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A decision making methodology for the selection of reverse logistics operating channels

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Abstract

An efficient management of product returns is a strategic issue. Nowadays, customer expect manufacturer to develop a reverse logistics system so that the returned products can be recovered. With the development and advancement of reverse logistics practice, the selection of reverse logistics operating channels becomes more important. There are three operating channels of reverse logistics; Manufacturer Operation, Third Party Operation, Joint Operation. 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 proposed for the selection and evaluation of reverse logistics operating channels. An example is included to validate the proposed method. This method helps the decision maker to select the best technology that meets the requirement.

*Keywords:*Reverse Logistics;Multicriteria Decision Making;AHP Method

1. Introduction

Due to the growing environmental legislations, more attention is given to Reverse Logistics. Reverse Logistics (RL) is the process of planning, implementing and 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 value, or proper disposal [1].The study of reverse logistics is in exploration stage. Cost reduction is possible in reverse logistics. A reverse logistics defines a supply chain that is redesigned to efficient manage the flow of products or parts designed for remanufacturing, recycling or disposal and to effectively utilize resources [2].The various functions executed through RL activities include gatekeeping, compacting disposition cycle times, remanufacturing and refurbishment, asset recovery, negotiation, outsourcing and customer service [3].In

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addition to disposition and transportation, value added services such as JIT, quick response and program solutions are also important functions in reverse logistics.

Recovery of products for remanufacturing, repair and recycling can create profitable business opportunities [4]. For managing the returns, the companies can reuse them, resell or destroy them. Retailers may return the goods due to seasonality, expiry or because of transit damage. Customers may return the goods due to poor quality. Managing the product returns increases the customer service level and retention level.

Each activity from procurement to distribution generates waste and reduction of this waste is a major goal of environmentally conscious business practices [5]. Manufactures see reverse logistics as a process of recovering defective products or reusable containers back from the user. In the e-commerce since buyers need assurance for refund, reverse logistics is an important issue. Owing to RL's interdisciplinary approach, this area present an opportunity for research.

A conceptual framework for managing retail reverse logistics operation is presented in [6].In the case study conducted by [7], three companies were visited and identified reverse logistics process flow and the strategic issues a firm may use for competitive advantage. An integrated forward logistics multi echelon distribution inventory supply chain model and closed loop multi echelon distribution for the built to order environment was designed using genetic algorithm and particle swarm optimization [8].A model for green supply chain management with incomplete information was developed [9].Reverse logistics was suggested as an area for future research and the advantages of soft computing is its capability to tolerate imprecision, uncertainty [10].A mathematical model for the design of Reverse Logistics network design was proposed[11,12,13]considering the location and allocation of facilities. A dynamic model was constructed and validated the same using the data collected from the computer company [14]. A distribution system which uses a combination of manufacturing and remanufacturing was proposed and the models were compared with respect to the various prices [15]. From the above references, studies have been done for the RL network design and the selection of third party logistics provider. But AHP and Fuzzy TOPSIS has not been used by any researcher for selection of RL operating channels selection.

The companies can choose three operating channels for performing the RL activities a) Manufacturer collecting the used products-Manufacturer Operation (MO). The manufacturer should control human resources, information systems and related equipment. b) Retailer will collect the used products- Joint Operation (JO). c) Outsourcing to third party-Third Party Operation (TPO). Remanufacturing costs may be reduced by third party. Since the third party logistics is using his latest technology and resource sharing advantages, uncertainty of recovery may be reduced. By outsourcing reverse logistics activities, the organizations can concentrate on their core business operation, but customer satisfaction and delivery performance may be improved[16].Third party reverse logistics provider will compete with each other in specific areas like price, quality and credit. Logistics costs will be reduced and order fill rate will be improved.Each channel has its distinct characters and suitable for companies with their sole service requirements.

Evaluating and selecting reverse logistics channels is regarded as Multi criteria decision making (MCDM) process in which a decision maker chooses the best option among the existing alternatives. This paper is organized as follows. Section 2 describes the problem and in section 3 an overview of method is given. Application of the model to a case study is given in section 4.Section 5 concludes the study and summarizes its findings.

2. Problem Definition

Reverse Logistics can be applied to wide variety of industries like automobile, electronic, chemical and computer manufacturers. Automobile companies recover the end of life auto parts. Electronic products that contain hazardous materials are disposed. Reverse Logistics may take place through

Manufacturer Operation (MO),Third Party Operation (TPO), or Joint Operation (JO).The criteria for the selection of RL operating channels are given in Table -1.

