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Abstract

Purpose – The paper aims to incorporate the relationship of reverse logistics into the economic, environmental, and social sustainability, known as triple bottom line and developed a framework for reverse logistics performance evaluation.

Design/methodology/approach – The performance measures, based on triple bottom line approach, were selected, and fuzzy analytical hierarchy process and extent analysis approach was applied for estimating the weights, global weights of performance measures and hence, the reverse logistics performance index. Reverse logistics performance of three electronic companies were evaluated and compared for the demonstration of the methodology.

Findings – The results show that economic performance has highest performance index followed by environmental performance and social performance. "Recapturing value" and "return on investment" from economic, "minimum energy consumption" and "optimum use of raw material" from environmental and "community complaints" and "customer health and safety" from social perspective have higher performance indexes. Over all, "reduced packaging", "use of recycled material" and "employee benefits" show very poor performance indexes.

Research Limitations/implications – The study will provide useful guidance to the academicians and practitioners for evaluating, improving and benchmarking the reverse logistics performance.

Originality/value – The analysis adds to the very few studies on triple bottom line aspects of reverse logistics and its performance evaluation. Also, fuzzy analytical hierarchy process and extent analysis is used first time being an efficient tool to tackle the fuzziness of the data involved in performance evaluation.

Keywords Sustainability, Reverse logistics, Triple bottom line, Performance evaluation, Extent fuzzy AHP

Paper type Research paper

1. Introduction

Sustainability has become an important issue for most of the organizations because of growing awareness of environment, environmental legislations and markets globalization. Business organizations and government institutions are forced to incorporate sustainable developments in their practices. According to Hubbard (2009), 75 per cent of large organizations within the wider business environment are reported as being under pressure to develop non-financial measures of performance in addition to traditional measures. They need to measure business success in terms of social and environmental performance along with economic performance. While addressing sustainability, organizations are more focused toward the forward supply chain

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activities and less attentive toward the reverse flows. This is also evident from the guidelines developed by the Global Reporting Initiative in which core indicators and additional indicators are generic and more inclined toward the forward flows. However, reverse logistics (RL) can make a significant contribution to the sustainable initiatives of an organization (Sarkis *et al.*, 2010a).

In recent years, growing concerns for the environment and government regulations in many countries has increased the interest of researchers and practitioners in the field of RL. Ravi *et al.* (2005a) stated that the environment, economic and corporate citizenship are the major factors for growing interest in RL. RL provides an alternative use of resources environmental-friendly and effectively by extending a product's life beyond its normal life and, hence, reducing environmental burdens from industrial operations (Jayaraman and Luo, 2007). Product's reuse decreases the negative impact on environment by reducing waste disposal, transport and distribution emissions. One of the prime issues in RL context is its performance evaluation. Most of the performance measurement systems for RL consider the factors related to economic performance and directly or indirectly related to environmental performance (Bai and Sarkis, 2013; Agrawal *et al.*, 2014; Harris and Twomey, 2014; Tsoulfas *et al.*, 2002; Huang *et al.*, 2012). Although these studies provided great insights into the literature on economic and environmental performance evaluation, little attention has been given to the RL performance evaluation that considers the economic, environmental and social aspects of RL performance altogether. Recently, Devika *et al.* (2014) reported that "there is a gap in quantitatively modeling social impacts together with environmental and economic impacts". McWilliams *et al.* (2014) also find that there is little research focusing on social aspects of triple bottom line (TBL). The proposed study makes an attempt to bridge the existing gaps in research area of TBL aspects of RL for performance evaluation. The main contribution of this paper is as follows:

- to provide the insight for TBL aspects of RL; and
- to develop an efficient RL performance evaluation system based on the TBL concept.

While TBL is used for defining the performance measures, a multiple criteria decision method (MCDM) is selected for performance evaluation because of the multi-criteria nature of the TBL aspects of RL. MCDM is an effective tool in real world to deal with subjective human biasness, and the human judgments may be vague and complex. This study will illustrate the fuzzy analytical hierarchy process and extent analysis (FAHPEA) approach for RL performance evaluation to address the above-mentioned concerns. Initially, the performance measures (criteria) associated with RL based on TBL were identified. The paper goes beyond traditional performance measures, and apart from economic and environmental performance criteria, social performance criteria were also included as top-level criteria. The sub-criteria for each of top-level criteria were selected, as shown in Table I. The overall objective is to measure the performance based on selected criteria and sub-criteria. Most of performance measures are qualitative in nature and are expressed in terms of linguistic variables. To evaluate them quantitatively, fuzzy-based analytical hierarchy process (AHP) is one of the useful multi-criteria decision-making techniques. An improved version of fuzzy AHP, FAHPEA approach is utilized for RL performance evaluation because of its ability to provide a more accurate and realistic picture of the decision-making process.

