Expert Systems with Applications 41 (2014) 50–58

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

A robust hybrid multi-criteria decision making methodology for contractor evaluation and selection in third-party reverse logistics

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ARTICLE INFO

Keywords:
Reverse logistics
AHP
TOPSIS
Multi-criteria decision making

ABSTRACT

Due to green legislations, industries track the used products through reverse logistics contractors. A reverse logistics programme offers significant cost savings in procurement, transportation, disposal and inventory carrying. Since reverse logistics operations and the supply chains they support are considerably more complex than traditional manufacturing supply chains, it can be offered to third party contractors. But availability of more number of contractors make evaluating and selecting the most efficient Reverse Logistics Contractor (RLC) a challenging task and treated as a multi-criteria decision making problem. In this paper, a hybrid method using Analytical Hierarchy Process (AHP) and the Fuzzy Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) is proposed. AHP is used to obtain the initial weights and Fuzzy TOPSIS is used to get the final ranking. A case study demonstrates the application of the proposed method. Finally sensitivity analysis is carried out to confirm the robustness.

1. Introduction

Two of the most significant problems of our era are the depletion of the natural energy and resources and the pollution caused from the disposal of waste end-of-life products. An effective reverse logistics (RL) operation can help organizations make good use of nature energy and resources and take healthy balance between economy and environment (Xiangru, 2008). Online purchases, mail order and after-sales have resulted in the rise of returns in the organization. However organizations have not concentrated more on the returns. Because of changes in legislation, both for environmental protection and service reasons, number of companies now take into account reverse flows, going backwards from customers to recovery centers within their logistics system (Rogers & Tibben-Lembke, 2011). Recycling of used products is not a new concept. Waste paper recycling, soft drink bottles collection, metal scrap brokers are there in day- to day cases. The recycling of used materials requires collection, sorting and processing and the success is manipulated by the competence achieved through proper co-ordination and integration. Several forces drive reverse logistics, like competition and marketing motives, direct economic motives and concerns with the environment. Reverse logistics has an significant environmental dimensions (Ciliberti, Pontrandolfo, & Scozzi, 2008; Zhu, Sarkis, & Lai, 2008) as well as dimensions relating to value reclamation (Dat, Linh, Chou, & Yu, 2012; Ilgin & Gupta, 2010; Mutha & Pokharel, 2009).

Rate of product returns is high for magazines, photocopiers, computers, cameras, cellular phones, books, apparels, and automobile, electronic, aircraft components, chemical and medical items. Customers are demanding resolution of products that are considered to be defective. The amount of product returns can be very high with some industries at the rate of over 50% of the sales. End of life take back laws have proliferated over the past decade in the developed countries, requiring business to effectively manage the entire life of the product. Customers also pressurized the businesses to take responsibility of the disposal of their product (Prahinski & Kocabasoglu, 2006). Returned products are collected, examined and categorized by employees to the best of their knowledge. Besides, the employee regulates if the return is accepted and further measures to be taken. However the major concern is that whether the recovery of products should be more economical than the disposal of the products.

Most of the supply chain research concentrates on the forward movement and transformation of the materials from the suppliers to the end customer and on the impact that transformation has on the bullwhip effect. However the reverse flow of products from the customer to upstream business has not received much interest (Rogers & Tibben-Lembke, 2011). Managing product returns increases customer service levels and customer satisfaction. Since managing returns requires specialized arrangement and data tracking systems, reverse logistics contractors are preferred. Using

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http://dx.doi.org/10.1016/j.eswa.2013.07.010

reverse logistics contractor (RLC), the companies strengthen the core competencies with significant benefits like reducing the logistics and operating risks. While outsourcing, it is necessary to have a reliable RLC. RLC offers value added services such as repackaging and relabeling. Decision making problem for selecting the RLC has been receiving much attention recently. The presence of multiple criteria and the opinion from the decision maker will increase the complexity of the selection.

The remainder of this paper is organized as follows. Section 2 presents the literature review. Section 3 describes the problem and in Section 4, the proposed methodology is given. Application of the model to case study is given in Section 5. The result of the sensitivity analysis is given in section 6.Concluding remarks are given in Section 7.

2. Literature review

Reverse logistics is a relatively new topic and it is in the exploration. A complete supply chain should include both forward logistics and reverse logistics. Forward logistics operations also subsequently increase the reverse logistics activities and thus it plays an important role in the organization success (Govindan, Palaniappan, Zhu, & Kannan, 2012). Majority of the studies on the reverse logistics focused on facility location, resource allocation, flows, and network design. A pricing decisions model for a fuzzy closed-loop supply chain with retail competition in the marketplace was considered by Wei and Zhao (2011). Delphi method is applied to differentiate the criteria for evaluating traditional suppliers and green suppliers (Lee, Gen, & Rhee, 2009; Liu & Wang, 2009). A mathematical programming model which minimizes the total processing cost of multiple types of waste electrical and electronic products was presented by Dat et al. (2012). Efendigil, Onut, and Kongar (2008) used artificial neural network and fuzzy AHP to select the third party logistics provider in the presence of vagueness. Pochampally and Gupta (2008) used fuzzy AHP in a reverse supply chain to select the most economical product to be reprocessed and identified the potential recovery facilities. A closely related methodology, analytic network process (ANP) was used by Ravi, Shankar, and Tiwari (2005) to evaluate alternatives for end-of-life computers, connecting diverse factors including financial, non-financial factors and tangible, intangible factors.

A QFD based framework which integrated analytic network process and the goal programming models was presented by Büyüközkan and Berkol (2011). Also Büyüközkan and Cifci (2012) proposed a hybrid fuzzy multi-criteria decision making model which assisted in evaluating green suppliers. Barker and Zabinsky (2011) presented a model using AHP that establishes preferences among eight alternative network configurations, considering various flow processes. Pishvaee, Torabi, and Razmi (2012) developed a new hybrid credibility based fuzzy mathematical programming for green logistics network design. In the work done by Lee et al. (2009) genetic algorithm is used for solving a three stage reverse logistics network model for minimizing the total cost. Kannan and Murugesan (2011) used fuzzy extent analysis for selecting third-party reverse logistics provider for the battery industry. Azadi and Saen (2011) proposed a chance-constrained data envelopment analysis for selection in the presence of dual role factors. Zhi-Hong and Qiang (2009) proposed a grey comprehensive model based on AHP and grey relational analysis for the selection of RL providers. Meade and Sarkis (2002) proposed ANP model for the reverse logistics provider selection. However the number of pairwise comparison required could become cumbersome.

