disassembly to the upgraded level, inspection, and replacement of broken components, 3) remanufacturing is to bring used products up to quality standards that are as rigorous as those for new products by complete disassembly down to the component level, and extensive inspection and replacement of broken/outdated parts, 4) can nibalization is to recover a relatively small number of reusable parts and modules from the used products, to be used in any of the three operations mentioned above, 5) recycling serves to reuse materials from used products and parts by various separation processes and reuse them in the production of the original or other products.

After entering products into collection centers and finishing the assessment/separation process,the main question is "what kind of recovery process is the well-suited one for the left materials to be recovered?" To answer this question, we are facing many crucial factors such as diverse managerial and technical criteria including cost, time, market, law factors, returned products quality and environmental factors. On the top of these, usually several decision makers exist which increase the complexity of the issue.

The literature of reverse logistics decision modeling systems and suitable recovery process is scarce, although reverse logistics have been receiving increasing attention. Selecting the most suitable recovery system process requires to deal with some challenging issues such as uncertainty andmissing or incomplete assessment of data in returned product quantity, quality and time. The goal of this study is to bridge this gab and provide a decision modeling system capable of handling aforementioned issues. Therefore, we propose a multi criteria decision making framework

based on the ERA and TOPSIS. ERA is deployed to tackle the uncertainty and missing or incomplete assessment of data. Then, a complete ranking is provided using TOPSIS. To show the applicability of the proposed multi-criteria decision model, it has been implemented in a heavy vehicles production company. The results of this study are presented in five subsequent sections. In the second section, a brief review on the concept and theory of reverse logistics and recovery systems is given. The third section will describe the proposed decision-making model in details. In the fourthsection,the results of model implementing and subsequent sensitivity analysis are presented. The final conclusion is given in fifth section.

2. LITERATURE REVIEW

In this section, two aspects of decision making problem of recovery process selection for managing reverse logistic studies have been addressed in designing an efficient reverse logistic system.

2. 1. Process of Reverse Logistics and Recovery Systems   In the last decade, considerable attention has been focused upon reverse logistics and recovery systems starting from returned products collection to distribution of recovered products. Aras and Aksen [3] have modeled the problem of collection centers for returned productsby considering theeffect of location distance on the final price of the returned products. Their proposed model formulated as a mixed integer nonlinear location-allocation problem. The most important variable suggested in this model is an incentive value to encourage customers for returning their used products. This variable depends on customer's distance from collection centers and quality of returned products. Lee and Chan [6] formulated this problem in which the collection centers can coveras many customers as possible. Separation and classification are the next steps following the product's collection. Xanthopoulos and Iakovou [7] proposed a new 2-phases algorithm for this problem. In the first phase, sub assembly unit for recovery process is conducted by a multi-criteria decision analysis to have the maximum desire for selection. The next phase determines the number of returned products which should be collected, disassembled, reproduced, remanufactured, stocked or cannibalized in each period. The next step of recovery system's activities is distribution of the recovered products to primary and secondary markets. Due and Evans [8] recognized a closed loop reverse supply chain including three stages (collection, recovering and production). Their objectives were to find the best location of recovery facilities and the flow between the facilities to minimize the

transportation cost and delays. Selecting the best remanufacturing process recovery option depends on various qualitative and quantitative criteria mentioned in the literature. Some of these criteria are quality, cost, inventory, market, as well as recently introduced environmental factors. Hence, Multi-Criteria Decision Making (MCDM) approach would be an efficient way to tackle this problem. The MCDM methods can be classified into two categories: Multi-attribute Decision Making(MADM) and Multi-Objective Decision Making (MODM). The MADM approaches can be recognized in three categories: attribute utility theory, outranking, and interactive methods [9]. For a recent review of these approaches, refer to Greco et al. [10]. In addition, there are many approaches which combine the aforementioned categories [11] or take into consideration group decision making [12]. To cope with uncertainty, more sophisticated approaches have been developed [13]. Our proposed approach includes two first categories, namely attribute utility theory and outranking. To employ attribute utility theory in an uncertain environment, ERA is developed. In addition, TOPSIS is used for ranking the preferences.

