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Fuzzy AHP-TOPSIS approaches to prioritizing solutions for reverse logistics barriers

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A B S T R A C T

Due to an increasing demand for green products and also pressures from customers and other players along the supply chain, which now pay more attention to environmental awareness and sustainable management, many companies especially in the electronics industry have begun to realize the importance of applying green supply chain management concepts into their activities; reverse logistics (RL) practice is one of the important strategies to provide efficient resource utilization and minimize waste from end of life (EOL) products by following legislation and green concepts. But recently reverse logistics practices are faced with some barriers which make the implementation of reverse logistics difficult and unsuccessful. To increase efficiency in reverse logistics adaptation of the electronics industry, companies need to understand and consider the priorities of both barriers and solutions for developing policies and strategies to overcome these barriers. Therefore, this study focused on the classification of reverse logistics barriers and ranking of both barriers and solutions of reverse logistics implementation in the electronics industry. This paper proposes a methodology based on fuzzy analytical hierarchy process (Fuzzy AHP) and fuzzy technique for order performance by similarity to ideal solution (Fuzzy TOPSIS) in which fuzzy AHP is applied to get the weights of each barrier by using pairwise comparison, and fuzzy TOPSIS is applied for the final ranking of the solutions of reverse logistics implementation. The case of Thailand's electronics industry is used in the proposed method. To illustrate the robustness of the method, sensitivity analysis is used in this study.

1. Introduction

Over the last decade environmental issues have become an important issue in various industries including the electronics industry due to an increase in environmental awareness, enforced legislation, industrial ecology and corporate citizenship (Prakash & Barua, 2015). The policy and decision makers have to consider environmental issues in each activity of their organization along their supply chain (Kannan, Jabbour, & Jabbour, 2014). Many companies have applied reverse logistics (RL) concept to their policies and strategies for sustainability development which focused on the reduction of waste and created value from return of used products (Sirisawat, Kiatcharoenpol, Choomrit, & Wangphanich, 2016). Rogers and Tibben-Lembke (1998), explained that RL is the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal. RL focuses on maximizing value from the returned item or minimizing the total RL cost from the backward flow of materials (Kannan, Pokharel, & Kumar, 2009).

According to law and legislation, it forced producers to take care of their End of Life (EOL) products and the Waste Electrical and Electronic Equipment (WEEE) directive (directive 2002/96/EC) enforced electronics manufacturers to efficiently manage the return and proper disposal of packaging or used products (Govindan, Soleimani, & Kannan, 2015; Nikolaou, Evangelinos, & Allan, 2013). Even though the RL concept is widely used in many companies, it still has a lots of barriers that make RL practices difficult and unsuccessful. Each barrier cannot be solved at the same time and might require different solutions or treatment (Prakash & Barua, 2015; Sharma, Panda, Mahapatra, & Sahu, 2011). Hence, priority and ranking of barriers and solutions is needed to solve such barriers.

Previous research has studied and introduced some barriers, drivers and also solutions for RL practices in many countries (Abdulrahman, Gunasekaran, & Subramanian, 2014; Govindan, Kaliyan, Kannan, & Haq, 2014; Prakash & Barua, 2015; Rahman & Subramanian, 2012; Ravi & Shankar, 2005; Sharma et al., 2011; Zaabi, Dhaheri, & Diabat, 2013). However, the study of barriers and solutions in Thailand's

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Table 1
RL practices barriers with criteria and sub-criteria.

Criteria	Criteria code	Sub-criteria	References
Management barriers	MB1	Lack of commitment by top management	Ravi and Shankar (2005), Mathiyazhagan et al. (2013), Prakash and Barua (2015), Sharma et al. (2011), Jindal and Sangwan (2011), Wiel et al. (2012), Zaabi et al. (2013), PWC (2008), Abdullah et al. (2011), Govindan et al. (2014), Abdulrahman et al. (2014), Yacob (2012), and Rogers and Tibben-Lembke (2001)
	MB2	Lack of strategic planning for ensuring RL practices	
	MB3	Lack of awareness and understanding in RL adaptation	
	MB4	Lack of specific goals for environment and waste management	
	MB5	Lack of policies for RL practices	
Organization barriers	OB1	Lack of proper organizational structure & support for RL practices	Prakash and Barua (2015), Luthra, Kumar, Kumar, and Haleem (2011), Yacob (2012), Jindal and Sangwan (2011), Wiel et al. (2012), Zaabi et al. (2013), Abdullah et al. (2011), Sharma et al. (2011), Rogers and Tibben-Lembke (2001), Govindan et al. (2014), and Pumpinyo and Nitivattananon (2014)
	OB2	Lack of training & education about RL	
	OB3	Lack of organization personnel resources	
Product barriers	PB1	Uncertain quality and quantity of return products from point of consumption	Ravi and Shankar (2005), Prakash and Barua (2015), Sharma et al. (2011), Jindal and Sangwan (2011), Abdullah et al. (2011), Yacob (2012), Rahman and Subramanian (2012), and Govindan et al. (2014)
	PB2	Less economic value recovered	
	PB3	Risk of storage of hazardous materials	
Legal barriers	LB1	Lack of enforced laws, legislation and directives for EoL products	Prakash and Barua (2015), Rogers and Tibben-Lembke (2001), Jindal and Sangwan (2011), Zaabi et al. (2013), Abdulrahman et al. (2014), Rahman and Subramanian (2012), Sharma et al. (2011), Luthra et al. (2011), Mathiyazhagan et al. (2013), Govindan et al. (2014), Pumpinyo and Nitivattananon (2014), and Sirisawat and Kiatcharoenpol (2016)
	LB2	Lack of government supportive policies on RL practices	
	LB3	Loopholes in Thai laws and regulations on waste management	
Technological barriers	TB1	Lack of information and technological systems for RL practices	Ravi and Shankar (2005), Prakash and Barua (2015), Sharma et al. (2011), Jindal and Sangwan (2011), Luthra et al. (2011), Zaabi et al. (2013), Mathiyazhagan et al. (2013), Pumpinyo and Nitivattananon (2014), and Govindan et al. (2014)
	TB2	Lack of available technological infrastructure to adopt RL practices	
	TB3	Lack of technical expertise to support RL practices	
	TB4	Lack of flexibility to change from traditional system to new system	
Infrastructural barriers	IB1	Lack of infrastructure facility to support RL implementation	Prakash and Barua (2015), Abdulrahman et al. (2014), Yacob (2012), Pumpinyo and Nitivattananon (2014), and Jindal and Sangwan (2011)
	IB2	Lack of efficient and effective systems to monitor returns and recalls	
	IB3	Increase of unstandardized waste management area	
Financial barriers	FB1	Financial constraints	Ravi and Shankar (2005), Sharma et al. (2011), Rogers and Tibben-Lembke (2001), Luthra et al. (2011), Wiel et al. (2012), Mathiyazhagan et al. (2013), Govindan et al. (2014), Abdulrahman et al. (2014), Yacob (2012), Pumpinyo and Nitivattananon (2014), Rahman and Subramanian (2012), Prakash and Barua (2015), Jindal and Sangwan (2011), and Zaabi et al. (2013)
	FB2	High investments and less return-on-investments	
	FB3	Expenditure in collection and storage of used products	
	FB4	Cost of environmentally friendly packaging	
	FB5	Cost of nonhazardous and hazardous waste disposal	
Involvement and support barriers	ISB1	Lack of coordination and collaboration with 3rd party logistics (3PL) providers	Ravi and Shankar (2005), Prakash and Barua (2015), Sharma et al. (2011), PWC (2008), Govindan et al. (2014), Abdulrahman et al. (2014), Yacob (2012), Rahman and Subramanian (2012), Jindal and Sangwan (2011), and Mathiyazhagan et al. (2013)
	ISB2	Lack of support of supply chain partners	
	ISB3	Lack of public focus on environmental issues	

electronics industry remains unstudied.

This research focuses on the identification of barriers in Thailand's electronics industry and ranks solutions to solve its barriers. Electronics companies or other related Thai industries could use the results from the ranking of solutions to solve RL practices barriers and also develop efficient and appropriate policies and strategies for their companies to improve competitiveness. A hybrid of decision making methods was used for prioritizing and ranking of solutions. And fuzzy approach was used to manage the vagueness and uncertainty of the human options in which human judgment in decision making has often been unclear and difficult to estimate with exact numerical values (Patil & Kant, 2014). Therefore this study proposed the hybrid fuzzy Analytical hierarchy process (Fuzzy AHP) and fuzzy technique for order performance by similarity to ideal solution (Fuzzy TOPSIS) method to prioritize and rank solutions of RL practices. Fuzzy AHP was used to determine the preference weights and Fuzzy TOPSIS was used to ranking solutions. The empirical case of Thailand's electronics industry is used for the proposed methods. The remainder of this paper is organized as follows: Section 2 is reviews of the literature on barriers and solutions of RL practices. Section 3 presents the fuzzy AHP and fuzzy TOPSIS method. Section 4 illustrates an approach for ranking solutions of RL practices. The results and discussion of the case study are shown in Section 5. Finally, a conclusion is given in Section 6.

2. Literature review

2.1. Reverse logistics practices

Electronics manufacturers of Thailand have faced some barriers from reverse logistics practices making the implementation of reverse logistics practices unsuccessful and inefficient. Many organizations have a lots of barriers such as lack of government support, lack of knowledge in reverse logistics practices, lack of research and development for new technology, some manufacturers still do not understand global standards such as WEEE and RoHS, lack of investment, increase of laws and legislation regarding the environment, etc. all of which have affected RL practices implementation within Thailand's electronics industry.

The barriers and solutions for RL practices identified in this paper are proposed and confirmed by the author's previous research. Literature review are carried out to set a group of categorized barriers and solutions then empirically tested in a case of Thai's electronics industry using Structural Equation Modeling (SEM) technique. All of them are statistically significant barriers and solutions. Therefore, the barriers and solutions of RL practices were classified as discussed below:

2.1.1. Barriers of RL practices

2.1.1.1. Management barriers. Management barriers include lack of commitment by top management, whereby the top management was unwilling to implement RL and less effort put into integrating RL to the supply chain management (Mathiyazhagan, Govindan, NoorulHaq, & Geng, 2013; Ravi & Shankar, 2005). Due to change in technology, customers and suppliers' behavior, marketing situation and environmental awareness, businesses lack strategic planning for ensuring RL implementation (Jindal & Sangwan, 2011; Prakash & Barua, 2015; PWC, 2008; Ravi & Shankar, 2005; Sharma et al., 2011; Wiel, Bossink, & Masurel, 2012; Zaabi et al., 2013). There is a lack of awareness of the benefits from RL implementation and lack of understanding about RL adaptation in business processes (Abdullah, Halim, Yaakub, & Abdullah, 2011; Abdulrahman et al., 2014; Govindan et al., 2014; Jindal & Sangwan, 2011; Mathiyazhagan et al., 2013; Prakash & Barua, 2015; Ravi & Shankar, 2005; Sharma et al., 2011; Wiel et al., 2012; Yacob, 2012). Companies did not have a specific goal for the environment, there was little planning for environmental pollution control and also a lack of good waste management practice (Abdulrahman et al., 2014; Govindan et al., 2014; Prakash & Barua, 2015). Due to the rapidly increasing competition and also change of business scenarios, companies were lacking policies to adapt RL practices in their organizations (Jindal & Sangwan, 2011; Prakash & Barua, 2015; PWC, 2008; Ravi & Shankar, 2005; Rogers & Tibben-Lembke, 2001; Sharma et al., 2011; Yacob, 2012). (See Table 1).

2.1.1.2. Organization barriers. Organization barriers include lack of proper organizational structure and support for RL practices (Luthra et al., 2011; Prakash & Barua, 2015; Yacob, 2012). The organizations pay less attention to training their staff or providing education about RL practices (Abdullah et al., 2011; Jindal & Sangwan, 2011; Prakash & Barua, 2015; Wiel et al., 2012; Zaabi et al., 2013). There is a lack of personnel resources of both specialists and proper training of staff for newly upgraded systems (Govindan et al., 2014; Luthra et al., 2011; Prakash & Barua, 2015; Pumpinyo & Nitivattananon, 2014; Rogers & Tibben-Lembke, 2001; Sharma et al., 2011; Yacob, 2012). (See Table 1).

2.1.1.3. Product barriers. Companies cannot control the quality and quantity of returned products from point of consumption (Abdullah et al., 2011; Jindal & Sangwan, 2011; Prakash & Barua, 2015; Rahman & Subramanian, 2012; Ravi & Shankar, 2005; Sharma et al., 2011; Yacob, 2012). Less economic value is recovered as companies cannot recapture the value and recover assets/materials from EoL products (Jindal & Sangwan, 2011; Prakash & Barua, 2015). Govindan et al. (2014) found that the return of EoL products and assets from recycling have risk in terms of storage of hazardous materials. (See Table 1).