Table1. Criteria for selection of RL operating channels

Criteria	References
Economy Factors(E)	Hendrik et al.[17],Andersson &Normann[18]
Reverse Logistics Functions(RL)	Schwartz[19],Dowlatshahi[20]
Management(M)	Razaqque and Sheng [21],Mohr and Spekman[22],Monczka et al.[23]
Time(T)	Kleindorfer and Partovi[24]
Flexibility(F)	Stank and Daugherty[25]
IT applications(IT)	Bun and Ishizuka[26]

3. Proposed Methodology

Decision makers find the problem of assessing the variety of alternatives and then selecting the best one using a set of criteria. Multiple criteria decision making methods (MCDM) are discrete with a restricted number of alternatives. A decision matrix in MCDM consists of three main parts a) Alternatives b) Criteria c) Weights of Relative importance. 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 calculated by applying the AHP method. The Fuzzy TOPSIS method is applied to get the final ranking results. Although AHP is a decision−making methodology in itself, its ability to get accurate 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.

Nomenclature

$A = \{A_1, A_2 ..., A_j\}$	A set of J alternatives
$C = \{C_1, C_2, ..., C_i\}$	A set of n criteria,
$\tilde{X} = \{\tilde{x}_{ij}\}$	A set of ratings of $Aj (j = 1,2,3,...,J)$ with respect to criteria
$w_i(i = 1,2,3,...,n)$	A set of weights of each criterion
CI	Consistency Index
CC	Closeness Coefficient
CR	Consistency Ratio
(A^+)	Positive Ideal Solution
(A^-)	Negative Ideal Solution
λ_{max}	Maximum Eigen Value
M	Size of the Matrix

3.1 Analytic Hierarchy Process

AHP method is developed by Prof. Thomas L. Saaty. AHP divides a complex problem into a hierarchy of interrelated decision elements. AHP can deal with objective as well as non-tangible subjective attributes. The procedure of AHP is as follows

3.1.1. Model the problem as a hierarchy

Develop a hierarchical structure with a goal at the top level, the criteria at the second level and alternatives at the third level. Alternatives are affected by uncertain events and are connected to all criteria.

3.1.2 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 capture a 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 2. A criteria compared with itself is given the value 1, so that the main diagonal elements are all 1.

Table 2. Scale of Preference

Preference weights	Definition	Explanation
1	Equally preferred	Two attributes contribute equally
3	Moderately	Experience and judgement slightly favour one activity over another
5	Strongly	Experience and judgement strongly favour one activity over another
7	Very Strongly	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extremely	The evidence favouring 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 [27]

3.1.3 Test the Consistency by calculating the Eigen Vectors

The relative normalized 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. Determine the consistency index (CI)

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

Table 3. 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 [27]

After obtaining the random index from table 3, consistency ratio is calculated using the relation

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

A consistency ratio of 0.1 or less is considered as acceptable for matrices $M \geq 5$. If a consistency ratio is more than the acceptable value, inconsistency occurs, and the judgements are untrustworthy ,the evaluation process needs to be improved. Consistency ratio helps to ensure decision maker reliability in determining the priorities for the criteria.

3.2Fuzzy TOPSIS Method

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was first established by Hwang &Yoon[28].The best alternative would be the one that is nearest to the positive ideal solution (the solution that maximizes the benefit criteria and minimizes the cost criteria) and farthest away from the negative ideal solution[29]. 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 that the uncertainty and imprecision related with representing decision maker's observations to crisp values. Therefore, the 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 [30].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. 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. The linguistic variables that are applied in the model can be expressed in triangular fuzzy Numbers for each criterion. Some basic definitions of fuzzy sets are given.

Definition 1. A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized by a membership function $\tilde{\mu}_A(x)$ which associates with each element x in X a real number in the interval [0, 1]. The function value is termed the grade of membership of x in $\tilde{A}$ [31].