2. 2. Decision Making Models for Recovery Process Selection

This paper proposes a new methodology using hybrid ERA with TOPSIS method to find the best process for products recovery. As far as our investigation of the literature revealed, there are a few researches in the field of selecting suitable recovery process. Ravi et al. [14] proposed approach that benefits from balance scored card merits, relates the financial and non-financial criteria for the selection of an alternative in the reverse logistic operations for end of life computers. Because of the interrelation between many criteria and sub criteria that are remarked in this paper, authors suggested analytic network process to consider this problem. Mergias et al. [15] proposed a model for addressing recycling of End-of- Life vehicle using the PROMETHEE method. They have considered multiple criteria such as environmental, social, financial and technical in their model. Bufardi et al., [16] proposed a multistage decision making model for selecting the reverse selection alternatives for end of life products. The criteria such as environmental, social and economic were considered. Also Chan [17] developed a multi criteria decision making using grey relational analysis for this problem. The developed model could find the optimal solution among the various options. Wadhwa et al. [5] proposed a fuzzy multi-criteria decision method to help in selection of the suitable recovery process. These processes include repairing, refurbishing, remanufacturing, cannibalization and recycling. In order to select the suitable processes, many items such as cost, quality, governmental rules, market and environmental factors have been considered. Due to

various technical and managerial items and existing more than one expert, selection process is almost becoming a complicated process. Therefore, there is a need to adopt an appropriate tool to handle MCDM problem of recovery process selection under various conditions such as uncertainty, data incompleteness, impreciseness and missing information and group decision making. That's the reason they have believed that the application of fuzzy multi-criteria decision method is inevitable. Although fuzzy is a powerful tool to express uncertainties, it has some incapability. Chin et al., [18] have expressed that fuzzy has incapabilityin dealing with uncertainties like incomplete or imprecise data. Incomplete, imprecise and missing information, however, are significantinherent items in assessment procedure by experts via decision making process of recovery process selection. The ERAcan be considered as a good choice to resolve the problem of considering of data incompleteness, impreciseness and missing information in the MADM problem [18, 19]. The ERA is based on Dempster-Shafer's theory [19]. The ERAhas been mentioned as a decision making method in uncertainty conditions in multi criteria decision making procedure [20]. Xu et al., [19] developed this method to IERA using an interval uncertainty implementation. Wang, et al. [21] have introduced a novel concept of interval belief in the pursuing of this development. Chin,et al. [22] proposeda new decision making method by combination of AHP and ERAto develop the processes for new products. In this study, we propose a new methodology of implementing incomplete assessment ERA and TOPSIS. The method of ERA has been expressed by Yang [23], has some shortcoming for offering complete ranking of alternatives. This method can only offer dominance and equality between two alternatives based on the related criteria. Therefore, it cannot implement complete ranking. So in the proposed method, after designing a decision matrix using theERA, the selection of proper process is performed using TOPSIS as a MCDM method presented by Hwang and Yoon [24]. Thus use of TOPSIS, has overcame ERA's shortcoming. Because of existing more than one expert in decision making process and the weight importance of any of criteria for any of them, in this study, AHP group methodology is used to appraise the weight importance of every criterion.

3. THE PROPOSED DECISIONMAKING MODEL

In this section, at first a selection of an MCDM method is explained and then each of the MCDM method's elements that are composed of ERA and TOPSIS are described. The final hybrid model will be then thoroughly described.

3. 1. Selection of Aproper MCDM Method   One of the most important activities in decision making is selection of the proper method among a wide variety of decision making methods. To increase the efficiency of the decision making process, the method selection must be properly compatible with situation of the considered problem. Since each method has some weakness and strength, so selecting a suitable method is significant. This problem has been addressed in the literature. Bufardi et al. [16] have developed a guideline for selecting suitable decision making method. This method is implemented in 4 levels in this study to design an efficient decision making method as follows:

❖ Level 1: Considering type of problem. In this level, the type of problem is defined. There are three main types of problem including the choice, sorting and ranking. In this study, the goal of the proposed model is a complete ranking of alternatives.

❖ Level 2: Considering type and nature of the data. In this level, the type and nature of the data are investigated. The proposed model has some alternatives and multi criteria which some of them are qualitative and some of them are quantitative. In this study, the data which used are extracted from the experts. Incomplete, imprecise and missing information are significantinherent items in assessment procedure by experts via decision making process.

