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Technical Paper

Integration of AHP-TOPSIS method for prioritizing the solutions of reverse logistics adoption to overcome its barriers under fuzzy environment

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ABSTRACT

Reverse logistics practices are gaining attention due to industrial ecology, enforced legislation and corporate citizenship but presence of barriers make reverse logistics (RL) implementation difficult and hence reduce the success rate. To increase RL adoption, robust and flexible strategies are required to overcome its barriers. This study focuses on identification and ranking the solutions of reverse logistics adoption in electronics industry to overcome its barriers. It aids firms to ponder on high rank solutions and develop strategies to implement them on priority. This paper proposes a methodology based on fuzzy analytical hierarchy process (AHP) and fuzzy technique for order performance by similarity to ideal solution (TOPSIS) to identify and rank the solutions of RL adoption to overcome its barriers. Fuzzy AHP is applied to get weights of the barriers as criteria by pairwise comparison and final ranking of the solutions of RL adoption is obtained through fuzzy TOPSIS. The empirical case of Indian electronics industry is shown to illustrate the use of the proposed method. This proposed method offers a more precise, efficient and effective decision support tool for stepwise implementation of the solutions due to consideration of fuzzy environment. Finally sensitivity analysis is performed to illustrate the robustness of the method.

1. Introduction

Reverse logistics (RL) practices are gaining momentum among various industries including electronics industry because of growing environmental concern, enforce legislation, industrial ecology, corporate citizenship, sustainability, intense global competition, profitability issues and increased products returns due to product recalls, warranty returns, service returns and so on [52]. Sustainable development is an essential concept for twenty first century organization and that could be managed by implementing reverse logistics operations in its supply chain [42]. RL practices can provide efficient resource utilization and prevention from pollution by minimizing the environmental burden of end-of-life (EoL) at its source [16,20,61]. The stringent law on Waste Electrical and Electronic Equipment (WEEE) enforced electronics manufacturers to work efficiently in return management and proper disposal of the products [33]. Moreover it is not the issue what are the factors, which are affecting successful implementation of RL, but one should clearly understand the opportunities embedded in reverse logistics supply chain in improvement of customer satisfaction and loyalty. There are multiple reasons which are influencing organizations to adopt RL practices but presence of barriers make RL implementation difficult and effect of these barriers cannot be overcome at the same time. Even a same barrier may needs different treatment and priority for same type of organizations due to varied nature of resources, capabilities and strategies. And hence it is desirable to adopt RL practices efficiently; factual, flexible and feasible solutions must be projected and ranked to overcome these barriers on priority basis. Previous studies suggested that little attention have been given on the barriers and drivers of RL practices implementation on developing countries [29,35,38,47,48,55,69]. However barriers analysis of electronics industry in Indian context is remain unexplored. The research done by Jindal and Sangwan [29] on RL adoption barriers in India was based on government, organizational and market related barriers those were not related to any particular industry/sector in India. An exponential growth due to industrialization, modernization, urbanization and existence of 20% of the world population in India has led to huge production and consumption, which required massive resource consumption and causes environmental pollution. Indian electronics and durables market in rural and semi-urban areas account for about 40% of the overall market and is growing approx. 30% compound annual growth rate (CAGR).

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The Indian electronics industry has emerged as a fast growing sector in terms of production, internal consumption and export. The growth of PC ownership per capita between 1993 and 2000 was 604%, whereas the world average increase was 181% during the same period [12,13]. That led to generate more e-waste. The report "Recycling – from E-Waste to Resources" [53] forecasted that e-waste production from old computers will increase by 500% in India from 2007 to 2020. The amount of e-waste from discarded mobile phones will be approximately 18 times higher from 2007 to 2020. By 2020, e-waste from televisions will be 1.5–2 times higher, and e-waste from discarded refrigerators will be twofold or threefold [62].

This inspired us to deal with the issues related to RL implementation, specifically to identify the barriers in Indian electronics industry and suggesting realistic solutions/strategies to overcome these barriers. The goal of this study is to identify and evaluate the barriers of RL adoption and suggest and rank the solutions to overcome these barriers. It is significant to rank these solutions so that organizations may develop appropriate strategies to execute these solutions on priority basis to overcome the barriers. These strategies can be applied in Indian electronics industry to attain and improve strategic competitive position. Moreover organizations can employ adoptive and responsive return management practices to achieve business success.

To rank the solutions of RL adoption is a hybrid decision making approach and involvement of human opinions through linguistic variables makes difficult to evaluate it by precise/certain numerical values. Hence fuzzy approach [67] is required to deal such problems characterized by vagueness and uncertainty. This study presents hybrid fuzzy Analytical hierarchy process (AHP) and fuzzy technique for order performance by similarity to ideal solution (TOPSIS) method to rank the solutions of RL adoption. AHP is multi criteria decision making method used to determine the relative importance/priority/ranking of the criteria and sub-criteria through pair-wise comparison and consider qualitative and quantitative variables/attributes; fuzzy AHP allows uncertainty and fuzziness in decision making. It has been used in many real world applications. This paper proposes fuzzy AHP to obtain relative weights of the barriers and fuzzy TOPSIS to prioritize the solutions. TOPSIS method is simple, easy to use and has many real world applications like Fuzzy AHP. It is based on ideal solution and considers the best alternative has the least distance from positive ideal solution and the longest distance from negative ideal solution. It allows cost, qualitative and quantitative variables/attributes and fuzzy TOPSIS consider uncertainty and vagueness in decision making. Lastly, an empirical case of Indian electronic industry is illustrated to exhibit the application of proposed approach.

The remainder of this paper is as follows. Section 2 concisely reviews the literature on barriers and solutions of RL adoption. The Fuzzy AHP and fuzzy TOPSIS approach are given in Section 3. The proposed approach for ranking the solutions of RL adoption is presented in Section 4. The results & discussions of empirical case with sensitivity analysis and managerial implications are shown in Section 5. Finally, the conclusion is given in Section 6.

2. Literature review

2.1. Barriers of RL practices implementation

It have been seen RL practices in developed countries derived by enforce legislation on manufacturers to take extended responsibility for recovery and disposal of end-of-life products. However it is in initial stage in developing countries including India [58]. The RL implementation is difficult in developing economies like India because of the lack of societal pressure, environmental issues, and price sensitive market. In India return management activities are often viewed as a cost of doing business and are generally processed through unorganized way and practiced traditionally by hawkers, peddlers and vendors [29]. The successful RL implementation needs economic and financial support from government along with coordination & cooperation from supply chain partners. Decision makers can fruitfully utilized information in their planning, obtained by a critical analysis of the RL barriers [46]. In order to implement RL practices effectively, some supported studies have provided several barriers of RL practices adoption (see Table 1). In this study we classify these barriers from the Indian manufacturers' point of view into seven criteria along with their sub-criteria. To explore the barriers classified into those criteria have discussed below-

2.1.1. Management barriers

Management barriers includes lack of management support, lack of awareness, less planning and effort on integrating the business process, lack change management practices, less focus on extended responsibility and drafting policies. Luthra et al. [36], Zhou et al. [68] and Rogers and Tibben-Lembke [47] found that top management was unwilling and less interested about RL. Due to change in current business scenario, competitive priority, technological up-gradation, behaviors of customers and suppliers management has to made policies and strategic planning about RL [43,46,47,60]. Companies did not want to compromise with quality of products by using returned products, hence it hinder companies to become active in RL practices [1,29,40,66]. Studies identified barriers are given in Table 1.

2.1.2. Organizational barriers

Organizational barriers are lack of proper organizational structure, less shared practices, lack of personnel resources, less attention on training & education about RL and inappropriate performance metrics system [2,39,47]. Lack of personnel resources and proper training for new upgraded scientific recycling methods were desired in proper implementation of RL practices [29,40,60,66]. Appropriate performance metrics system should be needed to measure, manage and improve RL practices in work integrated manner. Lack of such system had less scope of success in implementation [8,44,46,68]. Studies identified barriers are given in Table 1.

