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An Integrated Approach for Collection Center Selection in Reverse Logistics

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ABSTRACT

In this paper, a hybrid multi-criteria decision-making (MCDM)-method and mixed integer linear programming (MILP) approach in order to evaluation of the returned products' collectors along with their ordered quantities, is utilized. Firstly, the most important criteria of collection center in the car industry are identified. Then, in order to evaluate these proposed criteria, a hybrid Fuzzy Decision-Making Trial And Evaluation Laboratory (FDEMATEL)- evaluation of mixed qualitative and quantitative data (EVAMIX) approach is applied. By this method, the most important criteria and their weights along with collection centers' score are determined. In addition, an MILP mathematical model is proposed for selection of the best collection center and computation of ordering quantities. An efficient approach for collection center selection and a novel application of combined FDEMATEL, EVAMIX, and MILP model can be considered as the main contributions of this paper. It should be noted that, to measure the performance of this method a recycling company as a case study in Iran has considered which of this firm collects effete tire and ball bearings of cars. Implementation of this case study can be considered as the other contributions of this paper. At last, with help of obtained results the proper collection center and their ordered quantities are computed. In addition, for measure efficiency of the proposed model, some numerical example, in various dimensions is considered. Moreover, the managers of this industry with the help of a simple methodology can choose the appropriate suppliers.

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1. INTRODUCTION

Returned product management is a complex issue that needs to decide on both the strategic level and the operational level. Planned issues at a high level need to be answered at the strategic level, which includes determining the type of required facilities and their location, volume of returned goods, and etc. On the other hand, issues related to operational planning are planned at the lower level which includes the interval between recycled collection times, number and capacity of transportation vehicles, the corresponding routing problem, the number of needed workers, and etc. Despite the close relationship between these two types of decision-making, analyzing them is usually done separately. Strategic decisions often are responding to political and governance issues, while operational decisions are examined at lower levels. Hence, returned product issues should be checked out by a variety of products in different locations [1].

Nowadays, in developing countries, organizations focused on reverse logistics and supply chain processes, that this concept plays an effective role in creating the value of real economic goods and services with respect to environmental considerations. Now, this focus is increasing on all markets includes industrial and high-tech sectors, commercial, and consumer products. The Kodak Company can be noted as a successful example of these markets, which was a manufacturer of disposable cameras. This firm collects reclaimable part of the returned cameras such as boards, plastic parts, and lenses and renders them in production line after re-checking. The camera's board is an expensive part of the production and for the Kodak it was very valuable that a significant level of production costs decreased by restoring [2].

Researchers tried to find the success factors among the reverse logistics processes in various industries such

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as car tire industry and introduce it to decision-makers in this field [3, 4]. Capabilities of waste rubber products on the pollution of underground resources, becoming a living environment for animals such as mouse and insects which are carrier of dangerous and deadly diseases, the risk of firing the accumulated tires, reuse of rubber products as a national asset, and recovery of their materials and energy are the most important essential factors in recycling of rubber products [5]. Hence, industrial countries are trying to; recycling scrap tires by using various technologies, the use of recycled materials in the various area, and avoid of the burial or scattering scrap tires in the environment. In general, Scrap tires that still remained their useful life can be re-entered in the consumption cycle via two methods called groove and laminated. These methods have their special problems due to the poor quality of products. However, the scrap tires that are not repairable, can be included: depot and burial, incineration, pyrolysis, ebonite production, and rubber powder used in asphalt and flooring. Similarly, the broken and worn ball bearing can return in the metal industry by using reprocessing or recycling.

Recent literature has shown that today, returned products not only are expensive, but also is a tool to create value. For example, can refer to protecting the environment, providing key resources, and give more value to the customer. Probable revenues usually are more than the spent costs of creating the necessary measures for the return channels [6]. Many companies due to their limited resources, are not able to perform all reverse logistics activities. Therefore, these companies concede sectional or all activities related to collecting of returned products to outside suppliers. So, selecting best collectors of scrap tires can solve a large part of Reverse logistics problems or deleted them completely. For a better understanding of the last studies, a brief literature review of this field is presented.

Carter and Ellram [7] proposed an effective RL method that environmental benefits, and improving corporate aspects are provided in it. Most countries have implemented environmental laws on manufacturers or organizations to deal with the returned products after their useful life [8]. Nowadays, many advanced and developing countries consider the obligation for the collection of return goods includes electronics, packaging materials and vehicle [9]. By way of example, Jayaraman et al. [10] offered a mathematical programming model in the field of reverse logistics and with the help of a heuristic solution methodology, a final concentration set of potential facility sites is resulted. Moreover, many quantitative network design models in the field of the reverse logistics were presented by many investigators [9, 11, 12]. Environment friendly production methods along with difficulties in resumption and disassembly of electronic goods are another topics studied in the field of reverse logistics.

Ravi et al. [13] presented an Analytic Network Process (ANP) and balanced scorecard approach to assess options of RL processes for timeworn computers. Also, many studies found that RL processes are more arduous than forward processes [14]. In addition, due to the vague demand template, erratic scheduling, and quality of return goods; flexible capacity and logistics service are needed [15, 16]. So, organizations with inadequate properties and capabilities, attempt for outsourcing the RL activities to third parties [17]. The benefits of outsourcing to the third party could be observed via increased efficiency, responsiveness, and quality of goods and services throughout the supply chain [18]. Besides, supplier selection plays a significant role in the management of a supply chain and many researchers paid for the appraisal of suppliers based on various approaches such as Delphi method, VIKOR, DEMATEL, TOPSIS, ANP, AHP and etc. [19-24]. On the other hand, some of previous RL studies presented several other methods like as mathematical programming, multi-objective modeling to choose suppliers or partners [25-27]. By way of example, Kannan et al. [28] utilized a multiple criteria decision-making method for selection of suitable 3PRLP under fuzzy environment.

Recently, in the field of collection center selection, Yang et al. [29] in a study tried to decode a metro station location selection in Shenzhen city of China. In addition, a location selection of deep-water relief wells was suggested in the South China Sea [30]. Chen and Tsai [31] also proposed a data mining framework to improve location selection decisions using rough set theory which for assessment of this approach a restaurant chain as a case study was used. Malik et al. [32] attempt to select the best collection sites and matrix approach using the graph theory and for the efficiency of proposed framework a case study is applied.