❖ Level 3: Considering type of decision maker (DM). In this level, kind of DM, interaction between DM and decision aid process, and degree of familiarity of DM with decision making approach is investigated. In this study, there are multiple experts from different departments that are familiar with decision aid process. It is mentioned that there isn't any interaction between DM and decision aid process.

❖ Level 4: Considering type of the MCDM method. Due to the existence of incomplete, imprecise and missing information in the assessment, an efficient method should be adopted to address these issues. Multiple experts are engaged in the assessment process.Therefore in this study, the ERA has been selected based on the capability of this method to consider incomplete, imprecise and missing information in the group decision making process. The ERA is forming the decision matrix as applied input of the MCDM method for complete ranking alternatives based on several criteria. There are several methods which can be used for complete ranking such as PROMETHEE, ELECTRE and TOPSIS. Incomplete ranking may occur in both PROMETHEE and ELECTRE due to the weak preferences and special situation of problem [17]. But TOPSIS can offer complete ranking in all situations. Because ofexistence of multiple experts in the process of decision making, Group-AHP has been used for calculating preference of criteria. Therefore, a hybrid method based on the ERA and TOPSIS has been presented.

3. 2. Evidential Reasoning Approach   Some of criteria like quality, market and environmental factors, etc., have qualitative inherent properties and some of them like cost have quantitative inherent properties that are also considered as uncertain criteria. ERAcan be properly applied for such a situation. ERA, in fact, is an approach which uses belief measure and utility to solve uncertainty [25].

3. 2. 1. Belief   Belief is a fuzzy measure that depicts analyzer's opinion about an event according to achieved evidences. Sometimes we have not enough evidence either to prove or reject occurrence of an event. Thus we have a degree of ignorance. In these conditions, summation of beliefs is below 1. We assume experts opinion as evidences in our method.

3. 2. 2. Utility   Utility of an income is its value for decision maker. In all decision making techniques, there is a need to quantify the incomes under a unit scale. Therefore, we firstly require quantifying qualitative incomes using utility theory. Utilization of this theory has two main advantages as follows:(1) it is used to quantify the qualified criteria and (2) it can unify criteria with different units.

3. 2. 3. ERA as an Assessment Method   In a decision making process, assessment and ranking the alternative choices are of great importance. In the following of Yang's method [23] for alternative assessment and selection of the best choices, we use ERA for this purpose.

Assuming alternative a_l (l= 1,2,…,M), we intent to assess it comparing to other alternatives with respect to e_i as a criteria (i=1,2,…,L). Let a_l be an arbitrary alternative among N possible conditions, each possible status is shown with $H_{n,i}$(n=1,2,..,N) according to e_i. Assume $\beta_{n,i}(a_l)$ be decision maker's belief to be a_l according to the ith criterion. $\beta_{n,i}(a_l)$ is a value between 0 and 1 by following limitations.

$$\sum_n \beta \le 1, \beta \ge 0 \tag{1}$$

If the summation of beliefs be exactly equivalent to 1, then we will have a complete assessment. However, if this summation be smaller than 1, we can say that the assessment is incomplete which can be due to many reasons such as lack or imprecise data. Thus we define $\beta_H(a_l)$, value of incomplete assessment,as follows.

$$\beta_H(a_l)=1-\sum \beta \tag{2}$$

Assume $U(H_{n,i})$ the utility of $H_{n,i}$ condition. According to existence of $\beta_H(a_l)$, we can assume a maximum and minimum utility for each alternative a_l in a certain criterion e_i. Simple average between these two values is score of alternative in criterion.

$$u_{\max}(a_1, e_i) = \sum \beta_{n,i}(a_1).u(H_{n,i}) + \beta_H(a_1).u(H_N) \tag{3}$$

$$u_{\min}(a_1, e_i) = \sum \beta_{n,i}(a_1).u(H_{n,i}) + \beta_H(a_1).u(H_1) \tag{4}$$

$$u_{average}(a_1, e_i) = \frac{u_{\max}(a_1, e_i) + u_{\min}(a_1, e_i)}{2} \tag{5}$$

In the other words, in the above cases, we set our belief at high, low and medium levels in turn. Therefore, the a_l utility is achieved with respect to e_i criterion.