2.1.3. Economic barriers

Economic barriers can be classified as less economic value recovered from EoL products, high associated cost, less return on investment and returns of scale [1,24,29,60]. Lau and Wang [35] proposed that in developing countries manufacturers are still not able to recapture value and recover assets from recycling, probably due to low volume of returns. So, lack volume of EoL products is one of the greatest threats to industry [23]. Customers could make money to sell their used appliances so why they would show interest in paying for recycling and disposal [60]. Huge amount of initial capital and finance would require in implementing RL [42]. Transportation, Information and processing system required high capital investment that hinders companies to execute RL practices [47]. Timing, quality and quantity of return products were uncertain that reduce to achieve returns of scale. Studies identified barriers are given in Table 1.

2.1.4. Legal barriers

Legal barriers are lack of enforces legislation for end-of life products, lack of Govt. supportive policies, less green practices/environment concern and informal waste practices [1,5,8,18,24,29,31,38,45–47,68]. Wath et al. [64] stated that India

Table 1
Barriers of RL implementation along with criteria & sub-criteria.

Criteria	Criteria code	Sub criteria	References
Management barriers	MB1	Lack of top management commitment	Rogers and Tibben-Lembke [47], PWC report [43], Zhou et al. [68], Ravi and Shankar [46], Chung and Zhang [8], Subramanian et al. [1], Jindal & Sangwan [29], Xiaoming and Olorunniwo [66], Thierry et al. [60], Patil & Ravikant [40], Luthra et al. [36].
	MB2	Lack of awareness about RL	
	MB3	Lack of strategic planning	
	MB4	RL not integrated with SC business process	
	MB5	Resistance to change	
	MB6	Lack of waste management practice	
	MB7	Company policies	
Organizational barriers	OB1	Lack of proper organizational structure & support	Natti & Ojasalo [39], Ahmad & Daghfous [2], Zhou et al. [68], Rogers and Tibben-Lembke [47], Ravi and Shankar [46], Chung and Zhang [8], Subramanian et al. [1], Jindal & Sangwan [29], Xiaoming and Olorunniwo [66], Thierry et al. [60], Patil & Ravikant [40].
	OB2	Lack of shared understanding of best practices	
	OB3	Lack of training & education about RL	
	OB4	Lack of organization personnel resources	
	OB5	Lack of performance measurement system	
Economic barriers	EB1	Less economic value recovered from EoL (end-of-life) products	Jindal & Sangwan [29], Presley et al. [42], Srivastava and Srivastava [58], Ravi and Shankar [46], Hicks et al. [24], Thierry et al. [60], Rogers and Tibben-Lembke [47], Guide & Srivastava [23], Lau and Wang [35]. Subramanian et al. [1]
	EB2	High initial & operating cost	
	EB3	Lack of investment in RL products storage	
	EB4	Lack of investment in RL information system	
	EB5	Lack of economy of scale	
Legal barriers	LB1	Lack of law and directives for end of EoL products.	Rogers and Tibben-Lembke [47], Ravi and Shankar [46], Zhou et al. [68], Lau and Wang [35], Chung and Zhang [8], Miao et al. [38], Rahman and Subramanian [45], Chaabane et al. [5], Koh et al. [31], Jindal & Sangwan [29], Subramanian et al. [1], Hicks et al. [24], Srivastava [57], Rogers et al. [50], Guide & Wassenhove [22], Wath et al. [64]
	LB2	Lack of govt. supportive policies on RL	
	LB3	Customers are not informed to take back	
	LB4	Lack of public focus on environmental issues	
	LB5	Wide informal waste management practices	
	LB6	Lack of standard/green practices for recycling	
	LB7	Loopholes in Indian regulation on waste handling	
Technological barriers	TB1	Lack of availability of technology & information system	Srivastava [57], Ravi and Shankar [46], Thierry et al. [60], Xiaoming and Olorunniwo [66], Lau and Wang [35], Rogers and Tibben-Lembke [48], Rogers et al. [50], Patil & Ravikant [40], Jindal & Sangwan [29], Wong and Wong [65], Kumar and Thondikulam [32], Gunasekaran and Ngai [21], Hutzschenreuter and Horstkotte [25]
	TB2	Less development of recycling technologies	
	TB3	Lack of technological infrastructure to adopt RL	
	TB4	Low data and information security within SC (supply chain)	
	TB5	Lack of technical assistance to RL partners	
Infrastructural barriers	IB1	Lack of infrastructure facility (storage, transportation)	Rogers and Tibben-Lembke [47], Ravi and Shankar [46], Zhou et al. [68], PWC report [43], Chung and Zhang [8], Lau and Wang [35], Rahman and Subramanian [45], Subramanian et al. [1], Jindal & Sangwan [29]
	IB2	Limited forecasting & planning	
	IB3	Lack of system to monitor returns	
	IB4	Lack of coordination/collaboration with 3PL (3rd party logistics) providers	
Market related barriers	MRB1	Uncertain return & demand	Geyer and Jackson [19], Fleischmann [16], Stock [59], Inderfurth [27], Guide & Wassenhove [22], Pokharel and Mutha [41], Srivastava [57], Ravi and Shankar [46], Thierry et al. [60], Lau and Wang [35], Xiaoming and Olorunniwo [66], Jindal & Sangwan [29]
	MRB2	Marketing of remanufactured product	
	MRB3	Lack of support of SC partners	
	MRB4	Uncertain quality & quantity of return	
	MRB5	Customer perception about RL	

lacks actual legislation dealing with e-waste. Legal rules are one of the most effective tools for implementation of RL but were not greeted by companies [33]. The current Indian regulation on stating & handling of e-waste is ambiguous [11,22]. Due to the lack of proper legislation, e-waste illegally imported from developed nations [12,13,35,50]. Therefore, it is much needed that all the RL partners have to develop a long term effective plan for disposition of the e-waste and control informal recycling practices [57]. Studies identified barriers are given in Table 1.

2.1.5. Technological barriers

In this paper identified technological barriers are lack of technology and Information system in RL, less development in recycling technology, less available technological infrastructure, Ineffective security system, lack technical assistance to RL partners [29,35,40,46–48,57,60,66]. Firm performance directly depended on available technological infrastructure facility [65]. Due to less developed technology, security of information was key issue among SC (Supply Chain) partners [21,32]. Communication barrier was the biggest hurdle in transfer of knowledge among SC partners and very critical in case of inter departments and organizations [28]. Studies identified barriers are given in Table 1.

2.1.6. Infrastructural barriers

Infrastructural barriers include lack of infrastructure facility, limited forecasting & planning, lack of system to monitor returns and lack of coordination/collaboration with 3PL (3rd party logistics) providers [1,3,8,35,43,45–47,68]. A company could handle returns and recalls efficiently/effectively if it has good RL infrastructure facility [10,28]. Stock [59] suggested that presence of good returns-handling system could be a source of significant cost savings and even function as a profit center. However Jack et al. [28] told that the absence of RL infrastructure hampered firm's ability to effectively/efficiently deal with returns and/or recalls and any effort at handling returns would lead to increase firm's financial burden. Studies identified barriers are given in Table 1.

2.1.7. Market related barriers

Market related barriers are stochastic return & demand, difficulty in marketing of remanufactured products, lack of support of SC partners, uncertain quality & quantity of return and customer perception about RL [19,29,46,49,57,59,60,66]. Due to uncertainty in quantity and quality of returns product remanufacturing planning could not be done hence it increase amount of inventory and affect production planning [16,27]. It would be hard to market remanufactured products due to competition from new products. Apart from marketing, pricing of those products is very challenging and it is a sensitive issue in India. Also, seller of remanufactured product gets lower commission compare to new product [22,29,41]. One of the major problems to practice RL is less supportive partner in SC. Studies identified barriers are given in Table 1.

2.2. Solutions to overcome the barriers of RL practices adoption

The academicians, researchers, consultants, experts and industry associates all around the world have proposed different and situation based solutions to overcome the barriers of RL practices adoption (see Table 2).

