Green decision-making model in reverse logistics using FUZZY-VIKOR method

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A B S T R A C T

Due to the increasing global environmental consciousness and sustainability concerns, different industries that deal with Reverse Logistics (RL) are seeking methods to measure and analyze the impacts of their RL activities on the environment. However, making the greenest decision in the vague and complex area of RL makes this process somewhat difficult. Hence, to address these issues and provide a more meticulous and closer approach to the real-world situations, a FUZZY-VIKOR method using interval-valued trapezoidal fuzzy numbers is proposed in this research. As the further discussions explain, first, the significant factors in environmental sound practices together with the main processes and recovery options in RL are identified. Second, the influences of each green environmental factor on each RL recovery option are analyzed and ranked. To obtain concise results, the elicitation of experts is sought from various academics and industry. The final results illustrate that, intriguingly, disposing of the returns has the lowest negative impact on the environment; thereby the best recovery option, while reselling of the returns was perceived as the worst recovery option. This research also suggests new directions for future research. From the managerial point of view, it would be interesting to study a sustainable reverse logistics through the proposed model. We only considered the impacts of environmental factors on RL, while the final decision will be more exact if the economic and societal aspects of RL are also analyzed. In addition, to reflect the technical views of all the stakeholders in RL towards the best recovery option and also take into account their concerns, we suggest designing a group decision making model across the RL using the Fuzzy-MADM methods.

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1. Introduction

In recent years, the increasing awareness of environmental dilemmas in reverse logistics (RL) has attracted the attention of manufacturers and encouraged them to redesign their RL processes and networks according to green concepts. A number of efforts are being made to minimize the destructive effects of RL on the environment. In this respect, the environmental considerations, legal regulations, and the related economic advantages have also prompted several companies, such as General Motors, Kodak and Xerox, to consider RL and associated recovery processes (Meade et al., 2007; Öster et al., 2007). Since the main discussions about RL and its environmental matters were initiated by the works carried out by Rogers and Tibben-Lembek over the last decade, companies with RL processes have embarked on taking “green” and sustainability into account. In order to reduce the impacts of pollution on the environment, reverse logistics have been analyzed (Byrne and Deeb, 1993; Carte and Ellram, 1998; Wu and Dunn, 1995).

In this context, the Malaysian government has launched several progressive policies to support its national agenda on reverse logistics activities. For example, the Tenth Malaysia Plan (2011–2015) put forward by the government is based on the fundamental issue of sustainable production activities that could balance economic growth and environmental degradation. Moreover, many companies announced in their websites that they have reverse logistics programs. HP declared that it has two basic programs for reverse logistics; HP trade-in and HP buy-back. The HP Trade-In program offers HP customers cash payments for their old equipment when new HP products are purchased.

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In HP buy-back, HP collects, tests and evaluates the equipment. If the equipment has market value it will be refurbished, resold to the secondhand market. If the equipment has no value, it will be disposed of in accordance to HP’s strict global recycling standards (HP, 2007). Nokia designed a program for product take-back that aims at collecting products at the end of its service life with a view to recovering its material and energy content as well as ensuring safe treatment of substances that may cause harm to people or the environment (Nokia, 2002). Dell apply industry leading recycling program that enable customers to recycle or donate their PCs for free (Dell, 2007).

With respect to environmental matters, the role of reverse logistics and the associated influences on developing the concept of sustainability and environmental protection have been explained (Brito et al., 2003; Fernández, 2004; Krikke et al., 1998). Rogers and Tibben-Lembek (1998) discussed the negative impacts of recovery options on the environment, such as disposing, landfilling, and incineration of returns. In order to improve the recovery process within RL, an environmental study considering the life cycle analysis in the battery sector was carried out (Tsoulfas et al., 2002). The increase in CO2 emissions and greenhouse gases (GHG) due to unnecessary processes in RL, such as extra transportation, would be minimized if the green and RL processes could be integrated in a holistic and unique approach.

In addition, legislative policies with respect to environmental regulations and sustainability have enforced manufacturers to accept the responsibility of taking back their returns. Nonetheless, many companies are not capable of applying the current techniques and models to satisfy these requirements. One of the main obstacles in this regard is to measure the environmental contribution of certain activities in RL; especially, when the impacts of a group of environmental factors should be ranged and interpreted for a group of RL recovery options. Therefore, the need for a comprehensive technique that is able to cope with all these issues appears necessary.

In order to solve the ambiguous part of this problem, which is interpreting the impacts of environmental elements on RL recovery options, first, the linguistic terms and weights are defined in a reasonable range. This possibility facilitates the process of impact analysis for the experts during the interview sessions. Second, the equalization of qualitative terms into quantitative values by using interval-valued trapezoidal fuzzy numbers is performed. Ultimately, the FUZZY-VIKOR is applied to acquire the final ranking. The rest of this article is organized as follows: The following section briefly reviews the background literature. The third section describes the research methodology for testing the method of VIKOR, and the fifth section discusses the results of the data analyses. The article concludes with a delineation of the significance of the findings, managerial implications, and future research directions.

2. Literature review

2.1. Reverse logistics (RL) vs. green logistics (GL)

Rogers and Tibben-Lembek (1998) defined RL 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". According to the definition of Dowlatshahi (2000), RL is "a process in which a manufacturer systematically accepts previously shipped products or parts from the point for consumption for possible recycling, remanufacturing or disposal". He considered the strategic and operational factors for implementing efficient reverse logistics in the company. Based on his approach, in the process of implementing holistic reverse logistics, the strategic factors, such as cost, quality, customer service, environmental effects, and regulations, are more critical than the operational factors like cost benefit analysis, transportation, warehousing, supply management, remanufacturing, recycling, and packaging.

On the other hand, Fleischmann et al. (2001) described RL as: “a process of planning, implementing and controlling the efficient, effective inbound flow and storage of secondary goods and related information opposite to the traditional supply chain directions for the purpose of recovering value and proper disposal”. Reverse logistics requires supply chain members to coordinate and integrate environmental management with the traditional logistics functions of transportation, packaging, labeling and warehousing. Pohlen and Theodore Farris (1992) find that the requirements for reverse logistics vary noticeably across firms and have important environmental and economic implications. The environmental aspects focus on resource reduction, materials substitutions and waste reduction, whereby companies become more environmentally efficient and help finding solutions for environmental problems. The economic aspects emphasize recapturing value from the returned products, such as retrieving integrated circuit boards from electronic products, or recovering valuable materials from the product through the recycling process.

While, "Green Logistics (GL) is a form of logistics which is calculated to be environmentally and often socially friendly in addition to economically functional (Smith, 2012)". The MGC Institute of Logistics in Vietnam (2010) described green logistics as “The management of the logistics and supply chain process including the incorporation of environmentally sustainable strategies that assist in minimizing the effects of pollution, particulate emissions and the management of processes to overcome climate change”. Carter and Rogers (2008) stated that “Green logistics consists of all activities related to the eco-efficient management of the forward and reverse flows of products and information between the point of origin and the point of consumption whose purpose is to meet or exceed customer demand”. Rogers and Tibben-Lembek (1998) considered that "Green logistics, or ecological logistics, refers to understanding and minimizing the ecological impact of logistics. Green logistics activities include measuring the environmental impact of particular modes of transport, ISO 14000 certification, reducing energy usage of logistics activities, and reducing usage of materials”.