To calculate the utility of an alternative with respect to all considered criteria, the criteria should have combinational nature. Therefore, the H set should be the same in all cases. It is suggested that a reference set is defined for the whole problem and the other sets are adapted according to the reference set. Through standardization and combination of criteria, we can calculate the S set with respect to the weight of each criterion, W.

3. 3. TOPSIS This method introduced by Hwang and Yoon [24] is based on closeness to the ideal solution and distant from the worst case. After normalization and calculation ofthe weighting matrix, distance of each alternative from ideal solution and worst case has been computed. After computing relative closeness value, the alternatives are ranked in descending order[26].

3. 4. The Proposed MCDM Method: ERA-TOPSIS
The suggested algorithm has 11 steps as follows.

Step 1: First of all, expert gives out his/her belief about alternatives in sub-criteria which are equal in value (see Figure 1). We assume that expert can perform an incomplete assessment.

$$\sum_i \beta_{ijm} \leq 1 \ , \forall j, m, \ \beta_{ijm} \geq 0 \tag{6}$$

where m index stands for mth expert. The relation (7) indicates that the evaluation can be done incompletely.

Step 2: In this step, all expert's opinions are summarized.

$$\beta_{ij} = \frac{\sum_m \beta_{ijm}}{\sum m} \qquad \forall i, j \tag{7}$$

Step 3: Calculating the probability density function [19]. In this step, the probability density function is calculated regarding each sub-criterion for the evaluated quantities, i.e. m_j. In case of the incomplete assessment, this probability is also calculated for the non-evaluated quantities, i.e. m_{1N}. m_H is used in the aggregated process of the evaluation of the sub-criteria and its value indicates the weights of the other sub criteria of the main studying criterion in the assessment process. m and n are two selected sub-criteria in the aggregating process. Equations (10)-(15) show the above explanations.

$$m_j = \omega_i * \beta_{j,i} \qquad \forall j = 1,...N \tag{8}$$

$$m_N = \omega_i * \beta_{1N,i} = \omega_i * (1 - \sum_{j=1}^{N} \beta_{j,i}) \tag{9}$$

$$m_H = 1 - \left(\sum_{j=1}^{N} m_j + m_N\right) = 1 - \omega_i * \left(\sum_{j=1}^{N} \beta_{j,i} + \beta_{1N,i}\right) = 1 - \omega_i \tag{10}$$

$$n_j = \omega_i * \beta_{j,i} \qquad \forall j = 1,...,N \tag{11}$$

$$n_{1N} = \omega_i * \beta_{1N,i} = \omega_i * \left(1 - \sum_{j=1}^{N} \beta_{j,i}\right) \tag{12}$$

$$n_H = 1 - \left(\sum_{j=1}^{N} n_j + m_{1N}\right) = 1 - \omega_i * \left(\sum_{j=1}^{N} \beta_{j,i} + \beta_{1N,i}\right) = 1 - \omega_i \tag{13}$$

Step 4: Then the assessment carried out regarding both m and n sub-criteria belonging to a main criterion is aggregated. C_j indicates the probability density function of the jth criterion of the two aggregated sub-criteria. Also C_{1N} is the probability density function of the incomplete assessment value of the two aggregated sub-criteria. β_j values are the amounts of belief in the jth criterion of the two aggregated sub-criteria. Finally β_{1N} is the amount of the incomplete assessment belief in this aggregated sub criterion[19].

Utility		U_1	U_2	U_3	…	U_{n-1}	U_n
Assessment criteria		D_1	D_2	D_3	…	D_{n-1}	D_n
C	C_1	B_{11m}	B_{21m}	B_{31m}	…	$B_{n-1,1,m}$	$B_{n,1,m}$
	C_2	B_{12m}	B_{22m}	B_{32m}	…	$B_{n-1,2,m}$	$B_{n,2,m}$

Figure 1. Expressed belief about alternatives in sub-criteria by experts

$$C_j = \frac{1}{1-k} * \begin{bmatrix} m_j * n_j + m_j * n_{1N} \\ +m_{1N} * n_j + m_j * n_H \\ +m_H * n_j \end{bmatrix} \quad j=1,...,N \quad (14)$$

$$C_{1N} = \frac{1}{1-k} * [m_{1N} * n_{1N} + m_{1N} * n_H + m_H * n_{1N}] \quad (15)$$

$$C_H = \frac{m_H * n_H}{1-k} \quad (16)$$

$$k = \sum_{j=1}^{N} \sum_{\substack{l=1 \\ j \neq l}}^{N} m_j * n_l \quad (17)$$

$$\beta_j = \frac{C_j}{1-C_H} \quad j=1,...,N \quad (18)$$

$$\beta_{1N} = \frac{C_{1N}}{1-C_H} \quad j=1,...,N \quad (19)$$

Step 5: After aggregating belief values of sub-criteria of each main criterion (A), we can calculate u_{max}, u_{min} and u_{avg} values with respect to the belief set of each main criterion.