Customers need to aware about green and environment friendly practices. They should encourage about waste reduction strategies through return management practices, recycling and proper disposal of end of life products [35,43]. Wath et al. [64] stated that India lacks in legislation dealing with e-waste. India introduced new regulations, codified as the "2010 E-waste Management and Handling Rules" became effective in 2012. But unfortunately active implementation has not been seen till today. Another interesting thing has been seen that Indian judicial system banned the import of e-waste and termed it illegal, but these regulations evaded through such loopholes as mislabeling e-waste as charitable donations, scrap metal, or reusable products [37]. So there is a need to establish clear stated directives, rules and law for recycling and disposal of WEEE and also ensures for effective implementation and control of such legislation. Companies should develop adequate infrastructure facilities (storage, transportation, recycling facility etc.) for RL activities, which can manage recycling and waste disposal of return products [35]. Production design should be environment-friendly and do not use hazardous materials. Moreover design should facilitate easily recycling and reuse of products [35]. These green practices have been adopted by Xerox, Kodak, Volvo and Electrolux in their product design [52]. The fate of return products can be easily change by using advanced technology in recycling and disposal activities so there is a need to develop active recycling network centers [35]. To manage hurdle free coordination among SC partners, collaboration should be required. Electronic media would enable fast, effective, efficient and timely communication that would facilitate easy and active response of RL activities [30,40]. Supply chain performance could be improved by integrating forward and reverse SC partners to manage product, finance and information flow in both directions easily and efficiently [35]. In this competitive era where companies are trying to reduce cost of their operations; only outsourcing option could be available, possible and feasible alternative with them. By outsourcing companies can achieve effective recovery of end of life products. Outsourcing candidates could use latest technology and resources in fast and efficient recovery of the products [9,14,54]. The top most priority is to create awareness at senior management that must recognize a need for change and notice the potential improvement opportunities by implementing RL process [35,40,43,56]. Identify economic benefits associated with RL practices and create awareness that companies are adopting the right things for customer by focusing on RL operations [7,34,40,43]. Companies should boost reverse logistic operations frame to adapt RL operation specification process [6,35,40,43]. Identify and measure the profit not only in monetary terms but also in making corporate image associated with RL activities and performance throughout entire operations [35,40]. Company should involve all departments to influence RL practices [35,43]. Company should include reverse chain partners in planning and focus on process improvements and also collaborate with other companies to adopt best practices in this area [35,43]. PWC report [43] stated that, companies need to focus on customers and act accordingly to develop reverse chain process. Involvement of people, process, technology, infrastructure and organization structure would lead to comprehensive change. Organizations should have clear warranty schemes, harmonized and standardized returns policy and treat return as perishable products after recovering value or disposable activities. If used products will reuse and recycle that lead to less waste. So RL activities could be seen as a part of sustainable development, efficient resource utilization and environmental protection. Other reason is, it can maximize stakeholder value from RL efforts by sustainability initiatives and take-back innovations and will provide competitive advantage [13,16,17,20,43,61]. It has been seen returns management offer significant cost saving or value in procurement, recovery and inventory by practicing RL [43,57,58].

3. Research methodology

In this paper three phase methodology has been applied for prioritizing the solutions of reverse logistics adoption to overcome its barriers. This paper used fuzzy analytical hierarchical process to get weights of criteria of barriers and prioritize the solutions of RL practices adoption by Fuzzy technique for order performance by similarity to ideal solution. Although decision making can be done by FAHP itself, but multi-criteria decision making process can be improved if it is integrated with many other decision support tools. By using fuzzy framework impreciseness and uncertainty can be handled. The suitability of this approach in a complex multi-criteria decision environment compels to select this method. Fig. 1 represents a schematic diagram of the research methodology.

3.1. Phase I: Identification of RL adoption barriers and solutions to overcome these barriers

In this phase, decision making group has been formed which includes experts, researchers, industry people (senior managers, IT people), industry associates and customers. Then RL adoption barriers are identified and evaluated through relevant literature and decision making group. Similarly solutions to overcome these barriers have been identified and evaluated by another decision making group which comprising RL and SC experts, industry people and industry associates.

Table 2
Solutions of RL practices adoption.

Code	Solutions	Explanation	References
S1	Top management awareness and support	The highest priority is to create awareness at senior management that must recognize a need for change and notice the potential improvement opportunities by implementing RL process.	PWC report [43], Shih et al. [56], Patil & Ravikant [40], Lau and Wang [35]
S2	Balancing cost efficiency with customer responsiveness	Identify financial benefits associated with RL practices and create awareness that companies are adopting the right things for customer by focusing on RL operations.	PWC report [43], Lancioni et al. [34], Choi et al. [7], Patil & Ravikant [40]
S3	Simplified and standardized processes	Companies should optimize their reverse logistic operations and formulating, tailoring, RL operation specification process.	PWC report [43], Cheung et al. [6], Patil & Ravikant [40], Lau and Wang [35]
S4	Detailed insight of cost and performance	Identify and measure the actual cost along with revenue associated with RL activities and performance throughout entire operations.	PWC report [43], Lau and Wang [35]
S5	Cross-functional collaboration	Company should influence collaboration in all relevant departments (R&D to Operations)	Lau and Wang [35], PWC report [43]
S6	Strategic collaboration with reverse chain partners	Company should involve reverse chain partners in planning and mutual process improvements as like forward chain partners and also collaborate with other companies.	Lau and Wang [35], PWC report [43]
S7	Aligned policies and processes	To develop entire reverse chain is focused on customer and act accordingly. Involve people, process, Technology, Infrastructure and organization structure so comprehensive change can be achieved.	PWC report [43]
S8	Strategic focus on avoiding returns	In organizations unwanted large volume of products return has been seen to reduce this they should have clear warranty schemes, harmonized and standardized returns policy.	PWC report [43]
S9	Perceive returns as perishable goods	Companies should understand returns goods as perishable products after recovering value or disposable activities from products.	PWC report [43]
S10	Reverse Logistics as part of sustainability program	If used products will reuse and recycle that lead to less waste. So, reverse logistics can be seen as part of sustainable development, efficient resource utilization and environmental protection. Other reason is, it can maximize stakeholder value from RL efforts by sustainability initiatives and take-back innovations and will provide competitive advantage.	PWC report [43], Fleischmann et al. [17], Gunasekaran and Spalanzani [20], Fernaíndez et al. [15], Tsai et al. [60]
S11	Reclaiming value from returns	It has been seen returns management offer significant cost saving or value in procurement, recovery and inventory by practicing RL.	PWC report [43], Srivastava [57]
S12	Control over turnaround times	RL activities should implement with standardized operating procedures and Performance would measure and control with defined guidelines.	PWC report [43].
S13	Create public awareness on environmental issues and conservation	Customers need to educate about environmental concern and waste reduction practices. Enhance public awareness about recycling and involve in RL practices.	Lau and Wang [35], PWC report [43]
S14	Enforce environmental legislation, regulations, and directives	India needs to introduce and establish stringent law and directives on WEEE. Encourage, promote and control RL practices by involving all SC partners and customers. Clear guidelines and rules about responsibilities and obligations of SC members.	Lau and Wang [35]
S15	Develop Infrastructure support and facility	Companies should develop adequate infrastructure facility (storage, transportation, recycling facility etc.) for RL activities.	Lau and Wang [35]
S16	Implement green practices for electronic products	Production design should be environment-friendly and do not use hazardous materials. Moreover design should facilitate easily recycling and reuse of products.	Lau and Wang [35]
S17	Create, develop and Invest in RL technology	Create active recycling network and system for WEEE returns to safeguard smooth and easy RL flows and effective recycling operation.	Lau and Wang [35]
S18	Make e-collaboration for fast and effective coordination among SC members.	Collaboration through electronic media would enable fast, effective, efficient and timely communication that would facilitate easy and active response of RL activities.	Johnson and Whang [30], Patil & Ravikant [40]
S19	Develop closed loop SC by integrating RL	Integrate forward and reverse SC to manage product, finance and information flow in both directions easily and efficiently.	Lau and Wang [35]
S20	Develop outsourcing strategy for recovery and collection of end of life products.	By outsourcing companies can achieve effective recovery of end of life products. Outsourcing candidates could use latest technology and resources to fast and efficient recovery of the products.	Dat et al. [9], Efendigil et al. [14], Senthil et al. [54]