As is clear, DEMATEL approach is reported as a strong an efficient method to find the criteria weight in various studies such as [20]. Also, in order to achieve a better result in line with the real world, the fuzzy set is used. On the other hand, because of existence the both of qualitative and quantitative data in our decision process a mixed qualitative and quantitative approach called EVAMIX is needed. Thus, in this paper in order to find the best collection center of returned product in the automotive industry, a hybrid MCDM-MILP framework is proposed. Hence, for the efficiency of this framework a recycling company in the automotive industry is applied, which action to recycle the two returned items include scrap tires and ball bearing. Besides, at first the related criteria based on last studies are identified and then the most effective criteria along with their weight are calculated by using the fuzzy DEMATEL approach. In the next step, a score of each

collection center for each item by using an EVAMIX based methodology is found which these scores as the importance values are considered. Then, with the help of this importance values and an MILP mathematical model, selection of the best collection center for a recycling company and the assigned items of each collection center are obtained. In addition, to further investigation, several numerical examples in various dimensions are applied. The main contribution of this research is a presentation of a novel hybrid MCDM approach consist of FDEMATEL and EVAMIX in a dynamic automotive industry of a developing country.
The steps in this article are as follows: in Section 2 the methodology of research along with hybrid framework, and solving method are presented. Then, in Section 3 a case study along with numerical examples are presented, and finally, in Section 4 the results and future suggestions are presented.

2. PROBLEM DESCRIPTION

In this paper, a hybrid MCDM approach based on FDEMATEL, EVAMIX method and MILP model has been suggested. For identification of pairwise comparison matrices, three experts are selected. For this propose, three joint meetings over a period of two months for three DMs has held which each meeting lasted two hours. During the meeting, in order to choose the appropriate criteria and sub-criteria, exchange of information is done.

2. 1. MILP Model

At first, the importance value of each collection center (CC) is obtained via hybrid FDEMATEL-EVAMIX. Then, these values are applied in the MILP model to introduce the best CC and the allocated items. Also, the importance value of each CC respect to the each item is assumed unequal. The proposed model is presented as below:

Subscripts

i: Item {1,2,...,I}

j: Collection center {1,2,..,J}

Decision variables

A_{ij}: Amount of the item *i* collected by CC *j*

X_{ij}: 1 if the item *i* is collected by CC *j*, 0 otherwise

Y_j: 1 if CC *j* is selected, 0 otherwise

Parameters

SIV_{ij}: Importance value of CC *j* with respect to item *i*

S_{ij}: The amount of the item *i* that CC *j* can collect

S_j: The set of the items that the CC *j* can collect

D_i: The demand of item *i*

maxNS: Maximum number of CC that can be selected

M: A big positive number

Objective Function

$$\max z = \sum_{i=1}^{I}\sum_{j=1}^{J}\left(SIV_{ij} * X_{ij}\right) \quad (1)$$

$$\sum_{j=1}^{J} A_{ij} = D_i \qquad \forall i \in I \quad (2)$$

$$\sum_{i \notin S_j}^{J} X_{ij} = 0 \qquad \forall j \in J \quad (3)$$

$$A_{ij} \le S_{ij} \qquad \forall i \in I, \forall j \in J \quad (4)$$

$$M * X_{ij} \ge A_{ij} \qquad \forall i \in I, \forall j \in J \quad (5)$$

$$M * Y_j \ge \sum_{i=1}^{I} X_{ij} \qquad \forall j \in J \quad (6)$$

$$\sum_{j=1}^{J} Y_j \le \max NS \quad (7)$$

$$X_{ij}, Y_j = \{0,1\} \quad (8)$$

$$A_{ij} = positive \ \&int \quad (9)$$

Equation (1) presented the objective of the model and attempt to providing the highest importance value of selected CC for each item by maximizing the related expression. Constraint (2) ensures that demand for each item is satisfied. Constraint (3) ensures that an item which is not collected by the related CC cannot be devoted to those CC. Constraint (4) proves that the capacity of *j*th CC with respect to the item *i* cannot be exceeded. Constraint (5) presents that if the item *i* is collected by *j*th CC, X_{ij} becomes 1 otherwise becomes 0. Constraint (6) proves that if any item *i* is collected by *j*th CC then Y_j becomes 1 otherwise becomes 0. Constraint (7) ensures that the number of selected collection center is restricted by a maximum number. Constraint (8) presents the binary decision variables. Constraint (9) presents the integer and positive variables.

3. NUMERICAL EXAMPLE

3. 1. Case Study

To confirm the suggested methodology, an application is performed in the recycling company of car which is located in Iran. The company pays to recycle two items: scrap tires and recycled ball bearings (Figure 1) via some external collection centers. According to this case, the proposed integrated approach is applied and solutions are procured for assigning the best collection center. Since, the offered practical example is based on the real application in a recycling company, the names of the collection center have not been provided expressly. Besides, parameter's values have been determined with respect to the case study. This recycling company, with the help of three collection centers represented by A, B, and C is assessed for the items with respect to each criterion. In this regard, the authorities of each collection center to collect returned products should be calculated.

Therefore, three experts and managers proposed the research framework. In order to perform offered framework, at first proper criteria should be identified. Hence, through the literature investigation and experts' opinions, four criteria and nine sub-criteria are proposed in Table 1.

3. 2. Solution Approach On of the efficient MCDM method is DEMATEL [33], which to the effectiveness and proximity to the real world, researchers used the fuzzy state of this method [34]. Fuzzy set theory as a decision-making process in the absence of sufficient information is proposed by Zadeh [35]. This theory is used as an evaluation method for unknown and linguistic explanation. Also, to describe the importance of the criteria, we used linguistic terms and linguistic values suggested by Lin and Wu [36] that expressed in Table 2.