$$u_{max}(A) = \sum_{j=1}^{N-1} \beta_j * u(H_j) + (\beta_N + \beta_{1N})u(H_N) \quad (20)$$

$$u_{min}(A) = \sum_{j=2}^{N} \beta_j * u(H_j) + (\beta_{1N} + \beta_1)u(H_1) \quad (21)$$

$$u_{avg}(A) = \frac{u_{max}(A) + u_{min}(A)}{2} \quad (22)$$

The decision matrix is constructed using u_{avg} values calculated for the main criteria regarding each alternative.

Step 6: Due to the high rank of importance for every criterion in comparison to others in the TOPSIS method and also existing of many experts in the making decision process, it is possible to estimate the relative weight (W_i) of criteria using Group-AHP.

Step 7: A decision matrix using calculated utility for every alternative can be established.

Step 8: Decision matrix should be normalized as follows.

$$\pi_{ij} = \frac{u_{ij}}{\sqrt{\sum u_{ij}^2}} \quad , \quad \forall i,j \quad (23)$$

Step 9: A weighted matrix can be calculate by following product. V_{ij} indicates the element (i,j) of weighted matrix.

$$V_{ij} = w_j * \pi_{ij} \quad , \quad \forall i,j \quad (24)$$

Step 10: We estimate distances of alternatives from positive (S_i^*) and negative (S_i^-) ideals.

$$S_i^* = \sqrt{\sum (V_{ij} - V_j^*)^2} \quad , \forall i,j) \quad (25)$$

$$S_i^- = \sqrt{\sum (V_{ij} - V_j^-)^2} \quad , \forall i,j \quad (26)$$

Step 11: By descending sort of R_i^* which is calculated by following formula, we will have a complete rank. R_i^* represents the rank of alternative i.

$$R_i^* = \frac{S_i^-}{S_i^* + S_i^-} \quad , \forall i \quad (27)$$

4. NUMERICAL EXAMPLE AND RESULTS

To illustrate the applicability of the proposed model a multi criteria decision making framework based on the ERA and TOPSIS to handle the problem of reverse process selection has been implemented in a heavy vehicles production companyin Iran as a case study. This company has lots of post sales centers in various points of Tehran and other cities. Each of these post sales centers ships back many products and modules to the factory time to time. This company attempts to manage the reverse flow for improving efficiency and decrease cost of production such as raw materials. Therefore, the company has organized a return committee in the company formed with the fixed representatives of each relative department such as production, quality control, technical and financial. After arriving return products or parts of them like engine, dashboard, shaft and etc. to the company, return committee seeks to make decision about return products with respect to some criteria like cost, quality, available resource and etc. Making decision includes determination of the reverse manufacturing alternatives following receiving the return products. That is, what kind of process should be applied for the reverse product among the processes of repairing, remanufacturing, recycling, cannibalization and refurbishing. Selecting the most suitable recovery system process requires to deal with some challenging issues, such as uncertainty and missing or incomplete assessment of data in returned product quantity, quality

and time, which are considered in this study.The main criteria are considered as cost, time, market, law factors, returned products quality and environmental factors. Any of them has own sub-criteria which are shown in Figure 2.