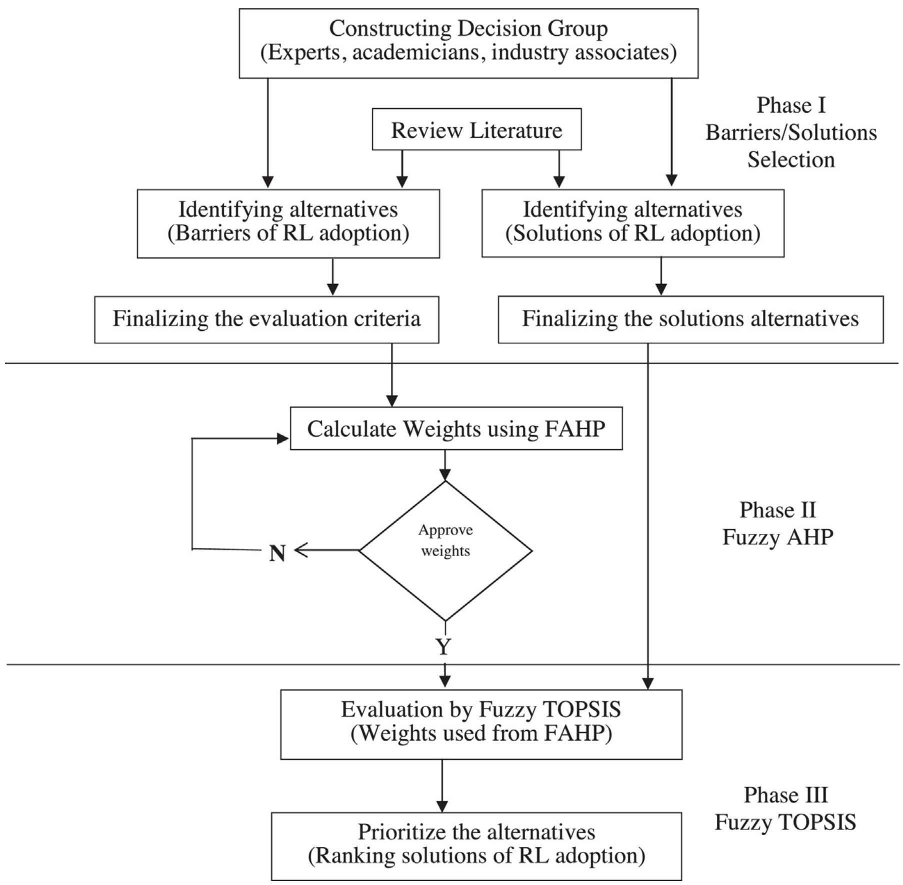

Fig. 1. Proposed three phase methodology for prioritizing the solutions of reverse logistics practices adoption to overcome its barriers.

The identified barriers are classified into criteria and sub-criteria and solutions to overcome these barriers are presented in phases as shown in Fig. 2.

3.2. Phase II: Fuzzy analytical hierarchy process

Satty [51] had given AHP; it was a quantitative technique of multi criteria decision making [63]. The application of Satty's AHP has some limitation due to usability of AHP in Crisp environment, Judgmental scale is unbalanced, and absence of uncertainty, selection of judgment is subjective. So there is a need to utilize Fuzzy approach to solve such problem. The fuzzy AHP method includes uncertain imprecise judgment of experts by utilizing linguistic variables. Recently many researchers have used this approach in various areas [4].

Definition 1. If $\breve{A}_1 = (l_1, m_1, u_1)$ and $\breve{A}_2 = (l_2, m_2, u_2)$ are representing two triangular fuzzy numbers then algebraic operations can be expressed as follows [40]

$$\breve{A}_1 \oplus \breve{A}_2 = (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (3.1)$$

$$\breve{A}_1 \odot \breve{A}_2 = (l_1, m_1, u_1) \odot (l_2, m_2, u_2) = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \quad (3.2)$$

$$\breve{A}_1 \otimes \breve{A}_2 = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (3.3)$$

$$\breve{A}_1 \emptyset \breve{A}_2 = (l_1, m_1, u_1) \emptyset (l_2, m_2, u_2) = (l_1/u_2, m_1/m_2, u_1/l_2) \quad (3.4)$$

$$\alpha \otimes \breve{A}_1 = (\alpha l_1, \alpha m_1, \alpha u_1) \text{ where } \alpha > 0 \quad (3.5)$$

$$\breve{A}_1^{-1} = (l_1, m_1, u_1)^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \quad (3.6)$$

To apply the fuzzy analytical hierarchical process according to the method of Chang's (1992) extent analysis used in [4]

$$M_{g_i}^1, M_{g_i}^2, M_{g_i}^3, \ldots, M_{g_i}^m$$

where g_i is the goal set ($i = 1, 2, 3, 4, 5, \ldots, n$) and all the $M_{g_i}^j$ ($j = 1, 2, 3, 4, 5, \ldots, m$) are triangular fuzzy numbers given in Table 3. The steps of Chang's analysis can be given as in the following:

Step 1. The fuzzy synthetic extent value (S_i) with respect to the ith criterion is defined as,

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

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

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right]^{-1} = \left(\frac{1}{\sum_{n}^{i=1}\sum_{m}^{j=1} u_{ij}}, \frac{1}{\sum_{n}^{i=1}\sum_{m}^{j=1} m_{ij}}, \frac{1}{\sum_{n}^{i=1}\sum_{m}^{j=1} l_{ij}}\right) \quad (3.10)$$

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

Step 2. The degree of possibility of $S_2 = (l_2, m_2, u_2) \geq S_1 = (l_1, m_1, u_1)$ is defined as below

$$V(S_2 \geq S_1) = \sup_{y \geq x} [\min(\mu_{S_1}(x), \mu_{S_2}(y))]$$

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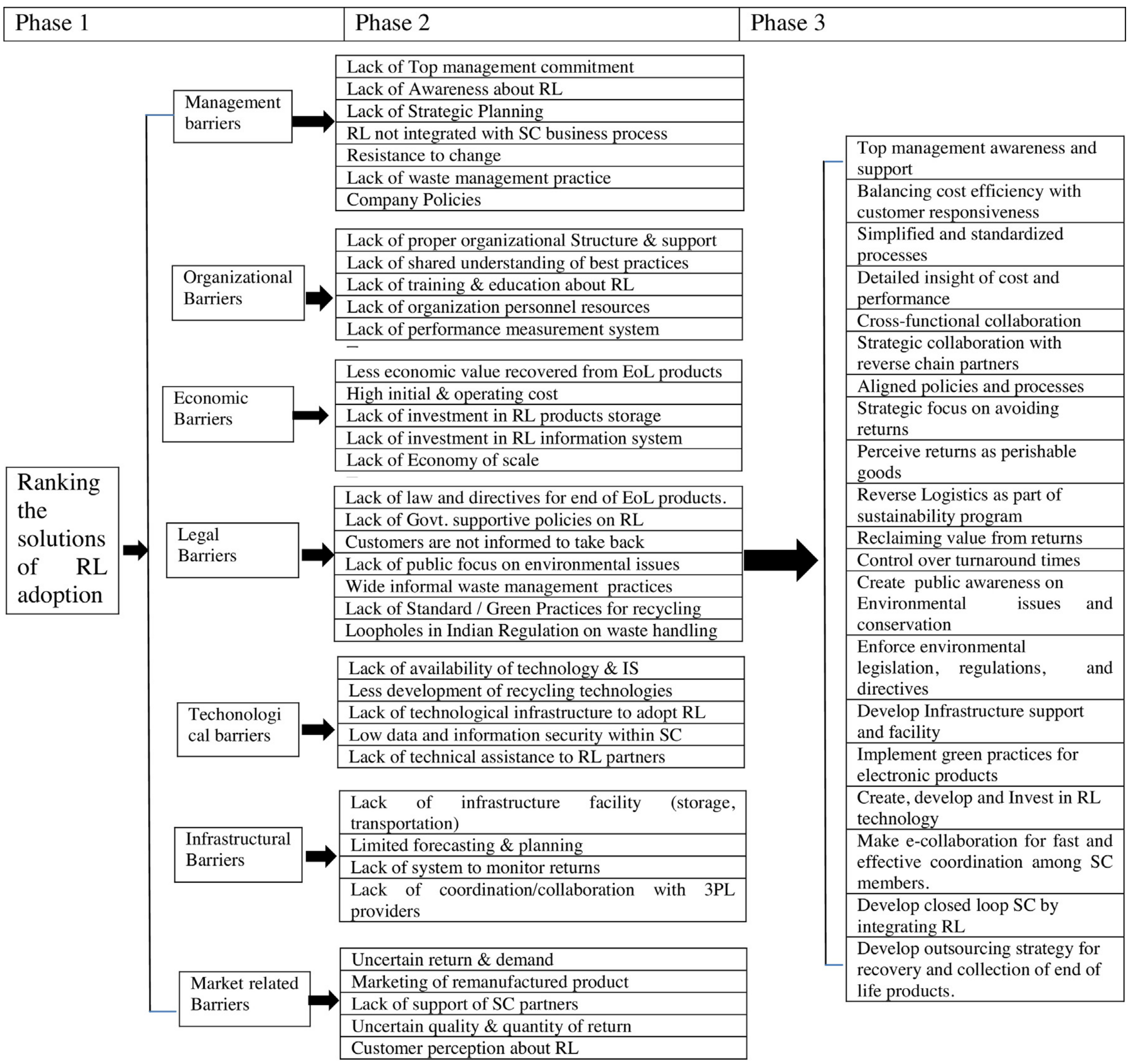

Fig. 2. Decision sequence for prioritizing solutions to overcome barriers for RL adoption.