Table I. Selected performance criteria and sub criteria

Criteria/sub-criteria	Authors	Remarks
Economic performance		
Return on investment	Presley *et al.* (2007), Lee *et al.* (2009), Jacobs *et al.* (2010), Carter (2005)	Positive "return on investment" may be a major driver for the stakeholders to adopt RL practices
Recapturing value	Meade and Sarkis (2002), Ravi *et al.* (2005b), Kannan *et al.* (2009)	Recapturing value from recovered products and it is important for sustaining the RL operations
Logistics cost optimization	Hu *et al.* (2002), Tan *et al.* (2003), Lee *et al.* (2009)	It involves the optimization of cost of product acquisition, collection, inspection, and transportation
Recycle efficiency	Olugu *et al.* (2011), Michelini and Razzoli (2011)	Recycling efficiency refers to the recycling of used product back into the useful raw material
Annual sales	Shaik and Kader (2012), Shaik and Kader (2014)	Annual amount of products sold to the customers that are remanufactured or refurbished
Disposal costs	Tan *et al.* (2003), Knemeyer *et al.* (2002), Lai *et al.* (2013), Presley *et al.* (2007)	Costs of disposal of returned products ensuring safety and protecting environment which can not be remanufactured or recycled
Environmental performance		
Minimum energy consumption	Nikolaou *et al.* (2013), Liu *et al.* (2014), Bhattacharya *et al.* (2013), Vachon and Mao (2008)	Minimization of the energy consumption for the product/material recovery
Optimum use of raw material	Hu *et al.* (2002), Meade and Sarkis (2002), Johnson (1998), Hervani *et al.* (2005), Clemens (2006)	Minimization of the raw material used which are not good for environment
Transport optimization	Krikke (2011), Hervani *et al.* (2005), Clemens (2006), Vachon and Mao (2008)	Transport optimization refers to the minimization of fuel consumption vehicle fleet and reduction in emission
Reduced packaging	Handfield *et al.* (2002), Carter and Easton (2011), Shen *et al.* (2013)	Minimum use of packaging material containing less toxic materials
Use of recycled material	Field and Sroufe (2007), Azevedo *et al.* (2011), Sarkis *et al.* (2010b), Winkler (2011), Hervani *et al.* (2005)	Materials reused from the product recovery or percent of product reclaimed
Waste reduction	Rao and Holt (2005), Carter (2005), Lai and Wong (2012), Azevedo *et al.* (2011), Presley *et al.* (2007), Vachon and Mao (2008)	Waste to landfill and recycling waste reduction for the reduction of negative environmental impact
Social performance		
Community complaints	Garza (2013), Bai and Sarkis (2014), Presley *et al.* (2007)	Number of complaints received and the number of complaints resolved to the satisfaction of the complainants
Customer health and safety	Nikolaou *et al.* (2013), Bhattacharya *et al.* (2013)	Lost time injury rate, sickness absence rate, number of incidents of non-compliance concerning health and safety impacts of products and services
Stakeholders participation	Nikolaou *et al.* (2013), Presley *et al.* (2007)	Stake holder engagement and empowerment
Employment stability	Sarkis *et al.* (2010a), Hasan (2013)	Attrition rate of employees
Donations to community	Jindal and Sangwan (2013), Nikolaou and Evangelinos (2013)	Donations and in-kind support to community
Employee benefits	Nikolaou *et al.* (2013), Nikolaou and Evangelinos (2013)	Comparative wage levels

The remainder of the paper is organized as follows: Section 2 comprises a literature review on sustainability, RL and performance evaluation systems including performance measures. In Section 3, FAHPEA approach has been discussed to develop framework for performance evaluation. Subsequently, the proposed framework is illustrated with the help of a case example by comparison of performances of three electronic firms in Section 4. Results are discussed in Section 4. Finally, Section 5 summarizes all the findings and concludes the study including future scope of research.

2. Literature review

The Brundtland report (1987) brought the attention to the society's dependence on natural systems and how the society may be jeopardizing the Earth's resources. Businesses worldwide realized that they should protect the environment, and ensure the safety and welfare of current and future generations along with economic benefits by working toward sustainability (Gunasekaran and Spalanzani, 2011). Businesses have taken the initiatives to capture value from the concept of sustainability (McMullen, 2001). Sen (2014) explored the need of sustainability differentiation for the development. Bansal (2002) recognized the relationship among three important components of sustainability: economic, environmental and social sustainability. These three main components of sustainability are often referred as "triple bottom line" (Elkington, 1997). The economic aspects generate enough cash flow to produce persistent returns (Vachon and Mao, 2008), and the environmental aspects protect the environmental resources for the society (Bansal, 2002). The social aspects support the creation and development of skills, and the capabilities of current and future generations, to promote health and support fairly and equitably to everyone (McKenzie, 2004). Carter and Rogers (2008) suggested that the intersection of TBL activities not only positively affect the natural environment and the society but also results in long-term economic benefits and competitive advantage. In other words, firms must adopt a long-term horizon and let economic growth sustain the social progress and the environment (Lamming and Hampson, 1996). Sarkis *et al.* (2010a) mentioned that RL may help the firms in improving sustainability performance substantially.

RL is defined:

> […] as 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 (Rogers and Tibben, 1999).

RL activities include collection, inspection and sorting, disposition (reuse, repair, remanufacture or recycle) and redistribution of returned products. These products are either reused or remanufactured or repaired or recycled to recapture maximum value through RL practices. A well-managed RL can provide important cost savings in procurement, disposal, inventory carrying and transportation (Kannan *et al.*, 2009). RL handling end-of-life products involves environmentally conscious recycling and remanufacturing practices which can potentially reduce negative environmental impacts (Gungor and Gupta, 1999). Thus, RL provides both economic and environmental benefits to the firms. In fact, implementing RL programs to reduce, reuse and recycle wastes produce tangible and intangible value and may lead to better corporate image (Carter and Ellram, 1998). RL can make a significant contribution to the number of social issues along with environmental concerns (Sarkis *et al.*, 2010a). One of the prime issues in RL context is the evaluation of RL performance. RL and its sustainability performance can be improved if it could be measured and monitored precisely.