Both definitions as above, however, have led some authors to suggest that reverse logistics is imperative to the green logistics (Autry et al., 2001; Knemeyer et al., 2002), green marketing (Wu and Dunn, 1995; Carter and Rogers, 2008) and sustainability (Markley and Davis, 2007; Carter and Easton, 2011). By transforming the returns into products with value in the market, reverse logistics allow the supply chain to be in circulation so that the waste can be minimized through the process (Andic et al., 2012). Hence, the best approach by companies to achieve the environmental protection is by introducing the reverse flow of supply chain that can maximize the value of the product returns (Kumar and Malegeant, 2006). The reverse logistics therefore, have been widely recognized in the literature as the major component that creates value for managing the product recovery, product returns or excessive stock in the market (Jayant et al., 2012). Reverse logistics also has become a main part of green logistics due to its contribution in reducing the waste generated through several recovery activities such as reuse, remanufacturing and recycling (Hervani et al., 2005).

Nevertheless, besides the benefits that firms may enjoy by implementing effective reverse logistics, many business organizations still ignored and not proactive in carrying out the reverse logistics activities (González-Torre et al., 2010). This is because many of them believe
that the impediments are much greater than the benefits they will obtain in adopting the reverse logistics activities (Tibben-Lembke, 2002) and prefer to rely on the traditional way of doing business by concentrating on the forward logistics to achieve the competitive advantage (Fine et al., 2002). In this circumstance, the focus of building the green value chain by business organization lies in the scope of forward rather than reverse logistics. Nevertheless, such conventional approach appeared to be incomplete due to the imbalance focus in creating value of returns products.

2.2. Reverse logistics and recapitulating the value of returns

Most of the manufacturer’s targets are just to deliver their products to their customers, while by ignoring the efficient return and refurbishment or disposal of the product, many companies miss out on a significant return on investment. Logisticians who treat reverse logistics as a way to maximize the value of returned assets make a significant contribution to their company’s bottom line (Andel, 1997; Clendenin, 1997; South, 1998). By improving customer satisfaction, leveraging resource investment, and reducing warehouse and transportation costs the effective reverse logistics will be achieved to direct benefits (Guinetti and Andel, 1994; Andel, 1997). Reverse logistics also affects on customer satisfaction by accelerating the process of returns handling when any critical repair or remanufacturing is needed (Blumberg, 2001). Companies with the ability of making the value of the returns may stay longer in the business. If a company implements the reverse logistics system, it will gain money (Stock, 1998). Recapitulating the value of the returns through refurbishment, remanufacturing, repair, and recycling can bring various profits for the company in the competitive markets (Giuntini and Andel, 1995).

2.3. Multi criteria decision-making models and reverse logistics

“MCDM can be defined as the study of methods and procedures by which concerns about multiple conflicting criteria can be formally incorporated into the management planning process” (International Society on Multiple Criteria Decision Making). MCDM also refers as Multi-Criteria Decision Analysis (MCDA) or Multiple Criteria Analysis (MCA); Multi-Dimensions Decision Making (MDDM), and Multi Attributes Decision Making (MADM). The aim of MCDM is to give solutions and proposes the best or a set of good alternative(s) for solving the problems with multiple criteria. The results will be affected by decision makers’ priorities during giving ranks to the criteria and subcriteria. These methods can be applied in both quantitative and qualitative criteria by sharing the common characteristics of oppose among criteria, incommensurable units, and hard in design/selection of alternatives (Pohekar and Ramachandran, 2004).

According to the reviewed literature, MCDM methods have been widely employed in various domains of reverse logistics, including evaluating and selection the Third-Party Reverse Logistics Providers (3PRLPs), modeling product recovery, waste management, assessment of different alternatives for End-of-Life (EOL). Table 1 shows some application of the MCDM methods in the RL literature.

Unlike the majority of the researches on supplier evaluation and selection in RL in which the FAHP model has been opted, in a recent study which has been done by Amin and Zhang (2012), a method based on linguistic variables and triangular fuzzy numbers (TFNs) has been proposed for the supplier evaluations. According to the authors, the new model would take lesser time than FAHP method and it is more appropriate when there are a large number of assessment criteria.

2.4. Fuzzy sets and theory

Fuzzy logic has been proposed (Zadeh, 1965, 1996, 1997) as an analytical approach to integrate uncertainty into decision-making models. Incomplete information also has this possibility to take into account in all necessary calculation in Fuzzy logic despite the behind reasons. In fact, fuzzy logic provides a suitable and applicable basis for considering the vague reasoning instead of the exact one. By employing fuzzy tools many advantages deliver to the users. Fuzzy tools provide a new methodology which is more simple and it can reduce the analysis and development time of the model. Consequently, the implementation and adoption of fuzzy tools are uncomplicated. Fuzzy tools have presented a higher level of performance than other soft methods in decision making problems under uncertainty. Nonetheless, they have a user-friendly platform (Azadegan et al., 2011).

A rapid growth has been seen in using fuzzy logic to different fields of manufacturing during the past two decades. Fuzzy logic considers the variables according to their degree of membership, rather than absolute membership at its most basic form. A level of tolerance for vagueness consider by fuzzy logic, instead of exactness and precision. All imperfect information, which could be the result of imprecise measurements or obtained through inaccurately codifying expert elicitation, is able to take into consideration in a fuzzy modeling. Indeed, the attempts of fuzzy logic are to imitate the human brain to apply the methods of reasoning effectively which are imprecise instead of rigorous. Fuzzy logic provides the recognition of indefinite dependencies among models, by considering the involvement of inexactitude in membership. Crisp logic is a totally different approach, which reasoning and assessments are binary and based on propositional logic. Variables take a range between 0 and 1 in fuzzy logic and they are not essentially limited to that binary restriction. In this regard, a variable has a degree of membership in a fuzzy set (Azadegan et al., 2011).

A fuzzy set has been defined as a class of objects which have a continuum of membership grades and is typically shown by putting a tilde ‘~’ above the specified symbol in this matter (Kahraman et al., 2004). Chen (1985) and Chen and Hsieh (1999) specified generalized trapezoidal fuzzy numbers and their related operations. In Fig. 1 General trapezoidal fuzzy numbers (Chen and Chen, 2003b) are presented \( A = (a_1, a_2, a_3, a_4; w_A) \) and \( B = (b_1, b_2, b_3, b_4; w_B) \) representing two different decision-makers ideas, which \( 0 < w_A \leq 1 \) and \( 0 < w_B \leq 1 \); \( w_A \) and \( w_B \) indicate the level of assurance regarding the decision-maker’s ideas \( \tilde{A} \) and \( \tilde{B} \), respectively (Chen and Chen, 2003a,b, 2007).

2.5. Vlsekriterijumska optimizacija I kompromisno rešenje (VIKOR) method

“The VIKOR method was proposed to solve MCDM problems with conflicting and noncommensurable (different units) criteria, assuming that compromising is acceptable for conflict resolution, the decision maker wants a solution that is the closest to the ideal, and the alternatives are evaluated according to all established criteria” (Opricovic et al., 2007). Opricovic (1998) developed the initial VIKOR method. The VIKOR method is the optimization and compromise solution in MCDM, which is appropriate for estimating each alternative
Table 1