Definition 2. A triangular fuzzy number is characterized by a triple 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.

$$\mu(x) = \begin{cases} 0, x \leq a_1 \\ \dfrac{x - a_1}{a_2 - a_1}, a_1 \leq x \leq a_2 \\ \dfrac{x - a_3}{a_2 - a_3}, a_2 \leq x \leq a_3 \\ 0, x \geq a3 \end{cases} \tag{3}$$

If $\tilde{A}$ and $\tilde{B}$ 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

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

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

$$\widetilde{A}(\times)\widetilde{B}=(a_1,a_2,a_3)(\times)(b_1,b_2,b_3)=(a_1.b_1,a_2.b_2,a_3.b_3) \quad (6)$$
$$\widetilde{A}(\times)\widetilde{B}=(a_1,a_2,a_3)(\times)(b_1,b_2,b_3)=(\ a_1/b_3,a_2/b_2,a_3/b_3) \quad (7)$$
$$K\widetilde{A}=(ka_1,ka_2,ka_3,ka_4) \quad (8)$$
$$(\widetilde{A})^{-1}=(1/a_3,1/a_2,1/a_1) \quad (9)$$

Definition3. 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.

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

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

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

Where $\widetilde{v}_{ij}=\widetilde{x}_{ij}\times w_i$.

Based on the above fuzzy theory concepts, Onut &Soner [32] indicated the various steps in the Fuzzy TOPSIS method

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 (x_{ij}) preserves the property that the range of normalized triangular fuzzy numbers belonging to $(0,1)$thus three is no need for normalization

Step 2: Calculate the weighed normalized fuzzy matrix. The weighed normalized value is calculated using equation.

Step 3: Identify positive ideal and negative ideal solutions using the equations:

$$A^+=\{v_1^+,v_2^+,...,v_i^+\}=\{(\max v_{ij}\mid i\in I')\times(\min v_{ij}\mid i\in I'')\} \quad i=1,2,...,n \quad j=1,2,...,J \quad (12)$$
$$A^-=\{v_1^-,v_2^-,...,v_i^-\}=\{(\min v_{ij}\mid i\in I')\times(\max v_{ij}\mid i\in I'')\} \quad i=1,2,...,n \quad j=1,2,...,J \quad (13)$$

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:

$$D_j^+=\sum_{j=1}^{n}d(v_{ij},v_i^+) \qquad j=1,2,...,J \quad (14)$$
$$D_j^-=\sum_{j=1}^{n}d(v_{ij},v_i^-) \qquad j=1,2,...,J \quad (15)$$

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

$$CCj=\frac{D_j^+}{D_j^-+D_j^+} \qquad j=1,2,...,J \quad (16)$$

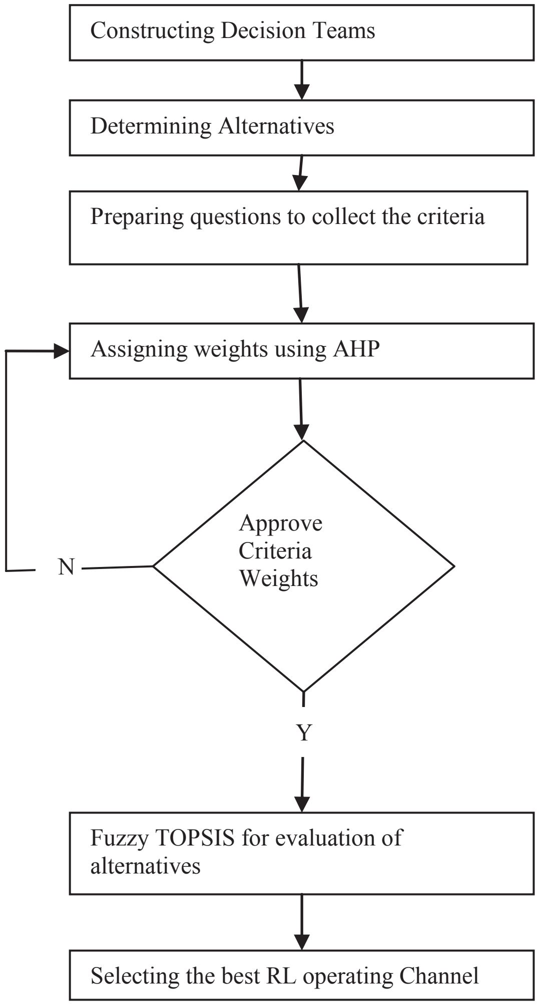

Fig.1. Proposed model for the selection of RL operating channel

4. Numerical Illustration

Proposed model is applied to a real problem in industry. A printing industry located in the Southern part of India is selected. The industry wanted a systematic way to implement the reverse logistics operations. Reverse Logistics brings significant improvements in the manufacturing process and the correct decisions made brings the industry competitive advantage. Therefore selecting the most important operating channels is of great importance for the industry. To collect the used papers and magazines from the customers, the industry may choose MO, TPO, JO. A hybrid methodology combing AHP and TOPSIS under fuzzy environment is utilized for the selection. Schematic diagram of the proposed model is presented in figure 1.First a team comprising two engineers and one manager was formed. The data required for selection are obtained through direct questions.