Based on the above literature, it is quite clear that very few studies have addressed the selection of RLC in the case of plastic recycling. Besides, sensitivity analysis was not carried out in any of the literature. Many industries have no suitable method to evaluate and select third-party reverse logistics providers. Hence, there is a necessity for a straightforward, organized and rational scientific method to direct user organizations to taking a proper decision.

3. Problem definition

Since RL takes many steps to process the returns it can be given to third party contractors to manage outbound logistics. By outsourcing reverse logistics activities, the organizations can concentrate on their core business operation. Third party reverse logistics contractor will compete with each other in specific areas like price, quality and credit. Since the third party reverse logistics contractor is using his latest technology and resource sharing advantages, uncertainty of recovery may be reduced .The majority of US industry appears to have negative experiences with outsourcing (Liou, Wang, Hsu, & Yin, 2011). This negative experience might be the result of the lack of comprehensive evaluation to discover the best candidates for outsourcing. This paper presents a case study from a company in a plastic industry which aims to show how it may choose a third party logistics contractor (RLC). Selecting the most efficient reverse logistics contractors from *n* number of contractors is a complicated and time consuming task which is considered as multi-criteria decision making problem. Selection process is as shown in the Fig. 1. To select the RLC, the industry should identify the criteria and the sub criteria.

The first step in the selection process is to develop a team of persons who have got knowledge and experience in logistics activities. The team should have members from all functional areas within the organization. The relevant criteria for the selection of a contractor, which are widely discussed in the literature, are presented in Table 1. The decision makers use the linguistic assessment to rate the criteria and the alternatives. Based on the literature survey and with the validation of industrial experts, possible evaluation criteria were defined and given in Table 1.

4. Proposed methodology

In this paper, a hybrid methodology based on Analytical Hierarchy Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) under fuzzy environment is presented. The weights of criteria are considered by applying the AHP method. The Fuzzy TOPSIS method is applied to get the final ranking. Although AHP is a decision-making methodology in itself, its ability to get exact ratio scale measurements and combine them across multiple criteria has led to AHP applications in conjunction with many other decisions support tool and methodologies. Uncertainty and imprecision is handled with linguistic values parameterized by the triangular fuzzy number. The main reason for choosing this hybrid methodology for selecting the reverse logistics contractor is due to its suitability in offering solutions in a complex

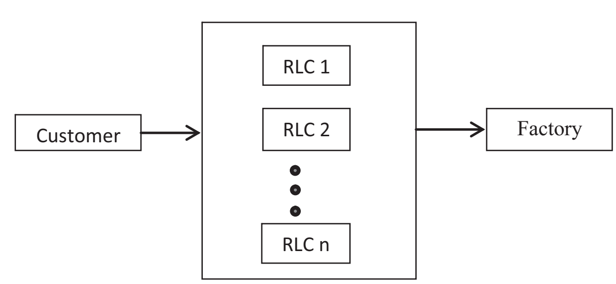

Fig. 1. RLC selection process.

Table 1
Evaluation criteria for selection.

S.No	Criteria	Sub criteria	References
1	Organizational performance criteria (OC)	Time, cost, flexibility	Meade and Sarkis (2002), Chen (2011), Efendigil, Onut, and Kongar (2008), Gunasekaran, Patel, and McGaughey (2004), Liu and Wang (2009), Büyüközkan and Cifci (2012), Ha and Krishnan (2008), Liou et al. (2011), Gunasekaran, Mcgaughy, Ngai, and Rai (2009), Chang and Hung (2010), Kwang et al. (2007), Boran, Genc, Kurt, and Akay (2009)
2	Reverse logistics process functions (RPF)	Collection, packing storage, sorting, transitional process, delivery	Meade and Sarkis (2002), Ha and Krishnan (2008), Dowlatshahi (2000), Schwartz (2000), Boran et al. (2009)
3	Organizational role of reverse logistics (OR)	Reclaim, recycle, remanufacture, reuse, take back disposal	Meade and Sarkis (2002), Schwartz (2000), Dowlatshahi (2000)
4	Resources capacity (RC)	Financial capacity to invest, level of advanced equipment, network capacity, transport capacity	Xiangru (2008), Darvish, Yasaei, and Saeedi (2009), Liu and Wang (2009), Chen (2011), Amin and Razmi, (2009), Chen and Chao (2012), Lee, Kang, Hsu, and Hung (2009)
5	Quality of service (Q)	Timeliness of service, personalized service, ability to deal with problems	Xiangru (2008), Liou et al. (2011), Liu and Wang (2009), Zouggari and Benyoucef (2012), Ha and Krishnan, (2008), Chen (2011), Boran et al. (2009), Chamodrakos, Batis, and Martakos (2010)
6	Enterprise aliance (EA)	Sharing of benefits and risks, enterprise culture compatibility	Zhi-Hong and Qiang (2009), Amin and Razmi, (2009),
7	Location (L)	Being familiar with the area, geographical location,cultural fit, human resources.	Darvish et al. (2009), Liu and Wang (2009), Ha and Krishnan (2008), Amin and Razmi, (2009)
8	Experience (E)	Performance history	Darvish et al. (2009), Liu and Wang (2009), Chen (2011), Amin and Razmi, (2009), Ha and Krishnan (2008), Amin and Zhang (2012)
9	Communication systems (CS)	EDI capacity, IT level	Liu and Wang (2009), Chen (2011), Khaleie, Fasanghari, and Tavassoli (2012), Wong, Lai, and Ngai (2009)

multi-criteria decision environment. Schematic diagram of the proposed methodology is shown in Fig. 2.