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Objective</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Zhang and Feng</td>
<td>Selection process of reverse logistics provider</td>
<td>FAHP</td>
</tr>
<tr>
<td></td>
<td>Stakos and Rahimifard</td>
<td>Product recovery of shoes</td>
<td>AHP</td>
</tr>
<tr>
<td>2008</td>
<td>Pati et al.</td>
<td>Manage the paper recycling in logistics systems</td>
<td>Mixed integer goal programming (MIGP)</td>
</tr>
<tr>
<td></td>
<td>Efendigil et al.</td>
<td>Select the best 3PRLPs</td>
<td>FAHP and ANN</td>
</tr>
<tr>
<td></td>
<td>Fernandez and Kekale</td>
<td>A conceptual decision-making model under multiple conflicting criteria: the case of reverse logistics</td>
<td>AHP and Delphi</td>
</tr>
<tr>
<td>2009</td>
<td>Kanan</td>
<td>Selection of 3PRLPs</td>
<td>AHP and FAHP</td>
</tr>
<tr>
<td></td>
<td>Kanan et al.</td>
<td>The selection of 3PRLPs</td>
<td>Interpretive structural modeling (ISM) and fuzzy TOPSIS</td>
</tr>
<tr>
<td></td>
<td>Wadhwa et al.</td>
<td>Designing effective and efficient flexible return policy</td>
<td>FAHP</td>
</tr>
<tr>
<td>2010</td>
<td>Hernandez et al.</td>
<td>Analyzed the effect of reverse logistics practice on automobile corporate performance</td>
<td>AHP and ANP</td>
</tr>
<tr>
<td></td>
<td>Geethan et al.</td>
<td>Selection of collect center location in the reverse logistics network</td>
<td>AHP and TOPSIS</td>
</tr>
<tr>
<td>2011</td>
<td>Govindan and Murugesan</td>
<td>Select the 3PRLPs</td>
<td>Fuzzy extent analysis</td>
</tr>
<tr>
<td></td>
<td>Sasikumar and Haq</td>
<td>Selection of the best 3PRLP</td>
<td>FMCDM and VIKOR</td>
</tr>
<tr>
<td></td>
<td>Azadi and Saen</td>
<td>Selecting 3PRLPs</td>
<td>New chance-constrained data envelopment analysis (CCDEA)</td>
</tr>
<tr>
<td></td>
<td>Jang et al.</td>
<td>Selecting remanufacturing technology</td>
<td>AHP</td>
</tr>
<tr>
<td></td>
<td>Barker and Zabinsky</td>
<td>Designing the reverse logistics network</td>
<td>AHP</td>
</tr>
<tr>
<td>2012</td>
<td>Dwihar and Sudhalhar</td>
<td>Selecting and evaluating of RL providers</td>
<td>FUZZY AHP-TOPSIS</td>
</tr>
<tr>
<td></td>
<td>Govindan et al.</td>
<td>Selection of 3PRLP</td>
<td>ISM</td>
</tr>
<tr>
<td></td>
<td>Senthil et al.</td>
<td>Selection and evaluation of RL channels</td>
<td>DEMATEL-ANP (DanP)</td>
</tr>
<tr>
<td></td>
<td>Hsu et al.</td>
<td>Select the vendors for the recycled material</td>
<td>Linguistic variables and triangular fuzzy numbers (TFNs)</td>
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<td></td>
<td>Amin and Zhang</td>
<td>Supplier evaluations in RL</td>
<td>FAHP</td>
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<td></td>
<td>Chiu et al.</td>
<td>Analyze the important criteria and sub-criteria in RL implementation</td>
<td>AHP</td>
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<td></td>
<td>Akdoğan and Coşkun</td>
<td>Surveyed the drivers involved in RL activities in the house appliance industry in Turkey and ranked them</td>
<td>FUZZY AHP-TOPSIS</td>
</tr>
<tr>
<td>2013</td>
<td>Govindan et al., 2013</td>
<td>Select a third-party reverse logistics provider</td>
<td>FUZZY AHP-TOPSIS</td>
</tr>
<tr>
<td></td>
<td>Jandal and Sangwan</td>
<td>Evaluation of sustainable reverse logistics network models</td>
<td>AHP</td>
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<td></td>
<td>Shalik and Abdul-Kader, 2013a</td>
<td>A comprehensive performance measurement methodology for transportation in reverse logistics</td>
<td>AHP</td>
</tr>
<tr>
<td></td>
<td>Shaik and Abdul-Kader, 2013b</td>
<td>Comprehensive performance measurement and causal-effect decision making model for reverse logistics enterprise</td>
<td>DEMATEL</td>
</tr>
<tr>
<td>2014</td>
<td>Shaik and Abdul-Kader, 2014</td>
<td>Contractor evaluation and selection in third-party reverse logistics</td>
<td>AHP-Fuzzy TOPSIS</td>
</tr>
<tr>
<td></td>
<td>Senthil et al.</td>
<td>Sustainable third-party reverse logistics provider selection</td>
<td>FUZZY AHP-TOPSIS</td>
</tr>
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</table>

![Fig. 1. General trapezoidal fuzzy numbers $\tilde{A}$ and $\tilde{B}$.](image)

for each criterion (Opricovic, 1998; Opricovic and Tzeng, 2002, 2004; Opricovic et al., 2007; Huang et al., 2009). This method can be applied in the complex multi-criteria system (Opricovic and Tzeng, 2004). The extended VIKOR method was developed and compared with TOPSIS, PROMETHEE, and ELECTRE (Opricovic et al., 2007). A comparative analysis for identifying the differences and similarities between the VIKOR and TOPSIS methods was performed (Opricovic and Tzeng, 2004). The results showed that these two methods employ various normalizations with different aggregating functions for ranking. In another comparison, the extended VIKOR method was compared with VIKOR, TOPSIS, ELECTRE, and PROMETHEE on the basis of resolving the algorithm (Opricovic et al., 2007).

Chatterjee et al. (2009) compared two methods – VIKOR and ELECTRE – for material selection. Tsai et al. (2011) proposed a combined MADM model by integrating ANP and the VIKOR method, which is applicable for governments to evaluate their policies and the efforts for improving their policies, effectively. Mohaghar et al. (2012) used FAHP and the VIKOR method in selecting marketing strategy. In this study, the VIKOR method was used to rank the strategies with regard to sub criteria. Chang and Hsu (2011) applied the modified VIKOR method and proposed a modified VIKOR index $Q^*$ for identifying the environmental factors and the level of vulnerability that can affect
the land use within the watershed. Fazli and Jafari (2012) developed a hybrid multi-criteria model for the stock market and the VIKOR algorithm was applied to rank and choose the best investment alternatives.

Sasikumar and Haq (2011) used the VIKOR method in a fuzzy multi-criteria decision-making (MCDM) model for the selection of best 3PLP. Sanayei et al. (2010) employed the VIKOR method for the supplier selection under the fuzzy environment. In the field of supplier selection, a fuzzy VIKOR method based on the entropy measure for objective weighting has been discussed (Shemshadi et al., 2011). Valahzaghard et al. (2011) used Fuzzy Delphi, FAHP, and SIR.VIKOR for supplier selection. Combining VIKOR, GRA and interval valued fuzzy sets has been studied to estimate the service quality of Chinese cross-strait passenger airline via customer survey, and to identify the gaps, weaknesses and strengths in the quality of the services (Kuo, 2011).

3. Methodology

The methodological approach in the current research is divided into three main steps. In the first step, the concept of the generalized trapezoidal fuzzy numbers is explained. In the second step, the working steps in the VIKOR method are described. In the final step, in order to obtain the appropriate results and verify the proposed model, expert interviews are performed. In this part, the environmental factors are adopted from the “Sustainable Distribution: A Strategy” (DETR, 1999), as shown in Fig. 2, and the six recovery options are chosen from Rogers and Tibben-Lembek (1998).