Figure 1. Recycled tires and ball bearings (items)

TABLE 1. Explanation of proposed criteria and sub-criteria

Index	Criteria	Index	Sub-criteria
S	Security	S	The security of locations in terms of an accident, theft and risks
TC	Transportation Conditions	TC1	Quality of transportation
		TC2	The possibility of connecting locations with different ways of transportation
C	Costs	C1	The cost of selected land
		C2	Operational cost
		C3	Cost of human resources
		C4	Transportation cost
EC	Environmental Conditions	EC1	Weather conditions
		EC2	Amount of proximity to the customer and target market

TABLE 2. Linguistic terms and linguistic values [36]

Symbol	Linguistic terms	Linguistic value
VH	Very High Influence	(0.75, 1.0, 1.0)
H	High Influence	(0.5, 0.75, 1.0)
L	Low Influence	(0.25, 0.5, 0.75)
VL	Very Low Influence	(0, 0.25, 0.5)
No	No Influence	(0, 0, 0.25)

Besides, the procedure of the fuzzy DEMATEL is presented as follows:

Step 1. For calculation of the group direct-influence matrix, K expert offered k pairwise comparison matrices $Z_k = \left[Z_{ij}^{k} \right]_{n \times n}$ for selected criteria via linguistic terms of Table 1. Then, the average of these matrices is computed by:

$$\tilde{Z} = (\tilde{x}^1 \oplus \tilde{x}^2 \oplus \ldots \oplus \tilde{x}^P)/P \quad (1)$$

In initial direct relation fuzzy matrix $\tilde{Z}$ each element is a triangular fuzzy numbers as $\tilde{Z}_{ij} = \left(l_{ij}, m_{ij}, u_{ij} \right)$.

Step 2. Afterward, normalized direct-relation fuzzy matrix $\tilde{H}$ through normalization of $\tilde{Z}$ via formula (2, 3) is resulted:

$$\tilde{H}_{ij} = \tilde{Z}_{ij} \times r \quad (2)$$

$$r = \min\left(1/(max_{1 \le i \le n} \sum_{j=1}^{n} |\tilde{Z}_{ij}|), 1/(max_{1 \le j \le n} \sum_{i=1}^{n} |\tilde{Z}_{ij}|) \right) \quad (3)$$

Step 3. Then, the total- relation fuzzy matrix $\tilde{T}$ is computed as:

$$T = \lim_{k \to \infty} \left(\tilde{H}^1 \oplus \tilde{H}^2 \oplus \ldots \oplus \tilde{H}^K \right) \quad (4)$$

where $T_{ij} = (l_{ij}^*, m_{ij}^*, u_{ij}^*)$ and:

$$l_{ij}^* = \tilde{H}_l \times \left(I - \tilde{H}_l \right)^{-1} \quad (5)$$

$$m_{ij}^* = \tilde{H}_m \times \left(I - \tilde{H}_m \right)^{-1} \quad (6)$$

$$u_{ij}^* = \tilde{H}_u \times \left(I - \tilde{H}_u \right)^{-1} \quad (7)$$

Step 4. For defuzzification of total-relevance fuzzy matrix Equation (8) is used.

$$T = \frac{l + 4m + u}{6} \quad (8)$$

Step 5. Calculation of the threshold to eliminate low-impact criteria.This threshold is shown by Ts, that if one element was more than Ts, put it in the matrix U and else if less than the threshold instead of it putting zero in the matrix U.

$$Ts = \frac{\sum_{i=1}^{n} \sum_{j=1}^{m} T_{ij}}{m \times n} = \frac{\sum_{i=1}^{n} D_i}{m \times n} = \frac{\sum_{j=1}^{m} R_j}{m \times n} \quad (9)$$

$$\begin{cases} U_{ij} = T_{ij} & T_{ij} > Ts \\ U_{ij} = 0 & OW \end{cases} \quad (10)$$

Step 6. To obtain the influential relation map (IRM), first the sum of the rows and columns of matrix (T) are computed which respectively expressed the D_i and R_i.

$$D = \left[\sum_{j=1}^{n} T_{ij} \right]_{n \times 1} \quad (11)$$

$$R = \left[\sum_{i=1}^{n} T_{ij} \right]_{1\times n} \quad (12)$$

Then, with help of horizontal axis vector *(D+R)* and vertical axis vector *(D-R)*, IRM can be produced by drawing the ordered pairs of *(D+R, D-R)*. Also, if *(D_i-R_i)* was positive, then factor *i* has a more effect on other factors, and if it was negative, then factor *i* is being influenced by other factors.

Step 7. To discern the final weights of criteria the Equation (13), (14) are used.

$$W_j = \left[(D_i + R_i)^2 + (D_i - R_i)^2 \right]^{\frac{1}{2}} \quad (13)$$

$$\overline{W_j} = W_j / \sum_{j=1}^{n} W_j \quad (14)$$

where, $\overline{W_j}$ is the normalized weight of each criterion.

To rank the proposed alternatives, mixed qualitative and quantitative data (EVAMIX) method is used which this approach was suggested by Voogd [37] and later was promoted by Martel and Matarazzo [38]. The main steps of this method are presented as below:

Step 8: A data matrix of *(m×n)* size with *m* alternatives and *n* criteria are created. Then, the ordinal and cardinal criteria of this matrix are separated. For changing the linguistic preference to crisp number the suggested values by Chen and Hwang [39] are used.

Step 9: Compute the evaluative discrepancy of i^{th} alternative on each ordinal and cardinal criterion with respect to other alternatives. This step involves the calculation of discrepancy in criteria values between different alternatives pairwise. Pairwise is done based on FDEMATEL. The numbers 3, 4, 5, and 6 related to the verbal judgments "moderate importance", "strong importance", "very strong importance", and "absolute importance" and the numbers 2 ,1, and 0 correspond to the verbal judgments "low importance", "very low importance", and "absolute low importance".

Step 10: Compute the dominance scores of each alternative pair, *(i, i')* for all criteria .

$$\alpha_{ii'} = \left[\sum_{j\in O} \{ W_j \ sgn(e_{ij} - e_{i'j}) \}^B \right]^{\frac{1}{B}} \quad (15)$$

where

$$sgn(e_{ij} - e_{i'j}) = \begin{cases} +1 & if \ e_{ij} > e_{i'j} \\ 0 & if \ e_{ij} = e_{i'j} \\ -1 & if \ e_{ij} < e_{i'j} \end{cases}$$

$$\gamma_{ii'} = \left[\sum_{j\in C} \{ W_j \ sgn(e_{ij} - e_{i'j}) \}^B \right]^{\frac{1}{B}} \quad (16)$$

The symbol *B* means a constant number, which can be equal to any positive odd number, like 1, 3, 5, and *O* and *C* are the sets of ordinal and cardinal criteria respectively, and $a_{ii'}$ and $\gamma_{ii'}$ are the dominance score of each pair of alternatives with respect to ordinal and cardinal criteria respectively and the "higher" score have a "large" preference.