Table 3
TFN of linguistic comparison matrix.

Linguistic variables	Assigned TFN
Equal	(1, 1, 1)
Very low	(1, 2, 3)
Low	(2, 3, 4)
Medium	(3, 4, 5)
High	(4, 5, 6)
Very high	(5, 6, 7)
Excellent	(6, 7, 8)

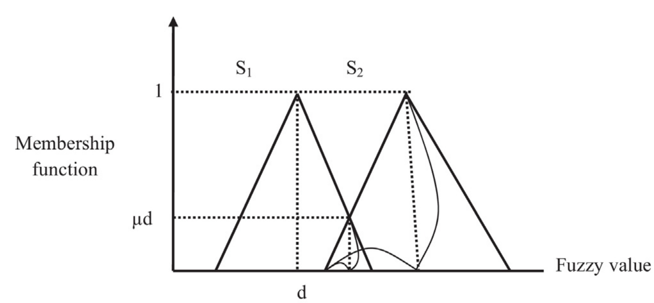

Fig. 3. The intersection of fuzzy numbers.

and x and y are the values on the axis of membership function of each criterion. This expression can be equivalently written as given in Eq. (3.11):

$$V(S_2 \geq S_1) = \begin{cases} 1 & \text{if } m_2 \geq m_1 \\ 0 & \text{if } l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases} \quad (3.11)$$

where μd is the highest intersection point μ_{S_1} and μ_{S_2} (see Fig. 3).

To compare S_1 and S_2 we need both $V(S_1 \geq S_2)$ and $V(S_2 \geq S_1)$.

Step 3. The degree of possibility for a convex fuzzy number S to be greater than k convex fuzzy numbers S_i (i = 1, 2, . . ., k) can be defined by

$$\begin{aligned} V(S \geq S_1, S_2, \ldots, S_k) &= V[(S \geq S_1), (S \geq S_2), \ldots, (S \geq S_k)] \\ &= \min V(S \geq S_i), \quad i = 1, 2, \ldots, k \quad (3.12) \\ \text{Assume that } d'(A_i) &= \min V(S_i \geq S_k) \end{aligned}$$

Table 4
Linguistics variables ratings.

Linguistic variables	Assigned TFN
Very low	(1, 2, 3)
Low	(2, 3, 4)
Medium	(3, 4, 5)
High	(4, 5, 6)
Very high	(5, 6, 7)
Excellent	(6, 7, 8)

For $k = 1, 2, \ldots, n, k \neq i$, Than the weight vectors are given in Eq. (3.13) as,

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_m))^T \tag{3.13}$$

Step 4. Via normalization, the normalized weight vectors are given in Eq. (3.14) as,

$$W = (d(A_1), d(A_2), \ldots, d(A_m))^T \tag{3.14}$$

3.3. Phase III: Fuzzy TOPSIS

TOPSIS is another MCDM method was presented by Hwang and Yoon [26]. It is based on the selective attribute should be at the least distance and longest distance from the positive ideal solution and the negative ideal solution respectively. In the classical TOPSIS approach, individual preferences are assigned with crisp values. But in reality, a better approach is that which would consider uncertainty and impreciseness rather than crisp value. Fuzzy environment incorporate uncertainty in decision making, that's why, fuzzy TOPSIS method is quite appropriate tool for the solution of real life problems [40,54].

The fuzzy TOPSIS approach used in this research paper is as follows:

Step 1. Assign rating values for the linguistic variables with respect to criteria. The scale used for rating is given in Table 4. And construct matrix for alternatives in fuzzy form.

Step 2 (Computation of aggregate fuzzy ratings for the solutions). If fuzzy rating of the Nth decision maker is $\breve{X}_{abN} = (l_{abN}, p_{abN}, u_{abN})$ where $a = 1, 2, 3, \ldots, m$, $b = 1, 2, 3, \ldots, n$ then the fuzzy aggregated fuzzy ratings $\breve{X}_{ab}$ of solutions with respect to each criteria is given by $\breve{X}_{ab}(l_{ab}, p_{ab}, u_{a,b})$, where

$$a = \min_N\{l_{abN}\}, \quad b = \frac{1}{N}\sum_{N=1}^{N} p_{abN}, \quad c = \max_N\{u_{abN}\} \tag{4.0}$$

Step 3 (Normalized fuzzy decision matrix). To get comparable scale by utilizing linear scale transformation, data is normalized. It is given by $\breve{B}$ where:

$$\breve{B} = [p_{ij}]_{m\times n}$$

where $i = 1, 2, 3, \ldots, m$ and $j = 1, 2, 3, \ldots, n$

$$\breve{p}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \text{ and } c_j^* = \max c_{ij} (\text{benefit criteria}) \tag{4.1}$$

$$\breve{p}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \text{ and } a_j^- = \min a_{ij} (\text{cost criteria}) \tag{4.2}$$

Step 4. Construct the weighted normalized matrix by using given Eq. (4.3)

$$\breve{V} = [\breve{v}_{ij}]_{m\times n} \quad \text{where } i = 1, 2, 3, \ldots, m \text{ and } j = 1, 2, 3, \ldots, n$$
$$\text{where } \breve{v} = \breve{p}_{ij} \otimes w_j \tag{4.3}$$

Step 5. Determine the ideal and fuzzy negative ideal solution (FNIS) and positive ideal solution (FPIS) as follows respectively:

$$A^+ = \{v_1^+, \ldots, v_n^+\}, \text{ where } v_j^+ = \{\max(v_{ij}) \text{ if } j \in J; \min(v_{ij}) \text{ if } j \in J'\}, \quad j = 1, \ldots, n \tag{4.4}$$

$$A^- = \left\{v_1^-, \ldots, v_n^-\right\}, \text{ where } v_j^- = \{\min(v_{ij}) \text{ if } j \in J;\ \max(v_{ij}) \text{ if } j \in J'\}, \quad j = 1, \ldots, n \tag{4.5}$$

Step 6. Calculate the distance of each alternative from FNIS and FPIS is computed as follows:

$$d_i^+ = \left\{\sum_{j=1}^{n}\left(v_{ij} - v_{ij}^+\right)^2\right\}^{1/2}, \quad i = 1, \ldots, m$$
$$d_i^- = \left\{\sum_{j=1}^{n}\left(v_{ij} - v_{ij}^-\right)^2\right\}^{1/2}, \quad i = 1, \ldots, m \tag{4.6}$$

Step 7. Closeness coefficient (CC_i) of each alternative is calculated by using Eq. (4.7)

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+}, \quad i = 1, \ldots, m. \quad C_i \in (0, 1) \tag{4.7}$$

Step 8. Rank the alternatives as per closeness rating by using CC_i in descending order.

4. Application of the proposed method for RL adoption in indian electronics industry

4.1. Problem definition

Indian companies have realized the importance of RL practices in today's business scenario. However few organizations have adopted these practices but getting less success due to barriers. To improve the success rate suggested solutions should be implemented to overcome identified barriers. This can be done by prioritizing the solutions of RL adoption. So Indian organizations can focus on the high ranking solutions and implement them to overcome the barriers.