3.1. The conception of generalized trapezoidal fuzzy numbers

Definition (Chen, 1985): The definition of a generalized trapezoidal fuzzy number is presented as a vector $\tilde{A} = (a_1, a_2, a_3, a_4; w_A)$, and also the membership function $\alpha(x) : R \rightarrow [0, 1]$ can be illustrated as follows:

$$
\alpha(x) = \begin{cases} 
\frac{x - a_1}{a_2 - a_1} \times w_A, & x \in (a_1, a_2) \\
\frac{w_A}{a_2 - a_1}, & x \in (a_2, a_3) \\
\frac{x - a_4}{a_3 - a_4} \times w_A, & x \in (a_3, a_4) \\
0, & x \in (-\infty, a_1] \cup (a_4, \infty)
\end{cases}
$$

where $a_1 \leq a_2 \leq a_3 \leq a_4$ and $w_A \in [0, 1]$

The generalized trapezoidal fuzzy numbers elements $x \in R$ are real numbers, and its membership function $\alpha(x)$ is defined as the frequent and continuous convex function, which demonstrates the membership degree of the fuzzy sets. If $-1 \leq a_1 \leq a_2 \leq a_3 \leq a_4 \leq 1$, then $\tilde{A}$ is recognized as the normalized trapezoidal fuzzy number. Particularly, if $w_A = 1$, then $\tilde{A}$ can be called trapezoidal fuzzy number $(a_1, a_2, a_3, a_4)$; if $a_1 < a_2 = a_3 < a_4$, then $\tilde{A}$ is decreased to a triangular fuzzy number. If $a_1 = a_2 = a_3 = a_4$, then $\tilde{A}$ is decreased to a real number.
3.1.1. The generalized trapezoidal fuzzy numbers operation rules

Assume that $\tilde{a} = (a_1, a_2, a_3, a_4; w_8)$ and $\tilde{b} = (b_1, b_2, b_3, b_4; w_b)$ are two generalized trapezoidal fuzzy numbers, then the operational rules of the generalized trapezoidal fuzzy numbers $\tilde{a}$ and $\tilde{b}$ are demonstrated as follows (Chen and Chen, 2009):

$$\tilde{a} \oplus \tilde{b} = (a_1, a_2, a_3, a_4; w_a) \oplus (b_1, b_2, b_3, b_4; w_b)$$

$$= (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4; \min(w_a, w_b))$$

$$\tilde{a} \ominus \tilde{b} = (a_1, a_2, a_3, a_4; w_a) \ominus (b_1, b_2, b_3, b_4; w_b)$$

$$= (a_1 - b_1, a_2 - b_2, a_3 - b_3, a_4 + b_4; \min(w_a, w_b))$$

$$\tilde{a} \odot \tilde{b} = (a_1, a_2, a_3, a_4; w_a) \odot (b_1, b_2, b_3, b_4; w_b) = (a, b, c, d; \min(w_a, w_b))$$

(2)

(3)

(4)

where,

$$a = \min(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)$$

$$b = \min(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3)$$

$$c = \max(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3)$$

and,

$$d = \max(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)$$

If $a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4$ are real numbers, then:

$$\frac{\tilde{a}}{\tilde{b}} = \left(\frac{a_1}{b_1}, \frac{a_2}{b_2}, \frac{a_3}{b_3}, \frac{a_4}{b_4}; \min(w_a, w_b)\right)$$

(5)

3.1.2. The center of gravity (COG) point of generalized trapezoidal fuzzy numbers

The concept of COG point of generalized trapezoidal fuzzy numbers was presented by Chen and Chen, 2003a; it assumes that the COG point of the generalized trapezoidal fuzzy number $\tilde{a} = (a_1, a_2, a_3, a_4; w_b)$ is $(x_0, y_0)$, then:

$$\begin{cases}
    y_a = \frac{wa \times \left(\frac{a_1 - a_2}{a_4 - a_1} + 2\right)}{\frac{a_1 - a_2}{a_4 - a_1} + 2} & \text{if} a_1 \neq a_4 \\
    \frac{b}{w_b} & \text{if} a_1 = a_4
\end{cases}
$$

$$x_0 = \frac{w_a \cdot 2(a_1 + a_4) + (a_1 + a_4) \times (w_a - y_a)}{2 \times w_a}$$

(6)

3.1.3. Interval-valued trapezoidal fuzzy numbers (Wei and Chen, 2009)

Wang and Li (2001) proposed the interval-valued trapezoidal fuzzy numbers

$$\tilde{A} = [(a_1^L, a_1^U, a_2^L, a_2^U, a_3^L, a_3^U, a_4^L, a_4^U; w_A^L), (a_1^L, a_2^L, a_2^U, a_3^L, a_3^U, a_4^L, a_4^U; w_A^U)]$$

where $0 \leq a_1^L \leq a_2^L \leq a_3^L \leq a_4^L \leq 1$, $0 \leq a_1^U \leq a_2^U \leq a_3^U \leq a_4^U \leq 1$, $0 \leq w_A^L \leq w_A^U \leq 1$ and $[a_1^L, a_3^L, a_4^L] \subset w_A^L$.

3.1.4. The operation rules of interval-valued trapezoidal fuzzy numbers (Wei and Chen, 2009)

Assume that:

$$\tilde{A} = [(a_1^L, a_1^U, a_2^L, a_2^U, a_3^L, a_3^U, a_4^L, a_4^U; w_A^L), (a_1^L, a_2^L, a_2^U, a_3^L, a_3^U, a_4^L, a_4^U; w_A^U)]$$

and:

$$\tilde{B} = [(b_1^L, b_1^U, b_2^L, b_2^U, b_3^L, b_3^U, b_4^L, b_4^U; w_B^L), (b_1^L, b_1^U, b_2^L, b_2^U, b_3^L, b_3^U, b_4^L, b_4^U; w_B^U)]$$

are the two interval-valued trapezoidal fuzzy numbers, where $0 \leq a_1^L \leq a_1^L \leq a_2^L \leq a_3^L \leq a_4^L \leq 1$, $0 \leq a_1^U \leq a_2^U \leq a_3^U \leq a_4^U \leq 1$, $0 \leq w_A^L \leq w_A^U \leq 1$ and $[a_1^L, a_3^L, a_4^L] \subset w_A^L$, $0 \leq b_1^L \leq b_2^L \leq b_3^L \leq b_4^L \leq 1$, $0 \leq b_1^L \leq b_2^L \leq b_3^L \leq b_4^L \leq 1$, $0 \leq w_B^L \leq w_B^U \leq 1$ and $[b_1^L, b_3^L, b_4^L] \subset w_B^L$.

The operations are presented as follows:

1. The sum of two interval-valued trapezoidal fuzzy numbers $\tilde{A} \oplus \tilde{B}$:

$$\tilde{A} \oplus \tilde{B} = [(a_1^L + b_1^L, a_1^U + b_1^U, a_2^L + b_2^L, a_2^U + b_2^U, a_3^L + b_3^L, a_3^U + b_3^U, a_4^L + b_4^L, a_4^U + b_4^U; w_A^L + w_B^L)]$$

(7)
• The difference of two interval-valued trapezoidal fuzzy numbers $\tilde{A} - \tilde{B}$:

$$\tilde{A} - \tilde{B} = [(a_{1L}, a_{1U}, a_{2L}, a_{2U}; w_A L), (a_{3L}, a_{3U}, a_{4L}, a_{4U}; w_A U)] - [(b_{1L}, b_{1U}, b_{2L}, b_{2U}; w_B L), (b_{3L}, b_{3U}, b_{4L}, b_{4U}; w_B U)]$$

$$= [(a_{1L} - b_{1L}, a_{1U} - b_{1U}, a_{2L} - b_{2L}, a_{2U} - b_{2U}; \min(w_A L, w_B L)), (a_{3L} - b_{3L}, a_{3U} - b_{3U}, a_{4L} - b_{4L}, a_{4U} - b_{4U}; \min(w_A U, w_B U))]$$

$$- [b_{1L}, b_{1U}, b_{2L}, b_{2U}; \min(w_A U, w_B U)]$$

(8)