Step 11: In order to drive $a_{ii'}$ and $\gamma_{ii'}$ in same scale a standardization is needed. The standardized ordinal rate $\delta_{ii'}$ and cardinal rate $d_{ii'}$ are calculated via:

$$(\delta_{ii'}) = \left(\frac{\alpha_{ii'} - \alpha^-}{\alpha^+ - \alpha^-} \right) \quad (17)$$

where, a^+*(a^-)* is the highest (lowest) ordinal score for each pair alternatives.

$$(d_{ii'}) = \left(\frac{\gamma_{ii'} - \gamma^-}{\gamma^+ - \gamma^-} \right) \quad (18)$$

and γ^+*(γ^-)* is the highest (lowest) cardinal score for each pair alternatives.

Step 12: calculating the overall dominance measure $D_{ii'}$ for each pair alternatives *(i, i')* by using:

$$D_{ii'} = W_O \ \delta_{ii'} + W_C d_{ii'} \quad (19)$$

where, ($W_O=\Sigma_{j\epsilon O} W_j$) is the sum of the ordinal criteria's weights and ($W_C=\Sigma_{j\epsilon C} W_j$) is the sum of the weights of cardinal criteria and for each pair it is confirmed that $D_{ii'} + D_{i'i} = 1$.

Step 13: To calculate the appraisal score of i^{th} alternative (S_i), Equation (20) is applied and the higher value of score is better.

$$(S_i) = \sum_{i'} (D_{i'i} / D_{ii'})^{-1} \quad (20)$$

3. 3. Examples

Then, a set of fuzzy linguistic scale for performing FDEMATEL method are proposed, that every expert offered pairwise relationships between each pair of 9 sub-criteria (Table 3). Hence, three appraisal data fuzzy matrix are resulted. So, initial-direct fuzzy matrix $\tilde{Z}$ (average of these assessment matrices) by using Equation (1) is obtained. The results are presented in Table 4. Then, the normalized direct-relation fuzzy matrix $\tilde{H}$ via Equation (2) is formed. The partial results of our case study are depicted in Table 5. Following Equations (4)-(7), the total-relation fuzzy matrix is obtained which illustrated in Table 6. Then, total-relation fuzzy matrix is defuzified through defuzzification Equation (8) and achieved results are presented in Table 7. To access the casual relationships between criteria, *(D_i+R_i)* and *(D_i-R_i)* is calculated which these results are shown in Table 8. In addition, the threshold to eliminate low-impact criteria is *Ts=0.097*, that compute for criteria in this research. Then, two sets of numbers are obtained: *(D_i+R_i)* which shows the significance of all criteria by association of all managers' preferences and *(D_i-R_i)* which assign criteria into cause and effect groups. As the shown in Table 8, the criteria are divided into two groups.

TABLE 3. Expert opinion for criteria and sub-criteria

	S	TC1	TC2	C1	C2	C3	C4	EC1	EC2
S	-	L,L,L	VL,VL,VL	AN,AN,AN	L,L,L	L,L,L	AN,AN,AN	L,L,L	VL,VL,VL
TC1	L,H,L	-	VL,VL,VL	AN,AN,AN	VL,VL,VL	VL,VL,VL	AN,AN,AN	L,L,L	VL,VL,VL
TC2	H,H,L	L,L,H	-	VL,VL,AN	L,L,H	L,L,VH	VL,VL,VL	H,H,H	L,L,L
C1	VH,VH,VH	VH,VH,VH	H,VH, H	-	VH,H,VH	VH, H, H	L,H,H	VH,VH,VH	L,H,H
C2	L,L,L	L,L,L	VL,VL,VL	AN,AN,AN	-	L,L,L	AN,AN,AN	L,L,L	VL,VL,VL
C3	L,VL,L	L,L,L	VL,VL,VL	AN,AN,AN	L,L,L	-	AN,AN,AN	L,L,L	VL,VL,VL
C4	VH,VH,H	H,H,VH	L,L,VL	L,L,H	H, H, H	VH,VH,VH	-	VH,VH,VH	L,L,L
EC1	VL,AN,VL	VL,VL,VL	AN,AN,AN	AN,AN,AN	VL,VL,VL	L,L,L	AN,AN,AN	-	VL,VL,VL
EC2	H,H,H	H,H,H	L,L,H	VL,L,VL	H,H,H	H,H,H	VL,L,L	H,H,VH	-

TABLE 4. The initial-direct fuzzy matrix (Z)

	S	TC1	TC2	C1	C2	C3	C4	EC1	EC2
S	0,0,0	0.25,0.5,0.75	0,0.25,0.5	0,0,0.25	0.25,0.5,0.75	0.25,0.5,0.75	0,0,0.25	0.25,0.5,0.75	0,0.25,0.5
TC1	0.33,0.58,0.83	0,0,0	0,0.25,0.5	0,0,0.25	0,0.25,0.5	0,0.25,0.5	0,0,0.25	0.25,0.5,0.75	0,0.25,0.5
TC2	0.42,0.67,0.92	0.33,0.58,0.83	0,0,0	0,0.17,0.42	0.33,0.58,0.83	0.42,0.67,0.83	0,0.25,0.5	0.5,0.75,1	0.25,0.5,0.75
C1	0.75,1,1	0.75,1,1	0.58,0.83,1	0,0,0	0.67,0.92,1	0.58,0.83,1	0.42,0.67,0.92	0.75,1,1	0.42,0.67,0.92
C2	0.25,0.5,0.75	0.25,0.5,0.75	0,0.25,0.5	0,0,0.25	0,0,0	0.25,0.5,0.75	0,0,0.25	0.25,0.5,0.75	0,0.25,0.5
C3	0.17,0.42,0.67	0.25,0.5,0.75	0,0.25,0.5	0,0,0.25	0.25,0.5,0.75	0,0,0	0,0,0.25	0.25,0.5,0.75	0,0.25,0.5
C4	0.67,0.92,1	0.58,0.83,1	0.17,0.42,0.67	0.33,0.58,0.83	0.5,0.75,1	0.75,1,1	0,0,0	0.75,1,1	0.25,0.5,0.75
EC1	0,0.17,0.42	0,0.25,0.5	0,0,0.25	0,0,0.25	0,0.25,0.5	0.25,0.5,0.75	0,0,0.25	0,0,0	0,0.25,0.5
EC2	0.5,0.75,1	0.5,0.75,1	0.33,0.58,0.83	0.08,0.33,0.58	0.5,0.75,1	0.5,0.75,1	0.17,0.42,0.67	0.58,0.83,1	0,0,0