4.2. Phase I: Identification of RL adoption barriers and solutions to overcome these barriers

The decision group has been formed and includes 18 experts comprising three senior managers (strategic planning, legal dept., commercial dept.), three IT managers, three operations managers, three senior executives (marketing, finance, quality), three industry associates and three customers. In this research 38 barriers (sub-criteria) including quantitative and qualitative, identified through literature review and brain storming session with decision group (see Table 1). Similarly 8 experts (RL and SC Senior members) suggested 20 solutions to overcome these barriers by literature review and mutual discussion (see Table 2).

4.3. Phase II: Fuzzy AHP to calculate the weights of the barriers of RL adoption

Decision group has to make pair-wise comparison of 7 criteria and 38 sub-criteria, defined by TFN as given in Table 3. The fuzzy comparison matrices of criteria and their sub-criteria along with calculated weights are given in Tables 5–12.

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Table 5
The fuzzy comparison matrix of the criteria.

	MB	OB	EB	LB	TB	IB	MRB	Weight	Rank
MB	(1, 1, 1)	(1, 2, 3)	(0.33, 0.5, 1)	(3, 4, 5)	(0.25, 0.33, 05)	(2, 3, 4)	(0.25, 0.33, 05)	0.151	3
OB	(0.33, 0.5, 1)	(1, 1, 1)	(0.25,0.33, 0.5)	(0.33, 0.5, 1)	(3, 4, 5)	(1, 2, 3)	(0.33, 0.5, 1)	0.124	7
EB	(1, 2, 3)	(2, 3, 4)	(1, 1, 1)	(3, 4, 5)	(0.33, 0.5, 1)	(0.25, 0.33, 05)	(0.2, 0.25,0.33)	0.149	4
LB	(0.2, 0.25,0.33)	(1, 2, 3)	(0.2, 0.25,0.33)	(1, 1, 1)	(2, 3, 4)	(2, 3, 4)	(1, 2, 3)	0.155	1
TB	(2, 3, 4)	(0.2, 0.25,0.33)	(1, 2, 3)	(0.25, 0.33, 05)	(1, 1, 1)	(0.33, 0.5, 1)	(1, 2, 3)	0.13	6
IB	(0.25,0.33, 0.5)	(0.33, 0.5, 1)	(2, 3, 4)	(0.25, 0.33, 05)	(1, 2, 3)	(1, 1, 1)	(2, 3, 4)	0.138	5
MRB	(2, 3, 4)	(1, 2, 3)	(3, 4, 5)	(0.33, 0.5, 1)	(0.33, 0.5, 1)	(0.25, 0.33, 05)	(1, 1, 1)	0.152	2

Table 6
The pair-wise comparison matrix of the sub-criteria w.r.t. criteria MB.

	MB1	MB2	MB3	MB4	MB5	MB6	MB7	Weight	Rank
MB1	(1, 1, 1)	(3, 4, 5)	(2, 3, 4)	(2, 3, 4)	(3, 4, 5)	(0.33, 0.5, 1)	(3, 4, 5)	0.275	1
MB2	(0.2, 0.25,0.33)	(1, 1, 1)	(0.2, 0.25, 0.33)	(0.25,0.33, 0.5)	(3, 4, 5)	(3, 4, 5)	(0.25, 0.33, 0.5)	0.109	4
MB3	(0.25, 0.33, 0.5)	(3, 4, 5)	(1, 1, 1)	(0.2, 0.25,0.33)	(1, 2, 3)	(0.25, 0.33, 0.5)	(0.25, 0.33, 0.5)	0.070	5
MB4	(0.25, 0.33, 0.5)	(2, 3, 4)	(3, 4, 5)	(1, 1, 1)	(3, 4, 5)	(0.33, 0.5, 1)	(2, 3, 4)	0.226	2
MB5	(0.2, 0.25,0.33)	(0.2, 0.25,0.33)	(0.33, 0.5, 1)	(0.2, 0.25, 0.33)	(1, 1, 1)	(1, 2, 3)	(3, 4, 5)	0.073	6
MB6	(1, 2, 3)	(0.2, 0.25, 0.33)	(2, 3, 4)	(1, 2, 3)	(0.33, 0.5, 1)	(1, 1, 1)	(3, 4, 5)	0.180	3
MB7	(0.2, 0.25, 0.33)	(2, 3, 4)	(2, 3, 4)	(0.25, 0.33, 0.5)	(0.2, 0.25,0.33)	(0.2, 0.25, 0.33)	(1, 1, 1)	0.063	7

Table 7
The pair-wise comparison matrix of the sub-criteria w.r.t. criteria OB.

	OB1	OB2	OB3	OB4	OB5	Weight	Rank
OB1	(1, 1, 1)	(2, 3, 4)	(3, 4, 5)	(0.25,0.33, 0.5)	(0.2, 0.25,0.33)	0.232	2
OB2	(0.25,0.33, 0.5)	(1, 1, 1)	(0.33, 0.5, 1)	(0.33, 0.5, 1)	(3, 4, 5)	0.152	3
OB3	(0.2, 0.25,0.33)	(1, 2, 3)	(1, 1, 1)	(0.2, 0.25,0.33)	(1, 2, 3)	0.119	5
OB4	(2, 3, 4)	(1, 2, 3)	(3, 4, 5)	(1, 1, 1)	(2, 3, 4)	0.360	1
OB5	(0.25,0.33, 0.5)	(3, 4, 5)	(0.33, 0.5, 1)	(0.25,0.33, 0.5)	(1, 1, 1)	0.137	4

Table 8
The pair-wise comparison matrix of the sub-criteria w.r.t. criteria EB.

	EB1	EB2	EB3	EB4	EB5	Weight	Rank
EB1	(1, 1, 1)	(0.25, 0.33, 0.5)	(0.2, 0.25,0.33)	(2, 3, 4)	(3, 4, 5)	0.221	2
EB2	(2, 3, 4)	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	(0.2, 0.25,0.33)	0.235	1
EB3	(3, 4, 5)	(0.33, 0.5, 1)	(1, 1, 1)	(0.33, 0.5, 1)	(1, 2, 3)	0.211	3
EB4	(0.25, 0.33, 0.5)	(0.25, 0.33, 0.5)	(1, 2, 3)	(1, 1, 1)	(2, 3, 4)	0.177	4
EB5	(0.2, 0.25,0.33)	(3, 4, 5)	(0.33, 0.5, 1)	(0.25, 0.33, 0.5)	(1, 1, 1)	0.156	5

Table 9
The pair-wise comparison matrix of the sub-criteria w.r.t. criteria LB.

	LB1	LB2	LB3	LB4	LB5	LB6	LB7	Weight	Rank
LB1	(1, 1, 1)	(2, 3, 4)	(3, 4, 5)	(2, 3, 4)	(3, 4, 5)	(2, 3, 4)	(0.2, 0.25,0.33)	0.234	1
LB2	(0.25, 0.33, 0.5)	(1, 1, 1)	(0.25, 0.33, 0.5)	(0.2, 0.25,0.33)	(3, 4, 5)	(3, 4, 5)	(0.2, 0.25,0.33)	0.104	6
LB3	(0.2, 0.25,0.33)	(2, 3, 4)	(1, 1, 1)	(3, 4, 5)	(1, 2, 3)	(2, 3, 4)	(0.25, 0.33, 0.5)	0.171	2
LB4	(0.25, 0.33, 0.5)	(3, 4, 5)	(0.2, 0.25,0.33)	(1, 1, 1)	(3, 4, 5)	(0.25, 0.33, 0.5)	(2, 3, 4)	0.157	3
LB5	(0.2, 0.25,0.33)	(0.2, 0.25,0.33)	(0.33, 0.5, 1)	(0.2, 0.25, 0.33)	(1, 1, 1)	(3, 4, 5)	(3, 4, 5)	0.108	5
LB6	(0.25, 0.33, 0.5)	(0.2, 0.25, 0.33)	(0.25, 0.33, 0.5)	(2, 3, 4)	(0.2, 0.25,0.33)	(1, 1, 1)	(3, 4, 5)	0.085	7
LB7	(3, 4, 5)	(2, 3, 4)	(2, 3, 4)	(0.25, 0.33, 0.5)	(0.2, 0.25,0.33)	(0.2, 0.25, 0.33)	(1, 1, 1)	0.141	4

Table 10
The pair-wise comparison matrix of the sub-criteria w.r.t. criteria TB.