2.1.1.4. Legal barriers. Legal barriers include lack of enforced laws, legislation and directives for EoL products (Abdulrahman et al., 2014; Jindal & Sangwan, 2011; Prakash & Barua, 2015; Rahman & Subramanian, 2012; Rogers & Tibben-Lembke, 2001; Zaabi et al., 2013). Lack of government supportive policies on RL and few standard/green practices for environmental friendly products (Govindan et al., 2014; Luthra et al., 2011; Mathiyazhagan et al., 2013; Prakash & Barua, 2015; Pumpinyo & Nitivattananon, 2014; Sharma et al., 2011). Thailand still has loopholes in its laws and regulations on waste management (Sirisawat & Kiatcharoenpol, 2016). (See Table 1).

2.1.1.5. Technological barriers. Technological barriers include lack of information and technological systems for RL practices, lack of available technological infrastructure to adopt RL practices, Lack of technical expertise to support RL practices, Lack of flexibility to change from traditional system to new system (Govindan et al., 2014; Jindal & Sangwan, 2011; Luthra et al., 2011; Mathiyazhagan et al., 2013; Prakash & Barua, 2015; Pumpinyo & Nitivattananon, 2014; Ravi & Shankar, 2005; Sharma et al., 2011; Zaabi et al., 2013). (See Table 1).

2.1.1.6. Infrastructural barriers. Infrastructural barriers include lack of infrastructure facilities to support RL implementation such as storage areas, equipment and transportation. Companies have a lack of efficient and effective systems to monitor returns and recalled products. There has been an increase of unstandardized waste management area (Abdulrahman et al., 2014; Jindal & Sangwan, 2011; Prakash & Barua, 2015; Pumpinyo & Nitivattananon, 2014; Yacob, 2012). (See Table 1).

2.1.1.7. Financial barriers. Financial barriers include financial constraints, companies have to allocate funds and other resources for RL adaptation (Abdulrahman et al., 2014; Govindan et al., 2014; Luthra et al., 2011; Mathiyazhagan et al., 2013; Pumpinyo & Nitivattananon, 2014; Rahman & Subramanian, 2012; Ravi & Shankar, 2005; Rogers & Tibben-Lembke, 2001; Sharma et al., 2011; Wiel et al., 2012; Yacob, 2012), high investments of information and technology systems, less return-on-investments (Govindan et al., 2014; Jindal & Sangwan, 2011; Mathiyazhagan et al., 2013; Prakash & Barua, 2015). Companies also have to consider the expenditure in collecting and storing used products, the cost of environmentally friendly packaging and also the cost of both nonhazardous and hazardous waste disposal (Govindan et al., 2014; Zaabi et al., 2013). (See Table 1).

2.1.1.8. Involvement and support barriers. Involvement and support barriers include lack of coordination and collaboration with 3rd party logistics (3PL) providers along the supply chain (Abdulrahman et al., 2014; Govindan et al., 2014; Prakash & Barua, 2015; PWC, 2008; Rahman & Subramanian, 2012; Ravi & Shankar, 2005; Sharma et al., 2011; Yacob, 2012). A lack of support of supply chain partners, and a lack of public focus on environmental issues (Abdulrahman et al., 2014; Govindan et al., 2014; Jindal & Sangwan, 2011; Luthra et al., 2011; Mathiyazhagan et al., 2013; Prakash & Barua, 2015). (See Table 1).

2.1.2. Solutions to RL practices

2.1.2.1. Top management awareness and support. Top management need to understand and be aware of the benefits of changing from traditional systems to new systems and the potential to increase competitive advantage by adapting RL practices to business processes (Prakash & Barua, 2015; PWC report, 2008). (See table 2).

2.1.2.2. Standardized reverse logistics processes. Companies need to use simplified and standardized processes to implement RL practices which focus on maximizing value from the returned item or minimizing the total RL cost from the backward flow (Badenhorst, 2016; Kannan et al., 2009; Prakash & Barua, 2015; PWC report, 2008). (See table 2).

2.1.2.3. Implementing cross-functional collaboration. Companies need to create collaboration and integration across all departments for an efficient and effective RL process (Prakash & Barua, 2015; PWC report, 2008). (See table 2).

Table 2
Solutions of RL practices.

Code	Solutions	References
S1	Top management awareness and support	PWC report (2008) and Prakash and Barua (2015)
S2	Standardized reverse logistics processes	Kannan et al. (2009), PWC report (2008), Prakash and Barua (2015), and Badenhorst (2016)
S3	Implementing cross-functional collaboration	PWC report (2008) and Prakash and Barua (2015)
S4	Strategic collaboration with RL partners	PWC report (2008), Prakash & Barua, 2015, and Badenhorst and Nel (2012)
S5	Determined clear policies and processes	PWC report (2008), Prakash and Barua (2015), and Badenhorst (2016)
S6	Implement return avoidance strategies	PWC report (2008), Prakash and Barua (2015)0, and Badenhorst (2016)
S7	Determined RL as part of sustainability program	PWC report (2008) and Prakash and Barua (2015)
S8	Enforce environmental legislation, regulations, and directives	Prakash and Barua (2015) and Badenhorst and Nel (2012)
S9	Develop infrastructure and facilities for supporting RL activities	Prakash and Barua (2015) and Badenhorst and Nel (2012)
S10	Implement green practices for electronic products	Prakash and Barua (2015)
S11	Develop and invest in RL technology	Prakash and Barua (2015) and Badenhorst (2016)
S12	Establish e-collaboration among supply chain members	Prakash and Barua (2015) and Badenhorst (2016)
S13	Develop closed loop supply chain by integrating RL	Prakash and Barua (2015)
S14	Establish outsourcing strategy to third parties for EoL products	Prakash and Barua (2015) and Badenhorst (2016)

2.1.2.4. Strategic collaboration with RL partners. Companies should combine all RL partners into their planning and strategy for RL practices and also create collaboration, improvement and development of business process with RL partners along the supply chain (Badenhorst & Nel, 2012; Prakash & Barua, 2015; PWC report, 2008). (See table 2).

2.1.2.5. Determined clear policies and processes. Companies should determine clear policies and process to effectively managed RL practices which depend on being properly designed and communicated to all partners (Badenhorst, 2016; Prakash & Barua, 2015; PWC report, 2008). (See table 2).

2.1.2.6. Implement return avoidance strategies. Companies should focus on return avoidance strategies to control the volume of returned products which can help companies increase the predictability and manageability of product returns (Badenhorst, 2016; Prakash & Barua, 2015; PWC report, 2008). (See table 2).

2.1.2.7. Determined RL as part of sustainability program. Companies need to determine RL as part of a sustainability program, as RL can reduce raw materials or other resources from reuse and recycle activities, reduce waste and environmental pollution and can create competitive advantage to organizations in customers' environmental perspectives (Prakash & Barua, 2015; PWC report, 2008). (See table 2).

2.1.2.8. Enforce environmental legislation, regulations, and directives. The government need to encourage, promote and enforce environmental legislation, regulations, and directives to all players within the supply chain to serve as a guideline for RL practices of supply chain members (Badenhorst & Nel, 2012; Prakash & Barua, 2015). (See table 2).

2.1.2.9. Develop infrastructure and facilities for supporting RL activities. Companies should improve and develop infrastructure and other facilities such as warehousing, transportation, material handling equipment, sorting factories, recycling factories, disposal areas, etc. in order to support RL activities (Badenhorst & Nel, 2012; Prakash & Barua, 2015). (See table 2).

2.1.2.10. Implement green practices for electronic products. Companies have to reduce hazardous materials, focus on design products with environmental friendly concepts and also use materials to create products that can be easily recycled or reused. The companies have to do business follow global standard of hazardous materials such as waste electrical and electronic equipment (WEEE), the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS), etc. (Prakash & Barua, 2015). (See table 2).

2.1.2.11. Develop and invest in RL technology. Develop and invest in RL technology for returned products, use return software and RL information management systems to communicate and integrate with supply chain partners and also create an effective recycling operation (Badenhorst, 2016; Prakash & Barua, 2015). (See table 2).

2.1.2.12. Establish e-collaboration among supply chain members. Using e-collaboration will create a more effective and efficient means of communication among supply chain members, and a fast, accurate and active response of RL activities (Badenhorst, 2016; Prakash & Barua, 2015). (See table 2).

2.1.2.13. Develop a closed loop supply chain by integrating RL. Companies need to integrate both forward logistics and RL to manage products, financial and information flow, and to increase an efficient and effective closed loop supply chain (Prakash & Barua, 2015). (See table 2).

2.1.2.14. Establish outsourcing strategy to third parties for EoL. Using 3PL can reduce costs of technology investment for RL practices as they can use their own resources and latest technology to manage EoL products, fast and with flexibility (Badenhorst, 2016; Prakash & Barua, 2015). (See table 2).

Fig. 1 illustrates the hierarchical structure of the ranking solutions of RL practices. It includes four levels; the first level is the overall goal that aims to rank the solutions of RL practices. The second level presents the classified main criteria of RL barriers. The third level presents the classified sub-criteria of RL barriers. Lastly the fourth level presents the classified solutions of RL practices.

2.2. Fuzzy AHP and fuzzy TOPSIS methods

Several studies applied fuzzy AHP and fuzzy TOPSIS methods to solve different situations and problems. Patil and Kant (2014) applied fuzzy AHP-TOPSIS to identify and prioritize the solutions of Knowledge Management (KM) adoption in Supply Chain to overcome its barriers in which the results can help organizations to concentrate on high rank solutions and develop strategies to implement them as priority. Sun (2010) proposed a performance evaluation model based on fuzzy AHP and fuzzy TOPSIS methods. Senthil, Srirangacharyulu, and Ramesh (2014) adopted a hybrid multi-criteria decision making method in which AHP and fuzzy TOPSIS were used for contractor evaluation and selection in third-party reverse logistics. Wang, Liu, Li, and Niu (2016) integrated OWA–TOPSIS framework in intuitionistic fuzzy settings for multiple attribute decision making problems. Yalcin, Bayrakdaroglu, and Kahraman (2012) applied fuzzy multi-criteria decision making methods in which fuzzy AHP, TOPSIS and VIKOR were used for financial performance evaluation of Turkish manufacturing industries.

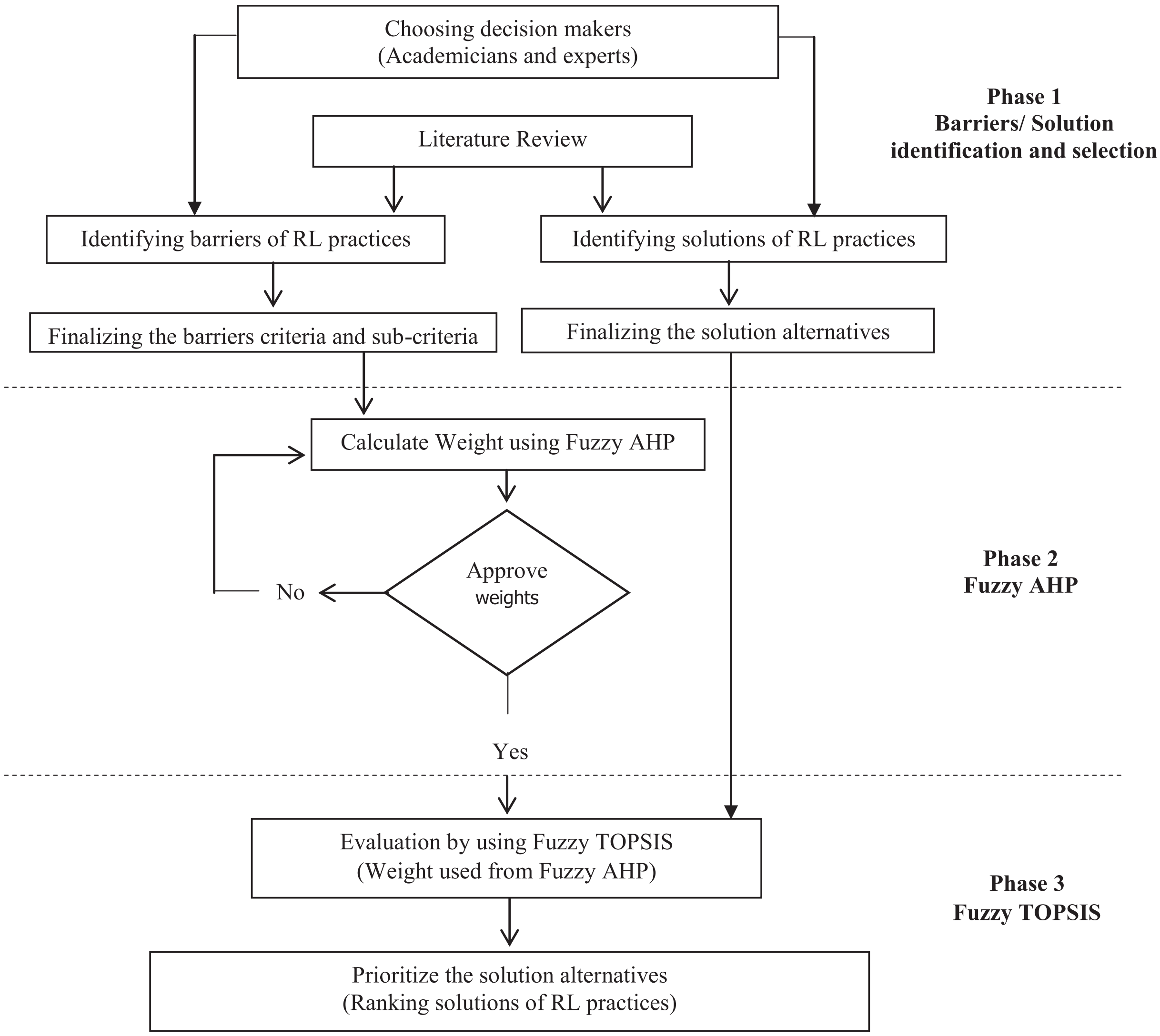

Fig. 1. Hierarchical structure of the ranking solutions of RL practices.