4.1. Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is a powerful and flexible decision-making process (Saaty, 2000) to help managers set priorities and make the best decision when both qualitative and quantitative aspects of a decision need to be considered. AHP occurs in two phases: hierarchy design, which involves decomposing the decision problem into a hierarchy of interrelated decision elements (i.e., goal, and evaluation criteria) and hierarchy evaluation, which involves determining the weights of the criteria and synthesizing these weights and preferences to determine alternative priorities.

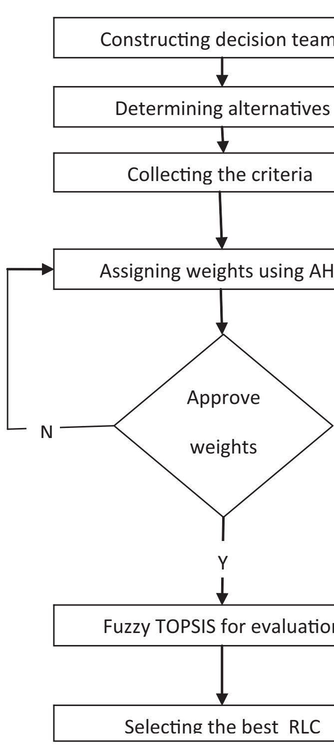

Fig. 2. Proposed hybrid methodology for RLC selection.

4.1.1. Development of decision hierarchies

The proposed model comprised of 4 levels. The top most level represents the overall goal of the problem i.e. selecting the RLC. The second level denotes the attributes. Bottom level indicates the number of RLC. The nomenclature used for the proposed methodology is presented in Table 2.

4.1.2. Construct a pairwise comparison matrix

A set of comparison matrix with respect to an element of immediately higher level is constructed. The pair-wise comparisons indicate the decision maker's perception of which element dominates the other. The scale used in AHP for preparing the pairwise comparison matrix is a discrete scale from 1 to 9, as presented in Table 3. A criteria compared with itself is given the value 1, so that the main diagonal elements are all 1.

The weight of each attribute is determined by calculating the geometric mean of the row and then normalizing the geometric means of rows in comparison matrix. The maximum eigenvalue is $\lambda_{\max}$. Consistency Index (CI) is obtained from

$$CI = \frac{(\lambda_{\max} - M)}{(M - 1)} \quad (1)$$

Random index (RI) is obtained from Table 4.

It should be noted that the quality of the output of the AHP is related to the consistency of the pairwise comparison judgments. Consistency ratio (CR) is used to calculate whether the evaluations are sufficiently consistent. It is the ratio of the consistency index to the random index. As a rule, only if $CR < 0.1$, the consistency of the matrix is considered as acceptable. If the final consistency ratio exceeds this value, the evaluation procedure has to be repeated to improve consistency. The measurement of consistency can be used to evaluate the consistency of decision makers as well as the consistency of overall hierarchy.

Table 2
The nomenclatures.

$A = \{A, A \ldots, A_j\}$	A set of J alternatives
$C - \{C_1, C_2, \ldots C_j\}$	A set of n criteria,
$\widetilde{X} = (\widetilde{x}_{ij})$	A set of ratings of Aj = (j = 1,2,3,.. . J) with respect to criteria
$w_i(i = 1, 2, 3, \ldots,)$	A set of weights of each criterion
CI	Consistency index
CC	Closeness Coefficient
CR	Consistency ratio
(A^{+})	Positive ideal solution
(A^{-})	Negative ideal solution
$\lambda_{\max}$	Maximum eigen value
M	Size of the matrix

Table 3
Scale of preference.

Preference weights	Definition	Explanation
1	Equally preferred	Two attributes contribute equally
3	Moderately	Experience and judgement slightly favor one activity over another
5	Strongly	Experience and judgement strongly favor one activity over another
7	Very strongly	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extremely	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed
Reciprocals	Reciprocals for inverse comparison	

Source: Saaty (2000).

$$CR = CI/RI \tag{2}$$

Though a scale of 1–9 is used, it does not take into consideration of uncertainty, vagueness or fuzziness commonly used in human decision making processes. AHP is criticized for its unbalanced judgement and failure to handle the uncertainty and vagueness in performing the pair-wise comparison. In practice, crisp data are often inadequate to model real life situation since human judgment are vague. Hence there is a necessity of introducing a fuzzy multiple criteria decision making method.

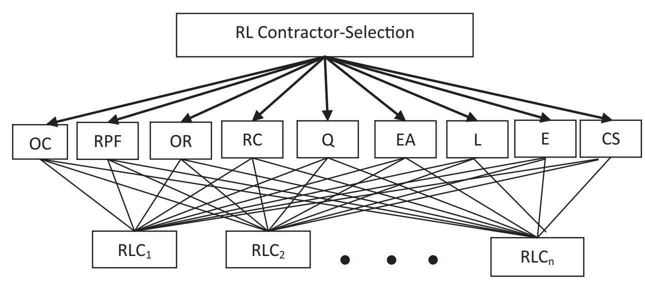

Fig. 3. Hierarchy model.

4.2. Fuzzy TOPSIS

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was first established by Hwang and Yoon (1981). TOPSIS differentiate between the benefit and the cost category and selects solutions that are closer to the positive ideal solution and far away from the negative ideal solution. In the traditional TOPSIS method, the weights of the criteria are known precisely and crisp values are used in the evaluation procedure. However the major drawback is the uncertainty and imprecision related with representing decision maker's observations to crisp values. Hence fuzzy TOPSIS method is proposed. Fuzzy set theory allows the decision maker to incorporate unquantifiable information, incomplete information and non-obtainable information and partially ignorant facts into the decision model (Kulak, Durmusoglu, & Kahraman, 2005).

The fuzzy set theory is intended to deal with the abstraction of the main viable effect from an array of information that is expressed in vague and imprecise terms (Zadeh, 1965). A fuzzy set is general form of a crisp set. A fuzzy number belong to the closed interval 0 and 1, which 1 addresses full membership and 0 expresses non-membership. Fuzzy TOPSIS method is simple to understand and it is preferred when compared to all other evaluation process. Linguistic variable is very useful in dealing with circumstances, which are too multifaceted or not well defined to be reasonably described in typical quantitative terms. This study uses triangular fuzzy number for fuzzy TOPSIS. The reason for using a triangular fuzzy number is that it is intuitively easy for the decision-makers to use and calculate. In the following some basic definitions of fuzzy sets are given (Chen, 1996; Onut & Soner, 2008; Zadeh, 1965).