According to Song and Hong (2008):

> […] the performance measurement systems can provide companies with relevant, appropriate, complete, and accurate information. The companies have opportunities to monitor and reposition their management and operations to obtain highly competitive environment.

Performance evaluation framework provides a balanced view between external and internal activity (Keegan *et al.*, 1989), between results and its determinants (Fitzgerald *et al.*, 1991), between the four balanced scorecard perspectives (Kaplan and Norton, 1992) and the multiple perspective of the stakeholders of the performance prism (Kennerley and Neely, 2000). Balanced scorecard has been utilized by researchers and practitioners frequently in defining goals and performance measures of RL. Yellepeddi *et al.* (2005) proposed a balanced scorecard approach and utilized analytic network process technique for the development of effective RL performance evaluation system. Ravi *et al.* (2005a) used balanced card approach and analytic network process technique for the selection of alternatives for end-of-life computers. Shaik and Kader (2012) developed an RL performance evaluation framework by using balanced scorecard approach and AHP. In another study, they developed an RL performance evaluation system by integrating balanced scorecard characteristics with performance prism (Shaik and Kader, 2014). Huang *et al.* (2012) proposed an RL performance evaluation system for recycled computers from the financial, operational procedure, learning and growth, reverse relationship and flexibility perspectives. The balanced scorecard-based performance evaluation systems allow managers to look at the business from four divergent important perspectives: customer, internal business, innovation and learning and finance (Kaplan and Norton, 1992). The merits of the approach are to integrate strategic, operational and financial measures to consider the balanced key perspectives of performance. However, it does not consider external environment which is important from the perspectives of the stakeholders and their satisfaction.

Apart from balanced scorecard approach, other approaches have been applied for the performance evaluation of RL. Biehl *et al.* (2007) developed a performance measurement system for carpet recycling by evaluating the system's economic and environmental performance. Paksoy *et al.* (2011) developed a mathematical model for investigating a number of operational and environmental performance measures including total transportation costs, total environmental costs, emission rates and customer demand. Recently, Nagalingam *et al.* (2013) developed a framework for measuring performance in terms of estimated utilization value of a manufactured product optimizing recovery cost, landfill waste and quality characteristic. Bai and Sarkis (2013) introduced a performance evaluation framework by using AHP approach for evaluating the economic, environmental and the operational performance. Kannan *et al.* (2009) proposed a fuzzy multi-criteria decision-making model for the selection of alternative environmental management practices in RL. Presley *et al.* (2007) introduced the relationships of RL to TBL dimensions and developed a strategic sustainability evaluation framework. Govindan *et al.* (2013) developed a fuzzy multi-criteria decision-making model for measuring sustainability performance of a supplier based on TBL approach. Nikolaou *et al.* (2013) developed a framework for evaluating RL social responsibility, based on the

TBL approach in which performance measures were selected using Global Reporting Initiative guidelines. The model developed is comprehensive but difficult to manage practically in real life because of its complexity. The literature on sustainability aspects of RL are limited and little attention has been given until recently. The proposed study developed a framework for the economic, environmental and social aspects of the RL and utilized FAHPEA for RL performance evaluation. Some representative criteria and sub-criteria were selected from the TBL perspective with the help of information and knowledge gathered from the past literature and experts. Economic performance measures include sustainability-specific economic measures along with measures related to RL process performances. A number of criteria and sub-criteria are summarized in Table I.

3. Fuzzy–AHP and extent analysis approach

MCDM is a very powerful tool which is widely used for dealing with the unstructured problems containing multiple and potentially conflicting objectives (Lee and Eom, 1990). There are number of approaches proposed for solving MCDM problems such as AHP, data envelopment analysis and technique for order of preference by similarity to ideal solution. These are classical MCDM approaches which measures the alternative ratings and weights of the criteria's in crisp or precise numbers, depending upon judgment/preferences of decision makers (Wang and Lee, 2009). Saaty (1980) developed AHP approach to solve complex problems involving multiple criteria by considering number of criteria and sub-criteria at different levels of hierarchy for prioritizing the alternatives. Applications of the approach have been reported in numerous fields such as project selection, budget allocation, supply chain, health care, manufacturing and supplier selection (Wang *et al.*, 2004; Sharma and Bhagwat, 2007; Avikal *et al.*, 2014; Yadav and Sharma, 2015). The traditional AHP method considers ratings and weights of criteria's in crisp numbers. However, crisp data are inadequate to represent the real-life situation because human judgments are vague and may not be estimated with exact numeric values. In such situations, the fuzzy set theory is useful for capturing the uncertainty of human judgments. Fuzzy set theory was introduced into MCDM including AHP by Zadeh (1965) for effectively working with the vagueness and ambiguity of the human judgments.