• The product of two interval-valued trapezoidal fuzzy numbers $\tilde{A} \otimes \tilde{B}$:

$$\tilde{A} \otimes \tilde{B} = [(a_{1L}, a_{1U}, a_{2L}, a_{2U}; w_A L), (a_{3L}, a_{3U}, a_{4L}, a_{4U}; w_A U)] \otimes [(b_{1L}, b_{1U}, b_{2L}, b_{2U}; w_B L), (b_{3L}, b_{3U}, b_{4L}, b_{4U}; w_B U)]$$

$$= [(a_{1L} \times b_{1L}, a_{1U} \times b_{1U}, a_{2L} \times b_{2L}, a_{2U} \times b_{2U}; \min(w_A L, w_B L)), (a_{3L} \times b_{3L}, a_{3U} \times b_{3U}, a_{4L} \times b_{4L}, a_{4U} \times b_{4U}; \min(w_A U, w_B U))]$$

$$\times [b_{1L}, b_{1U}, b_{2L}, b_{2U}; \min(w_A U, w_B U)]$$

(9)

• The quotient of two interval-valued trapezoidal fuzzy numbers $\tilde{A} / \tilde{B}$:

$$\tilde{A} \div \tilde{B} = [(a_{1L}, a_{1U}, a_{2L}, a_{2U}; w_A L), (a_{3L}, a_{3U}, a_{4L}, a_{4U}; w_A U)] / [(b_{1L}, b_{1U}, b_{2L}, b_{2U}; w_B L), (b_{3L}, b_{3U}, b_{4L}, b_{4U}; w_B U)]$$

$$= [(a_{1L} / b_{1L}, a_{1U} / b_{1U}, a_{2L} / b_{2L}, a_{2U} / b_{2U}; \min(w_A L, w_B L)), (a_{3L} / b_{3L}, a_{3U} / b_{3U}, a_{4L} / b_{4L}, a_{4U} / b_{4U}; \min(w_A U, w_B U))]$$

$$\times [b_{1L}, b_{1U}, b_{2L}, b_{2U}; \min(w_A U, w_B U)]$$

(10)

• The product between an interval-valued trapezoidal fuzzy number and a constant $\lambda$:

$$\lambda \tilde{A} = \lambda \times [(a_{1L}, a_{1U}, a_{2L}, a_{2U}; w_A L), (a_{3L}, a_{3U}, a_{4L}, a_{4U}; w_A U)]$$

$$= [(\lambda a_{1L}, \lambda a_{1U}, \lambda a_{2L}, \lambda a_{2U}; w_A L), (\lambda a_{3L}, \lambda a_{3U}, \lambda a_{4L}, \lambda a_{4U}; w_A U)], \lambda > 0$$

(11)

3.1.5 The distance of interval-valued trapezoidal fuzzy numbers

Assume that:

$$\tilde{A} = [\tilde{A} L, \tilde{A} U] = [(a_{1L}, a_{1U}, a_{2L}, a_{2U}; w_A L), (a_{3L}, a_{3U}, a_{4L}, a_{4U}; w_A U)]$$

and:

$$\tilde{B} = [\tilde{B} L, \tilde{B} U] = [(b_{1L}, b_{1U}, b_{2L}, b_{2U}; w_B L), (b_{3L}, b_{3U}, b_{4L}, b_{4U}; w_B U)]$$

are two generalized trapezoidal fuzzy numbers, then the distance of two interval-valued trapezoidal fuzzy numbers ($\tilde{A}$ and $\tilde{B}$) is computed as follows:

1. Use the formula (6) to calculate the coordinate of COG points $(x_A L, y_A L), (x_A U, y_A U), (x_B L, y_B L), (x_B U, y_B U)$, which belong to the generalized trapezoidal fuzzy numbers $\tilde{A} L, \tilde{A} U, \tilde{B} L, \tilde{B} U$, respectively.

2. The distance of two interval-valued trapezoidal fuzzy numbers is:

$$d(\tilde{A}, \tilde{B}) = \sqrt{((x_A L - x_B L)^2 + (x_A U - x_B U)^2 + (y_A L - y_B L)^2 + (y_A U - y_B U)^2) / 4}$$

(12)

where $d(\tilde{A}, \tilde{B})$ satisfies the following properties:

(i) If $\tilde{A}$ and $\tilde{B}$ are normalized interval-valued trapezoidal fuzzy numbers, then: $0 \leq d(\tilde{A}, \tilde{B}) \leq 1$

(ii) $\tilde{A} = \tilde{B} \iff d(\tilde{A}, \tilde{B}) = 0$

(iii) $d(\tilde{A}, \tilde{B}) = d(\tilde{B}, \tilde{A})$

(iv) $d(\tilde{A}, \tilde{C}) + d(\tilde{C}, \tilde{B}) \geq d(\tilde{A}, \tilde{B})$

3.2 The working steps in the VIKOR method

It can be difficult to obtain the type of generalized interval-valued trapezoidal fuzzy numbers for the attribute values and weights directly by the decision makers in the real decision-making situation. Accordingly, the form of linguistic terms is usually adopted. Hence, Wei and
Table 2

Interval linguistic terms and relative interval-valued trapezoidal fuzzy numbers.

<table>
<thead>
<tr>
<th>Linguistic term (the attribute values)</th>
<th>Linguistic terms (weights)</th>
<th>Generalized interval-valued trapezoidal fuzzy numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolutely-poor (AP)</td>
<td>Absolutely-Low (AL)</td>
<td>$([0.00,0.00,0.00,0.00;0.00,0.00,0.00,0.00;0.00,0.00,0.00,1.00])$</td>
</tr>
<tr>
<td>Very-poor (VP)</td>
<td>Very-low (VL)</td>
<td>$([0.00,0.00,0.00,0.00;0.00,0.00,0.02,0.07;0.00,0.00,0.02,0.07;0.00,0.00,1.00,1.00])$</td>
</tr>
<tr>
<td>Poor (P)</td>
<td>Low (L)</td>
<td>$([0.00,0.00,0.00,0.00;0.04,0.10,0.18,0.23;0.04,0.10,0.18,0.23;0.04,0.10,1.00,1.00])$</td>
</tr>
<tr>
<td>Medium-poor (MP)</td>
<td>Medium-low (ML)</td>
<td>$([0.00,0.00,0.00,0.00;0.17,0.22,0.36,0.42;0.17,0.22,0.36,0.42;0.17,0.22,1.00,1.00])$</td>
</tr>
<tr>
<td>Medium (M)</td>
<td>Medium (M)</td>
<td>$([0.00,0.00,0.00,0.00;0.32,0.41,0.58,0.65;0.32,0.41,0.58,0.65;0.32,0.41,1.00,1.00])$</td>
</tr>
<tr>
<td>Medium-good (MG)</td>
<td>Medium-high (MH)</td>
<td>$([0.00,0.00,0.00,0.00;0.58,0.63,0.80,0.86;0.58,0.63,0.80,0.86;0.58,0.63,1.00,1.00])$</td>
</tr>
<tr>
<td>Good (G)</td>
<td>High (H)</td>
<td>$([0.00,0.00,0.00,0.00;0.72,0.78,0.92,0.97;0.72,0.78,0.92,0.97;0.72,0.78,1.00,1.00])$</td>
</tr>
<tr>
<td>Very-good (VG)</td>
<td>Very-high (VH)</td>
<td>$([0.00,0.00,0.00,0.00;0.03,0.08,1.00,1.00;0.03,0.08,1.00,1.00;0.03,0.08,1.00,1.00])$</td>
</tr>
<tr>
<td>Absolutely-good (AG)</td>
<td>Absolutely-high (AH)</td>
<td>$([0.00,0.00,0.00,0.00;1.00,1.00,1.00,1.00;1.00,1.00,1.00,1.00;1.00,1.00,1.00,1.00])$</td>
</tr>
</tbody>
</table>

Chen (2009) applied the interval-valued trapezoidal fuzzy numbers and its relative 9-member linguistic terms, which are presented in Table 2.