Table 4
Average random index values.

Attributes	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.39	1.11	1.25	1.35	1.40	1.45	1.49

Source: Saaty (2000).

Definition 1. A fuzzy set $\widetilde{A}$ in a universe of discourse X is characterized by a membership function $\widetilde{\mu}_A(x)$ which associates with each element x in X a real number in the interval [0, 1]. The function value is termed as the grade of membership of x in $\widetilde{A}$

Definition 2. A triangular fuzzy number $\widetilde{A}$ is characterized by a triplet of real numbers (a_1, a_2, a_3) where a_2 indicates the value of membership function, a_1 and a_3 represent the lower and upper bound.

$$\mu(x) = \begin{cases} 0, & x \leqslant a_1 \\ \frac{x-a_1}{a_2-a_1}, & a_1 \leqslant x \leqslant a_2 \\ \frac{x-a_3}{a_2-a_3}, & a_2 \leqslant x \leqslant a_3 \\ 0, & x \geqslant a3 \end{cases} \tag{3}$$

Table 5
Pairwise comparison matrix.

Criteria	OC	RPF	OR	RC	Q	EA	L	E	CS	Weights
Organisational performance criteria (OC)	1	1	1	1/3	3	3	4	3	2	0.1513
Reverse logistics process functions (RPF)	1	1	3	1/3	3	3	3	2	3	0.1767
Organizational role of RL (OR)	1	1/3	1	1/2	4	3	3	2	1	0.1337
Resources capacity (RC)	3	3	2	1	1	1	2	3	1	0.1926
Quality of service (Q)	1/3	1/3	1/4	1	1	2	2	3	1	0.0890
Enterprise alliance (EA)	1/3	1/3	1/3	1	1/2	1	2	2	1	0.0730
Location (L)	1/4	1/3	1/3	1/2	1/2	1/2	1	1	1/2	0.0450
Experience (E)	1/3	1/2	1/2	1/3	1/3	1/2	1	1	1	0.0515
Communication Systems (CS)	1/2	1/3	1	1	1	1	2	1	1	0.0846

Table 6
CR ratio obtained from AHP.

Maximum. eigen value ($\lambda_{\max}$)	10.0643
Consistency index(CI)	0.1330
Random index (RI)	1.45
Consistency ratio (CR)	0.091

Table 7
Linguistic terms and fuzzy numbers.

Linguistic terms	Fuzzy Numbers
Very low (VL)	(0.0,0.0,0.2)
Low (L)	(0.0,0.2,0.4)
Medium (M)	(0.2,0.4,0.6)
High (H)	(0.4,0.6,0.8)
Very high (VH)	(0.6,0.8,1.0)
Excellent (E)	(0.8,1.0,1.0)

If $\widetilde{A}$ and $\widetilde{B}$ be two triangular fuzzy numbers defined by (a_1, a_2, a_3) and (b_1, b_2, b_3) then the operational laws of these triangular numbers are as follows

$$\widetilde{A}(+)\widetilde{B} = (a_1, a_2, a_3)(+)(b_1, b_2, b_3) = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \quad (4)$$

$$\widetilde{A}(-)\widetilde{B} = (a_1, a_2, a_3)(-)(b_1, b_2, b_3) = (a_1 - b_1, a_2 - b_2, a_3 - b_3) \quad (5)$$

$$\widetilde{A}(\times)\widetilde{B} = (a_1, a_2, a_3)(\times)(b_1, b_2, b_3) = (a_1.b_1, a_2.b_2, a_3.b_3) \quad (6)$$

$$\widetilde{A} \div \widetilde{B} = (a_1, a_2, a_3) \div (b_1, b_2, b_3) = (a_1/b_3, a_2/b_2, a_3/b_1) \quad (7)$$

$$K\widetilde{A} = (ka_1, ka_2, ka_3) \quad (8)$$

$$\left(\widetilde{A}\right)^{-1} = (1/a_3, 1/a_2, 1/a_1) \quad (9)$$

Definition 3. If $\widetilde{A} = (a_1, a_2, a_3)$ and $\widetilde{B} = (b_1, b_2, b_3)$ be the two triangular numbers, then the distance between them is calculated using the vertex method.

$$d\left(\widetilde{a}, \widetilde{b}\right) = \sqrt{\frac{1}{3}\left[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2\right]} \quad (10)$$

Definition 4. The weighed normalized fuzzy decision matrix is obtained using.

$$\widetilde{V} = \left[\widetilde{v}_{ij}\right]_{n\times J} \quad i = 1, 2, \ldots, n \quad j = 1, 2, \ldots, J \quad (11)$$

where $\widetilde{v}_{ij} = \widetilde{x}_{ij} \times w_i$ (Onut & Soner, 2008).

Based on the above fuzzy theory concepts, the steps of Fuzzy TOPSIS method can be expressed as

Step 1: Choose the linguistic values (x_{ij}, i = 1, 2, ..., n, J = 1, 2, ..., J) for alternatives with respect to criteria. The fuzzy linguistic rating $(\widetilde{x}_{ij})$ preserves the property that the range of normalized triangular fuzzy numbers belonging to [0, 1], thus three is no need for normalization.

Table 8
Fuzzy evaluation matrix.