4. 1. The Reverse Process Selection Via the Proposed ERA-TOPSIS

In the suggested decision making process, at first, every expert will fill out a questioner about each returned product and reverse manufacturing alternative considering the above-mentioned criteria. The response for each question in the questioner will answer the next step for the returned product by choosing the reverse manufacturing alternative. By using of ERA, we show the answering results as follows. Table 1 shows the extracted information from experts choosing alternatives for one dashboard.Due to the uncertainty nature of this assessment process, the obtained results could be incomplete. The results of Table 1 indicate the higher frequency of the incomplete assessmentsthan complete

assessments which are extracted based on the experts' opinions.Utilization for each scale is shown in Table 2. Alternatives utilitarian is equally distributed. Utility of the input alternatives in TOPSIS are provided by ERA following the extraction of the expert's information. By resolving the decision making model, we rank the reverse manufacturing alternatives which are ranked. Finally, the best choice is being selected. By use of ERA through the steps from 1 to 5 mentioned in 3.4, we have applied the information provided by experts in questioners and the result for one return product is a decision matrix given in Table 3. This table includes utilities extracted from aggregation of expert's belief by ERA. Calculations have been performed by C++ coding program.Relative weight criteria calculated by group AHP are shown in Table 4. Implementation of the decision making model given through steps 6 to 9 in section 3.4 are illustrated in Tables 5 to 7. It is easy to find that the obtained results using the proposed model are in good agreement with expert's opinions in most cases which could validate the suggested model.
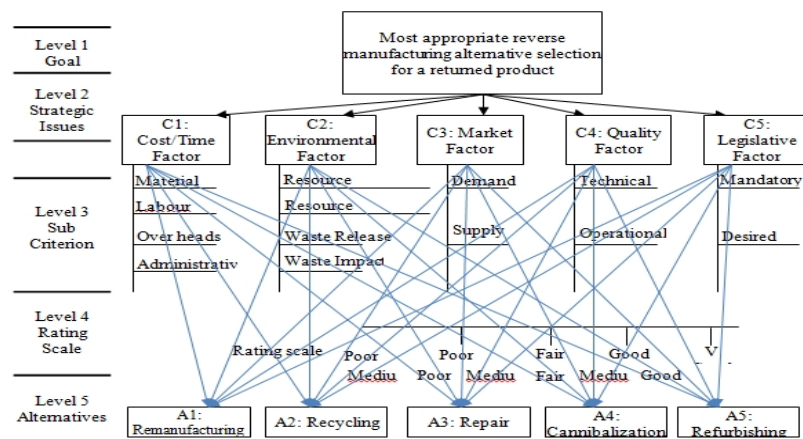

Figure 2. Hierarchical structure of alternative selection in a reverse logistics system

TABLE 1. Extracted information from experts choosing alternatives for one product

Criteria	Sub criteria	Expert₁	Expert₂	Expert₃
Cost/time	Material	(0.1) MF-0.8G	(0.2) MG- (0.8) VG	(0.3) MG- (0.7) VG
	Labor	(0.2) MF- (0.7) G	(0.6) MG- (0.3) VG	(0.3) MG- (0.5) VG
	Over heads	(0.8) MP- (0.2) F	(0.1) MG- (0.8) VG	(0.2) MG- (0.7) VG
	Administrative	(0.7) MP- (0.3) F	(0.9) G	(0.2) MG- (0.7) VG
Environmental	Resource consumption	(0.1) MF- (0.9) G	(0.2) MG- (0.7) VG	(0.1) MG- (0.8) VG
	Resource conservation	(0.3) MF- (0.7) G	(0.9) G	(0.2) MG- (0.8) VG
	Waste release	(0.7) MF- (0.2) G	(0.2) MG- (0.8) VG	(0.3) MG- (0.7) VG
	Waste impact	(0.1) MF- (0.8) G	(0.2) MG- (0.8) VG	(0.9) VG
Market	Demand	(0.2) MF- (0.8) G	(0.2) MG- (0.7) VG	(0.1) MG- (0.9) VG
	Supply	(0.1) MP- (0.9) F	(0.7) F- (0.2) MF	(0.2) MG- (0.7) VG
Quality	Technical	(0.8) F- (0.1) MF	(0.2) MF- (0.7) G	(0.8) MG- (0.1) VG
	Operational	(0.2) MP- (0.7) F	(0.8) MF- (0.1) G	(0.7) MG- (0.1) VG
Legislative	Mandatory	(0.5) G- (0.5) MG	(0.3) MG- (0.6) VG	(1) VG
	Desired	(0.2) MG- (0.8) VG	(0.1) MG- (0.9) VG	(0.1) MG- (0.8) VG

Note 1:Poor(P),Medium Poor(MP),Fair(F),Medium Fair(MF),Good(G),Medium Good(MG),Very Good(VG)}, and the incomplete assessments are highlighted in gray