Fuzzy logic has been combined and used along with AHP and has resulted in a fuzzy AHP approach. The fuzzy logic has been combined with AHP because of the following characteristics of fuzzy systems (Kahraman *et al.*, 2007):

- fuzzy systems are suitable for uncertain or approximate reasoning, especially for the system with a mathematical model that is difficult to derive;
- fuzzy logic allows decision-making with estimated values under incomplete or uncertain information; and
- in fuzzy AHP, all the ratings and weights are defined by means of linguistic variables.

Buckley *et al.* (1988) addressed the concept of consistency into fuzzy AHP model by using geometric mean method. Logarithmic least square method was developed to obtain triangular fuzzy weights from a triangular fuzzy comparison matrix (Weck *et al.*, 1997). The direct fuzzification method by Csutora and Buckley (2001), fuzzy preference programming by Mikhailov (2003), two-stage logarithmic programming by Wang *et al.* (2005) and extent analysis method by Chang (1992) are some of the examples of fuzzy AHP. Among all of these approaches, the extent analysis method introduced by Chang (1992) has been employed in many applications because of its computational simplicity. Compared to eigenvectors which are used to calculate the weight vectors in conventional AHP, the FAHPEA is simple and easy to implement. Chang (1996) introduced triangular fuzzy numbers for handling FAHPEA. FAHPEA approach has been utilized by many authors as an MCDM approach for different RL issues (Singh and Sharma, 2014; Chan *et al.*, 2012; Kumar and Singh, 2012; Senthil *et al.*, 2012). A step by step approach of FAHPEA is described in the following section.

Let X = $\{x_1, x_2, \ldots, x_n\}$ be an object set and U = $\{u_1, u_2, \ldots, u_m\}$ be a goal set. According to the method of Chang's (1992) extent analysis, each object is taken and extent analysis for each goal g_i, is performed, respectively. Therefore, M-extent analysis values for each object can be obtained and are represented as follows:

$$M^1_{g_i}, M^2_{g_i}, \ldots, M^m_{g_i}, \qquad i = 1, 2, \ldots, n, \tag{1}$$

Where all the $M^j_{g_i}$ $(j = 1, 2, \ldots, \ldots, m)$ are triangular fuzzy numbers represented by (l, m, u), l is the least possible value, m is the most likely value and u is the largest possible value. The steps of the extent analysis AHP (Chang, 1996) are as follows:

- *Step 1*: The value of fuzzy synthetic extent with respect to the i_{th} object is defined as follows:

$$S_i = \sum^m_{j=1} M^j_{g_i} \otimes \left[\sum^n_{i=1} \sum^m_{j=1} M^j_{g_i}\right]^{-1} \tag{2}$$

To obtain $\sum^m_{j=1} M^j_{g_i}$, perform the fuzzy addition operation of M-extent analysis values for a particular matrix such that:

$$\sum^m_{j=i} M^j_{g_i} = \left(\sum^m_{j=1} l_j, \sum^m_{j=1} m_j, \sum^m_{j=1} u_j\right) \tag{3}$$

and to obtain $[\sum^n_{i=1} \sum^m_{j=1} M^j_{g_i}]^{-1}$, perform the fuzzy addition operation of $M^j_{g_i}$ $(j = 1, 2, \ldots, \ldots, m)$ values such that:

$$\left[\sum^n_{i=1} \sum^m_{j=i} M^j_{g_i}\right] = \left(\sum^m_{j=1} l_j, \sum^m_{j=1} m_j, \sum^m_{j=1} u_j\right) \tag{4}$$

The inverse of the vector in "equation (2)" can be computed as follows:

$$\left[\sum^n_{i=1} \sum^m_{j=1} M^j_{g_i}\right]^{-1} = \left(\frac{1}{\sum^m_{j=1} l_j}, \frac{1}{\sum^m_{j=1} m_j}, \frac{1}{\sum^m_{j=1} u_j}\right) \tag{5}$$

- *Step 2*: The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as follows:

$$V(M_2 \geq M_1) = \sup_{y \geq x}\left[\min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right)\right] \tag{6}$$

and can be equivalently expressed as follows:

$$V(M_2 \geq M_1) = hgt(M1 \cap M2) = \mu_{M_2}(d) = \begin{cases} 1, & \text{if } m_2 \geq m_1, \\ 0, & \text{if } l_1 \geq u_2, \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise,} \end{cases} \quad (7)$$

Where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_1}, as shown in Figure 1.

To compare M_1 and M_2, we need both the values of $V(M_2 \geq M_1)$ and $V(M_1 \geq M_2)$.

- *Step 3*: The degree possibility for a convex fuzzy number to be greater than k, convex fuzzy numbers M_i (i = 1, 2, ……, k) can be defined as follows:

$$V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1)\, and\, (M \geq M_2)\, and \ldots and\, (M \geq M_k)] = \min V(M \geq M_i), i = 1, 2, 3, \ldots, k \quad (8)$$

Assume that,

$$d'(A_i) = \min V(S \geq S_k) \quad (9)$$

for, k=1, 2, ……, n and k ≠ 1. Now the weight vector can be given by the following formulae:

$$W' = \{d'(A_1), d'(A_2), \ldots, d'(A_n)\}^T, \quad (10)$$

Where Ai (i = 1, 2, 3 ….., n) are n elements.