	OC	RPF	OR	RC	Q	EA	L	E	CS
RLC1	Medium (0.2,0.4,0.6)	Medium (0.2,0.4,0.6)	Medium (0.2,0.4,0.6)	High (0,4,0.6,0.8)	High (0,4,0.6,0.8)	High (0,4,0.6,0.8)	Low (0.0,0.2,0.4)	Medium (0.2,0.4,0.6)	Very High (0.6,0.8,1.0)
RLC2	High (0,4,0.6,0.8)	Very High (0.6,0.8,1.0)	High (0,4,0.6,0.8)	High (0,4,0.6,0.8)	High (0,4,0.6,0.8)	Low (0.0,0.0,0.2)	Medium (0.2,0.4,0.6)	Very Low (0.0,0.0,0.2)	Very High (0.6,0.8,1.0)
RLC3	Very High (0.6,0.8,1.0)	High (0,4,0.6,0.8)	Low (0.0,0.2,0.4)	High (0,4,0.6,0.8)	Medium (0.2,0.4,0.6)	Medium (0.2,0.4,0.6)	Very Low (0.0,0.0,0.2)	High (0.4,0.6,0.8)	Low (0.0,0.2,0.4)
RLC4	High (0,4,0.6,0.8)	Very High (0.6,0.8,1.0)	Low (0.0,0.2,0.4)	High (0,4,0.6,0.8)	Medium (0.2,0.4,0.6)	Medium (0.2,0.4,0.6)	High (0,4,0.6,0.8)	Very Low (0.0,0.0,0.2)	Medium (0.2,0.4,0.6)
RLC5	Very High (0.6,0.8,1.0)	High (0,4,0.6,0.8)	Medium (0.2,0.4,0.6)	High (0,4,0.6,0.8)	High (0,4,0.6,0.8)	High (0,4,0.6,0.8)	Low (0.0,0.2,0.4)	Very Low (0.0,0.0,0.2)	High (0,4,0.6,0.8)
RLC6	Low (0.0,0.2,0.4)	Low (0.0,0.2,0.4)	High (0,4,0.6,0.8)	Medium (0.2,0.4,0.6)	High (0,4,0.6,0.8)	Low (0.0,0.2,0.4)	Low (0.0,0.2,0.4)	Very High (0.6,0.8,1.0)	Very Low (0.0,0.0,0.2)
RLC7	Very Low (0.0,0.0,0.2)	Medium (0.2,0.4,0.6)	Very High (0.6,0.8,1.0)	Very Low (0.0,0.0,0.2)	Medium (0.2,0.4,0.6)	Medium (0.2,0.4,0.6)	High (0,4,0.6,0.8)	High (0,4,0.6,0.8)	Medium (0.2,0.4,0.6)
RLC8	High (0,4,0.6,0.8)	Medium (0.2,0.4,0.6)	Medium (0.2,0.4,0.6)	Medium (0.2,0.4,0.6)	Very High (0.6,0.8,1.0)	High (0,4,0.6,0.8)	Low (0.0,0.2,0.4)	High (0,4,0.6,0.8)	Low (0.0,0.2,0.4)
RLC9	Medium (0.2,0.4,0.6)	High (0,4,0.6,0.8)	High (0,4,0.6,0.8)	Medium (0.2,0.4,0.6)	Medium (0.2,0.4,0.6)	Very Low (0.0,0.0,0.2)	Medium (0.2,0.4,0.6)	Medium (0.2,0.4,0.6)	Medium (0.2,0.4,0.6)
Weights	0.1513	0.1767	0.1337	0.1926	0.0890	0.0730	0.0450	0.0515	0.0846

Table 9
Weighed fuzzy evaluation matrix.

	OC	RPF	OR	RC	Q	EA	L	E	CS
RLC1	(0.0302, 0.0605, 0.0908)	(0.0353, 0.0706, 0.1060)	(0.0267, 0.0534, 0.0802)	(0.0770, 0.1155, 0.1540)	(0.0356, 0.0534, 0.0712)	(0.0292, 0.0438, 0.0584)	(0.0000, 0.009 0.0180)	(0.0103, 0.0206, 0.0309)	(0.0508, 0.0677, 0.0846)
RLC2	(0.0605, 0.0908, 0.1210)	(0.1060, 0.1413, 0.1767)	(0.0534, 0.0802, 0.1069)	(0.0770, 0.1155, 0.1540)	(0.0356, 0.0534, 0.0712)	(0.0000, 0.0146, 0.0292)	(0.0090, 0.0180, 0.0271)	(0.0000, 0.0000, 0.0103)	(0.0508, 0.0677, 0.0846)
RLC3	(0.0000, 0.0302, 0.0605)	(0.0706, 0.1060, 0.1413)	(0.0000, 0.0267, 0.0534)	(0.0770, 0.1155, 0.1540)	(0.0178, 0.0356, 0.0534)	(0.0146, 0.0292, 0.0438)	(0.0000, 0.0000, 0.0090)	(0.0206, 0.0309, 0.0412)	(0.0000, 0.0169, 0.0338)
RLC4	(0.0605, 0.0907, 0.1210)	(0.1060, 0.1413, 0.1767)	(0.0000, 0.0267, 0.0534)	(0.0770, 0.1156, 0.1540)	(0.0178, 0.0356, 0.0534)	(0.0146, 0.0292, 0.0438)	(0.0180, 0.0270, 0.0360)	(0.0000, 0.0000, 0.0103)	(0.0169, 0.0338, 0.0508)
RLC5	(0.0908, 0.1210, 0.1513)	(0.0708, 0.1060, 0.1413)	(0.0267, 0.0534, 0.0802)	(0.0770, 0.1155, 0.1540)	(0.0356, 0.0534, 0.0712)	(0.0292, 0.0438, 0.0584)	(0.0000, 0.0090, 0.0180)	(0.0000, 0.0000, 0.0103)	(0.0338, 0.0507, 0.0676)
RLC6	(0.0000, 0.0302, 0.0605)	(0.0000, 0.0353, 0.1060)	(0.0534, 0.0802, 0.1069)	(0.0385, 0.0770, 0.1155)	(0.0356, 0.0534, 0.0712)	(0.0000, 0.0146, 0.0292)	(0.0000, 0.0090, 0.0180)	(0.0309, 0.0412, 0.0515	(0.0000, 0.0000, 0.0169
RLC7	(0.0000, 0.0000, 0.0302)	(0.0353, 0.0706, 0.1060)	(0.0802, 0.1069, 0.1337)	(0.0000, 0.0000, 0.0385)	(0.0178, 0.0356, 0.0534)	(0.0146, 0.0292, 0.0438)	(0.0180, 0.0270, 0.0360)	(0.0206, 0.0309, 0.0412)	(0.0169, 0.0338, 0.0507)
RLC8	(0.0605, 0.0908, 0.1210)	(0.0354, 0.0706, 0.1060)	(0.0267, 0.0534, 0.0802)	(0.0385, 0.0770, 0.1156)	(0.0534, 0.0712, 0.0890)	(0.0292, 0.0438, 0.0584)	(0.0000, 0.0090, 0.0180)	(0.0206, 0.0309, 0.0412)	(0.0000, 0.0000, 0.0169)
RLC9	(0.0302, 0.0605, 0.0908)	(0.0706, 0.1060, 0.1413)	(0.0534, 0.0802, 0.1069)	(0.0385, 0.0770, 0.1156)	(0.0178, 0.0356, 0.0534)	(0.0000, 0.0000, 0.0146)	(0.0090, 0.0180, 0.0270)	(0.0103, 0.0206, 0.0309)	(0.0169, 0.0338, 0.0507)
A^+A^-	$\tilde{v}_1^+=(0,0,0)\,\tilde{v}_1^-=(1,1,1)$	$\tilde{v}_1^+=(1,1,1)\,\tilde{v}_1^-=(0,0,0)$	$\tilde{v}_1^+=(1,1,1)\,\tilde{v}_1^-=(0,0,0)$	$\tilde{v}_1^+=(1,1,1)\,\tilde{v}_1^-=(0,0,0)$	$\tilde{v}_1^+=(1,1,1)\,\tilde{v}_1^-=(0,0,0)$	$\tilde{v}_1^+=(0,0,0)\,\tilde{v}_1^-=(1,1,1)$	$\tilde{v}_1^+=(1,1,1)\,\tilde{v}_1^-=(0,0,0)$	$\tilde{v}_1^+=(1,1,1)\,\tilde{v}_1^-=(0,0,0)$	$\tilde{v}_1^+=(1,1,1)\,\tilde{v}_1^-=(0,0,0)$