Assuming that each alternative is evaluated according to each attribute function, the compromise ranking could be performed by comparing the measure of closeness to the ideal alternative. The multi-attribute measure for compromise ranking is developed from the LP - metric used as an aggregation function in a compromise programming method (Florov, 1973; Zeleny, 1982). The various m alternatives are denoted as A₁, A₂, ..., Aₘ. For alternative Aᵢ, the rating of the jth aspect is denoted by fᵢj, that is, fᵢj is the value of jth attribute function for the alternative Aᵢ; n is the number of attribute. Development of the VIKOR method is started with the following form of LP - metric:

$$L_{p,i} = \left\{ \sum_{j=1}^{n} \left[ w_{ij} (f_{ij} - f_{ij}^*) (f_{ij}^* - f_{ij}^-) \right] \right\}^{1/p}, \quad 1 \leq p \leq \infty; \quad i = 1, 2, ..., m$$

In the VIKOR method, $L_{1,i}$ (as $S_i$) and $L_{\infty,i}$ (as $R_i$) are used to formulate ranking measure. The solution obtained by min$_i S_i$ is with a maximum group utility (“majority” rule), and the solution obtained by min$_i R_i$ is with a minimum individual regret of the “opponent”.

1 Establish the positive ideal solution and the negative ideal solution of the evaluation objects.

Assume that the positive ideal solution and the negative ideal solution are $\tilde{V}^+ = [\tilde{v}_{ij}^+]_{1 \times n}$, $\tilde{V}^- = [\tilde{v}_{ij}^-]_{1 \times n}$, then:

$$\tilde{v}_{ij}^+ = [(\mu_{ij}^+, \mu_{ij}^+, \mu_{ij}^+, \mu_{ij}^+; \mu_{ij}^+); (\mu_{ij}^+, \mu_{ij}^+, \mu_{ij}^+, \mu_{ij}^+; \mu_{ij}^+); (\mu_{ij}^+, \mu_{ij}^+, \mu_{ij}^+, \mu_{ij}^+; \mu_{ij}^+); (\mu_{ij}^+, \mu_{ij}^+, \mu_{ij}^+, \mu_{ij}^+; \mu_{ij}^+)]$$

$$= \left[ \max_i (v_{ij}^+), (\max_i (v_{ij}^+), (\max_i (v_{ij}^+), (\max_i (v_{ij}^+))) \right]$$

$$\tilde{v}_{ij}^- = [(\mu_{ij}^-, \mu_{ij}^-, \mu_{ij}^-, \mu_{ij}^-; \mu_{ij}^-); (\mu_{ij}^-, \mu_{ij}^-, \mu_{ij}^-, \mu_{ij}^-; \mu_{ij}^-); (\mu_{ij}^-, \mu_{ij}^-, \mu_{ij}^-, \mu_{ij}^-; \mu_{ij}^-); (\mu_{ij}^-, \mu_{ij}^-, \mu_{ij}^-, \mu_{ij}^-; \mu_{ij}^-)]$$

$$= \left[ \min_i (v_{ij}^-), (\min_i (v_{ij}^-), (\min_i (v_{ij}^-), (\min_i (v_{ij}^-))) \right]$$

• Compute the weighted matrix and the COG of every attribute with respect to the positive ideal solution and the negative ideal solution.

According to the formula (6), we can compute the COG $[(y_i, x_i)_{n \times 5}$ of every element in the weighted matrix and the barycentric coordinates $[(y_i, x_i)_{n \times 5}$ and $[(y_i, x_i)_{n \times 5}$ of each element with respect to the positive ideal solution and the negative ideal solution.

• Calculate the values $S_i$ and $R_i$, $i = 1, 2, ..., m$ by the relations:

$$S_i = \sum_{j=1}^{n} \left[ d(\tilde{v}_{ij}^+, \tilde{v}_j) + d(\tilde{v}_{ij}^+, \tilde{v}_j^-) \right]$$

$$R_i = \max_j \left[ d(\tilde{v}_{ij}^+, \tilde{v}_j) + d(\tilde{v}_{ij}^+, \tilde{v}_j^-) \right]$$

• Calculate the values $Q_i$, $i = 1, 2, ..., m$ by the following relation:

$$Q_i = \frac{S_i - S^*}{S^- - S^*} + (1 - \nu) \left( \frac{R_i - R^*}{R^- - R^*} \right)$$
Table 3
Weights for environmental factors according to the decision-makers.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Climate change (contributes to GHG reduction)</th>
<th>Air quality (meets international standard)</th>
<th>Noise (meets international standard)</th>
<th>Land use and biodiversity (minimizes the impacts on biodiversity of species habitats and landscapes)</th>
<th>Waste management (minimizes waste and impact of wastes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision maker</td>
<td>VH</td>
<td>MH</td>
<td>M</td>
<td>VL</td>
<td>AH</td>
</tr>
</tbody>
</table>

Table 4
Impacts of reverse logistics' decision option (alternative) on environmental factors.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Climate change (contributes to GHG reduction)</th>
<th>Air quality (meets international standard)</th>
<th>Noise (meets international standard)</th>
<th>Land use and biodiversity (minimizes the impacts on biodiversity of species habitats and landscapes)</th>
<th>Waste management (minimizes waste and impact of wastes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative</td>
<td>Remanufacture</td>
<td>VG</td>
<td>G</td>
<td>AG</td>
<td>AP</td>
</tr>
<tr>
<td>Resell</td>
<td>MG</td>
<td>MG</td>
<td>G</td>
<td>AP</td>
<td>AG</td>
</tr>
<tr>
<td>Repair</td>
<td>F</td>
<td>F</td>
<td>MP</td>
<td>AP</td>
<td>MP</td>
</tr>
<tr>
<td>Recycle</td>
<td>F</td>
<td>MG</td>
<td>VG</td>
<td>AP</td>
<td>AG</td>
</tr>
<tr>
<td>Disposal</td>
<td>AG</td>
<td>AG</td>
<td>G</td>
<td>AG</td>
<td>AG</td>
</tr>
</tbody>
</table>

where, \( S^+ = \min_i S_i, S^- = \max_i S_i, R^+ = \min_i R_i, R^- = \max_i R_i \), and \( v \) is presented as weight of the strategy of “the majority of criteria” (or “the maximum group utility”), here suppose that \( v = 0.5 \).

- Prioritize the alternatives. Ranking by the values \( S, R \) and \( Q \) in decreased order, in which the position in the front is better than that of the one behind.

3.3. The expert elicitation step

In this step, the experts in the field of RL and green have been asked to express their technical views about the impacts of RL on green environmental factors, as presented in Table 3, and Table 4. In Table 3, the decision makers (experts) were asked to weigh environmental factors based on their importance, by using the weights from Table 2. The most important item considered in weighting the environmental factors is to weigh each factor without considering their integration with the reverse logistics functions. The aim of this consideration was to figure out how much each factor could be important in current environmental matters. Furthermore, the experts were asked to rank the impacts of each reverse logistics’ decision option on each environmental factor by using the attribute value from Table 2. The results of these rankings are illustrated in Table 4.

4. Results and discussion

According to the VIKOR method and the concept of generalized interval-valued trapezoidal fuzzy numbers, which was discussed in the above, the following results are acquired.