4.1 Model the Problem as a hierarchy

There are three levels in the hierarchy. The goal is at the topmost level of the hierarchy. The second level characterizes the criteria. The required criteria are identified through the results of the questions. The criteria identified by the decision teams are given in table 1. The third level represents the alternatives.

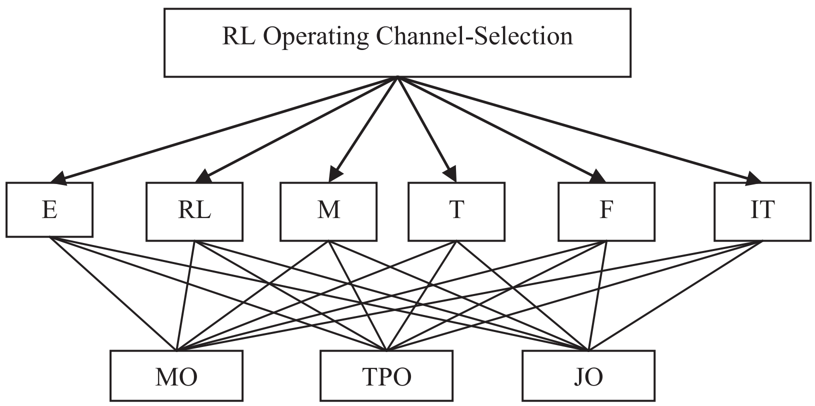

Fig .2. Hierarchy model for the selection of RL operating channels

4.2 Construct a pairwise comparison matrix

After structuring a hierarchy, the pairwise comparison matrix for each level is constructed. A nominal scale is used for the evaluation.

Table 4. Pairwise Comparison matrix

Criteria	E	RL	M	T	F	IT	Weights
Economy Factors(E)	1	6	5	3	7	6	0.483
Reverse Logistics Functions(RL)	1/6	1	1/4	2	2	3	0.105
Management(M)	1/5	4	1	2	5	4	0.213
Time(T)	1/3	1/2	1/2	1	2	3	0.101
Flexibility(F)	1/7	1/2	1/5	1/2	1	2	0.054
IT applications(IT)	1/6	1/3	1/4	1/3	1/2	1	0.042

4. 3 Test the Consistency by calculating the Eigen Vectors

Consistency Index and Random Index are determined. Since the calculated Consistency Ratio is less than 0.1, the matrix is accepted. The weights are consistent and they are used in the selection process.

Table 5. CR ratio obtained from AHP

Maximum. Eigen Value	6.460
Consistency Index(CI)	0.092
Random Index(RI)	1.24
Consistency Ratio(CR)	0.074

4. 4 Determine the final rank using Fuzzy TOPSIS

The team member options expressed in the linguistic values are converted into triangular fuzzy numbers using table 6.

Table 6. Linguistic terms and Fuzzy Numbers

Linguistic terms	Fuzzy Numbers
Very Low(VL)	(0.0,0.2,0.4)
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)

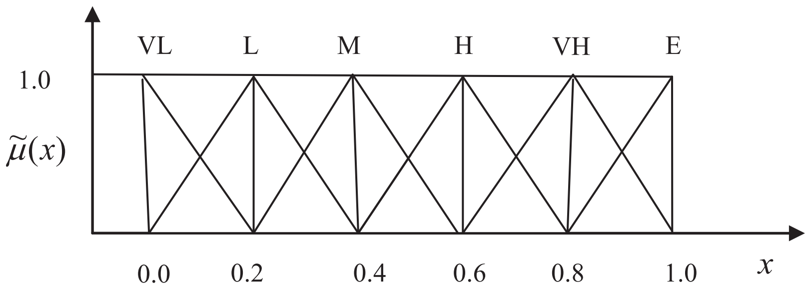

Fig. 3.Membership functions of linguistic values

Fuzzy Evaluation matrix for the evaluation of RL modes is constructed with the linguistic variables followed by the triangular fuzzy number in parenthesis.