TABLE 5. The normalized direct-relation fuzzy matrix (H)

	S	TC1	TC2	C1	C2	C3	C4	EC1	EC2
S	0,0.03,0.15	0.03,0.09,0.24	0,0.05,0.17	0,0,0.1	0.03,0.09,0.23	0.03,0.09,0.24	0,0,0.1	0.04,0.09,0.25	0,0.05,0.17
TC1	0.04,0.09,0.23	0,0.02,0.14	0,0.04,0.16	0,0,0.09	0,0.05,0.19	0,0.06,0.2	0,0,0.1	0.03,0.09,0.23	0,0.05,0.16
TC2	0.06,0.13,0.3	0.05,0.12,0.3	0,0.03,0.14	0,0.03,0.14	0.05,0.12,0.29	0.06,0.13,0.3	0,0.04,0.16	0.07,0.15,0.33	0.03,0.09,0.24
C1	0.12,0.21,0.38	0.12,0.21,0.38	0.08,0.15,0.3	0,0.02,0.12	0.1,0.19,0.37	0.1,0.19,0.38	0.05,0.1,0.24	0.12,0.22,0.4	0.06,0.14,0.3
C2	0.03,0.09,0.23	0.03,0.09,0.24	0,0.05,0.17	0,0,0.1	0,0.03,0.14	0.03,0.09,0.24	0,0,0.1	0.04,0.09,0.25	0,0.05,0.17
C3	0.02,0.08,0.22	0.03,0.09,0.23	0,0.04,0.16	0,0,0.1	0.03,0.08,0.23	0,0.03,0.15	0,0,0.1	0.03,0.09,0.24	0,0.05,0.17
C4	0.1,0.19,0.36	0.09,0.18,0.36	0.03,0.09,0.25	0.04,0.08,0.21	0.08,0.16,0.35	0.11,0.2,0.36	0,0.02,0.12	0.12,0.21,0.37	0.04,0.11,0.27
EC1	0,0.04,0.17	0,0.05,0.18	0,0.01,0.12	0,0,0.09	0,0.05,0.17	0.03,0.08,0.21	0,0,0.09	0,0.02,0.13	0,0.04,0.15
EC2	0.08,0.16,0.35	0.08,0.16,0.35	0.04,0.11,0.26	0.01,0.05,0.18	0.07,0.15,0.34	0.08,0.16,0.35	0.02,0.06,0.19	0.09,0.18,0.36	0,0.04,0.18

TABLE 6. The total-relation fuzzy matrix (T)

	S	TC1	TC2	C1	C2	C3	C4	EC1	EC2
S	0,0.03,0.15	0.03,0.09,0.24	0,0.05,0.17	0,0,0.1	0.03,0.09,0.23	0.03,0.09,0.24	0,0,0.1	0.04,0.09,0.25	0,0.05,0.17
TC1	0.04,0.09,0.23	0,0.02,0.14	0,0.04,0.16	0,0,0.09	0,0.05,0.19	0,0.06,0.2	0,0,0.1	0.03,0.09,0.23	0,0.05,0.16
TC2	0.06,0.13,0.3	0.05,0.12,0.3	0,0.03,0.14	0,0.03,0.14	0.05,0.12,0.29	0.06,0.13,0.3	0,0.04,0.16	0.07,0.15,0.33	0.03,0.09,0.24
C1	0.12,0.21,0.38	0.12,0.21,0.38	0.08,0.15,0.3	0,0.02,0.12	0.1,0.19,0.37	0.1,0.19,0.38	0.05,0.1,0.24	0.12,0.22,0.4	0.06,0.14,0.3
C2	0.03,0.09,0.23	0.03,0.09,0.24	0,0.05,0.17	0,0,0.1	0,0.03,0.14	0.03,0.09,0.24	0,0,0.1	0.04,0.09,0.25	0,0.05,0.17
C3	0.02,0.08,0.22	0.03,0.09,0.23	0,0.04,0.16	0,0,0.1	0.03,0.08,0.23	0,0.03,0.15	0,0,0.1	0.03,0.09,0.24	0,0.05,0.17
C4	0.1,0.19,0.36	0.09,0.18,0.36	0.03,0.09,0.25	0.04,0.08,0.21	0.08,0.16,0.35	0.11,0.2,0.36	0,0.02,0.12	0.12,0.21,0.37	0.04,0.11,0.27
EC1	0,0.04,0.17	0,0.05,0.18	0,0.01,0.12	0,0,0.09	0,0.05,0.17	0.03,0.08,0.21	0,0,0.09	0,0.02,0.13	0,0.04,0.15
EC2	0.08,0.16,0.35	0.08,0.16,0.35	0.04,0.11,0.26	0.01,0.05,0.18	0.07,0.15,0.34	0.08,0.16,0.35	0.02,0.06,0.19	0.09,0.18,0.36	0,0.04,0.18

TABLE 7. The total-relation fuzzified matrix (T^{df})

	S	TC1	TC2	C1	C2	C3	C4	EC1	EC2
S	0.044	0.104	0.058	0.019	0.101	0.104	0.020	0.109	0.060
TC1	0.108	0.039	0.055	0.018	0.068	0.071	0.019	0.103	0.057
TC2	0.149	0.140	0.043	0.043	0.135	0.149	0.053	0.167	0.106
C1	0.222	0.222	0.163	0.032	0.206	0.208	0.114	0.235	0.150
C2	0.104	0.104	0.058	0.019	0.041	0.104	0.020	0.109	0.060
C3	0.093	0.103	0.057	0.019	0.100	0.044	0.020	0.108	0.060
C4	0.200	0.193	0.109	0.097	0.178	0.210	0.031	0.219	0.122
EC1	0.053	0.062	0.026	0.016	0.060	0.091	0.017	0.034	0.051
EC2	0.174	0.175	0.122	0.066	0.169	0.176	0.078	0.192	0.057

TABLE 8. The partial results

Criteria	D	R	D+R	D-R
S	0.618	1.147	1.766	-0.529
TC1	0.538	1.140	1.679	-0.602
TC2	0.984	0.691	1.675	0.293
C1	1.553	0.328	1.881	1.226
C2	0.618	1.057	1.675	-0.438
C3	0.602	1.158	1.760	-0.555
C4	1.360	0.372	1.732	0.987
EC1	0.409	1.275	1.684	-0.866
EC2	1.208	0.724	1.933	0.484

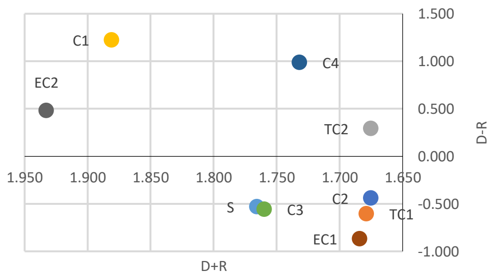

Figure 2. The IRM chart of FDEMATEL

The first is cause group which implies C1, C4, EC2, TC2 and effect group which insinuate the rest of the criteria.