Awasthi, Chauhan, and Omrani (2011) used fuzzy TOPSIS to generate aggregate scores for sustainability assessment of transportation and selection of best alternative. Yang, Bonsall, and Wang (2011) adopted fuzzy TOPSIS for vessel selection under uncertain environment. Lee, Chen, and Kang (2011) used fuzzy AHP and ISM to analyze strategic products for photovoltaic silicon thin-film solar cell power industry. Wang and Lee (2009) proposed a new fuzzy TOPSIS for evaluating alternatives by integrating using subjective and objective weights. Gumus (2009) adopted fuzzy-AHP and TOPSIS to evaluate hazardous waste transportation firms. Javanbarg, Scawthorn, Kiyono, and Shahbodaghkhan (2012) presented particle swarm optimization (PSO) to solve multi criteria decision making (MCDM) systems based on a fuzzy AHP. Krohling and Campanharo (2011) applied fuzzy TOPSIS to evaluate the ratings of response alternatives to a simulated oil spill. Sindhu, Nehra, and Luthra (2017) used hybrid AHP-TOPSIS to investigation of feasibility study of solar farms deployment.

Wang, Fan, and Wang (2010) integrated fuzzy AHP, fuzzy preference programming (FPP) and TOPSIS methods to determine the relative weights of multiple evaluation criteria and synthesize the ratings of candidate aeroengines. Önüt, Kara, and Işik (2009) developed a supplier evaluation approach based on fuzzy ANP and fuzzy TOPSIS methods for a telecommunications company Kaya and Kahraman (2011) proposed multi-criteria decision making based on fuzzy TOPSIS in energy planning which was used to select the best energy technology alternative. Paksoy, Pehlivan, and Kahraman (2012) applied fuzzy AHP and fuzzy TOPSIS to the organization strategy of distribution channel management for an edible-vegetable oils manufacturing firm operating in Turkey. Ertuğrul and Karakaşoğlu (2009) adopted fuzzy AHP and TOPSIS for performance evaluation of Turkish cement firms. Rostamzadeh and Sofian (2011) applied fuzzy AHP and fuzzy TOPSIS to improve production systems performance. Amiri (2010) used AHP and fuzzy TOPSIS methods to project selection for oil-fields development in the National Iranian Oil Company. Yu, Guo, Guo, and Huang (2011) proposed an evaluation model for B2C e-commerce websites in e-alliance based on AHP and fuzzy TOPSIS. Kelemenis, Ergazakis, and Askounis (2011) applied fuzzy TOPSIS to support managers' selection in a large Greek IT firm. Dağdeviren, Yavuz, and Kılınç (2009) adopted AHP and TOPSIS methods under fuzzy environment to the weapon selection problem. Awasthi, Chauhan, Omrani, and Panahi (2011) used a hybrid approaches of SERVQUAL and fuzzy TOPSIS for evaluating transportation service quality. Zyoud, Kaufmann, Shaheen, Samhan, and Fuchs-Hanusch (2016) integrated fuzzy AHP and fuzzy TOPSIS for water loss management in developing countries. Mandic, Delibasic, Knezevic, and Benkovic (2014) proposed a fuzzy multi-criteria model for analyzing of the financial parameters of Serbian banks. Taylan, Bafail, Abdulaal, and Kabli (2014) proposed hybrid methods of fuzzy AHP and fuzzy TOPSIS for construction projects selection and risk assessment. Torfi, Farahani, and Rezapour (2010) proposed fuzzy AHP and fuzzy TOPSIS to evaluate the alternative options in respect to the user's preference orders. Mahdevari, Shahriar, and Esfahanipour (2014) applied fuzzy TOPSIS to evaluate human health and safety risks management in underground coal mines.

Vinodh, Prasanna, and Prakash (2014) integrated fuzzy AHP–-TOPSIS to determine the best method for recycling plastics among the various plastic recycling processes. Shidpour, Shahrokhi, and Bernard (2013) a multi-objective linear programming (MOLP) model integrated to fuzzy AHP and TOPSIS in order to optimize product design.

From the review of previous studies it was found that many researchers applied many kinds of multiple criteria decision-making (MCDM) methods and also used hybrid methods of MCDM to help the decision makers understand and have more concentration on the high rank of criteria and also provide the ranking of the best alternatives in different problems and situations. But only a few pieces of research adopted hybrid methods of fuzzy AHP and fuzzy TOPSIS to RL adaptation problems of the electronics industry. Therefore, the context of Thailand's electronics industry remains unstudied and unexplored. Hence, hybrid methods of fuzzy AHP and fuzzy TOPSIS were proposed to this research which focus on RL practices and implementation problems of Thailand's electronics industry which is presented in Section 4.

3. Materials and methods

In this study, three phase methodology has been applied for identifying, prioritizing and ranking both barriers and solutions. The first phase studied the current situation in the electronics industry of Thailand and identified RL practice barriers and solutions to solve these barriers. The second phase used fuzzy AHP to get weight of criteria and sub-criteria of barriers and prioritized barriers. The third phase applied fuzzy TOPSIS to prioritize and rank the solutions of RL practice. Even though decision making can be done by using fuzzy AHP, multi-criteria decision making process can be improved if it is integrated with other decision support tools (Prakash & Barua, 2015). Therefore, this study proposed hybrid methods of fuzzy AHP and fuzzy TOPSIS to ranking solutions of RL practices in which the research methodology of this study is illustrated in Fig. 2.

3.1. Phase 1: Identification of RL practices, barriers and solutions

In this phase, RL practices, barriers and solutions for RL practices have been identified and evaluated by experts, academicians and researchers through the relevant literature reviews in which the identified barriers and solutions were illustrated in Fig. 1.

3.2. Phase 2: Fuzzy AHP

Analytic hierarchy process (AHP) was first presented by Saaty (1980), it was multiple criteria decision-making methods which are one of the most extensively used and powerful methods to solve complex decision problems (Sun, 2010). Saaty's AHP has some limitations due to usability of AHP, such as the judgmental scale is unbalanced and absence of uncertainty; selection of judgment is subjective. Therefore, Fuzzy approach was used to solve such problems (Prakash & Barua, 2015).

Fuzzy AHP approach was presented by Chang (1996), triangular fuzzy number (TFN) are preferred for pairwise comparison scale of Fuzzy AHP and extent analysis method was used for the synthetic extent value of pairwise comparison.

Definition 1. A fuzzy number M on R to be TFN if its membership function $\mu_M(x)$: $R \rightarrow [0,1]$ is equal to following Eq. (1) (Chang, 1996)

$$\mu_M(x) = \begin{cases} \frac{(x-l)}{(m-l)} & x \in [l,m] \\ \frac{(x-u)}{(m-u)} & x \in [m,u] \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

From Eq. (1), $l \leqslant m \leqslant u$, which l and u mean the lower and upper value of fuzzy number M, and m is the modal value (as Fig. 3). TFN can be denoted by $M = (l,m,u)$. The operational laws of TFN $M_1 = (l_1,m_1,u_1)$ and $M_2 = (l_2,m_2,u_2)$ are shown as following Eqs. (2)–(6) (Chang, 1996); Sun, 2010; Prakash & Barua, 2015).

$$\begin{aligned} M_1 + M_2 &= (l_1,m_1,u_1) + (l_2,m_2,u_2) \\ &= (l_1 + l_2,m_1 + m_2,u_1 + u_2) \\ &\text{for } l_1,l_2 > 0;m_1,m_2 > 0;u_1,u_2 > 0 \end{aligned} \tag{2}$$

$$\begin{aligned} M_1 - M_2 &= (l_1,m_1,u_1) - (l_2,m_2,u_2) \\ &= (l_1 - u_2,m_1 - m_2,u_1 - l_2) \\ &\text{for } l_1,l_2 > 0;m_1,m_2 > 0;u_1,u_2 > 0 \end{aligned} \tag{3}$$

$$\begin{aligned} M_1 \times M_2 &= (l_1,m_1,u_1) \times (l_2,m_2,u_2) \\ &= (l_1 l_2,m_1 m_2,u_1 u_2) \\ &\text{for } l_1,l_2 > 0;m_1,m_2 > 0;u_1,u_2 > 0 \end{aligned} \tag{4}$$

$$\begin{aligned} M_1 \div M_2 &= (l_1,m_1,u_1)/(l_2,m_2,u_2) \\ &= (l_1/u_2,m_1/m_2,u_1/l_2) \\ &\text{for } l_1,l_2 > 0;m_1,m_2 > 0;u_1,u_2 > 0 \end{aligned} \tag{5}$$

$$\begin{aligned} M^{-1} &= (l_1,m_1,u_1)^{-1} \\ &= (l/u_1,l/m_1,l/l_1) \\ &\text{for } l_1,l_2 > 0;m_1,m_2 > 0;u_1,u_2 > 0 \end{aligned} \tag{6}$$

According to the method of extent analysis of Chang (1996).

$$M_{g_i}^1,M_{g_i}^2,M_{g_i}^3,\ldots,M_{g_i}^m \quad i = 1,2,3,4,5,\ldots,n \tag{7}$$

where all the M_{gi}^j $(j = 1,2,3,4,5,\ldots,m)$ are triangular fuzzy numbers given in Table 3.

The steps of Chang's analysis can be displayed as follows:

Step 1. The fuzzy judgment matrix $\widetilde{A}(a_{ij})$ can be expressed mathematically as in Eq. (8) (Efendigil, Önüt, & Kongar, 2008)

$$\widetilde{A} = \begin{Bmatrix} 1 & \widetilde{a}_{12} & \widetilde{a}_{13} & \cdots & \widetilde{a}_{1(n-1)} & \widetilde{a}_{1n} \\ \widetilde{a}_{21} & 1 & \widetilde{a}_{23} & \cdots & \widetilde{a}_{2(n-1)} & \widetilde{a}_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \widetilde{a}_{(n-1)1} & \widetilde{a}_{(n-1)2} & \widetilde{a}_{(n-1)3} & \cdots & 1 & \widetilde{a}_{(n-1)n} \\ \widetilde{a}_{n1} & \widetilde{a}_{n2} & \widetilde{a}_{n3} & \cdots & \widetilde{a}_{n(n-1)} & 1 \end{Bmatrix} \tag{8}$$

The judgment matrix $\widetilde{A}$ is an $n \times n$ fuzzy matrix containing fuzzy numbers $\widetilde{a}_{ij}$.

$$\widetilde{A}_{ij} = \begin{cases} 1, & i = j \\ 1,3,5,7,9 \text{ or } \ldots 1^{-1},3^{-1},5^{-1},7^{-1},9^{-1} & i \neq j \end{cases} \tag{9}$$

Step 2. The values of fuzzy synthetic extent with respect to i-th criterion is defined as:

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \times \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right] \tag{10}$$