	TB1	TB2	TB3	TB4	TB5	Weight	Rank
TB1	(1, 1, 1)	(3, 4, 5)	(3, 4, 5)	(0.2, 0.25,0.33)	(2, 3, 4)	0.289	1
TB2	(0.2, 0.25,0.33)	(1, 1, 1)	(0.2, 0.25,0.33)	(2, 3, 4)	(3, 4, 5)	0.19	3
TB3	(0.2, 0.25,0.33)	(3, 4, 5)	(1, 1, 1)	(0.2, 0.25,0.33)	(1, 2, 3)	0.159	4
TB4	(3, 4, 5)	(0.25, 0.33, 0.5)	(3, 4, 5)	(1, 1, 1)	(0.33, 0.5, 1)	0.231	2
TB5	(0.25, 0.33, 0.5)	(0.2, 0.25,0.33)	(2, 3, 4)	(1, 2, 3)	(1, 1, 1)	0.131	5

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Table 11
The pair-wise comparison matrix of the sub-criteria w.r.t. criteria IB.

	IB1	IB2	IB3	IB4	Weight	Rank
IB1	(1, 1, 1)	(0.2, 0.25,0.33)	(0.25, 0.33, 0.5)	(3, 4, 5)	0.184	3
IB2	(3, 4, 5)	(1, 1, 1)	(3, 4, 5)	(0.25, 0.33, 0.5)	0.40	1
IB3	(2, 3, 4)	(0.2, 0.25,0.33)	(1, 1, 1)	(2, 3, 4)	0.303	2
IB4	(0.2, 0.25,0.33)	(2, 3, 4)	(0.25, 0.33, 0.5)	(1, 1, 1)	0.113	4

Table 12
The pair-wise comparison matrix of the sub-criteria w.r.t. criteria MRB.

	MRB1	MRB2	MRB3	MRB4	MRB5	Weight	Rank
MRB1	(1, 1, 1)	(3, 4, 5)	(2, 3, 4)	(0.2, 0.25,0.33)	(0.2, 0.25,0.33)	0.196	3
MRB2	(0.2, 0.25,0.33)	(1, 1, 1)	(0.25, 0.33, 0.5)	(3, 4, 5)	(0.2, 0.25,0.33)	0.049	5
MRB3	(0.25, 0.33, 0.5)	(2, 3, 4)	(1, 1, 1)	(0.2, 0.25,0.33)	(2, 3, 4)	0.162	4
MRB4	(3, 4, 5)	(0.2, 0.25,0.33)	(3, 4, 5)	(1, 1, 1)	(0.2, 0.25,0.33)	0.233	2
MRB5	(3, 4, 5)	(3, 4, 5)	(0.25, 0.33, 0.5)	(3, 4, 5)	(1, 1, 1)	0.36	1

Table 13
V values for criteria.

	MB	OB	EB	LB	TB	IB	MRB
MB		0.817	0.992	1	0.855	0.912	1
OB	1		1	1	1	1	1
EB	1	0.822		1	0.861	0.919	1
LB	0.977	0.801	0.964		0.84	0.889	0.984
TB	1	0.979	1	1		1	1
IB	1	0.894	1	1	0.924		1
MRB	0.988	0.805	0.977	1	0.845	0.898	

Table 14
Final ranking of barriers of RL adoption.

Criterion	Weight	Sub-criterion	Weight	Finalized weight	Global rank
Management barriers	0.151	MB1	0.275	0.041525	4
		MB2	0.109	0.016459	30
		MB3	0.070	0.01057	36
		MB4	0.226	0.034126	10
		MB5	0.073	0.011023	35
		MB6	0.180	0.02718	16
		MB7	0.063	0.009513	37
Organizational barriers	0.124	OB1	0.232	0.028768	15
		OB2	0.152	0.018848	26
		OB3	0.119	0.014756	33
		OB4	0.36	0.04464	3
		OB5	0.137	0.016988	28
Economic barriers	0.149	EB1	0.221	0.032929	11
		EB2	0.235	0.035015	9
		EB3	0.211	0.031439	12
		EB4	0.177	0.026373	18
		EB5	0.156	0.023244	23
Legal barriers	0.155	LB1	0.234	0.03565	7
		LB2	0.104	0.01612	31
		LB3	0.171	0.026505	17
		LB4	0.157	0.024335	22
		LB5	0.108	0.01674	29
		LB6	0.085	0.013175	34
		LB7	0.141	0.021855	24
Technological barriers	0.13	TB1	0.289	0.03744	6
		TB2	0.19	0.0247	20
		TB3	0.159	0.02067	25
		TB4	0.23	0.0299	13
		TB5	0.131	0.01703	27
Infrastructural barriers	0.138	IB1	0.184	0.025208	19
		IB2	0.40	0.0548	1
		IB3	0.303	0.041374	5
		IB4	0.113	0.015618	32
Market related barriers	0.152	MRB1	0.196	0.029792	14
		MRB2	0.049	0.007448	38
		MRB3	0.162	0.024624	21
		MRB4	0.233	0.035416	8
		MRB5	0.36	0.05472	2

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Table 15
Linguistics variables ratings matrix for the solutions (expert 1).

	MB1	MB2	MB3	...	...	MRB3	MRB4	MRB5
S1	H	M	H	...	...	H	L	M
S2	M	H	H	...	...	M	M	H
S3	H	VH	VH	...	...	M	M	L
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
S18	VH	H	M	...	...	M	L	M
S19	M	M	H	...	...	VH	M	M
S20	M	M	VH	...	...	VH	M	M

Table 16
TFN evaluation matrix for solutions (expert 1).

	MB1	MB2	MB3	...	...	MRB3	MRB4	MRB5
S1	(4, 5, 6)	(3, 4, 5)	(4, 5, 6)	...	...	(4, 5, 6)	(2, 3, 4)	(3, 4, 5)
S2	(3, 4, 5)	(4, 5, 6)	(4, 5, 6)	...	...	(3, 4, 5)	(3, 4, 5)	(4, 5, 6)
S3	(4, 5, 6)	(5, 6, 7)	(5, 6, 7)	...	...	(3, 4, 5)	(3, 4, 5)	(2, 3, 4)
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
S18	(5, 6, 7)	(4, 5, 6)	(3, 4, 5)	...	...	(3, 4, 5)	(2, 3, 4)	(3, 4, 5)
S19	(3, 4, 5)	(3, 4, 5)	(2, 3, 4)	...	...	(5, 6, 7)	(3, 4, 5)	(3, 4, 5)
S20	(3, 4, 5)	(3, 4, 5)	(5, 6, 7)	...	...	(5, 6, 7)	(3, 4, 5)	(3, 4, 5)

Table 17
Aggregate fuzzy decision matrix for solutions.

	MB1	MB2	MB3	...	...	MRB3	MRB4	MRB5
S1	(3, 5.6, 7)	(2, 4.1, 6)	(4, 6.1, 8)	...	...	(3, 4.1, 6)	(1, 2.5, 4)	(3, 5, 7)
S2	(2, 5.5, 7)	(4, 5.6, 7)	(3, 4.5, 6)	...	...	(2, 3.5, 5)	(1, 3, 5)	(4, 5.8, 7)
S3	(1, 3, 5)	(5, 6.5, 8)	(5, 6.2, 8)	...	...	(2, 4, 6)	(1, 2.1, 4)	(2, 3.6, 5)
...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...
S18	(5, 6.6, 8)	(4, 5.8, 7)	(1, 3.1, 5)	...	...	(4, 6, 8)	(1, 3, 5)	(3, 4.5, 6)
S19	(2, 4.1, 6)	(3, 4.5, 6)	(3, 5.5, 7)	...	...	(2, 4.4, 7)	(3, 4.5, 6)	(3, 5, 7)
S20	(2, 4.5, 6)	(3, 5.6, 7)	(4, 6.5, 8)	...	...	(4, 5.5, 7)	(3, 5, 7)	(3, 4.6, 6)

Table 18
Normalized fuzzy decision matrix for solutions.