TABLE 2. Utilization for each scale

0.142	0.285	0.428	0.571	0.714	0.857	1
P	MP	F	MF	G	MG	G

TABLE 3. Decision matrix

		C_j				
		C1	C2	C3	C4	C5
	A1	0.255	0.235	0.203	0.562	0.269
	A2	0.223	0.228	0.184	0.582	0.481
A_i	A3	0.228	0.239	0.252	0.610	0.280
	A4	0.240	0.273	0.220	0.598	0.307
	A5	0.208	0.228	0.225	0.584	0.352

TABLE 4. Weight criteria calculated by group AHP

Weight criteria	W_1	W_2	W_3	W_4	W_5
Value	0.45	0.05	0.15	0.3	0.05

TABLE 5. Weighed matrix

		C_j				
		C1	C2	C3	C4	C5
	A1	0.024	0.130	0.062	0.021	0.156
	A2	0.021	0.126	0.056	0.022	0.279
A_i	A3	0.022	0.133	0.077	0.023	0.162
	A4	0.023	0.151	0.067	0.022	0.178
	A5	0.020	0.126	0.069	0.022	0.204

TABLE 6. Distances of alternatives from positive and negative ideals

	A1	0.125623		A1	0.0084
	A2	0.032972		A2	0.122892
S_i^+	A3	0.117929	S_i^-	A3	0.023031
	A4	0.101146		A4	0.035551
	A5	0.079332		A5	0.049929

TABLE 7. Ranking of the alternatives

| A1	0.062677	5	
A2	0.788456	1	
A3	0.163387	4	Final rank
A4	0.260072	3	
A5	0.386265	2	

4. 2. Efficiency Evaluation of the Proposed ERA-TOPSIS

In this section, results of the proposed ERA-TOPSIS are compared with ERA approach which

was proposed by Yang et al. [23] to evaluate the efficiency of the proposed methodology. Results of proposed MCDM methodology and Yang's method are shown in Table 8.In section 3.4 calculation of utility has been shown. The ranking of two alternatives is based on their utilities by Yang et al. [23]. If $U_{min}(A_l) > U_{max}(A_k)$ then alternative l is preferred to alternative k. if $U_{min}(A_l) = U_{min}(A_k)$ and $U_{max}(A_l) = U_{max}(A_k)$ then alternative $l$is indifferent to alternative k. Also Xu et al.[19] used another condition for ranking alternatives. Alternative l is preferred to alternative k, if U_{max}, U_{min} and $U_{average}$ of l is greater than U_{max}, U_{min} and $U_{average}$ of k. According to these conditions due to the narrow state that is considered, in most cases, complete ranking of alternatives is reachable. By using above conditions for ranking of reverse manufacturing alternatives, recycling is preferred to remanufacturing and repair ispreferred to cannibalizations. Among refurbishing, recycling and repair there is no preference. As mentioned before and based on the obtained results of Table 9, the ERA is not able to present complete ranking in most cases. But the proposed methodology (i.e., ERA-TOPSIS) in this paper can improve this lack. Table 8 shows complete ranking of alternatives.

4. 3. Sensitivity Analysis

Robustness of the obtained results of applied proposed ERA-TOPSIS against input variations should be analyzed. To analyze the effect of variation of obtained data from the assessment process, a value of each cell of decision matrix in TOPSIS model which is shown in Table 9 has been increased and decreased to 10 percent. Following five inputs were sensitive. Red cells related to sensitivity against increase and yellows against decrease. Varying the ranking of the alternatives because of the sensitivity against decrease of cost/time for recycling choices is shown in Figure 3. As shown in the Figure 3, the priority of recycling has decreased which is reasonable due to the getting worse the cost/time input.
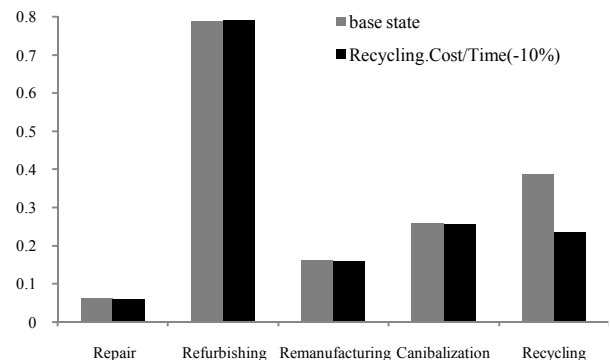
Figure 3. Varying the ranking of the alternatives