Table 7. Fuzzy evaluation matrix for the RL modes

	E	RL	M	T	F	IT
MO	Very high (0.6,0.8,1.0)	Medium (0.2,0.4,0.6)	Very high (0.6,0.8,1.0)	Medium (0.2,0.4,0.6)	Low (0.0,0.2,0.4)	Medium (0.2,0.4,0.6)
TPO	Low (0.0,0.2,0.4)	Excellent (0.8,1.0,1.0)	High (0.4,0.6,0.8)	Very High (0.6,0.8,1.0)	High (0.4,0.6,0.8)	Very high (0.6,0.8,1.0)
JO	Medium (0.2,0.4,0.6)	Low (0.0,0.2,0.4)	Medium (0.2,0.4,0.6)	Medium (0.2,0.4,0.6)	Very low (0.0,0.0,0.2)	Low (0.0,0.2,0.4)
Weights	0.483	0.105	0.213	0.101	0.054	0.042

Using equation (11) the weighed fuzzy evaluation matrix is established. Economic factor is considered as cost criterion and assigned the positive ideal solution as $\tilde{v}_1^+ = (0,0,0)$ and negative ideal solution as $\tilde{v}_1^- = (1,1,1)$.Other criteria are benefit criteria and assigned the values as $\tilde{v}_1^+ = (1,1,1)$ for positive ideal solution and $\tilde{v}_1^- = (0,0,0)$ for the negative ideal solution.

Table 8. Weighed Evaluation matrix

	E	RL	M	T	F
MO	(0.289,0.386,0.483)	(0.021,0.042,0.063)	(0.128,0.170,0.213)	(0.020, 0.040,0.061)	(0.000,0.010,0.022)
TPO	(0.000,0.096,0.193)	(0.084,0.105,0.105)	(0.085,0.128,0.170)	(0.061,0.081,0.101)	(0.022,0.032,0.043)
JO	(0.096,0.193,0.289)	(0.000,0.021,0.042)	(0.042,0.085,0.128)	(0.020,0.040,0.061)	(0.000,0.000,0.010)
A^+	$\tilde{v}_1^+$=(0,0,0)	$\tilde{v}_1^+$=(1,1,1)	$\tilde{v}_1^+$=(1,1,1)	$\tilde{v}_1^+$=(1,1,1)	$\tilde{v}_1^+$=(1,1,1)
A^-	$\tilde{v}_1^-$=(0,0,0)	$\tilde{v}_1^-$=(0,0,0)	$\tilde{v}_1^-$=(0,0,0)	$\tilde{v}_1^-$=(0,0,0)	$\tilde{v}_1^-$=(0,0,0)
					IT

MO	(0.084,0.016,0.025)
TPO	(0.025,0.033,0.042)
JO	(0.000,0.084,0.016)
A^{+}	$\tilde{v}_1^{+}$ =(1,1,1)
A^{-}	$\tilde{v}_1^{-}$ =(0,0,0)

The distances to ideal solution defined in Equations (14) and (15) is evaluated and the closeness coefficient is calculated using equation (16).

Table 9. Distances to Ideal solution

Alternatives	D_j^{+}	D_j^{-}	CC_j
MO	5.085	1.301	0.203
TPO	4.749	1.286	0.213
JO	4.938	1.025	0.171

The results are summarized in the table 10.

Table10. Overall Values

Alternatives	CC_j	Rank
MO	0.203	II
TPO	0.213	I
JO	0.171	III

The higher the closeness coefficient the better is the rank. Hence the order of rating among the alternatives is TPO>JO>MO. The result obtained is discussed with the industry and they found that it is meaningful.

5. Conclusions

Since financial and operational attributes are involved, the implementation of reverse logistics may be an unsafe task for the industry. However growing environmental concerns have forced the industries to opt for reverse logistics. The question is by which channel the industries will be able to collect the returned product. A methodology based on AHP and TOPSIS under fuzzy environment is proposed for the selection of RL operating channels. The problem has been described as a multi-criteria decision making method under uncertainty, prompting the need for the method to handle imprecise judgments from decision makers. Future research includes incorporating a two phase methodology combining AHP and Fuzzy VIKOR and carrying out sensitivity analysis to confirm the robustness.

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