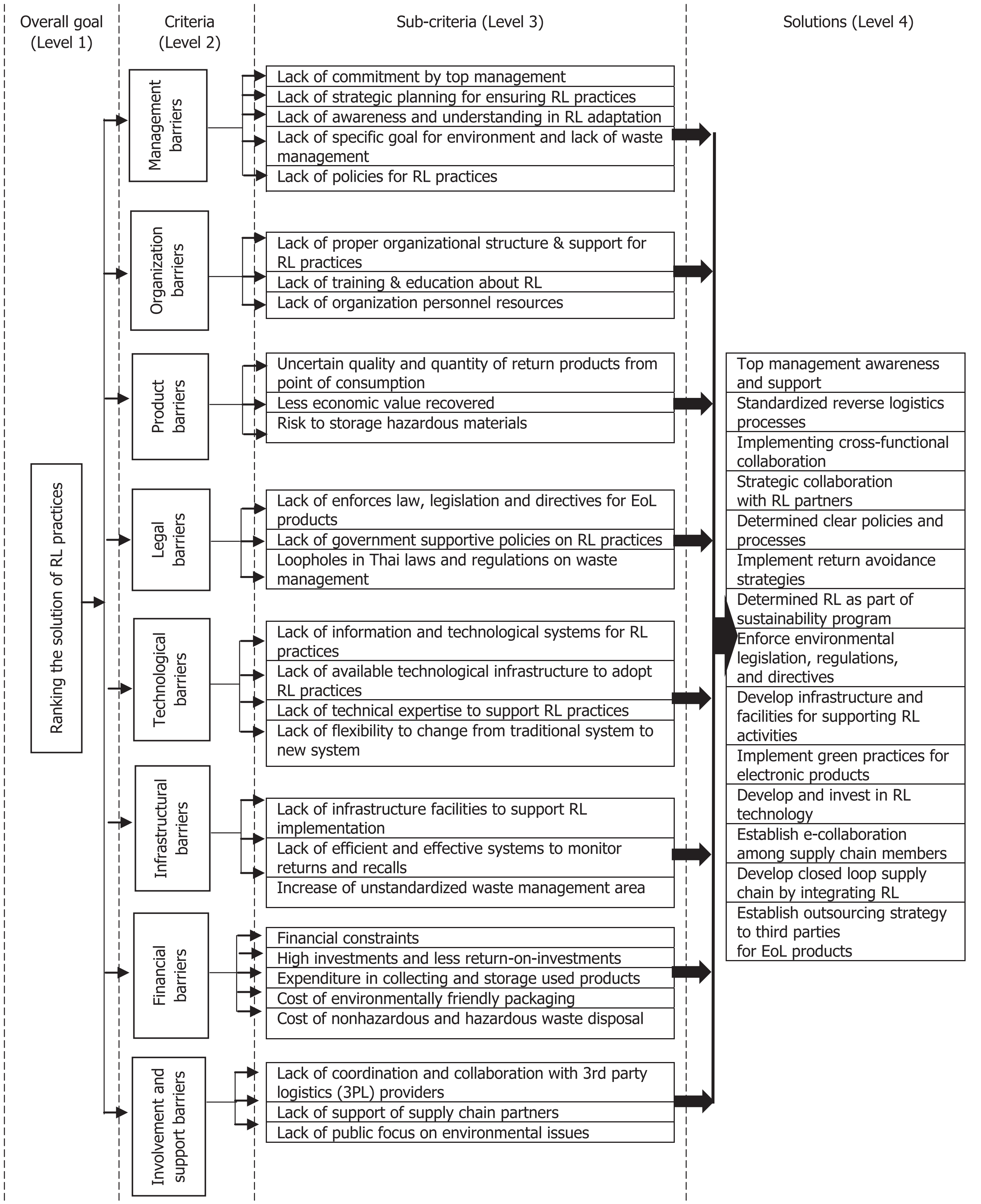

Fig. 2. Proposed research methodology for prioritizing the barriers and solutions of RL practices.

$$\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_{ij}, \sum_{j=1}^{m} m_{ij}, \sum_{j=1}^{m} u_{ij}\right)$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right] = \left(\frac{1}{\sum_{n}^{i=1}\sum_{m}^{j=1} u_{ij}}, \frac{1}{\sum_{n}^{i=1}\sum_{m}^{j=1} m_{ij}}, \frac{1}{\sum_{n}^{i=1}\sum_{m}^{j=1} l_{ij}}\right)$$

where l is the lower limit value, m is the most promising value and u is the upper limit value.

Step 3. The degree of possibility of $M_2 = (l_2,m_2,u_2) \geqslant M_1 = (l_1,m_1,u_1)$ can be defined as:

$$V(M_2 \geqslant M_1) = hgt(M_2 \cap M_1) = \mu(d)$$

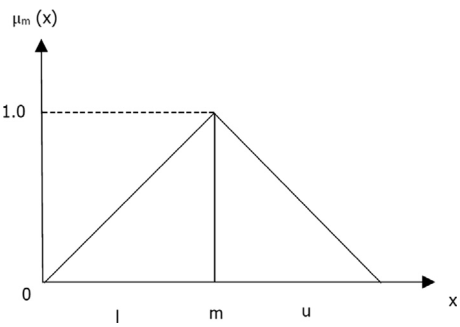

Fig. 3. The membership functions of TFN.

Table 3
Linguistic variables and triangular fuzzy numbers for criteria and sub-criteria ratings.

Fuzzy number	Linguistic variables	Triangular fuzzy numbers
$\tilde{9}$	Extreme importance	(8, 9, 10)
$\tilde{8}$	Very strong to Extreme importance	(7, 8, 9)
$\tilde{7}$	Very strong importance	(6, 7, 8)
$\tilde{6}$	Strong to very strong importance	(5, 6, 7)
$\tilde{5}$	Strong importance	(4, 5, 6)
$\tilde{4}$	Moderate to strong importance	(3, 4, 5)
$\tilde{3}$	Moderate importance	(2, 3, 4)
$\tilde{2}$	Equal to moderate importance	(1, 2, 3)
$\tilde{1}$	Equal importance	(1, 1, 1)

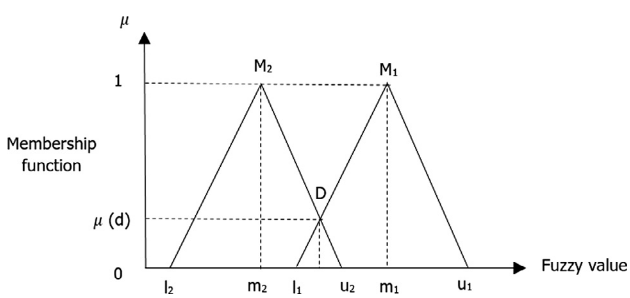

Fig. 4. The intersection between two fuzzy numbers.

Table 4
Linguistic variables and triangular fuzzy numbers for solutions ratings.

Fuzzy number	Linguistic variables	Triangular fuzzy numbers
$\tilde{6}$	Excellent (E)	(6, 7, 8)
$\tilde{5}$	Very high (VH)	(5, 6, 7)
$\tilde{4}$	High (H)	(4, 5, 6)
$\tilde{3}$	Medium(M)	(3, 4, 5)
$\tilde{2}$	Low (L)	(2, 3, 4)
$\tilde{1}$	Very Low (VL)	(1, 2, 3)

$$= \begin{cases} 1 & \text{if } m_2 \geqslant m_1 \\ 0 & \text{if } l_2 \geqslant u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2)(m_1 - l_1)} & \text{otherwise} \end{cases} \quad (11)$$

where μd is the highest intersection between two fuzzy (see Fig. 4)

To compare between M_1 and M_2 it is required to compute both $V(M_2 \geqslant M_1)$ and $V(M_1 \geqslant M_2)$. The degree of possibility for convex fuzzy numbers to be greater than k convex fuzzy numbers $M_i (i = 1,2,3,...,k)$ can be defined as:

$$V(M \geqslant M_1,M_2,...,M_k) = V[(M \geqslant M_1),(M \geqslant M_2),...,(M \geqslant M_k)] = \min V(M \geqslant M_1), \quad i = 1,2,3,...,k \quad (12)$$

By assuming that $d'(A_i) = \min V(S_i \geqslant S_k)$

For $k = 1,2,3,4,5,...,n (k \neq i)$, Then the weight vector is given by

$$W' = (d'(A_1),d'(A_2),...,d'(A_n))^T \quad (13)$$

where $A_i (i = 1,2,3,4,5,...,n)$ are n elements.

Step 4. Via normalization, the normalized weight vectors are given by

$$W = (d(A_1),d(A_2),...,d(A_n))^T \quad (14)$$

where W is a non-fuzzy number.

3.3. Phase 3: Fuzzy TOPSIS

TOPSIS is one of the multiple criteria decision making methods (MCDM), proposed by Hwang and Yoon (1981). It is widely used for ranking problems. The selective attribute should be at the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution (Prakash & Barua, 2015; Zyoud et al., 2016). TOPSIS method has some limitations in capturing the vagueness of data under fuzzy environment (Kannan et al., 2014), which Yu (2002) stated that fuzziness and vagueness are characteristics of many decision-making problems. Hence, under fuzzy environment could be effected to an uncertainty of the decision making process. Therefore, fuzzy TOPSIS method was proposed and it is quite appropriate and effective more than conventional TOPSIS method to solve multi criteria decision making problems under fuzzy environment and to manage with uncertainty in the judgments and evaluations of the decision makers. (Kannan et al., 2014; Prakash & Barua, 2015).

The steps of fuzzy TOPSIS method used in this study, according to Sun (2010), Prakash and Barua (2015), Kannan et al. (2014) can be given as in the following:

Step 1. Determine rating value for the linguistic variables with the respective criteria and scale used for rating is given in Table 4, and in order to determine weight of evaluation criteria, this study applied fuzzy AHP to find the fuzzy preference weight.

Step 2. Construct the fuzzy performance/matrix for alternatives by considering a group of k decision makers $(D_1,D_2,D_3,...,D_k)$ containing m alternatives $(A_1,A_2,A_3,...,A_m)$ and n criteria $(C_1,C_2,C_3,...,C_n)$

Table 5
Fuzzy decision matrix of criteria.

	MB	OB	PB	LB	TB	IB	FB	ISB	Weight	Rank
MB	(1, 1, 1)	(0.14, 0.17, 0.20)	(4, 5, 6)	…	…	…	(3, 4, 5)	(0.13, 0.14, 0.17)	0.1244	5
OB	(5, 6, 7)	(1, 1, 1)	(0.14, 0.17, 0.20)	…	…	…	(4, 5, 6)	(0.14, 0.17, 0.20)	0.1257	3
PB	(0.17, 0.20, 0.25)	(5, 6, 7)	(1, 1, 1)	…	…	…	(5, 6, 7)	(0.14, 0.17, 0.20)	0.1252	4
LB	…	…	…	…	…	…	…	…	0.1243	6
TB	…	…	…	…	…	…	…	…	0.1269	1
IB	…	…	…	…	…	…	…	…	0.1234	8
FB	(0.20, 0.25, 0.33)	(0.17, 0.20, 0.25)	(0.14, 0.17, 0.20)	…	…	…	(1, 1, 1)	(0.13, 0.14, 0.17)	0.1240	7
ISB	(6, 7, 8)	(5, 6, 7)	(5, 6, 7)	…	…	…	(6, 7, 8)	(1, 1, 1)	0.1261	2

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \dots & C_n \end{array} \\ \begin{pmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{pmatrix} \end{array} \quad (15)$$

where r_{mn} is the rating of alternative A_m with respect to criterion C_n

Step 3. Aggregate fuzzy rating for the solutions

Fuzzy rating of the Nth decision maker $\widetilde{X}_{abN} = (l_{abN},p_{abN},u_{abN})$ where $a = 1,2,3,4,5,...,m$ and $b = 1,2,3,4,5,...,n$ then the fuzzy aggregated fuzzy rating $\widetilde{X}_{ab}$ of solutions with respect to each criteria is given by $\widetilde{X}_{ab} = (l_{ab},p_{ab},u_{ab})$, where

$$a = \frac{\min}{N}\{l_{abN}\},b = \frac{1}{N}\sum_{n=1}^{N} p_{abN},c = \frac{\max}{N}\{u_{abN}\} \quad (16)$$

Step 4. Normalized fuzzy decision matrix

The normalized fuzzy decision matrix denoted by $\widetilde{B}$ is defined as follows:

$$\widetilde{B} = [p_{ij}]_{m\times n} \quad (17)$$

where $i = 1,2,3,4,5,...,m$ and $j = 1,2,3,4,5,...,n$

$$\widetilde{p} = \left(\frac{a_{ij}}{c_j^*},\frac{b_{ij}}{c_j^*},\frac{c_{ij}}{c_j^*}\right) \text{ and } c_j^* = \max c_{ij} \text{ (benefit criteria)} \quad (18)$$

$$\widetilde{p} = \left(\frac{a_j^-}{c_{ij}},\frac{a_j^-}{b_{ij}},\frac{a_j^-}{a_{ij}}\right) \text{ and } a_j^- = \min a_{ij} \text{(cost criteria)} \quad (19)$$

Step 5. Weighted fuzzy normalized decision matrix is shown as follows:

$$\widetilde{V} = [\widetilde{v}_{ij}]_{m\times n} \quad i = 1,2,3,...,m \text{ and } j = 1,2,3,...,n$$
$$\text{where } \widetilde{V} = \widetilde{p}_{ij} \times w_j \quad (20)$$

Step 6. Determine the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS) as per the following formula:

$$A^+ = \{v_1^+,...,v_n^+\}, \text{ where } v_j^+ = \{\max(v_{ij}) \text{ if } j\in J;\min(v_{ij}) \text{ if } j\in J'\},$$
$$j = 1,2,3,4,5,...,n \quad (21)$$

$$A^- = \{v_1^-,...,v_n^-\}, \text{ where } v_j^- = \{\min(v_{ij}) \text{ if} j\in J;\max(v_{ij}) \text{ if } j\in J'\},$$
$$j = 1,2,3,4,5,...,n \quad (22)$$

Step 7. Calculate the distance of each alternative from FPIS and FNIS

The calculation of distance ($\widetilde{d}_i^+$ and $\widetilde{d}_i^-$) of each alternative from $A^+$and A^- is computed as follows:

$$d_i^+ = \left\{\sum_{j=1}^{n} (v_{ij}-v_{ij}^+)^2\right\}^{1/2},i = 1,...,m$$
$$d_i^- = \left\{\sum_{j=1}^{n} (v_{ij}-v_{ij}^-)^2\right\}^{1/2},i = 1,...,m \quad (23)$$

Step 8. Calculate the closeness coefficient (CC_i) of each alternative by using the following eq:

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+},i = 1,...,m. \quad C_i \in (0,1) \quad (24)$$

Step 9. Find the ranks of alternatives

The alternatives are ranked by their CC_i to the ideal solution in descending order.