1. Convert the linguistic terms into interval-valued trapezoidal fuzzy numbers, and then get:

\[
[\tilde{w}_0]_{1.5} = [(0.93, 0.98, 1.00, 1.00; 0.8), (0.93, 0.98, 1.00, 1.00; 1.0)],
[(0.58, 0.63, 0.80, 0.86; 0.8), (0.58, 0.63, 0.80, 0.86; 1.0)],
[(0.32, 0.41, 0.58, 0.65; 0.8), (0.32, 0.41, 0.58, 0.65; 1.0)],
[(0.00, 0.00, 0.02, 0.07; 0.8), (0.00, 0.00, 0.02, 0.07; 1.0)],
[(1.00, 1.00, 1.00, 1.00; 0.8), (1.00, 1.00, 1.00, 1.00; 1.0)]
\]

\[
[\tilde{x}_0]_{1.5} = 
[(0.93, 0.98, 1.00, 1.00; 0.8), (0.93, 0.98, 1.00, 1.00; 1.0)],
[(0.58, 0.63, 0.80, 0.86; 0.8), (0.58, 0.63, 0.80, 0.86; 1.0)],
[(0.32, 0.41, 0.58, 0.65; 0.8), (0.32, 0.41, 0.58, 0.65; 1.0)],
[(0.32, 0.41, 0.58, 0.65; 0.8), (0.32, 0.41, 0.58, 0.65; 1.0)],
[(1.00, 1.00, 1.00, 1.00; 0.8), (1.00, 1.00, 1.00, 1.00; 1.0)]
\]
\[
\begin{align*}
&[[0.72, 0.78, 0.92, 0.97:0.8], (0.72, 0.78, 0.92, 0.97:1.0)], \\
&[(0.58, 0.63, 0.80, 0.86:0.8), (0.58, 0.63, 0.80, 0.86:1.0)], \\
&[(0.32, 0.41, 0.58, 0.65:0.8), (0.32, 0.41, 0.58, 0.65:1.0)], \\
&[(0.58, 0.63, 0.80, 0.86:0.8), (0.58, 0.63, 0.80, 0.86:1.0)], \\
&[(0.17, 0.22, 0.36, 0.42:0.8), (0.17, 0.22, 0.36, 0.42:0.8)], \\
&[(1.00, 1.00, 1.00, 1.00:0.8), (1.00, 1.00, 1.00, 1.00:1.0)], \\
&[[0.72, 0.78, 0.92, 0.97:0.8], (0.72, 0.78, 0.92, 0.97:1.0)], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)], \\
&[[0.72, 0.78, 0.92, 0.97:0.8], (0.72, 0.78, 0.92, 0.97:1.0)]
\end{align*}
\]

- Calculate the weighted decision making matrix:

\[
\hat{\mathbf{V}}_{k_5} \equiv = \begin{bmatrix}
[(0.86, 0.96, 1.00, 1.00:0.8), (0.86, 0.96, 1.00, 1.00:1.0)], \\
[(0.54, 0.62, 0.80, 0.86:0.8), (0.54, 0.62, 0.80, 0.86:1.0)], \\
[(0.30, 0.40, 0.58, 0.65:0.8), (0.30, 0.40, 0.58, 0.65:1.0)], \\
[(0.30, 0.40, 0.58, 0.65:0.8), (0.30, 0.40, 0.58, 0.65:1.0)], \\
[(0.30, 0.40, 0.58, 0.65:0.8), (0.30, 0.40, 0.58, 0.65:1.0)], \\
[(0.93, 0.98, 1.00, 1.00:0.8), (0.93, 0.98, 1.00, 1.00:1.0)]. \\
\end{bmatrix}
\]

\[
\begin{align*}
&[[0.42, 0.49, 0.74, 0.83:0.8], (0.42, 0.49, 0.74, 0.83:1.0)], \\
&[(0.34, 0.40, 0.64, 0.74:0.8), (0.34, 0.40, 0.64, 0.74:1.0)], \\
&[(0.19, 0.26, 0.46, 0.56:0.8), (0.19, 0.26, 0.46, 0.56:1.0)], \\
&[(0.34, 0.40, 0.64, 0.74:0.8), (0.34, 0.40, 0.64, 0.74:1.0)], \\
&[(0.10, 0.14, 0.29, 0.36:0.8), (0.10, 0.14, 0.29, 0.36:1.0)], \\
&[(0.58, 0.63, 0.80, 0.86:0.8), (0.58, 0.63, 0.80, 0.86:1.0)], \\
&[0.32, 0.41, 0.58, 0.65:0.8], (0.32, 0.41, 0.58, 0.65:1.0], \\
&[0.23, 0.32, 0.53, 0.63:0.8], (0.23, 0.32, 0.53, 0.63:1.0], \\
&[0.05, 0.09, 0.21, 0.27:0.8], (0.05, 0.09, 0.21, 0.27:1.0], \\
&[0.30, 0.40, 0.58, 0.65:0.8], (0.30, 0.40, 0.58, 0.65:1.0], \\
&[0.30, 0.40, 0.58, 0.65:0.8], (0.30, 0.40, 0.58, 0.65:1.0], \\
&[0.23, 0.32, 0.53, 0.63:0.8], (0.23, 0.32, 0.53, 0.63:1.0], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)], \\
&[(0.00, 0.00, 0.00, 0.00:0.8), (0.00, 0.00, 0.00, 0.00:1.0)]. \\
\end{align*}
\]
\[
[0.72, 0.78, 0.92, 0.97; 0.8], (0.72, 0.78, 0.92, 0.97; 1.0)]
[1.00, 1.00, 1.00, 1.00; 0.8], (1.00, 1.00, 1.00, 1.00; 1.0)]
[0.17, 0.22, 0.36, 0.42; 0.8], (0.17, 0.22, 0.36, 0.42; 1.0)]
[1.00, 1.00, 1.00, 1.00; 0.8], (1.00, 1.00, 1.00, 1.00; 1.0)]
[1.00, 1.00, 1.00, 1.00; 0.8], (1.00, 1.00, 1.00, 1.00; 1.0)]

- Determine the positive ideal solution and the negative ideal solution:

\[
\hat{\mathbf{V}} = [(0.93, 0.98, 1.00; 0.8), (0.93, 0.98, 1.00, 1.00; 1.0)],
(0.58, 0.63, 0.80, 0.86; 0.8), (0.58, 0.63, 0.80, 0.86; 1.0)],
(0.32, 0.41, 0.58, 0.65; 0.8), (0.32, 0.41, 0.58, 0.65; 1.0)],
(0.00, 0.00, 0.02, 0.07; 0.8), (0.00, 0.00, 0.02, 0.07; 1.0)],
(1.00, 1.00, 1.00, 1.00; 0.8), (1.00, 1.00, 1.00, 1.00; 1.0)]
\]

\[
\tilde{\mathbf{V}} = [(0.30, 0.40, 0.58, 0.65; 0.8), (0.30, 0.40, 0.58, 0.65; 1.0)],
(0.10, 0.14, 0.29, 0.36; 0.8), (0.10, 0.14, 0.29, 0.36; 1.0)],
(0.05, 0.09, 0.21, 0.27; 0.8), (0.05, 0.09, 0.21, 0.27; 1.0)],
(0.00, 0.00, 0.00, 0.00; 0.8), (0.00, 0.00, 0.00, 0.00; 1.0)],
(0.17, 0.22, 0.36, 0.42; 0.8), (0.17, 0.22, 0.36, 0.42; 1.0)]
\]