Then, the IRM of the given application can be created in Figure 2. Finally, the relative importance of the criteria is depicted in Table 9.

The weights of the criteria are calculated by FDEMATEL, and then these values can be used in EVAMIX. So, the EVAMIX methodology must be started at the second step. Alternatives and their evaluation linguistic terms and numerical factors are constructed in Table 10. Then, after evaluating by EVAMIX method, the amount of $a_{ii'}$, $\gamma_{ii'}$, $\delta_{ii'}$, $d_{ii'}$ and $D_{ii'}$ per each item are resulted in Table 11. After calculation of this variable, the appraisal score of each alternative respect to each item is shown in Table 12.

According to the above experimental study, the proposed method provides some important findings. First, in accordance with the results of FDEMATEL (see Table 9), the cost of selected land (C1) is the most important sub-criterion, and weather conditions (EC1) is the least important one.

TABLE 9. The relative importance of the criteria

Cr.	S	TC_1	TC_2	C_1	C_2	C_3	C_4	EC_1	EC_2
$\overline{w_j}$	0.11	0.10	0.10	0.13	0.10	0.11	0.12	0.11	0.12

TABLE 10. The value of CC respect to each item

It.	Cr. / CC	S	TC_1	TC_2	C_1	C_2	C_3	C_4	EC_1	EC_2
	A	VH	H	VVH	100	10	40	30	VL	VH
1	B	H	VH	VVH	120	12	35	28	L	VVH
	C	VH	M	VH	150	8	40	32	M	H
	A	VH	H	VH	110	11	30	30	L	VH
2	B	H	VH	VVH	90	12	35	35	L	VVH
	C	H	M	VVH	120	11	35	32	M	VH

TABLE 11. The result of EVAMIX method

Pair (i, i')	Item 1: tire				
	$a_{ii'}$	$\gamma_{ii'}$	$\delta_{ii'}$	$d_{ii'}$	$D_{ii'}$
(1,1)	0	0	0	0	0
(1,2)	-0.225	-2.07	0	0.344	0.1578
(1,3)	0.211	-6.63	0.969	0	0.5242
(2,1)	0.225	2.07	1	0.656	0.8421
(2,2)	0	0	0	0	0
(2,3)	0.103	-4.56	0.729	0.156	0.4660
(3,1)	-0.211	6.63	0.031	1	0.4758
(3,2)	-0.103	4.56	0.271	0.844	0.5340
(3,3)	0	0	0	0	0

Pair (i, i')	Item 2: ball bearing				
	$a_{ii'}$	$\gamma_{ii'}$	$\delta_{ii'}$	$d_{ii'}$	$D_{ii'}$
(1,1)	0	0	0	0	0
(1,2)	-0.214	1.413	0	0.7014	0.3220
(1,3)	0.002	-2.094	0.505	0.2014	0.3655
(2,1)	0.214	-1.413	1	0.2985	0.6780
(2,2)	0	0	0	0	0
(2,3)	0.111	-3.507	0.759	0	0.4108
(3,1)	-0.002	2.094	0.495	0.7985	0.6345
(3,2)	-0.111	3.507	0.241	1	0.5892
(3,3)	0	0	0	0	0

TABLE 12. The appraisal score of alternative per each item

i	Item 1: tire			Item 2: ball bearing		
	CC	S_i	Rank	CC	S_i	Rank
1	A	0.160178	3	A	0.260287	3
2	B	0.749944	1	B	0.523809	2
3	C	0.506538	2	C	0.785381	1

Second, the FDEMATEL method can also be utilized to understand the interrelationship among dimensions and criteria (Figure 2). The IRM shows that the cost of selected land (C1), transportation cost (C4), the amount of proximity to the customer and target market (EC2), and the possibility of connecting locations with different ways of transportation (TC2) have more influence over the other five sub-criteria. This finding means that they are the most important relative to the other criteria. Third, from the results obtained by EVAMIX (see Tables 11, 12), the ranking order of the alternatives (collection centers) for item (1) is B>C>A, and for item (2) is C> B>A, suggesting (B, C) as the most suitable collection center for this project.

After implementing the last step of the hybrid MCDM technique, the importance value of each collection center is obtained via ($\mathrm{SIV} = S_i / \sum_i S_i$) equation. Then, the mathematical model is applied by using these obtained importance values. The mathematical model is coded by using one of a commercial program called LINGO 9, and the optimum solution along with ordered quantities of each collection center are found. In the first example, a real world case study is applied and value of parameters is presented in Table 13. Also, it should be noticed that the value of *maxNS* as one of the model parameters equal with number of CC is considered. By way of example, in a case study the value of (*maxNS=3*) is considered.

After running this model by LINGO 9 software, the optimum solution is attained in a short time. The selected CC and the ordered quantities of each CC are shown in Table 14 and Figure 3.

In addition, four numerical test problem for further investigation of the model are proposed which their appraisal score of alternative per each item are obtained similarly by EVAMIX method, and the final results of the model are presented in Table 15.