4. Application of the proposed model for RL practices in Thailand's electronics industry

4.1. Problems description

Thailand's electronics companies have implemented more RL practices to their business processes due to an increasing awareness of the importance of RL practices which can achieve greater benefits for the organizations. But there are only a few businesses that have been successful with RL practices adaptation due to fact they are faced with various barriers in their implementation. Hence, to solve these barriers the companies need to understand and consider the high ranking of barriers which effected RL practices implementation and also focus on the high ranking of solutions to overcome these barriers.

Therefore, in this study a three-phase methodology is utilized to prioritize and rank barriers and solutions of RL practices in the electronics industry of Thailand and the methodology is explained as follows:

4.2. Phase 1: Identification of RL barriers and solutions

The decision makers were selected which comprise of 10 academic experts. In this study, 8 criteria and 29 sub-criteria were used for prioritizing RL barriers (see Table 1) and 14 solutions to solve these barriers are identified through the literature review (see Table 2).

4.3. Phase 2: Calculate weight of barriers of RL practices by using fuzzy AHP

Decision makers evaluate criteria and sub-criteria by using TFN as given in Table 3. The fuzzy decision matrix and fuzzy aggregated decision matrix of criteria and sub-criteria with calculated weight are given in Tables 5–14.

Fuzzy synthetic extent of 8 criteria are shown in Table 15 by using Eq. (10). The calculations of degree of possibility of criteria (V-values) are given in Table 16 by using Eq. (11) then using Eq. (12) to determine minimum values of degree of possibility are given below:

$$d'(MB) = \min V(S_1 = S_k) = \min(0.991,0.994,1,0.980,1,1,0.987) = 0.980$$

For other criteria using the same process $d'(OB) = 0.990,d'(PB) = 0.987,d'(LB) = 0.980,d'(TB) = 1,d'(IB) = 0.973,d'(FB) = 0.977,d'(ISB) = 0.994.$

The weight vector of each criteria is given by

$$W' = (0.980,0.990,0.987,0.980,1,0.973,0.977,0.994)^T$$

Via normalization of weight vector, the final weight vector obtained as

$$W = (0.1244,0.1257,0.1252,0.1243,0.1269,0.1234,0.1240,0.1261)$$

Due to the same process of weight calculation, the weights of remaining criteria and the final results of pairwise comparison of criteria and sub-criteria also illustrated in Table 17.

Table 6
Calculated fuzzy aggregated decision matrix of criteria.

	MB	OB	PB	LB	TB	IB	FB	ISB	Weight	Rank
MB	(1, 1, 1)	(0.10, 1.20, 6)	(0.11, 2.60, 7)	…	…	…	(0.13, 2.85, 7)	(0.10, 1.13, 6)	0.1244	5
OB	(0.17, 3.95, 10)	(1, 1, 1)	(0.13, 2.09, 7)	…	…	…	(0.13, 2.73, 7)	(0.13, 3, 10)	0.1257	3
PB	(0.14, 2.21, 9)	(0.14, 3.05, 8)	(1, 1, 1)	…	…	…	(0.13, 3.56, 7)	(0.14, 2.17, 6)	0.1252	4
LB	…	…	…	…	…	…	…	…	0.1243	6
TB	…	…	…	…	…	…	…	…	0.1269	1
IB	…	…	…	…	…	…	…	…	0.1234	8
FB	(0.14, 1.40, 8)	(0.14, 1.61, 8)	(0.14, 1.15, 8)	…	…	…	(1, 1, 1)	(0.10, 1.87, 9)	0.1240	7
ISB	(0.17, 3.75, 10)	(0.10, 2.20, 8)	(0.17, 1.85, 7)	…	…	…	(0.11, 3.87, 10)	(1, 1, 1)	0.1261	2

Table 7
Calculated fuzzy aggregated decision matrix of sub-criteria (MB).

	MB1	MB2	MB3	MB4	MB5	Weight	Rank
MB1	(1, 1, 1)	(2, 6.30, 10)	(4, 7.70, 10)	(4, 7.50, 10)	(1, 5.80, 10)	0.231	1
MB2	(0.10, 0.19, 0.50)	(1, 1, 1)	(0.13, 3.84, 10)	(0.11, 4.05, 10)	(0.13, 1.92, 10)	0.200	3
MB3	(0.10, 0.13, 0.25)	(0.10, 1.41, 8)	(1, 1, 1)	(0.10, 1.61, 9)	(0.10, 0.35, 3)	0.174	5
MB4	(0.10, 0.14, 0.25)	(0.10, 1.35, 9)	(0.11, 3.83, 10)	(1, 1, 1)	(0.10, 0.85, 7)	0.189	4
MB5	(0.10, 0.33, 1)	(0.10, 3.36, 8)	(0.33, 5.95, 10)	(0.14, 5.02, 10)	(1, 1, 1)	0.206	2

Table 8
Calculated fuzzy aggregated decision matrix of sub-criteria (OB).

	OB1	OB2	OB3	Weight	Rank
OB1	(1, 1, 1)	(0.14, 3.77, 10)	(1, 4.20, 10)	0.360	1
OB2	(0.10, 1.12, 7)	(1, 1, 1)	(0.17, 3.55, 10)	0.343	2
OB3	(0.10, 0.46, 1)	(0.10, 1.25, 6)	(1, 1, 1)	0.297	3

Table 9
Calculated fuzzy aggregated decision matrix of sub-criteria (PB).

	PB1	PB2	PB3	Weight	Rank
PB1	(1, 1, 1)	(0.13, 4.25, 10)	(0.10, 2.08, 7)	0.337	2
PB2	(0.10, 1.18, 8)	(1, 1, 1)	(0.10, 1.63, 8)	0.324	3
PB3	(0.14, 3.45, 10)	(0.13, 3.43, 10)	(1, 1, 1)	0.339	1

Table 10
Calculated fuzzy aggregated decision matrix of sub-criteria (LB).

	LB1	LB2	LB3	Weight	Rank
LB1	(1, 1, 1)	(0.10, 1.26, 10)	(0.10, 0.18, 0.50)	0.301	3
LB2	(0.10, 4.21, 10)	(1, 1, 1)	(0.13, 3.24, 10)	0.347	2
LB3	(2, 6.10, 10)	(0.10, 2.35, 8)	(1, 1, 1)	0.352	1

4.4. Phase 3: Ranking solutions for RL practices by using fuzzy TOPSIS

The decision maker evaluated rating of linguistics variables matrix for solutions of RL practices by using linguistic variables and triangular fuzzy numbers are given in Table 4 in which TFN evaluation matrix of the solutions are represented in Table 18. Then Eq. (16) is used to calculate aggregate fuzzy decision matrix of solutions and the results are given in Table 19. Due to the benefit or cost criteria by following Eqs. (18) and (19), this study considered all of the barriers criteria as cost criteria. Hence, Eq. (19) was used to normalize fuzzy decision matrix of solutions as shown in Table 20. To calculate weight fuzzy normalized decision matrix for solutions, weights obtained from using fuzzy AHP method in Phase 2 (see Table 17) were used to calculate using Eq. (20) as given in Table 21. As this study considered barriers criteria as cost criteria, it is defined the fuzzy positive ideal solution (FPIS) as $A^{+}(0,0,0)$ and fuzzy negative ideal solution (FNIS) as $A^{-}(1,1,1)$ then the distance from FPIS and FNIS were calculated by using Eq. (23) and the closeness coefficient can be obtained with Eq. (24) which is shown in Table 22. Therefore, the CC_i values were used in final ranking of solutions for RL practices.

Table 12
Calculated fuzzy aggregated decision matrix of sub-criteria (IB).

	IB1	IB2	IB3	Weight	Rank
IB1	(1, 1, 1)	(0.11, 1.93, 10)	(0.10, 0.29, 1)	0.310	3
IB2	(0.10, 3.96, 9)	(1, 1, 1)	(0.10, 2.60, 10)	0.340	2
IB3	(1, 5.30, 10)	(0.10, 4.07, 10)	(1, 1, 1)	0.350	1

5. Result and discussions

The hybrid fuzzy AHP and fuzzy TOPSIS methods made it more systematic and helpful for the decision maker to choose the best alternative from RL practices barriers and solutions to solve its barriers by prioritizing and ranking processes due to the difficulty of comparison of

Table 11
Calculated fuzzy aggregated decision matrix of sub-criteria (TB).

	TB1	TB2	TB3	TB4	Weight	Rank
TB1	(1, 1, 1)	(0.10, 2.86, 8)	(0.10, 3.53, 9)	(0.14, 3.20, 10)	0.259	2
TB2	(0.13, 2.90, 10)	(1, 1, 1)	(1, 4.80, 10)	(1, 4.30, 10)	0.264	1
TB3	(0.11, 1.93, 10)	(0.10, 0.38, 1)	(1, 1, 1)	(0.25, 3.17, 10)	0.248	3
TB4	(0.10, 1.46, 7)	(0.10, 0.40, 1)	(0.10, 1.06, 4)	(1, 1, 1)	0.229	4

Table 13
Calculated fuzzy aggregated decision matrix of sub-criteria (FB).

	FB1	FB2	FB3	FB4	FB5	Weight	Rank
FB1	(1, 1, 1)	(0.11, 2.23, 9)	(0.11, 1.63, 9)	(0.11, 1.53, 9)	(0.10, 1.61, 9)	0.198	5
FB2	(0.11, 3.15, 9)	(1, 1, 1)	(0.14, 2.72, 9)	(0.13, 3.65, 9)	(0.10, 2.01, 9)	0.201	2
FB3	(0.11, 3.48, 9)	(0.11, 1.97, 7)	(1, 1, 1)	(0.11, 3.05, 8)	(0.11, 1.02, 6)	0.1987	4
FB4	(0.11, 3.74, 9)	(0.11, 2.13, 8)	(0.13, 1.50, 9)	(1, 1, 1)	(0.11, 1.30, 9)	0.1988	3
FB5	(0.11, 3.93, 10)	(0.11, 3.70, 10)	(0.17, 3.97, 9)	(0.11, 4.16, 9)	(1, 1, 1)	0.204	1

Table 14
Calculated fuzzy aggregated decision matrix of sub-criteria (ISB).

	ISB1	ISB2	ISB3	Weight	Rank
ISB1	(1, 1, 1)	(0.13, 2.85, 9)	(0.11, 0.83, 4)	0.325	2
ISB2	(0.11, 2.07, 8)	(1, 1, 1)	(0.11, 0.98, 6)	0.324	3
ISB3	(0.25, 4.77, 9)	(0.17, 4.67, 9)	(1, 1, 1)	0.352	1

which one is more important than the other. This approach was used in RL practices implementation of Thailand's electronics industry to improve and develop RL practices implementation in the electronic business supply chain. It also encourages an awareness of the benefits of RL practices to the organization and reduces the environmental impact. The highest weightage value used to consider the most important RL practices barriers which were represented such that TB > ISB > OB > PB > MB > LB > FB > IB which is given in Tables 5 and 6. It is shown that technological barriers are the most important barrier for RL practices implementation.

Sub-criteria in this study represented that technological barriers sub-criteria are TB2 > TB1 > TB3 > TB4 (Table 11), which show a lack of available technological infrastructure to adopt RL practices is the highest weightage barrier and lack of flexibility to change from traditional system to new system is the lowest weightage barrier of all technological barriers. Ranking value of involvement and support barriers are ISB3 > ISB1 > ISB2 (Table 14) respectively, in which lack of public focus on environmental issues is the highest weightage barrier. Organization barriers ranking value are OB1 > OB2 > OB3 (Table 8) respectively, in which lack of proper organizational structure and support for RL practices is the highest weightage barrier. Product barriers ranking value are PB3 > PB1 > PB2 (Table 9) respectively, in which risk of storage of hazardous materials is the highest weightage

Table 17
Final Ranking of RL barriers practices.

Criterion	Weight	Sub-criteria	Weight	Finalized weight	Global rank
Management Barriers	0.124	MB1	0.231	0.02869	20
		MB2	0.200	0.02484	24
		MB3	0.174	0.02168	29
		MB4	0.189	0.02351	28
		MB5	0.206	0.02564	21
Organization Barriers	0.126	OB1	0.360	0.04525	1
		OB2	0.343	0.04313	6
		OB3	0.297	0.03729	15
Product barriers	0.125	PB1	0.337	0.04220	8
		PB2	0.324	0.04056	12
		PB3	0.339	0.04246	7
Legal barriers	0.124	LB1	0.301	0.03737	14
		LB2	0.347	0.04318	5
		LB3	0.352	0.04375	3
Technological barriers	0.127	TB1	0.259	0.03287	17
		TB2	0.264	0.03347	16
		TB3	0.248	0.03147	18
		TB4	0.229	0.02907	19
Infrastructural barriers	0.123	IB1	0.310	0.03828	13
		IB2	0.340	0.04195	9
		IB3	0.350	0.04322	4
Financial barriers	0.124	FB1	0.198	0.02453	27
		FB2	0.201	0.02491	23
		FB3	0.199	0.02464	26
		FB4	0.199	0.02465	25
		FB5	0.204	0.02527	22
Involvement and support barriers	0.126	ISB1	0.325	0.04093	10
		ISB2	0.324	0.04082	11
		ISB3	0.352	0.04436	2

Table 15
Values of fuzzy synthetic extent of criteria.