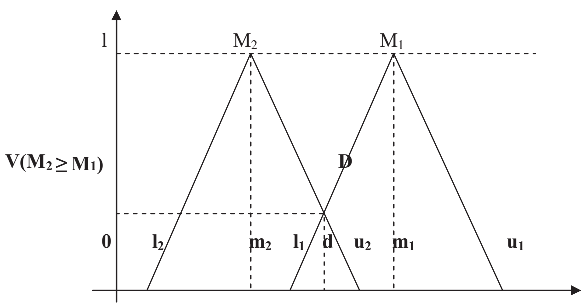

Figure 1.
The interaction between triangular fuzzy numbers, M_1 and M_2

- *Step 4*: Via normalization, the normalized weight vectors are given as follows:

$$W' = \{d(A_1), d(A_2), \ldots, d(A_n)\}^T,$$

Where "W" is a non-fuzzy number.

- *Step 5*: Integrate the opinions of decision makers and apply geometric average to combine the fuzzy weights of decision makers.

4. Case illustration

The FAHPEA approach has been applied for evaluating the RL performance of three electronic companies in India. Firstly, an AHP model is developed for applying FAHPEA in Section 4.1. Weights and global weights of performance measures are estimated in Section 4.2. Relative weights of performance measures of three electronic companies are estimated in Section 4.3. Results are analyzed and discussed in Section 4.4.

4.1 Development of AHP model for application of FAHPEA

The decision problem is structured into its important components as shown in Figure 2. The relevant criteria and sub-criteria are structured in the form of a control hierarchy where the criteria at the top level in the model have the highest value. The top-level criteria in the model are economic performance (ECP), environmental performance (ENP) and social performance (SCP). In the second level of hierarchy, sub-criteria for each of top-level criteria are selected from all three perspectives of TBL top-level criteria, as shown in Figure 2. Return on investment (EC-1), recapturing value (EC-2), logistics cost optimization (EC-3), recycle efficiency (EC-4), annual sales (EC-5) and disposal costs (EC-6) are selected from economic performance perspectives. Minimum energy consumption (EN-1), optimum use of raw material (EN-2), transport optimization (EN-3),

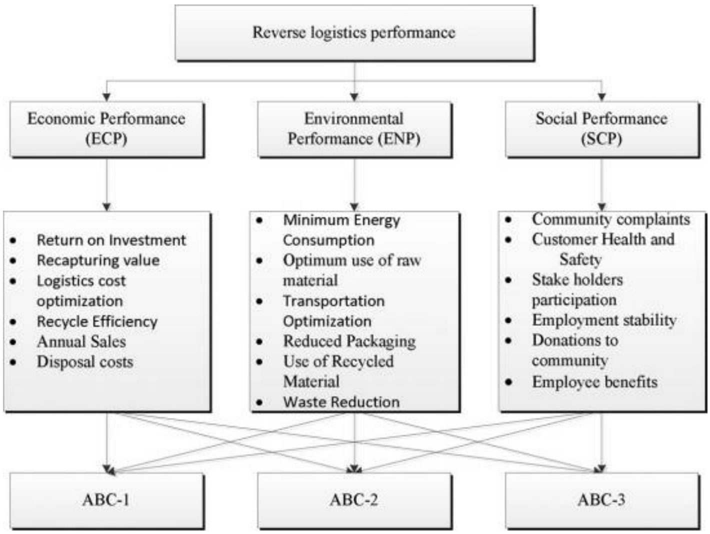

Figure 2.
AHP framework for the TBL performance evaluation of RL

reduced packaging (EN-4), use of recycled material (EN-5) and waste reduction (EN-6) are selected from the environmental performance perspective. Community complaints (SC-1), customer health and safety (SC-2), stakeholders participation (SC-3), employment stability (SC-4), donations to community (SC-5) and employee benefits (SC-6) are selected from the social performance perspectives. Three companies ABC-1, ABC-2 and ABC-3 are shown at the bottom level of the structure and are discussed later in the paper.

4.2 Estimation of weights and global weights for performance measures

The study comprised open and semi-structured interviews with the senior executives and key functional managers of the electronic industry. The discussions were focused on selection of sub-criteria for performance evaluation and pair-wise comparison of selected criteria/sub-criteria. Nine decision makers were asked to make pair-wise comparison for each criteria/sub-criteria by selecting one of nine linguistic variables (which are represented by positive triangular fuzzy numbers) listed in Table II.

4.2.1 Pair-wise comparison at top level. Paired-wise comparison of top-level criteria ECP, ENP and SCP, made by one of the decision makers, were transformed into triangular fuzzy numbers and are shown in Table III.