Step 2: Calculate the weighed normalized fuzzy matrix. The weighed normalized value is calculated using Eq. (11).

Step 3: Identify positive ideal (A^+) and negative ideal (A^-) solutions using the equations:

$$A^+ = \{v_1^+, v_2^+, \ldots, v_i^+\} = \{(\max v_{ij} | i \in I') \times (\min v_{ij} | i \in I'')\} \quad i = 1,2,\ldots,n.\ j = 1,2,\ldots,J. \tag{12}$$

$$A^- = \{v_1^-, v_2^-, \ldots, v_i^-\} = \{(\min v_{ij} | i \in I') \times (\max v_{ij} | i \in I'')\} \quad i = 1,2,\ldots,n\ j = 1,2,\ldots,J. \tag{13}$$

where I' is associated with the benefit criteria and I" is associated with the cost criteria.

Step 4: Calculate the distance of each alternative from A^+ and A^- using the equations:

$$D_j^+ = \sum_{j=1}^{n} d(v_{ij}, v_i^+) \quad j = 1,2,\ldots,J. \tag{14}$$

$$D_j^- = \sum_{j=1}^{n} d(v_{ij}, v_i^-) \quad j = 1,2,\ldots,J. \tag{15}$$

Step 5: Calculate the Closeness Coefficient (CC) and rank each CC of alternative in descending order.

$$CCj = \frac{D_j^+}{D_j^- + D_j^+} \quad j = 1,2,\ldots,J. \tag{16}$$

Step 6: The different alternatives are ranked according to the closeness coefficient in the decreasing order.

5. Application of the model to case study

To demonstrate the application of the model, an empirical case study was conducted with a plastic recycling plant located in southern part of India. India is well endowed with both technology and human resources. Despite this, the concept of reverse logistics is yet not widely accepted. India has witnessed a substantial growth in the consumption of plastic and increased production of plastic waste. Plastic waste is considered as an environmental waste. Around 10 thousand tons per day (TPD) of plastics waste is generated in India. The plastics waste constitutes two major category of plastics; (i) thermoplastics and (ii) thermoset plastics. Thermoplastics constitute 80% and thermoset constitutes approximately 20% of total post-consumer plastics waste generated in India. India is one of the largest consumers of PET bottles. The company considered for the case study started its business in mid 90's which recycles the Polyethylene terephthalate (PET) bottles. The collected PET bottles is sorted and separated from other materials. This sorted PET waste is crushed, pressed into bales .The further treatment process includes washing, separating and drying. The bottles are converted into flakes. PET flakes are used as the raw material for a range of products that would be made of polyester. These flakes are widely used for the manufacturing of different kinds of plastic items variety of useful products such as carpet fiber, strapping, molding compounds, and non-food containers. The industry collects the used PET bottles through reverse logistics contractor. The industry wanted a systematic way to select the suitable reverse logistics contractor. The industry finds it difficult to choose the most suitable among the contractors since one dominates the other in different attributes.

5.1. Model the problem as a hierarchy

A decision hierarchy shown in the Fig. 3 is constructed with three levels. The top level represents the ultimate goal. To construct the framework, a list of criteria was prepared from the literature. The second level indicates the criteria. Bottom level denotes the alternatives.

5.2. Evaluate the weights of the criteria

After determining the decision hierarchy, team members construct the pairwise comparison matrix for each level by using the scale given in Table 3 and the weights are calculated as shown in Table 5.

5.3. Assess the consistency by evaluating the eigen vectors

The consistency ratio is calculated using Eqs. (1) and (2) and shown in Table 6. Since the calculated Consistency Ratio is less than 0.1, the matrix is accepted; the weights are consistent and can be used for the selection process.

5.4. Decide the final ranking using fuzzy TOPSIS

The team members form the decision matrix by comparing each alternative with the criteria. The team members express their opinion in linguistic term which is converted into triangular fuzzy number using Table 7.

5.4.1. Fuzzy evaluation matrix

Fuzzy evaluation matrix for the evaluation of RLC is constructed with the linguistic variables followed by the triangular fuzzy number in parenthesis as shown in Table 8.

5.4.2. Weighed fuzzy evaluation matrix

Fuzzy weighed evaluation matrix is obtained using the Eq. (11) and shown in Table 9. Organisational performance criteria is considered as cost criterion and assigned the positive ideal solution as $\widetilde{v}_1^+ = (0,0,0)$ and negative ideal solution as $\widetilde{v}_1^- = (1,1,1)$. Other criteria are benefit criteria and assigned the values as $\widetilde{v}_1^+ = (1,1,1)$ for positive ideal solution and $\widetilde{v}_1^- = (0,0,0)$ for the negative ideal solution. Distance of each alternative is calculated using Eqs. (14) and Eq. (15) and shown in Table 10. The closeness coefficient is calculated using Eq. (16) and the results are summarized in Table 10.