MB	=	(1.77, 16.00, 52)	x	(1/463, 1/143.48, 1/15.80)	=	(0.004, 0.111, 3.292)
OB	=	(1.88, 20.47, 58)	x	(1/463, 1/143.48, 1/15.80)	=	(0.004, 0.143, 3.672)
PB	=	(1.90, 18.93, 55)	x	(1/463, 1/143.48, 1/15.80)	=	(0.004, 0.132, 3.482)
LB	=	(1.90, 14.25, 60)	x	(1/463, 1/143.48, 1/15.80)	=	(0.004, 0.099, 3.799)
TB	=	(1.85, 25.54, 68)	x	(1/463, 1/143.48, 1/15.80)	=	(0.004, 0.178, 4.305)
IB	=	(1.83, 12.92, 50)	x	(1/463, 1/143.48, 1/15.80)	=	(0.004, 0.090, 3.165)
FB	=	(1.88, 13.29, 58)	x	(1/463, 1/143.48, 1/15.80)	=	(0.004, 0.093, 3.672)
ISB	=	(2.79, 22.09, 62)	x	(1/463, 1/143.48, 1/15.80)	=	(0.006, 0.154, 3.925)

Table 16
Calculated degree of possibility of criteria (V-values).

	MB	OB	PB	LB	TB	IB	FB	ISB
MB	–	0.991	0.994	1	0.980	1	1	0.987
OB	1	–	1	1	0.990	1	1	0.997
PB	1	0.997	–	1	0.987	1	1	0.994
LB	0.997	0.989	0.991	–	0.980	1	1	0.986
TB	1	1	1	1	–	1	1	1
IB	0.993	0.984	0.987	0.997	0.973	–	0.999	0.980
FB	0.995	0.987	0.989	0.998	0.977	1	–	0.984
ISB	1	1	1	1	0.994	1	1	–

Table 18
TFN evaluations matrix of solutions.

	MB1	MB2	MB3	…	…	ISB1	ISB2	ISB3
S1	(6, 7, 8)	(6, 7, 8)	(6, 7, 8)	…	…	(6, 7, 8)	(6, 7, 8)	(6, 7, 8)
S2	(4, 5, 6)	(6, 7, 8)	(6, 7, 8)	…	…	(6, 7, 8)	(6, 7, 8)	(4, 5, 6)
S3	(4, 5, 6)	(6, 7, 8)	(6, 7, 8)	…	…	(5, 6, 7)	(6, 7, 8)	(4, 5, 6)
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
S13	(6, 7, 8)	(5, 6, 7)	(6, 7, 8)	…	…	(6, 7, 8)	(6, 7, 8)	(6, 7, 8)
S14	(3, 4, 5)	(3, 4, 5)	(3, 4, 5)	…	…	(2, 3, 4)	(2, 3, 4)	(2, 3, 4)

Table 19
Calculated aggregate fuzzy decision matrix of solutions.

	MB1	MB2	MB3	…	…	ISB1	ISB2	ISB3
S1	(5, 7, 8)	(5, 7, 8)	(2, 6, 8)	…	…	(1, 6, 8)	(5, 6, 8)	(1, 6, 8)
S2	(1, 5, 8)	(2, 5, 8)	(2, 5, 8)	…	…	(2, 6, 8)	(1, 5, 8)	(2, 5, 8)
S3	(1, 5, 8)	(3, 6, 8)	(3, 6, 8)	…	…	(2, 6, 8)	(2, 6, 8)	(1, 5, 8)
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
S13	(1, 5, 8)	(2, 6, 8)	(3, 6, 8)	…	…	(3, 6, 8)	(3, 6, 8)	(1, 5, 8)
S14	(1, 4, 8)	(1, 4, 8)	(1, 4, 8)	…	…	(1, 4, 6)	(1, 4, 6)	(1, 3, 6)

barrier. Management barriers ranking value are MB1 > MB5 > MB2 > MB4 > MB3 (Table 7), in which lack of commitment by top management is the highest weightage barrier and lack of awareness and understanding in RL adaptation is the lowest weightage barrier of all management barriers. Legal barriers ranking value are LB3 > LB2 > LB1 (Table 10) respectively, in which loopholes in Thai laws and regulations on waste management is the highest weightage barrier. Similarly, financial barriers ranking value are FB5 > FB2 > FB4 > FB3 > FB1 (Table 13), in which cost of nonhazardous and hazardous waste disposal is the highest weightage barrier and financial constraints is the lowest weightage barrier of the financial barriers. Finally, infrastructural barriers ranking value are IB3 > IB2 > IB1 (Table 12) respectively, in which increase of unstandardized waste management area is the highest weightage barrier.

To solve these barriers, ranking of solutions for RL practices barriers have been suggested to the decision makers to make the best alternative for solutions due to the fact that as mentioned above. Hence, the highest CC_i value were used to consider for ranking of solutions.

The CC_i values are S1 > S7 > S11 > S5 > S3 > S9 > S4 > S13 > S8 > S2 > S6 > S10 > S12 > S14 respectively, which is given in Table 22. The highest CC_i value is top management awareness and support and the lowest CC_i value is establish outsourcing strategies to third parties for EoL products. When we converted linguistic variable to fuzzy number (see Table 4) and

Table 20
Normalized fuzzy decision matrix of solutions.

	MB1	MB2	MB3	…	…	ISB1	ISB2	ISB3
S1	(0.13, 0.15, 0.20)	(0.13, 0.15, 0.20)	(0.13, 0.17, 0.50)	…	…	(0.13, 0.17, 1)	(0.13, 0.16, 0.20)	(0.13, 0.17, 1)
S2	(0.13, 0.22, 1)	(0.13, 0.20, 1)	(0.13, 0.19, 0.50)	…	…	(0.13, 0.17, 0.50)	(0.13, 0.20, 1)	(0.13, 0.20, 0.50)
S3	(0.13, 0.21, 1)	(0.13, 0.16, 0.33)	(0.13, 0.17, 0.33)	…	…	(0.13, 0.18, 0.50)	(0.13, 0.18, 0.50)	(0.13, 0.22, 1)
…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…
S13	(0.13, 0.21, 1)	(0.13, 0.17, 0.50)	(0.13, 0.17, 0.33)	…	…	(0.13, 0.18, 0.33)	(0.13, 0.18, 0.33)	(0.13, 0.20, 1)
S14	(0.13, 0.26, 1)	(0.13, 0.24, 1)	(0.13, 0.23, 1)	…	…	(0.17, 0.28, 1)	(0.17, 0.28, 1)	(0.17, 0.29, 1)

Table 21
Weighted normalized fuzzy decision matrix of solutions.

	MB1	MB2	MB3	…	ISB1	ISB2	ISB3
S1	(0.004, 0.004, 0.006)	(0.003, 0.004, 0.005)	(0.003, 0.004, 0.011)	…	(0.005, 0.007, 0.041)	(0.005, 0.006, 0.008)	(0.006, 0.008, 0.044)
S2	(0.004, 0.006, 0.029)	(0.003, 0.005, 0.025)	(0.003, 0.004, 0.011)	…	(0.005, 0.007, 0.020)	(0.005, 0.008, 0.041)	(0.006, 0.009, 0.022)
S3	(0.004, 0.006, 0.029)	(0.003, 0.004, 0.008)	(0.003, 0.004, 0.007)	…	(0.005, 0.007, 0.020)	(0.005, 0.007, 0.020)	(0.006, 0.010, 0.044)
…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…
S13	(0.004, 0.006, 0.029)	(0.003, 0.004, 0.012)	(0.003, 0.004, 0.007)	…	(0.005, 0.007, 0.014)	(0.005, 0.007, 0.014)	(0.006, 0.009, 0.044)
S14	(0.004, 0.008, 0.029)	(0.003, 0.006, 0.025)	(0.003, 0.005, 0.022)	…	(0.007, 0.011, 0.041)	(0.007, 0.011, 0.041)	(0.007, 0.013, 0.044)

Table 22
Closeness coefficient (CC_i) and final ranking of the solutions for RL practices.

Code	Solutions	D+	D-	CCi	Rank
S1	Top management awareness and support	0.7592	49.6431	0.98494	1
S2	Standardized reverse logistics processes	0.9156	49.5338	0.98185	10
S3	Implementing cross-functional collaboration	0.8652	49.5541	0.98284	5
S4	Strategic collaboration with RL partners	0.8757	49.5591	0.98264	7
S5	Determined clear policies and processes	0.8416	49.5857	0.98331	4
S6	Implement return avoidance strategies	0.9426	49.5099	0.98132	11
S7	Determined RL as part of sustainability program	0.7935	49.6206	0.98426	2
S8	Enforce environmental legislation, regulations, and directives	0.8909	49.5323	0.98233	9
S9	Develop infrastructure and facilities for supporting RL activities	0.8717	49.5491	0.98271	6
S10	Implement green practices for electronic products	0.9446	49.4959	0.98127	12
S11	Develop and invest in RL technology	0.8291	49.5770	0.98355	3
S12	Establish e-collaboration among supply chain members	0.9504	49.5011	0.98116	13
S13	Develop closed loop supply chain by integrating RL	0.8857	49.5548	0.98244	8
S14	Establish outsourcing strategies to third parties for EoL products	1.0173	49.4387	0.97984	14

Table 23
Total scores of fuzzy numbers.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
MB1	57	36	37	37	43	40	45	42	31	33	31	30	38	28
MB2	56	41	51	53	51	55	54	39	37	37	35	43	48	32
MB3	50	43	50	49	43	44	52	37	38	41	43	47	49	33
MB4	49	49	47	45	45	40	46	43	46	48	41	41	42	33
MB5	56	39	40	40	51	41	48	45	42	37	34	33	37	32
OB1	58	43	49	42	50	36	51	27	43	32	34	31	41	26
OB2	54	41	34	40	42	30	47	27	33	26	32	32	45	33
OB3	53	40	47	40	39	35	47	28	33	26	27	35	38	26
PB1	37	45	33	45	44	41	48	34	32	35	38	40	48	33
PB2	40	46	35	42	43	40	46	31	31	35	38	39	46	31
PB3	41	45	31	39	38	38	44	43	31	33	32	35	46	37
LB1	49	36	29	39	42	32	39	49	34	30	32	34	39	22
LB2	52	36	31	41	43	36	46	50	35	30	32	35	40	23
LB3	46	38	31	36	45	35	47	54	36	38	36	38	40	25
TB1	45	41	34	39	40	44	42	30	41	38	51	40	44	27
TB2	49	37	33	37	42	44	41	29	48	36	48	40	44	27
TB3	37	35	34	40	41	39	36	23	32	28	41	36	36	38
TB4	38	30	34	38	43	40	40	23	36	32	39	31	38	32
IB1	43	39	31	37	37	35	37	30	51	30	36	33	36	26
IB2	40	42	40	47	41	38	49	36	40	36	47	40	44	29
IB3	40	36	35	41	37	34	49	48	42	38	40	35	42	28
FB1	43	30	21	28	36	31	41	24	30	28	33	28	37	29
FB2	46	36	27	27	37	31	40	22	27	28	38	30	38	30
FB3	39	40	28	37	41	34	42	28	27	27	33	35	37	36
FB4	44	41	28	32	39	31	43	29	28	30	39	31	34	28
FB5	43	40	30	32	40	33	44	34	31	31	36	30	35	31
ISB1	48	48	46	51	48	41	52	32	34	30	31	39	47	26
ISB2	54	41	46	46	43	40	45	33	30	30	32	38	46	26
ISB3	48	41	35	44	40	36	45	43	35	35	31	33	39	24

analyzed the total scores of fuzzy number of each of the solutions from the experts, we found that if the decision makers use top management awareness and support (S1) to be the first priority for RL barriers solving, it can solve the lack of commitment by top management (MB1), lack of strategic planning for ensuring RL practices (MB2), lack of specific goal for environment and waste management (MB4), lack of policies for RL practices (MB5), lack of proper organizational structure and support for RL practices (OB1), lack of training and education about RL (OB2), lack of organization personnel resources (OB3), lack of enforced laws, legislation and directives for EoL products (LB1), lack of government supportive policies on RL practices (LB2), lack of available technological (TB2), financial constraints (FB1), high investments and less return-on-investments (FB2), cost of environment friendly packaging (FB4), lack of support of supply chain partners (ISB2) and lack of public focus on environmental issues (ISB3), in which the results are given in Table 23 and Fig. 5. Therefore, the decision makers of Thailand's electronics industry or other stakeholders should focus on the ranking of both RL barriers practices and solutions for RL practices implementation to be a guideline and choose for the most important barriers that affected the organization and also choose the most appropriate solutions to solve these barriers.

5.1. Sensitivity analysis

Sensitivity analysis was used to test the sensitivity of criteria weight and thirty experiments were tested by using fuzzy TOPSIS for CC_i values of which are given in Table 24. In this study, the high weights of criteria were replaced and other criteria weights were constant. In sensitivity analysis experiment 1, weight of the barriers MB1 = 0.44 and other barriers MB2-ISB3 = 0.02 remained constant. For experiment 2, weight of the barriers MB2 = 0.44 and weight of other barriers MB1, MB3-ISB3 = 0.02 remained constant. The same process was used to test the experiment right through until experiment 29. In the last test experiment, the weights of all barriers were assumed to have the same value MB1-ISB3 = 0.034.