The value of fuzzy synthetic extent with respect to the each criterion is calculated as follows [by using "equation (2)" and Table III]:

$$S_{ECP} = (4.000, 6.000, 8.000) \otimes \left[\frac{1}{15.500}, \frac{1}{11.333}, \frac{1}{7.917}\right] = (0.258, 0.529, 1.011)$$

$$S_{ENP} = (2.333, 3.500, 5.000) \otimes \left[\frac{1}{15.500}, \frac{1}{11.333}, \frac{1}{7.917}\right] = (0.151, 0.309, 0.632)$$

$$S_{SCP} = (1.583, 1.833, 2.500) \otimes \left[\frac{1}{15.500}, \frac{1}{11.333}, \frac{1}{7.917}\right] = (0.102, 0.162, 0.116)$$

Table II. Triangular fuzzy numbers

Linguistic variables	Positive triangular fuzzy no.	Positive reciprocal triangular fuzzy no.
Extremely strong	(9, 9, 9)	(1/9, 1/9, 1/9)
Intermediate	(7, 8, 9)	(1/9, 1/8, 1/7)
Very strong	(6, 7, 8)	(1/8, 1/7, 1/6)
Intermediate	(5, 6, 7)	(1/7, 1/6, 1/5)
Strong	(4, 5, 6)	(1/6, 1/5, 1/4)
Intermediate	(3, 4, 5)	(1/5, 1/4, 1/3)
Moderately strong	(2, 3, 4)	(1/4, 1/3, 1/2)
Intermediate	(1, 2, 3)	(1/3, 1/2, 1)
Equally strong	(1, 1, 1)	(1, 1, 1)

Table III. Triangular fuzzy comparison matrix for top-level criteria

Criteria	ECP	ENP	SCP
ECP	(1, 1, 1)	(4, 5 ,6)	(1/3, 1/2, 1)
ENP	(1/6, 1/5, 1/4)	(1, 1, 1)	(1, 2, 3)
SCP	(1, 2, 3)	(1/3, 1/2, 1)	(1, 1, 1)

The degree of possibility of S_i over S_k ($i \neq k$) can be determined by "equations (6)-(8)":

$$V(S_{ECP} \geq S_{ENP}) = 1$$

$$V(S_{ECP} \geq S_{SCP}) = 1$$

$$V(S_{ENP} \geq S_{ECP}) = \frac{(0.258 - 0.632)}{(0.309 - 0.632) - (0.529 - 0.258)} = 0.629$$

$$V(S_{ENP} \geq S_{SCP}) = 1$$

$$V(S_{SCP} \geq S_{ECP}) = \frac{(0.258 - 0.316)}{(0.162 - 0.316) - (0.529 - 0.258)} = 0.136$$

$$V(S_{SCP} \geq S_{ENP}) = \frac{(0.151 - 0.316)}{(0.162 - 0.316) - (0.309 - 0.151)} = 0.529$$

Now, by using "equation (9)":

$$d'(S_{ECP}) = V(S_{ECP} \geq S_{ENP}, S_{SCP}) = \min(1.000, 1.000) = 1.000$$

$$d'(S_{ENP}) = V(S_{ENP} \geq S_{ECP}, S_{SCP}) = \min(1.000, 0.629) = 0.629$$

$$d'(S_{SCP}) = V(S_{SCP} \geq S_{ECP}, S_{ENP}) = \min(0.136, 0.529) = 0.136$$

Hence, the weight vector is written as "equation (10)",

$$W' = (1.000, 0.629, 0.136)^T$$

Via normalization, we get:

$$W = (0.567, 0.356, 0.077)^T$$

Where W is a non-fuzzy number.

Similarly, weights for these three criteria were obtained for rest of the decision maker's responses and combined weights were calculated by taking geometric average of these weights.

Combined weight of decision makers:

$$W = (0.513, 0.335, 0.130)^T$$

4.2.2 Comparison at second level. Responses of one of the decision makers for comparison of economic performance with respect to sub-criteria are shown in Table IV. Similar steps, discussed for top level, were followed for this decision maker, and weight for all sub-criteria were found to be as follows:

$$W = (0.308, 0.334, 0.153, 0.044, 0.057, 0.104)^T$$

and combined weight of all nine decision makers were found as follows:

$$W = (0.336, 0.345, 0.175, 0.007, 0.029, 0.079)^T$$

All the weights for criteria and sub-criteria are summarized in Table V. Global weight for each of the performance measures are also calculated by multiplying top-level criteria weight with respective sub-criteria weight and are shown in Table V.

4.3 Comparison of the performances of three electronic companies

Three companies from Indian electronics industry were chosen for the study to achieve a fairly generalized set of results. The companies were selected on the basis of their interest in sustainable business operations as well as performance measurement-related practices.

First company, ABC-1, is a pioneer in the manufacturing of mobile phones. The company has annual turnover of approximately US$2000 million from its business in India. In India, the company has a mobile handset manufacturing facility in Chennai. At

Table IV. Triangular fuzzy comparison matrix at second level with respect to economic performance

Sub-criteria	EC-1	EC-2	EC-3	EC-4	EC-5	EC-6
EC-1	(1, 1, 1)	(1/3, 1/2, 1)	(3, 4, 5)	(3, 4, 5)	(2, 3, 4)	(2, 3 ,4)
EC-2	(1, 2, 3)	(1, 1, 1)	(2, 3, 4)	(5, 6, 7)	(2, 3, 4)	(1, 2, 3)
EC-3	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)	(1, 1, 1)	(3, 4, 5)	(1/3, 1/2, 1)	(2, 3, 4)
EC-4	(1/5, 1/4, 1/3)	(1/7, 1/6, 1/5)	(1/5, 1/4, 1/3)	(1, 1, 1)	(3, 4, 5)	(1/3, 1/2, 1)
EC-5	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(3, 4, 5)	(1/5, 1/4, 1/3)	(1, 1, 1)	(1/4, 1/3, 1/2)
EC-6	(1/4, 1/3, 1/2)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1, 2, 3)	(2, 3, 4)	(1, 1, 1)