- Calculate the weighted matrix and the COG of each attribute with respect to the positive ideal solution and the negative ideal solution \((y, x)\):

\[
[y, x]_W = \begin{bmatrix}
[(0.3053, 0.9491), (0.3810, 0.9491)], [(0.3480, 0.6206), (0.4350, 0.6206)],
[(0.3417, 0.7043), (0.4271, 0.7043)], [(0.3467, 0.5314), (0.4333, 0.5314)],
[(0.3552, 0.4813), (0.5519, 0.4813)], [(0.3387, 0.3687), (0.4234, 0.3687)],
[(0.3552, 0.4813), (0.5519, 0.4813)], [(0.3467, 0.5314), (0.4333, 0.5314)],
[(0.3552, 0.4813), (0.5519, 0.4813)], [(0.3436, 0.2235), (0.4295, 0.2235)],
[(0.3048, 0.9745), (0.3810, 0.9745)], [(0.3476, 0.7179), (0.4345, 0.7179)],
\end{bmatrix}
\]

\[
[(0.3354, 0.4892), (0.4192, 0.4892)], [(0.40, 0.00), (0.50, 0.00)],
[(0.3367, 0.4279), (0.4208, 0.4279)], [(0.40, 0.00), (0.50, 0.00)],
[(0.3394, 0.1558), (0.4242, 0.1558)], [(0.40, 0.00), (0.50, 0.00)],
[(0.3352, 0.4814), (0.4190, 0.4814)], [(0.40, 0.00), (0.50, 0.00)],
[(0.3352, 0.4814), (0.4190, 0.4814)], [(0.40, 0.00), (0.50, 0.00)],
[(0.3367, 0.4279), (0.4208, 0.4279)], [(0.3048, 0.0255), (0.3810, 0.0255)],
\]

\[
[(0.3413, 0.8741), (0.4267, 0.8471)],
[(0.4000, 1.0000), (0.5000, 1.0000)],
[(0.3413, 0.2929), (0.4267, 0.2929)],
[(0.4000, 1.0000), (0.5000, 1.0000)],
[(0.4000, 1.0000), (0.5000, 1.0000)],
[(0.4000, 1.0000), (0.5000, 1.0000)]
\]

\[
[y, x]_W^+ = \begin{bmatrix}
[(0.3048, 0.9745), (0.3810, 0.9745)], [(0.3476, 0.7179), (0.4345, 0.7179)],
[(0.3354, 0.4892), (0.4192, 0.4892)], [(0.3048, 0.0255), (0.3810, 0.0255)],
[(0.4000, 1.0000), (0.5000, 1.0000)]
\end{bmatrix}
\]

\[
[y, x]_W^- = \begin{bmatrix}
[(0.3352, 0.4814), (0.4190, 0.4814)], [(0.3436, 0.2235), (0.4295, 0.2235)],
[(0.3394, 0.1558), (0.4242, 0.1558)], [(0.4000, 0.0000), (0.5000, 0.0000)],
[(0.3413, 0.2929), (0.4267, 0.2929)]
\end{bmatrix}
\]

- Compute the values \(S_i\) and \(R_i\), \(i = 1, 2, 3, 4, 5, 6\).

\[S_1 = 1.4831, S_2 = 2.1145, S_3 = 4.7322, S_4 = 2.4289, S_5 = 3.0516, S_6 = 0.1841\]

\[R_1 = 1, R_2 = 1, R_3 = 1.0283, R_4 = 1.0283, R_5 = 1.0283, R_6 = 0.1841\]
Table 5
Final ranking of alternatives in VIKOR method.

<table>
<thead>
<tr>
<th></th>
<th>( S_i )</th>
<th>( R_i )</th>
<th>( Q_i )</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remanufacture (a1)</td>
<td>1.4831</td>
<td>1</td>
<td>0.626</td>
<td>2</td>
</tr>
<tr>
<td>Refurbishment (a2)</td>
<td>2.1145</td>
<td>1</td>
<td>0.6954</td>
<td>3</td>
</tr>
<tr>
<td>Resell (a3)</td>
<td>4.7322</td>
<td>1.0283</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Repair (a4)</td>
<td>2.4289</td>
<td>1.0283</td>
<td>0.7468</td>
<td>4</td>
</tr>
<tr>
<td>Recycle (a5)</td>
<td>3.0516</td>
<td>1.0283</td>
<td>0.8152</td>
<td>5</td>
</tr>
<tr>
<td>Disposal (a6)</td>
<td>0.1841</td>
<td>0.1841</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

- Compute the values \( Q_i, i = 1, 2, 3, 4, 5, 6 \):

\[
Q_1 = 0.626, \quad Q_2 = 0.6954, \quad Q_3 = 1, \quad Q_4 = 0.7468, \quad Q_5 = 0.8152, \quad Q_6 = 0
\]

- Rank the alternatives based on the value of \( Q, R \), and \( S \):

\[
a_6 > a_1 > a_2 > a_4 > a_5 > a_3
\]

According to the final computations (Table 5), the disposal recovery option turned out to be the best proposed option as it has the minimum \( Q_i \); thereby the lowest negative impact on the environment. The resell recovery option on the other hand was identified as the worst proposed option, with the highest \( Q_i \), as well. Consequently, the results obtained from the elicitation of the experts ranked the alternatives and verified the proposed decision making model.

5. Conclusion

This paper makes an attempt to fill the literature gap on identification and validation and prioritization of green decision making specific to reverse logistics in a fuzzy environment that will ultimately contribute to the conservation of resources. It was argued that the lack of a concise and comprehensive elaboration in the impact analysis of RL recovery options on the green environmental factors motivated the authors to undertake this research. To cope with the presented issue, the FUZZY-VIKOR method is proposed. In the current approach, the generalized interval-valued trapezoidal fuzzy numbers are employed to quantify the linguistic terms used in the ranking method through the elicitation of experts. In order to prioritize the greennest recovery options in RL, the VIKOR method was also used. According to the final results, disposing and reselling the returns are ranked as the best and worst alternatives in terms of the green metric, respectively.

In addition, from the methodological point of view, it is important to note that one of the biggest challenges in translating the practice into an applicable model is to use a reliable method that is able to precisely reflect the reality of each factor in the model as they exist in the practice. The approach of Fuzzy logic together with the VIKOR method assisted the researchers in providing results that are very close to the real world. To conclude, the findings from this study offer managers an audit tool of how and what to deploy with respect to reverse logistics efforts. One particular pragmatic tool that can be offered is to test the viability of the different reverse logistics activities (e.g., disposing and reselling) by way of focused process improvement projects that are aimed at improving sustainability.

5.1. Recommendations for further research

There are a lot of opportunities for future works. First, one of the limitations in this research was to only examine the impacts of green environmental factors on the RL recovery options. While from the managerial point of view, it would be interesting to study a sustainable reverse logistics through the proposed methodology. Therefore, the future works could identify and rank the economic and societal factors of RL that affect the final recovery options well and flowingly apply the same approach presented in this work. However, it is critical to choose the most primary factors that affect the choice of final decision; otherwise the computations might be complex and the analysis may become cumbersome. To avoid any difficulties that might be experienced in this regard, we suggest to the researchers to apply a multi-stage decision making model. Second, in this study, we have only conducted the interviews with the experts in the manufacturer companies, however, as different parties are involved in the RL cycle, the analyses would be more realistic if we could reflect the technical opinions of other decision makers in RL (e.g., third-party reverse logistics providers, suppliers and customers). Although the influences of designing the green products (Khor and Udin, 2013) or transportation on returns have been discussed in the literature, almost no research has explicitly argued the influences of a group decision making across the RL on the best recovery option. This requires that managers design a clear and cost-effective policy that thoroughly encompasses the needs and expectations of all the involved parties in RL. In order to maintain an efficient policy, it is essential that the critical metrics defined, measured, monitored and more importantly shared among all the stakeholders. Finally, another direction for the future research would be to apply some other Fuzz-MADM methods such Fuzzy-TOPSIS or Fuzzy-DEMATeil and compare the results of them with our results.

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References