Hence, the final rank of CC_i values were represented in Table 24. Fig. 6 illustrates the highest value of CC_i in which S1 has highest CC_i value in thirteen experiments (1, 2, 5–8, 11, 16, 17, 22, 23, 28, 30). S7 has highest CC_i value in five experiments (3, 4, 20, 21, 27). S4 has highest CC_i value in two experiments (9, 10). S5 has highest CC_i value in three experiments (12–14). S11 has highest CC_i value in three experiments (15, 18, 25). S9 has highest CC_i value in two experiments (19, 29). S13 and S14 have the highest CC_i value in one experiment (26 & 24 respectively). Therefore, the results of sensitivity analysis experiment represented that the ranking of solutions for RL practices implementation is relatively sensitive to the barriers weights.

6. Conclusion

Nowadays, many companies applied RL practices implementation into their business process due to the increasing of the environmental awareness and also for the sustainable of the business. But it is face with

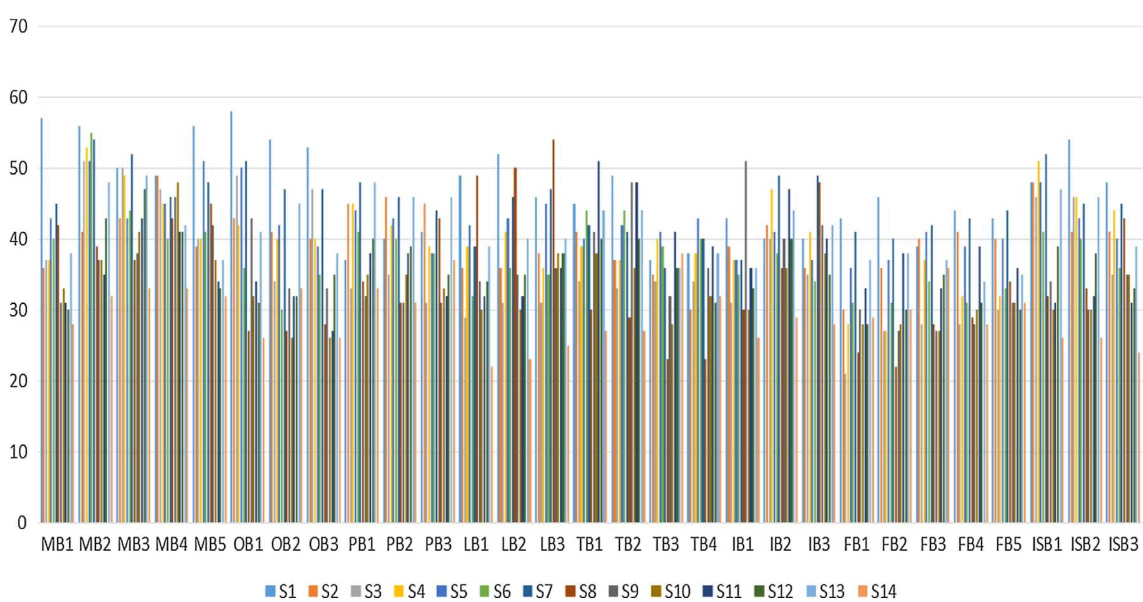

Fig. 5. Total scores of fuzzy number of each solution.

Table 24
Sensitivity analysis.

Expt. No.	Experiments conditions	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
1	MB1 = 0.44, MB2-ISB3 = 0.02	0.989	0.981	0.982	0.981	0.982	0.985	0.982	0.981	0.981	0.981	0.982	0.981	0.981	0.980
2	MB2 = 0.44, MB1, MB3-ISB3 = 0.02	0.989	0.981	0.987	0.985	0.987	0.987	0.988	0.985	0.985	0.985	0.986	0.985	0.985	0.980
3	MB3 = 0.44, MB1, MB2, MB4-ISB3 = 0.02	0.987	0.985	0.987	0.987	0.986	0.986	0.988	0.985	0.985	0.986	0.987	0.986	0.987	0.980
4	MB4 = 0.44, MB1-MB3, MB5-ISB3 = 0.02	0.987	0.987	0.987	0.985	0.987	0.985	0.988	0.986	0.987	0.986	0.986	0.985	0.985	0.980
5	MB5 = 0.44, MB1-MB4, OB1-ISB3 = 0.02	0.989	0.981	0.986	0.985	0.986	0.985	0.988	0.986	0.985	0.985	0.982	0.981	0.981	0.980
6	OB1 = 0.44, MB1-MB5, OB2-ISB3 = 0.02	0.989	0.981	0.987	0.981	0.987	0.981	0.988	0.981	0.982	0.981	0.982	0.981	0.981	0.980
7	OB2 = 0.44, MB1-OB1, OB3-ISB3 = 0.02	0.989	0.981	0.982	0.981	0.982	0.981	0.988	0.981	0.981	0.981	0.982	0.981	0.981	0.980
8	OB3 = 0.44, MB1-OB2, PB1-ISB3 = 0.02	0.988	0.981	0.987	0.981	0.982	0.981	0.988	0.981	0.981	0.981	0.982	0.981	0.981	0.980
9	PB1 = 0.44, MB1-OB3, PB2-ISB3 = 0.02	0.983	0.985	0.982	0.987	0.982	0.981	0.982	0.981	0.981	0.981	0.982	0.981	0.981	0.980
10	PB2 = 0.44, MB1-PB1, PB3-ISB3 = 0.02	0.983	0.986	0.982	0.987	0.982	0.981	0.982	0.981	0.981	0.981	0.982	0.981	0.981	0.980
11	PB3 = 0.44, MB1-PB2, LB1-ISB3 = 0.02	0.987	0.981	0.982	0.981	0.982	0.985	0.982	0.981	0.981	0.981	0.982	0.981	0.981	0.980
12	LB1 = 0.44, MB1-PB3, LB2-ISB3 = 0.02	0.983	0.981	0.981	0.981	0.987	0.981	0.982	0.987	0.981	0.981	0.982	0.981	0.985	0.980
13	LB2 = 0.44, MB1-LB1, LB3-ISB3 = 0.02	0.983	0.981	0.982	0.981	0.987	0.981	0.982	0.985	0.981	0.984	0.982	0.981	0.981	0.980
14	LB3 = 0.44, MB1-LB2, TB1-ISB3 = 0.02	0.983	0.981	0.982	0.981	0.987	0.981	0.982	0.987	0.981	0.985	0.982	0.981	0.985	0.980
15	TB1 = 0.44, MB1-LB3, TB2-ISB3 = 0.02	0.983	0.981	0.982	0.981	0.982	0.981	0.982	0.981	0.982	0.981	0.988	0.985	0.981	0.980
16	TB2 = 0.44, MB1-TB1, TB3-ISB3 = 0.02	0.988	0.981	0.982	0.981	0.982	0.981	0.982	0.981	0.987	0.981	0.988	0.985	0.981	0.980
17	TB3 = 0.44, MB1-TB2, TB4-ISB3 = 0.02	0.987	0.981	0.987	0.981	0.982	0.981	0.982	0.981	0.981	0.981	0.986	0.985	0.981	0.984
18	TB4 = 0.44, MB1-TB3, IB1-ISB3 = 0.02	0.983	0.981	0.982	0.981	0.982	0.981	0.982	0.981	0.981	0.981	0.987	0.981	0.981	0.980
19	IB1 = 0.44, MB1-TB4, IB2-ISB3 = 0.02	0.983	0.981	0.982	0.981	0.982	0.981	0.982	0.981	0.986	0.981	0.982	0.981	0.981	0.980
20	IB2 = 0.44, MB1-IB1, IB3-ISB3 = 0.02	0.983	0.981	0.982	0.987	0.982	0.981	0.988	0.981	0.987	0.981	0.987	0.981	0.981	0.980
21	IB3 = 0.44, MB1-IB2, FB1-ISB3 = 0.02	0.983	0.981	0.982	0.981	0.982	0.981	0.988	0.985	0.987	0.981	0.987	0.981	0.981	0.980
22	FB1 = 0.44, MB1-IB3, FB2-ISB3 = 0.02	0.983	0.981	0.981	0.981	0.982	0.981	0.982	0.981	0.981	0.981	0.982	0.981	0.981	0.980
23	FB2 = 0.44, MB1-FB1, FB3-ISB3 = 0.02	0.987	0.981	0.981	0.981	0.982	0.981	0.982	0.981	0.981	0.981	0.986	0.981	0.981	0.980
24	FB3 = 0.44, MB1-FB2, FB4-ISB3 = 0.02	0.983	0.981	0.982	0.981	0.982	0.981	0.982	0.981	0.981	0.981	0.982	0.981	0.981	0.984
25	FB4 = 0.44, MB1-FB3, FB5-ISB3 = 0.02	0.983	0.981	0.982	0.981	0.982	0.981	0.982	0.981	0.981	0.981	0.986	0.981	0.981	0.980
26	FB5 = 0.44, MB1-FB4, ISB1-ISB3 = 0.02	0.983	0.981	0.982	0.981	0.982	0.981	0.982	0.981	0.981	0.981	0.986	0.981	0.986	0.980
27	ISB1 = 0.44, MB1-FB5, ISB2-ISB3 = 0.02	0.983	0.985	0.986	0.987	0.987	0.981	0.988	0.981	0.981	0.981	0.982	0.981	0.987	0.980
28	ISB2 = 0.44, MB1-ISB1, ISB3 = 0.02	0.989	0.981	0.986	0.981	0.982	0.981	0.982	0.981	0.981	0.981	0.982	0.981	0.987	0.980
29	ISB3 = 0.44, MB1-ISB2 = 0.02	0.983	0.985	0.982	0.981	0.982	0.981	0.982	0.981	0.985	0.981	0.982	0.981	0.981	0.980
30	MB1-ISB3 = 0.034	0.985	0.982	0.983	0.983	0.984	0.982	0.984	0.983	0.983	0.982	0.984	0.982	0.983	0.980

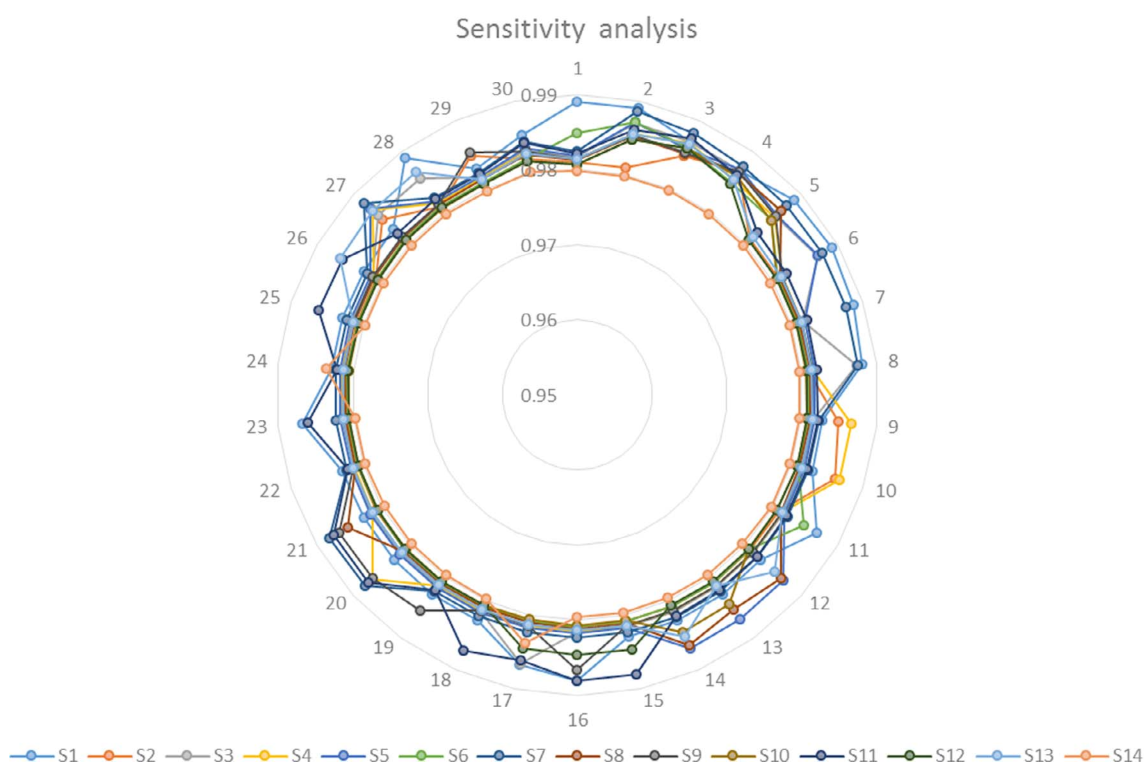

Fig. 6. The results of closeness coefficient values.

some barriers which make the implementation of RL practices unsuccessful. Hence, to solve these barriers need to use the appropriate solutions to overcome its barriers. In real situations, the decision makers cannot make decision due there being to a lot of solutions and it is so difficult to apply all of these solutions in the same time. Therefore, there is a need to ranking the solutions to solve the barriers of RL practices implementation. In this study presented the hybrid methods of fuzzy AHP and fuzzy TOPSIS to ranking solutions to solve berries for RL practices. Fuzzy AHP was used to get weight for RL barriers and fuzzy TOPSIS was used to get ranking of the solutions. In this study, through literature review and expert views 29 barriers and 14 solutions have been identified. The results of the study presented that top management awareness and support is the highest ranking value of solutions in this case study which Thailand electronics industry was used in the proposed framework. The ranking of solutions can be a guideline and support decision makers or top management to determine policy and strategies to solve RL practices barriers implementation. For the future research direction, this study can use other fuzzy multi-criteria decision making methods such as fuzzy VIKOR, fuzzy ANP and fuzzy ELETRE.