Table V. Weights of performance measures for electronic industry

Criteria	Sub-criteria	Weights Individual	Weights Global
ECP		0.513	
	Return on investment	0.336	0.172
	Recapturing value	0.345	0.177
	Logistics cost optimization	0.175	0.090
	Recycle efficiency	0.007	0.004
	Annual sales	0.029	0.015
	Disposal costs	0.079	0.041
ENP		0.335	
	Minimum energy consumption	0.267	0.071
	Optimum use of raw material	0.322	0.086
	Transport optimization	0.221	0.059
	Reduced packaging	0.010	0.003
	Use of recycled material	0.029	0.008
	Waste reduction	0.082	0.022
SCP		0.130	
	Community complaints	0.258	0.034
	Customer health and safety	0.283	0.037
	Stake holders participation	0.162	0.021
	Employment stability	0.110	0.014
	Donations to community	0.131	0.017
	Employee benefits	0.054	0.007

present, the company has approximately 110,000 outlets including 50,000 stores selling company's product exclusively having more than 5,000 employees. In the year 2010, the company introduced take back program in Indian to take back used mobile phones for remanufacturing/recycling. The company used its well-established supply chain for take back mobile phones. In the beginning, the company was using a third-party logistics service provider for the transportation of products from one city to another and local distributer's staff for managing dealer-level distribution. In the past few years, the company has developed its own distribution system at all levels from factory warehouse to the dealers and retailers.

Second company, ABC-2, limited manufactures, assembles and distributes a comprehensive range of electronic hardware including computer peripherals in India. The company has annual turnover of approximately US$1500 million. The company has manufacturing facilities in Chennai, Pondicherry and Uttaranchal, having approximately 2,300 employees across the India. It has a strong chain of distributors and dealers with 92,500 outlets in 8,700 towns in India. The company utilizes its current supply chain of distributors, dealers and retailers for the purpose of collection of returned products. The company has implemented an RL program to reduce cost and improve customer satisfaction. Recently, the company has established a recycling unit in Chennai and has integrated remanufacturing with its current manufacturing facility.

Third company, ABC-3, has annual turnover of approximately US$30 million. The company has a manufacturing facility in NCR Delhi, having more than 350 employees. The company manufactures, assembles and distributes color television sets in India. The repairing work is carried out at the retailer level and at their service centers. The company has its own recycling facility for rejected color television sets.

All three companies were compared for each of the sub-criteria of each top-level criteria. For example, "return on investment" sub-criteria of top-level criteria "economic performance" was compared by the researchers for three companies. Responses in terms of linguistic variables were converted into triangular fuzzy number by using Table II and are shown in Table VI. Further steps of FAHPEA approach were followed for all the sub-criteria and relative weights for each sub-criteria were obtained. Relative weights for all sub-criteria for three companies are shown in Table VII.

4.4 Results and discussion

The weights for each of the criteria and sub-criteria (performance measures) were obtained for the electronics industry. Global weights were calculated by multiplying each of the sub-criteria weight with respective top-level criteria weight, and all are summarized in Table V. Performance index for each of the sub-criteria for all three companies is calculated by multiplying global weight of sub-criteria with corresponding relative weight, as shown in Table VII. Performance index for each of the sub-criteria for all three companies are shown in Table VIII.

Firms	ABC-1	ABC-2	ABC-3
ABC-1	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)
ABC-2	(1/4, 1/3, 1/2)	(1, 1, 1)	(1, 2, 3)
ABC-3	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1, 1, 1)

Table VI. Comparison of three companies for sub-criteria "return on investment"

	Weight		
Sub-criteria	ABC-1	ABC-2	ABC-3
Return on investment	0.333	0.333	0.333
Recapturing value	0.366	0.356	0.279
Logistics cost optimization	0.380	0.306	0.314
Recycle efficiency	0.333	0.333	0.333
Annual sales	0.550	0.048	0.402
Disposal costs	0.449	0.351	0.200
Minimum energy consumption	0.438	0.275	0.287
Optimum use of raw material	0.298	0.317	0.385
Transport optimization	0.333	0.333	0.333
Reduced packaging	0.384	0.310	0.305
Use of recycled material	0.111	0.069	0.819
Waste reduction	0.567	0.356	0.077
Community complaints	0.550	0.048	0.402
Customer health and safety	0.427	0.088	0.485
Stake holders participation	0.550	0.048	0.402
Employment stability	0.449	0.200	0.351
Donations to community	0.333	0.333	0.333
Employee benefits	0.038	0.206	0.756

Table VII. Relative weights of performance measures for all sub-criteria

	Performance Index		
Sub-criteria	ABC-1	ABC-2	ABC-3
Return on investment	0.0574	0.0574	0.0574
Recapturing value	0.0647	0.0629	0.0493
Logistics cost optimization	0.0341	0.0274	0.0282
Recycle efficiency	0.0012	0.0012	0.0012
Annual sales	0.0082	0.0007	0.0060
Disposal costs	0.0182	0.0142	0.0081
Economic performance index	*0.1838*	*0.1639*	*0.1502*
Minimum energy consumption	0.0312	0.0196	0.0204
Optimum use of raw material	0.0256	0.0273	0.0331
Transport optimization	0.0197	0.0197	0.0197
Reduced packaging	0.0010	0.0008	0.0008
Use of recycled material	0.0009	0.0005	0.0063
Waste reduction	0.0124	0.0078	0.0017
Environmental performance index	*0.0908*	*0.0757*	*0.0820*
Community complaints	0.0184	0.0016	0.0135
Customer health and safety	0.0157	0.0032	0.0179
Stake holders participation	0.0116	0.0010	0.0085
Employment stability	0.0064	0.0029	0.0050
Donations to community	0.0057	0.0057	0.0057
Employee benefits	0.0003	0.0014	0.0053
Social performance index	*0.0581*	*0.0159*	*0.0558*
Reverse logistics performance index	*0.333*	*0.255*	*0.288*