TABLE 8. Results of implementing Yang's method

	A1	A2	A3	A1	A1
U_{max}	0.797	0.709	0.709	0.831	0.889
U_{min}	0.265	0.429	0.321	0.316	0.275
$U_{average}$	0.531	0.569	0.515	0.574	0.582

TABLE 9. Sensitivity against increase or decrease of each criterion for each alternative

	Weights				
	0.45	0.05	0.15	0.3	0.05
C_i A_i	C1	C2	C3	C4	C5
A1	0.269	0.562	0.203	0.235	0.255
A2	0.529	0.582	0.184	0.228	0.223
A3	0.280	0.610	0.252	0.239	0.228
A4	0.307	0.598	0.220	0.273	0.240
A5	0.352	0.584	0.225	0.228	0.208

5. CONCLUSION

An efficient multi-criteria decision making framework has been proposed for a recovery system process. The main core of the proposed framework is based on the ERA. ERA was used to tackle the inherent uncertainty of the recovery system process data and provided an incomplete ranking of the returned products regarding respective criteria. Then, TOPSIS was employed to provide a complete ranking. Moreover, in order to take into account the experts' opinions about relative importance of the alternatives to each other, Group-AHP has been utilized. Proposed approach has been appliedin a case in a real reverse logistic field. The obtained results using the proposed model are in good agreement with expert's opinions which confirms the prosperity of this model. Moreover, the comparison results show that this method in comparison with ERA can obtain a complete ranking. For the future study, another approach of ERA such as interval ERA compatible with the purpose problem can be used. This approach can be easily implemented in QFD and EFQM in the new research studies. This approach can be used in different applications dealing with uncertain and incomplete data such as medical quality, weapon system capability assessment, and supplier selection. Besides all advantages of the ERA, one of the disadvantages of exciting ERA framework is that its formulation involves complex formula.Therefore,another promising direction for future research is to provide simpler ERA framework that can be easily implemented in practical cases.

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Comprehensive Decision Modeling of Reverse Logistics System: A Multi-criteria Decision Making Model by using Hybrid Evidential Reasoning Approach and TOPSIS

TECHNICAL NOTE

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چکیده

در طی دو دهه اخیر، سیستم‌های احیای محصولات به‌واسطه دلایل مختلف همچون قوانین جدید دولتی و مزایای اقتصادی مورد توجه روزافزون قرار گرفته شده است. یکی از مهم‌ترین فعالیت‌های این سیستم‌ها، تخصیص محصولات برگشتی به گزینه‌های مناسب تولید برگشتی است. در این مطالعه، یک رویکرد جدید بر پایه تکنیک مبتنی بر شواهد و تاپسیس برای مواجهه با گزینه‌های سیستم احیا با در نظر گرفتن یک مدل جامع در لجستیک برگشتی ارایه شده است. این مطالعه تنها با توسعه یک مدل جدید به توسعه ادبیات موضوع نه پرداخته بلکه یک تکنیک کاربردی تصمیم‌سازی برای درنظر گرفتن داده‌های کمی و کیفی به صورت توام با استفاده از رویکرد مبتنی بر شواهد و تاپسیس ارایه نموده است. در نهایت، یک نمونه موردی در صنعت خودروبرای نمایش کارایی مدل ارایه‌شده در انتخاب گزینه‌های مناسب برای تولید برگشتی درنظر گرفته شده است. این شرکت مواجه است با محصولات برگشتی و انتخاب تصمیم درست با در نظر گرفتن معیارهای متفاوت نظیر هزینه، کیفیت و منابع موجود. عدم‌قطعیت محصولات برگشتی پیرامون کمیت، کیفیت و زمان مواجهه با این محصولات درنظر گرفته شده است. نتایج دریافت‌شده نشانگر انطباق مناسب آن‌ها با نظر خبرگان بوده و کارایی مدل تصمیم‌گیری ترکیبی پیشنهادشده را برای ارایه یک رتبه‌بندی کامل گزینه‌ها را نشان می‌دهد.

doi: 10.5829/idosi.ije.2015.28.06c.13