References

Abdullah, N., Halim, N. A., Yaakub, S., & Abdullah, H. H. (2011). Reverse logistics adoption among Malaysian manufacturers. In *International conference on management, economics and social sciences (ICMESS'2011) Bangkok Dec*.

Abdulrahman, M. D., Gunasekaran, A., & Subramanian, N. (2014). Critical barriers in implementing reverse logistics in the Chinese manufacturing sectors. *International Journal of Production Economics, 147*, 460–471.

Amiri, M. P. (2010). Project selection for oil-fields development by using the AHP and fuzzy TOPSIS methods. *Expert Systems with Applications, 37*, 6218–6224.

Awasthi, A., Chauhan, S. S., & Omrani, H. (2011). Application of fuzzy TOPSIS in evaluating sustainable transportation systems. *Expert Systems with Applications, 38*, 12270–12280.

Awasthi, A., Chauhan, S. S., Omrani, H., & Panahi, A. (2011). A hybrid approach based on SERVQUAL and fuzzy TOPSIS for evaluating transportation service quality. *Computers & Industrial Engineering, 61*, 637–646.

Badenhorst, A. (2016). Prioritizing the implementation of practices to overcome operational barriers in reverse logistics. *Journal of Transport and Supply Chain Management, 10*(1).

Badenhorst, A., & Nel, J. D. (2012). Identifying potential solutions for specific reverse logistics problems. *Journal of Transport and Supply Chain Management*.

Chang, D. Y. (1996). Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research, 95*, 649–655.

Dağdeviren, M., Yavuz, S., & Kılınç, N. (2009). Weapon selection using the AHP and TOPSIS methods under fuzzy environment. *Expert Systems with Applications, 36*, 8143–8151.

Efendigil, T., Önüt, S., & Kongar, E. (2008). A holistic approach for selecting a third-party reverse logistics provider in the presence of vagueness. *Computers & Industrial Engineering, 54*, 269–287.

Ertuğrul, İ., & Karakaşoğlu, N. (2009). Performance evaluation of Turkish cement firms with fuzzy analytic hierarchy process and TOPSIS methods. *Expert Systems with Applications, 36*, 702–715.

Govindan, K., Kaliyan, M., Kannan, D., & Haq, A. N. (2014). Barriers analysis for green supply chain management implementation in Indian industries using analytic hierarchy process. *International Journal of Production Economics, 147*, 555–568.

Govindan, K., Soleimani, H., & Kannan, D. (2015). Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. *European Journal of Operational Research, 240*, 603–626.

Gumus, A. T. (2009). Evaluation of hazardous waste transportation firms by using a two-step fuzzy-AHP and TOPSIS methodology. *Expert Systems with Applications, 36*, 4067–4074.

Hwang, C. L., & Yoon, K. (1981). *Multiple attributes decision making methods and applications.* Berlin: Springer.

Javanbarg, M. B., Scawthorn, C., Kiyono, J., & Shahbodaghkhan, B. (2012). Fuzzy AHP-based multi criteria decision making systems using particle swarm optimization. *Expert Systems with Applications, 39*, 960–966.

Jindal, A., & Sangwan, K. S., (2011). Development of an interpretive structural model of barriers to reverse logistics implementation in Indian industry. In *Proceedings of the 18th CIRP international 448 conference on life cycle engineering, Technische Universität Braunschweig, Braunschweig, Germany, May 2nd–4th*.

Kannan, D., Jabbour, A. B. L. D. S., & Jabbour, C. J. C. (2014). Selecting green suppliers based on GSCM practices: Using fuzzy TOPSIS applied to a Brazilian electronics company. *European Journal of Operational Research, 233*, 432–447.

Kannan, G., Pokharel, S., & Kumar, P. S. (2009). A hybrid approach using ISM and fuzzy TOPSIS for the selection of reverse logistics provider. *Resources, Conservation and Recycling, 54*, 28–36.

Kaya, T., & Kahraman, C. (2011). Multi criteria decision making in energy planning using a modified fuzzy TOPSIS methodology. *Expert Systems with Applications, 38*, 6577–6585.

Kelemenis, A., Ergazakis, K., & Askounis, D. (2011). Support managers' selection using an extension of fuzzy TOPSIS. *Expert Systems with Applications, 38*, 2774–2782.

Krohling, R. A., & Campanharo, V. C. (2011). Fuzzy TOPSIS for group decision making: A case study for accidents with oil spill in the sea. *Expert Systems with Applications, 38*, 4190–4197.

Lee, A. H. I., Chen, H. H., & Kang, H. Y. (2011). A model to analyze strategic products for photovoltaic silicon thin-film solar cell power industry. *Renewable and Sustainable Energy Reviews, 15*(2011), 1271–1283.

Luthra, S., Kumar, V., Kumar, S., & Haleem, A. (2011). Barriers to implement green supply chain management in automobile industry using interpretive structural modeling technique-An Indian perspective. *Journal of Industrial Engineering and Management,* 231–257.

Mahdevari, S., Shahriar, K., & Esfahanipour, A. (2014). Human health and safety risks management in underground coal mines using fuzzy TOPSIS. *Science of the Total Environment, 488–489*, 85–99.

Mandic, K., Delibasic, B., Knezevic, S., & Benkovic, S. (2014). Analysis of the financial parameters of Serbian banks through the application of the fuzzy AHP and TOPSIS methods. *Economic Modelling, 43*, 30–37.

Mathiyazhagan, K., Govindan, K., NoorulHaq, A., & Geng, Y. (2013). An ISM approach for the barrier analysis in implementing green supply chain management. *Journal of Cleaner Production, 47*, 283–297.

Nikolaou, I. E., Evangelinos, K. I., & Allan, S. (2013). A reverse logistics social responsibility evaluation framework based on the triple bottom line approach. *Journal of Cleaner Production, 56*, 173–184.

Önüt, S., Kara, S. S., & Işik, E. (2009). Long term supplier selection using a combined fuzzy MCDM approach: A case study for a telecommunication company. *Expert Systems with Applications, 36*, 3887–3895.

Paksoy, T., Pehlivan, N. Y., & Kahraman, C. (2012). Organizational strategy development in distribution channel management using fuzzy AHP and hierarchical fuzzy TOPSIS. *Expert Systems with Applications, 39*, 2822–2841.

Patil, S. K., & Kant, R. (2014). A fuzzy AHP-TOPSIS framework for ranking the solutions of Knowledge Management adoption in Supply Chain to overcome its barriers. *Expert Systems with Applications, 41*, 679–693.

Prakash, C., & Barua, M. K. (2015). Integration of AHP-TOPSIS method for prioritizing the solutions of reverse logistics adoption to overcome its barriers under fuzzy environment. *Journal of Manufacturing Systems, 37*, 599–615.

Price water house Coopers. (2008). Reverse Logistics, Integrated Supply Chain Solutions, May 2008.

Pumpinyo, S., & Nitivattananon, V. (2014). Investigation of barriers and factors affecting the reverse logistics of waste management practice: A case study in Thailand. *Sustainability, 6*, 7048–7062. http://dx.doi.org/10.3390/su6107048.

Rahman, S., & Subramanian, N. (2012). Factors for implementing end-of-life computer recycling operations in reverse supply chains. *International Journal of Production Economics, 140*, 239–248.

Ravi, V., & Shankar, R. (2005). Analysis of interactions among the barriers of reverse logistics. *Technological Forecasting & Social Change, 72*, 1011–1029.

Rogers, D. S., & Tibben-Lembke, R. S., (1998). Going backwards: Reverse logistics trends and practices. Reverse Logistics Executive Council, University of Nevada, Reno Center for Logistics Management (pp. 2).

Rogers, D. S., & Tibben-Lembke, R. S. (2001). An examination of reverse logistics practices. *Journal of Business Logistics, 22*(2).

Rostamzadeh, R., & Sofian, S. (2011). Prioritizing effective 7Ms to improve production systems performance using fuzzy AHP and fuzzy TOPSIS (case study). *Expert Systems with Applications, 38*, 5166–5177.

Saaty, T. L. (1980). *Analytic hierarchy process.* New York: McGraw Hill.

Senthil, S., Srirangacharyulu, B., & Ramesh, A. (2014). A robust hybrid multi-criteria decision making methodology for contractor evaluation and selection in third-party reverse logistics. *Expert Systems with Applications, 41*, 50–58.

Sharma, S. K., Panda, B. N., Mahapatra, S. S., & Sahu, S. (2011). Analysis of barriers for reverse logistics: An Indian perspective. *International Journal of Modeling and Optimization, 1*(2).

Shidpour, H., Shahrokhi, M., & Bernard, A. (2013). A multi-objective programming approach, integrated into the TOPSIS method, in order to optimize product design; in three-dimensional concurrent engineering. *Computers & Industrial Engineering, 64*, 875–885.

Sindhu, S., Nehra, V., & Luthra, S. (2017). Investigation of feasibility study of solar farms deployment using hybrid AHP-TOPSIS analysis: Case study of India. *Renewable and Sustainable Energy Reviews, 73*, 496–511.

Sirisawat, P., & Kiatcharoenpol, T. (2016). Correlation of barriers to reverse logistics performance using structural equation modeling. In *IEEE international conference on industrial engineering and engineering management*.

Sirisawat, P., Kiatcharoenpol, T., Choomrit, N., & Wangphanich, P. (2016). Study of green procurement practices: A case study of the computer parts industry in Thailand. In *Proceedings of the 2016 international conference on industrial engineering and operations management Kuala Lumpur, Malaysia, March 8–10*.

Sun, C. C. (2010). A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods. *Expert Systems with Applications, 37*, 7745–7754.

Taylan, O., Bafail, A. O., Abdulaal, R. M. S., & Kabli, M. R. (2014). Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies. *Applied Soft Computing, 17*, 105–116.

Torfi, F., Farahani, R. Z., & Rezapour, S. (2010). Fuzzy AHP to determine the relative weights of evaluation criteria and Fuzzy TOPSIS to rank the alternatives. *Applied Soft Computing, 10*, 520–528.

Vinodh, S., Prasanna, M., & Prakash, N. H. (2014). Integrated fuzzy AHP–TOPSIS for selecting the best plastic recycling method: A case study. *Applied Mathematical Modelling, 38*, 4662–4672.

Wang, J., Fan, K., & Wang, W. (2010). Integration of fuzzy AHP and FPP with TOPSIS methodology for aeroengine health assessment. *Expert Systems with Applications, 37*, 8516–8526.

Wang, T. C., & Lee, H. D. (2009). Developing a fuzzy TOPSIS approach based on subjective weights and objective weights. *Expert Systems with Applications, 36*, 8980–8985.

Wang, T., Liu, J., Li, J., & Niu, C. (2016). An integrating OWA–TOPSIS framework in intuitionistic fuzzy settings for multiple attribute decision making. *Computers & Industrial Engineering, 98*, 185–194.

Wiel, A. V. D., Bossink, B., & Masurel, E. (2012). Reverse logistics for waste reduction in cradle-to cradle oriented firms. *International Journal of Technology Management, 60*.

Yacob, P. (2012). Barriers to reverse logistics practices in Malaysian SMEs. *International Journal of Academic Research in Economics and Management Sciences, 1*(5).

Yalcin, N., Bayrakdaroglu, A., & Kahraman, C. (2012). Application of fuzzy multi-criteria decision making methods for financial performance evaluation of Turkish manufacturing industries. *Expert Systems with Applications, 39*, 350–364.

Yang, Z. L., Bonsall, S., & Wang, J. (2011). Approximate TOPSIS for vessel selection under uncertain environment. *Expert Systems with Applications, 38*, 14523–14534.

Yu, C. S. (2002). AGP-A HP method for solving group decision-making fuzzy AHP problems. *Computers & Operations Research, 29*, 1969–2001.

Yu, X., Guo, S., Guo, J., & Huang, X. (2011). Rank B2C e-commerce websites in e-alliance based on AHP and fuzzy TOPSIS. *Expert Systems with Applications, 38*, 2774–2782.

Zaabi, S. A., Dhaheri, N. A., & Diabat, A. (2013). Analysis of interaction between the barriers for the implementation of sustainable supply chain management. *International Journal of Advanced Manufacturing Technology, 68*, 895–905.

Zyoud, S. H., Kaufmann, L. G., Shaheen, H., Samhan, S., & Fuchs-Hanusch, D. (2016). A framework for water loss management in developing countries under fuzzy environment: Integration of Fuzzy AHP with Fuzzy TOPSIS. *Expert Systems with Applications, 61*, 86–105.