Table VIII. Performance indexes of three companies

Performance indexes for economic performance, environmental performance and social performance are determined by summing up performance indexes of respective sub-criteria. RL performance index is determined by summing the performance index for all 18 measures for each of three companies. ABC-1 has the best performance index (0.333), followed by ABC-3 (0.288), and ABC-3 has the lowest performance index (0.255). Economic performance indexes for all three companies are higher in comparison to the environmental and social performance indexes. Environmental performance indexes are higher than social performance indexes. Industry weights, shown in Table V, also indicate similar trends. It reveals that economic performance has been considered to be the most important, whereas the social performance has been rated the least. Social performance indexes of ABC-1 and ABC-3 are better than that of ABC-2. In a study of Indian companies, Mittal *et al.* (2008) observed that companies in India are still in process of discussion on community initiatives like corporate governance, transparency and disclosure issues rather than practicing them internally. Companies need to be attentive to improve their social performance to improve their TBL performance. For the company ABC-1, recapturing value (0.0647) has the highest performance index, and return on investment (0.0574) is the second best performance measure for the company. Similar trends are followed by ABC-2. Both of these performance measures are also best two performance measures for the company ABC-3. It is also evident from previous research. Ravi *et al.* (2005a) stated that recapturing value from used products is essential for RL. The recovery of the products for remanufacturing, repair, reconfiguration and recycling can lead to profitable business opportunities (Andel, 1997). Recapturing value can make significant contributions to return on investment. In fact, most of the other economic performance measures for three companies have higher performance indexes in comparison to the environmental and social performance measures. This shows that companies are most focused toward operational performance and profitability. Among environmental performance, minimum energy consumption, optimum use of raw material and transport optimization are the top three important performance measures for all three companies. Although these measures can make significant contributions to the environmental sustainability, these factors also contribute to the economic performance. In social performance perspective, community complaints (0.0184) is the most important performance measure for the company ABC-1, and customer health and safety (0.0157) is the second most important performance measure for the company. Similar trends are observed for ABC-3, but these performance indexes are comparatively low for ABC-2. Employee benefits show very poor performance for ABC-1 and ABC-2 in comparison to ABC-3. Chardine-Baumann and Botta-Genoulaz (2014) also found that customer issues and health and safety significantly impact the social performance of supply chain practices of a company. Generally, social sustainability has not been given adequate attention by the companies. Performance index also suggests that most of the sub-criteria with higher weights belong to economic and environmental performance, and lower weights for social performance measures. This is also evident from the weights shown in Table V for the electronic industry in India. In summary, above results indicate that all the three companies and electronic industry in India are more focused toward economic and environmental performance in comparison to the social performance. Companies need to focus on improving their social performance.

5. Conclusion

The study proposed a methodological framework based on TBL approach and FAHPEA approach for evaluating the RL performance. As the data involved in the assessment of the RL process were vague and imprecise, a fuzzy logic system which used linguistic variables was adopted for the study. The measures used in performance evaluation were selected based on the discussion with the experts and literature review. The proposed framework has been used for evaluating and comparing the RL performance of three electronic companies involved in practicing sustainable efforts. The results indicated that companies have the highest performance index for economic performance, followed by environmental performance and social performance. In economic performance, recapturing value and return on investment have higher performance indexes for all three companies. Minimum energy consumption, optimum use of raw material and transport optimization are the performance measures which have higher indexes from environmental performance perspectives. In social performance, community complaints and customer health and safety have higher performance indexes. Over all, reduced packaging, use of recycled material and employee benefits show very poor performance indexes. Improvements on these performances may help the companies for improving their RL performance. The proposed framework contributes to the limited number of present studies on performance measurement system for RL system, especially from TBL perspectives, which may help in overcoming the limitations of present models. Briefly, the contributions of this study are summarized as follows:

- The study provides the insight of RL from TBL perspective by integrating TBL components into the RL.
- The study identifies the criteria and sub-criteria for the RL performance evaluation system based on the TBL concept.
- The research work proposes a framework to obtain the weights of sub-criteria and criteria and to evaluate the performance of RL on the basis of these factors.
- The study compares the performances of three electronics companies for the purpose of illustration of the proposed framework.

In future, more models can be developed for RL performance measurement based on TBL approach by using other MCDM techniques and may be compared with proposed model. One of the limitations of application of FAHPEA example is that a large sample size could be used for estimating weights and global weights of performance measures. Findings of this study will help organizations in optimizing their RL system as well as in benchmarking of their performance with respect to best in industry. It will also motivate organizations to work on holistic manner rather than only on economical terms.

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