The higher the closeness coefficient, the better is the rank. Based on CC_j values, the ranking of the alternatives in descending order are RLC4, RLC8, RLC6, RLC9, RLC5, RLC7, RLC3, RLC1 and RLC2. Results indicate that RLC4 is the best alternative with CC_j value of 0.756042. Positive ideal solution value is high and the negative ideal solution is low for RLC8.A closer look at the attributes reveal that RLC 4 has very high value in RPF and high value in RC but very low or medium values in other attributes.

5.5. Managerial implications

Managers can gain information about those RLC that display best practices so that they may gain from the experience of these more efficient firms and this can lead to benefits derived from collaboration. RLC have become a significant player in the industries because they take part in the cost reduction and improvement of the service quality of the customers. Hence it was suggested that to succeed in the reverse logistics, contractors have to consider more on RPF and RC. The result obtained is discussed with the industry and they found it meaningful according to the used criteria and considering the sensitivity analysis. Supply chain managers should be encouraged to maintain this type of data, not only for application of this methodology, but for the general future management of their organization.

6. Sensitivity analysis

This technique is applied to determine the effect of criteria weights on decision making and creates different scenarios that may change the priority of alternatives. If the ranking order be changed by increasing or decreasing the importance of the criteria, the results is expressed to be sensitive otherwise it is robust. This is useful in situations where uncertainties exist in the definition of the importance of different factors. The main goal of sensitivity analysis is to see which criteria is most significant in influencing the decision making process. To analyze the impact of weights on the selection of RLC, we conducted 36 experiments. Sensitivity analysis was conducted to exchange each criterion weight with another so that 36 different calculations can be done. We want to find CC_j values for each calculation and different names are given for each calculation. For example CC12 means criterion 1 and criterion 2 weights have changed and CC34 means criterion 3 and criterion 4 weights have changed. The details of the experiments are presented in the Figs. 4 and 5

It can be seen that from Table 11 and Fig. 5, RLC4 has the highest score in 25 experiments, RLC8 has the highest score in 9 experiments and RLC6 has the highest score in 2 experiments. Hence it can be concluded that our methodology is robust and the decision making process is rarely sensitive to the criteria weights.

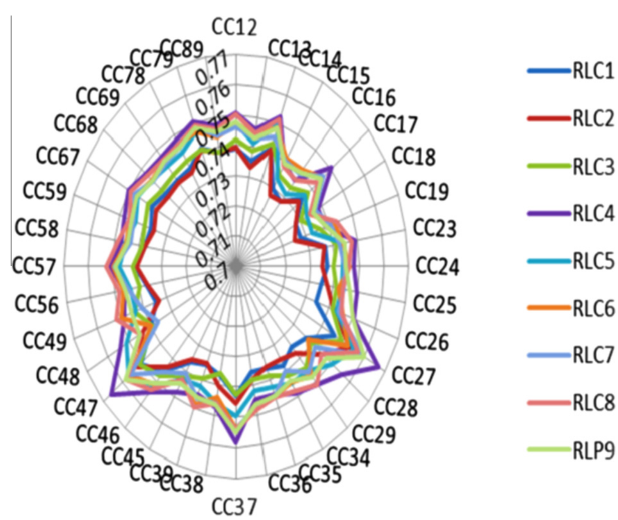

Fig. 4. Sensitivity analysis in radar chart.

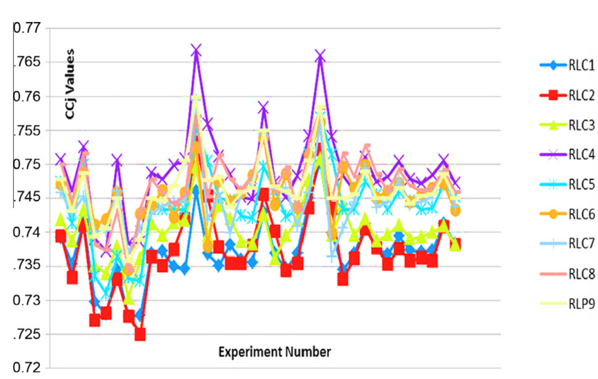

Fig. 5. Results of sensitivity analysis.

Table 10
Distances to ideal solution and overall value.

Alternatives	D_j^+	D_j^-	CC_j	Rank
RLC1	6.65337	2.376766	0.736796	8
RLC2	6.63887	2.387973	0.735459	9
RLC3	6.68490	2.355085	0.739482	7
RLC4	6.73791	2.293633	0.756042	1
RLC5	6.71027	2.317028	0.743331	5
RLC6	6.74472	2.299066	0.745785	3
RLC7	6.72663	2.309359	0.744427	6
RLC8	6.75445	2.277758	0.747818	2
RLC9	6.72815	2.303743	0.744933	4

Table 11
Results of Sensitivity Analysis.