TABLE 13. The parameters setting for the case study

CC	SIV per each item		Supply of each item	
	Tire	Ball bearing	Tire	Ball bearing
A	0.1131	0.1658	2000	2500
B	0.5294	0.3337	2500	1600
C	0.3576	0.5004	3000	2800
Demand			5000	4000

TABLE 14. Selected CC and ordered quantities of each CC

Collection center	Item	
	Tire	Ball bearing
A	0	1200
B	2000	0
C	3000	2800

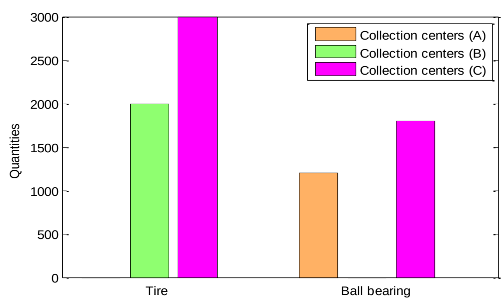

Figure 3. The bar chart of selected CC

TABLE 15. The parameter setting of four numerical test problems

EX.		SIV per each Item						Supply per each Item					
		Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6
1	CC1	0.2639	0.4190	0.2227	-	-	-	2000	1850	1000	-	-	-
	CC2	0.2946	0.1094	0.0371	-	-	-	2500	2300	2000	-	-	-
	CC3	0.2890	0.4513	0.0781	-	-	-	2800	2700	1550	-	-	-
	CC4	0.1525	0.0203	0.6621	-	-	-	1850	2600	2340	-	-	-
				Demand				6000	7000	4500	-	-	-
2	CC1	0.1850	0.2501	0.2924	0.1808	-	-	2100	1200	800	4020	-	-
	CC2	0.0628	0.0634	0.0874	0.1389	-	-	2700	1850	850	3800	-	-
	CC3	0.1246	0.0682	0.3337	0.1032	-	-	2630	1450	920	4100	-	-
	CC4	0.1721	0.1177	0.1257	0.2439	-	-	2790	2460	750	3570	-	-
	CC5	0.2193	0.3843	0.0706	0.1718	-	-	3000	2530	1000	3900	-	-
	CC6	0.2362	0.1162	0.0902	0.1614	-	-	2500	3100	1100	4500	-	-
				Demand				9000	9000	4000	15000	-	-
3	CC1	0.2419	0.1411	0.0466	0.1684	0.1379	-	3000	1100	2500	1200	150	-
	CC2	0.0754	0.2072	0.2282	0.1828	0.2552	-	4200	1200	1800	2350	240	-
	CC3	0.1997	0.2483	0.0894	0.1101	0.0200	-	2800	1000	1900	4500	362	-
	CC4	0.1988	0.0345	0.1518	0.0205	0.1134	-	2500	1050	2000	2500	200	-
	CC5	0.1003	0.1512	0.0476	0.0560	0.0273	-	3000	850	2400	2700	540	-
	CC6	0.1497	0.1248	0.1729	0.2232	0.2464	-	1200	1500	1300	2350	700	-
	CC7	0.0200	0.0032	0.0755	0.0372	0.0012	-	4000	780	1570	1900	570	-
	CC8	0.0142	0.0896	0.1879	0.2018	0.1985	-	1900	900	2630	3150	350	-
				Demand				15000	6000	9000	14000	2500	-
4	CC1	0.1211	0.1154	0.1370	0.1417	0.0767	0.0528	2000	1500	300	4000	700	100
	CC2	0.1287	0.0304	0.1434	0.1438	0.0416	0.0362	1000	1900	200	2000	580	80
	CC3	0.0125	0.1790	0.0745	0.0865	0.1044	0.0601	1500	2100	100	1300	900	95
	CC4	0.0592	0.1305	0.0742	0.0090	0.0265	0.0603	1350	3200	250	5000	1000	150
	CC5	0.0385	0.0736	0.0512	0.0353	0.0963	0.0966	2100	1800	320	2100	1100	240
	CC6	0.1186	0.1077	0.1366	0.0531	0.0257	0.0939	1800	2300	310	2400	950	195
	CC7	0.0639	0.0843	0.0560	0.1235	0.0517	0.0761	1750	1700	900	1900	450	420
	CC8	0.1349	0.0159	0.0169	0.0023	0.0877	0.0447	2500	3200	700	3200	635	312
	CC9	0.0269	0.0503	0.1184	0.0065	0.1094	0.0958	2900	900	500	4000	750	450
	CC10	0.0391	0.0259	0.0591	0.0254	0.0114	0.0629	1000	1600	420	2500	540	340
	CC11	0.0216	0.0386	0.0367	0.0976	0.1303	0.0414	1100	2300	320	4200	500	200
	CC12	0.0202	0.0503	0.0613	0.1100	0.1088	0.1109	3100	3400	420	4230	900	120
	CC13	0.1288	0.0876	0.0146	0.0974	0.0683	0.1034	2400	4000	120	3200	1500	140
	CC14	0.0859	0.0104	0.0200	0.0678	0.0611	0.0650	2700	2100	500	1000	1050	230
				Demand				21000	24000	4000	38000	8500	2500

After running the mathematical model, the optimum solution of each numerical example is achieved in a short time. The selected CC and the ordered quantities of each CC are shown in Table 16 and Figures 4-7.

TABLE 16. Selected CC and ordered quantities of each CC

Ex.		Item					
		Item 1	Item 2	Item 3	Item 4	Item 5	Item 6
1	CC1	700	0	1000	-	-	-
	CC2	2500	1700	0	-	-	-
	CC3	2800	2700	1160	-	-	-
	CC4	0	2600	2340	-	-	-
2	CC1	0	910	130	4020	-	-
	CC2	2700	0	850	0	-	-
	CC3	510	0	920	4100	-	-
	CC4	2790	2460	0	0	-	-
	CC5	3000	2530	1000	2380	-	-
	CC6	0	3100	1100	4500	-	-
3	CC1	3000	1100	2500	0	0	-
	CC2	4200	1200	0	0	0	-
	CC3	800	1000	0	4500	362	-
	CC4	0	1050	1470	2500	0	-
	CC5	3000	0	2400	2700	540	-
	CC6	0	1500	0	1150	700	-
	CC7	4000	0	0	0	570	-
	CC8	0	150	2630	3150	328	-
4	CC1	2000	0	0	4000	350	0
	CC2	0	1400	0	2000	0	0
	CC3	0	2100	0	0	900	0
	CC4	0	3200	0	5000	1000	113
	CC5	2100	0	320	2100	1100	240
	CC6	1800	2300	0	2400	950	195
	CC7	1500	0	900	1170	0	420
	CC8	2500	3200	700	3200	0	312
	CC9	2900	0	500	4000	750	450
	CC10	0	0	420	2500	0	340
	CC11	0	2300	240	4200	0	200
	CC12	3100	3400	420	4230	900	0
	CC13	2400	4000	0	3200	1500	0
	CC14	2700	2100	500	0	1050	230