S.No	Expt No	Ranking
1	CC12	RLC4 > RLC8 > RLC9 > RLC5 > RLC6 > RLC7 > RLC3 > RLC3 > RLC1
2	CC13	RLC4 > RLC8 > RLC6 > RLC9 > RLC7 > RLC5 > RLC3 > RLC1 > RLC2
3	CC14	RLC4 > RLC8 > RLC5 > RLC9 > RLC6 > RLC7 > RLC3 > RLC1 > RLC2
4	CC15	RLC6 > RLC7 > RLC9 > RLC4 > RLC8 > RLC3 > RLC5 > RLC1 > RLC2
5	CC16	RLC6 > RLC9 > RLC7 > RLC8 > RLC4 > RLC3 > RLC5 > RLC2 > RLC1
6	CC17	RLC4 > RLC7 > RLC6 > RLC9 > RLC8 > RLC3 > RLC5 > RLC1 > RLC2
7	CC18	RLC4 > RLC7 > RLC9 > RLC6 > RLC8 > RLC5 > RLC3 > RLC2 > RLC1
8	CC19	RLC8 > RLC6 > RLC7 > RLC9 > RLC4 > RLC3 > RLC5 > RLC1 > RLC2
9	CC23	RLC4 > RLC8 > RLC9 > RLC5 > RLC6 > RLC7 > RLC3 > RLC1 > RLC2
10	CC24	RLC4 > RLC6 > RLC8 > RLC9 > RLC7 > RLC5 > RLC3 > RLC1 > RLC2
11	CC25	RLC4 > RLC9 > RLC7 > RLC8 > RLC5 > RLC6 > RLC3 > RLC2 > RLC1
12	CC26	RLC4 > RLC9 > RLC6 > RLC8 > RLC7 > RLC5 > RLC2 > RLC3 > RLC1
13	CC27	RLC4 > RLC9 > RLC7 > RLC8 > RLC5 > RLC2 > RLC6 > RLC3 > RLC1
14	CC28	RLC4 > RLC5 > RLC9 > RLC2 > RLC8 > RLC7 > RLC3 > RLC6 > RLC1
15	CC29	RLC8 > RLC4 > RLC9 > RLC6 > RLC7 > RLC5 > RLC3 > RLC2 > RLC1
16	CC34	RLC4 > RLC8 > RLC5 > RLC6 > RLC9 > RLC3 > RLC7 > RLC2 > RLC1
17	CC35	RLC8 > RLC7 > RLC9 > RLC6 > RLC4 > RLC5 > RLC3 > RLC1 > RLC2
18	CC36	RLC8 > RLC6 > RLC7 > RLC9 > RLC4 > RLC5 > RLC3 > RLC2 > RLC1
19	CC37	RLC4 > RLC9 > RLC7 > RLC8 > RLC6 > RLC5 > RLC2 > RLC1 > RLC3
20	CC38	RLC4 > RLC9 > RLC5 > RLC7 > RLC8 > RLC6 > RLC2 > RLC1 > RLC3
21	CC39	RLC8 > RLC6 > RLC7 > RLC9 > RLC4 > RLC5 > RLC3 > RLC1 > RLC2
22	CC45	RLC4 > RLC9 > RLC6 > RLC8 > RLC5 > RLC3 > RLC7 > RLC1 > RLC2
23	CC46	RLC4 > RLC8 > RLC5 > RLC6 > RLC9 > RLC3 > RLC7 > RLC2 > RLC1
24	CC47	RLC4 > RLC9 > RLC8 > RLC5 > RLC6 > RLC7 > RLC2 > RLC3 > RLC1
25	CC48	RLC4 > RLC5 > RLC9 > RLC8 > RLC2 > RLC1 > RLC6 > RLC3 > RLC7
26	CC49	RLC8 > RLC6 > RLC4 > RLC9 > RLC3 > RLC5 > RLC7 > RLC1 > RLC2
27	CC56	RLC8 > RLC6 > RLC4 > RLC9 > RLC7 > RLC5 > RLC3 > RLC1 > RLC2
28	CC57	RLC8 > RLC4 > RLC6 > RLC7 > RLC9 > RLC5 > RLC3 > RLC1 > RLC2
29	CC58	RLC8 > RLC4 > RLC5 > RLC6 > RLC9 > RLC7 > RLC3 > RLC1 > RLC2
30	CC59	RLC4 > RLC8 > RLC6 > RLC9 > RLC7 > RLC5 > RLC3 > RLC1 > RLC2
31	CC67	RLC4 > RLC8 > RLC7 > RLC6 > RLC9 > RLC5 > RLC3 > RLC1 > RLC2
32	CC68	RLC4 > RLC8 > RLC5 > RLC6 > RLC9 > RLC7 > RLC3 > RLC1 > RLC2
33	CC69	RLC4 > RLC8 > RLC6 > RLC9 > RLC7 > RLC5 > RLC3 > RLC1 > RLC2
34	CC78	RLC4 > RLC8 > RLC6 > RLC9 > RLC7 > RLC5 > RLC3 > RLC1 > RLC2
35	CC79	RLC4 > RLC8 > RLC7 > RLC9 > RLC6 > RLC5 > RLC1 > RLC3 > RLC2
36	CC89	RLC4 > RLC8 > RLC5 > RLC9 > RLC7 > RLC6 > RLC1 > RLC3 > RLC2

7. Conclusion

The implementation of reverse logistics may be a risky endeavor for the top level management as it involves financial and operational aspects, which can determine the performance of the company in the long run. The question now is not whether to go for it or not but which contractors to pick up. This research is relevant in this sense .This study proposes a structured multi-criteria decision making method for evaluating and selecting the best reverse logistics contractor. First the criteria for evaluating RLC are selected based on the literature. Second, the decision making team provides linguistic ratings to the criteria and the alternatives, and fuzzy TOPSIS is used. Finally, we perform sensitivity analysis to determine the influence of criteria weights on the decision making process. Such methodology induces the decision maker to establish decision criteria and to assess the criteria relative importance, relying on the judgments of experts. Furthermore, the proposed evaluation method can also obtain the gap between ideal alternative and each alternative, and the ranking order of alternatives can be found. The strength of the proposed model is that the vagueness of experts' opinions is considered in the evaluation process and it is easy to apply. The main objective of this paper is to recycle the plastic waste and the decisions made regarding the selection. The results of this paper can be applied for both manufacturer and reverse logistics contactor. Manufacturer can use this method to select the best reverse logistics contractor. A reverse logistics contractor can use the results as a benchmark with other and can use the outcomes for service promotion. The proposed methodology can be used as decision support systems to help firms monitor RLC and to improve the relationships with their selected RLC. There are some limitations of this methodology. The criteria considered here are specific to one industry. However this methodology can easily be adapted to different situations and can consider any number of quantitative and qualitative attributes. Several extensions to this study are possible. We could also study the case with competition between manufacturing and remanufacturing processes, namely, the manufacturing and remanufacturing taken by different firms. Reverse logistics contractor selection in the presence of both stochastic data and slightly non-homogeneous DMUs can be done. User friendly and smart decision support system may also be developed based on this work.

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