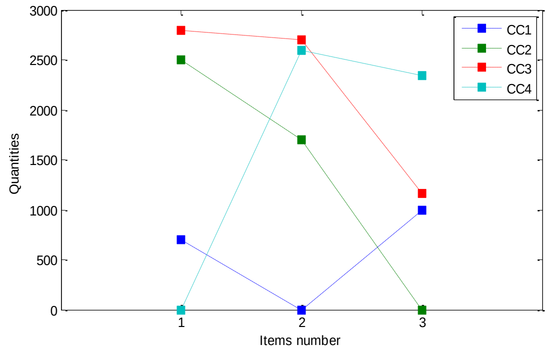

Figure 4. The chart of selected CC for example 1

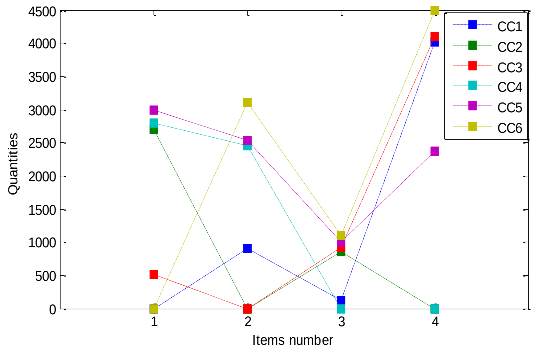

Figure 5. The chart of selected CC for example 2

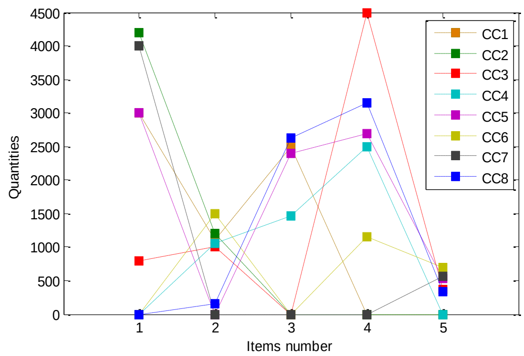

Figure 6. The chart of selected CC for example 3

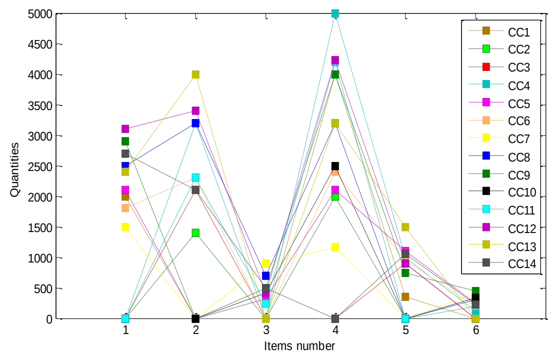

Figure 7. The chart of selected CC for example 4

4. CONCLUSION

Selection of collection centers for the returned productions in reverse logistics is an important, difficult, and time consuming task for superiors of any corporation. This problem exacerbates with an increase in the number of alternatives. There is also a risk of human error in umpire and decision making. Therefore, a computational model is needed which can increase the accuracy of decisions and reduce the time required. A hybrid FDEMATEL-EVAMIX approach along with an MILP model in this study are used. Then, a real case study as a recycling company of car in Iran was presented to show the applicability and performance of the approach. At first, with the opinions of the senior managers, all the criteria are gathered. Then, the FDEMATEL method applied to prioritize the importance of various criteria. The cost of selected land (C1), transportation cost (C4), amount of proximity to the customer and target market (EC2), and the possibility of connecting locations with different ways of transportation (TC2) have more influence over the other five sub-criteria. Besides, by using EVAMIX technique the appraisal score of alternatives and importance values of them are computed. The ranking order of the alternatives (collection centers) for item (1) is B>C>A, and for item (2) is C> B>A, suggesting (B, C) as the most suitable collection center for this project. Finally, the mathematical model is applied by using these obtained importance values and after running the mathematical model, selected collection centers and the order quantities of each collection center are resulted. In addition, for measure efficiency of the proposed model, some numerical examples in various dimensions are considered. Also, since the research data are related to the case study placed on Iran, hence, we cannot be sure that these results will be usable for another geographical area. So, this issue as a limitation of this research is raised that should be noted for future research. As a future suggestion in this paper, other fuzzy MCDM methods, like FTOPSIS, FAHP, and FANP can be used. Also, this method can be used for other fields or firms.

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An Integrated Approach for Collection Center Selection in Reverse Logistics

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چکیده

در دهه‌های اخیر، لجستیک معکوس به‌عنوان یکی از مهم‌ترین مسائل مطروح در زنجیره تأمین می‌باشد. امروزه بسیاری از مواد بی‌مصرف می‌توانند با اندکی اصلاح به‌عنوان یک ماده باارزش دوباره وارد زنجیره تأمین گردند. علاوه براین انتخاب و گزینش جمع‌آوری‌کنندگان محصولات بازگشتی به‌عنوان یک تصمیم‌گیری بحرانی با توجه به وجود معیارهای متعدد مدنظر است. در این پژوهش، مهم‌ترین معیارهای مؤثر بر مراکز جمع‌آوری در صنعت خودرو شناسایی می‌شوند. سپس، به‌منظور ارزیابی معیارهای پیشنهادی یک رویکرد ترکیبی تصمیم‌گیری چند معیاره متشکل از روش دیمتل فازی و روش EVAMIX ارائه می‌شود. با استفاده از این رویکرد، بااهمیت‌ترین معیارها و وزن هریک به همراه امتیازات مراکز جمع‌آوری تعیین می‌گردد. علاوه براین، یک مدل ریاضی برنامه‌ریزی خطی عدد صحیح مختلط به‌منظور انتخاب بهترین مراکز جمع‌آوری به همراه مقادیر تخصیص‌یافته از هرکدام ارائه‌شده است. همچنین به‌منظور سنجش بهتر کارایی رویکرد پیشنهادی یک کارخانه بازیافت در ایران به‌عنوان مطالعه موردی انتخاب شده است که این کارخانه به جمع‌آوری لاستیک‌های فرسوده خودرو و بلبرینگ‌های از رده خارج می‌پردازد.

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