	MB1	MB2	MB3	...	MRB3	MRB4	MRB5
S1	(0.14, 0.17, 0.33)	(0.16, 0.24, 0.5)	(0.12, 0.16, 0.25)	...	(0.16, 0.42, 0.33)	(0.25, 0.62, 1)	(0.14, 0.2, 0.33)
S2	(0.14, 0.18, 0.5)	(0.14, 0.17, 0.25)	(0.16, 0.22, 0.33)	...	(0.2, 0.28, 0.5)	(0.2, 0.6, 1)	(0.14, 0.17, 0.25)
S3	(0.2, 0.6, 1)	(0.12, 0.15, 0.2)	(0.12, 0.16, 0.2)	...	(0.16, 0.25, 0.5)	(0.25, 0.52, 1)	(0.2, 0.27, 0.5)
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
S18	(0.12, 0.15, 0.2)	(0.14, 0.17, 0.25)	(0.2, 0.62, 1)	...	(0.12, 0.16, 0.25)	(0.2, 0.6, 1)	(0.16, 0.22, 0.33)
S19	(0.16, 0.24, 0.5)	(0.16, 0.22, 0.33)	(0.14, 0.18, 0.33)	...	(0.14, 0.22, 0.5)	(0.16, 0.22, 0.33)	(0.14, 0.2, 0.33)
S20	(0.16, 0.22, 0.5)	(0.14, 0.17, 0.33)	(0.12, 0.15, 0.25)	...	(0.14, 0.18, 0.25)	(0.14, 0.2, 0.33)	(0.16, 0.21, 0.33)

Table 19
Weighted normalized fuzzy decision matrix for solutions.

	MB1	MB2	MB3	...	MRB3	MRB4	MRB5
S1	(0.005, 0.007, 0.013)	(0.002, 0.004, 0.008)	(0.001, 0.001, 0.002)	...	(0.004, 0.006, 0.008)	(0.008, 0.022, 0.035)	(0.007, 0.010, 0.018)
S2	(0.005, 0.007, 0.02)	(0.002, 0.002, 0.004)	(0.001, 0.002, 0.003)	...	(0.004, 0.007, 0.012)	(0.007, 0.021, 0.035)	(0.007, 0.009, 0.013)
S3	(0.008, 0.024, 0.041)	(0.002, 0.002, 0.003)	(0.001, 0.001, 0.002)	...	(0.004, 0.006, 0.012)	(0.008, 0.018, 0.035)	(0.010, 0.015, 0.027)
...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...
S18	(0.005, 0.006, 0.008)	(0.002, 0.002, 0.004)	(0.002, 0.006, 0.01)	...	(0.003, 0.004, 0.006)	(0.007, 0.021, 0.035)	(0.009, 0.012, 0.018)
S19	(0.006, 0.01, 0.02)	(0.002, 0.003, 0.005)	(0.001, 0.001, 0.003)	...	(0.003, 0.005, 0.012)	(0.005, 0.007, 0.011)	(0.007, 0.010, 0.018)
S20	(0.006, 0.009, 0.02)	(0.002, 0.002, 0.005)	(0.001, 0.001, 0.002)	...	(0.003, 0.004, 0.006)	(0.005, 0.007, 0.011)	(0.009, 0.011, 0.018)

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Table 20
Final ranking of the solutions.

Code	Solutions	d_i^+	d_i^-	CC_i	Rank
S1	Top management awareness and support	0.301517	37.72036	0.99207	14
S2	Balancing cost efficiency with customer responsiveness	0.29637	37.72514	0.992205	11
S3	Simplified and standardized processes	0.34135	37.68732	0.991024	20
S4	Detailed insight of cost and performance	0.332277	37.69331	0.991262	16
S5	Cross-functional collaboration	0.292016	37.72856	0.99232	9
S6	Strategic collaboration with reverse chain partners	0.299113	37.72293	0.992133	13
S7	Aligned policies and processes	0.337226	37.68988	0.991132	18
S8	Strategic focus on avoiding returns	0.313742	37.71111	0.991749	15
S9	Perceive returns as perishable goods	0.280938	37.73857	0.992611	5
S10	Reverse Logistics as part of sustainability program	0.298513	37.72562	0.992149	12
S11	Reclaiming value from returns	0.291667	37.72772	0.992328	8
S12	Control over turnaround times	0.332805	37.69378	0.991248	17
S13	Create public awareness on environmental issues and conservation	0.280039	37.73863	0.992634	4
S14	Enforce environmental legislation, regulations, and directives	0.29553	37.72617	0.992227	10
S15	Develop Infrastructure support and facility	0.279069	37.74033	0.99266	3
S16	Implement green practices for electronic products	0.29076	37.7304	0.992353	7
S17	Create, develop and invest in RL technology	0.251674	37.76353	0.99338	1
S18	Make e-collaboration for fast and effective coordination among SC members	0.340245	37.68764	0.991053	19
S19	Develop closed loop SC by integrating RL	0.26946	37.74839	0.992912	2
S20	Develop outsourcing strategy for recovery and collection of end of life products	0.283609	37.735	0.99254	6

Weights calculation by using Chang's extent analysis is given in Table 13. These calculations have done by using MS-Excel.

Calculation of the fuzzy synthetic extent of 7 criteria is given below by using Eq. (3.10). The final results of pair-wise comparison of criteria and sub-criteria are presented in Table 14. It shows limited forecasting or planning of RL products return is at the highest importance for RL adoption.

$$S(\mathrm{MB}) = (7.83, 11.17, 14) \otimes [49.80, 73.17, 88.5]^{-1} = (0.089, 0.153, 0.281)$$
$$S(\mathrm{OB}) = (6.25, 8.83, 11.5) \otimes [49.80, 73.17, 88.5]^{-1} = (0.071, 0.121, 0.231)$$
$$S(\mathrm{EB}) = (7.78, 11.08, 11.83) \otimes [49.80, 73.17, 88.5]^{-1} = (0.088, 0.151, 0.238)$$
$$S(\mathrm{LB}) = (7.40, 11.5, 15.33) \otimes [49.80, 73.17, 88.5]^{-1} = (0.084, 0.157, 0.308)$$
$$S(\mathrm{TB}) = (5.78, 9.08, 12.83) \otimes [49.80, 73.17, 88.5]^{-1} = (0.065, 0.124, 0.258)$$
$$S(\mathrm{IB}) = (6.83, 10.17, 11.5) \otimes [49.80, 73.17, 88.5]^{-1} = (0.077, 0.139, 0.231)$$
$$S(\mathrm{MRB}) = (7.92, 11.33, 11.55) \otimes [49.80, 73.17, 88.5]^{-1} = (0.089, 0.155, 0.231)$$

By using the Eq. (3.11), V values are calculated are shown in Table 13.

Then we determined minimum degree of possibility by using Eq. (3.12) as

$$m(\mathrm{MB}) = \min V(S_1 = S_k) = \min(1, 1, 0.977, 1, 1, 0.988) = 0.977$$

Similarly $m(\mathrm{OB}) = 0.801$, $m(\mathrm{EB}) = 0.964$, $m(\mathrm{LB}) = 1$, $m(\mathrm{TB}) = 0.84$, $m(\mathrm{IB}) = 0.889$, $m(\mathrm{MRB}) = 0.984$.

Then weight vector is represented by:

$$W_V = (0.977, 0.801, 0.964, 1, 0.84, 0.889, 0.984)^T$$

Final weights of the criteria would obtained after normalization of the weight vector as

$$W = (0.151, 0.124, 0.149, 0.155, 0.13, 0.137, 0.152)$$

Due to same process for calculation to determine other weights of the criteria are not given.

4.4. Phase III: Fuzzy TOPSIS for ranking the solutions of RL adoption

The decision making group have constructed fuzzy evaluation matrix into TFN by assigning linguistic variables given in Table 4. This matrix is developed by comparing solutions with each barrier which is given in Table 15. The corresponding evaluation matrix in TFN is given in Table 16. Here only one expert evaluation matrix in TFN is given due to space constraint. Then aggregate fuzzy weights of the solutions are calculated by using Eq. (4) and given in Table 17. This study considered all criteria of the barriers as cost criteria so goal minimization approach is used and normalization of aggregate fuzzy matrix is done by using Eq. (4.2) which is given in Table 18. And then fuzzy weighted matrix has been computed by multiplying barriers criteria weights obtained by using FAHP (see Table 14) given in Table 19 by using Eq. (4.3). This study considers all barriers as cost criteria and allocated the fuzzy positive ideal solution as $\tilde{v}_1^+ = (0, 0, 0)$ and the fuzzy negative ideal solution as $\tilde{v}_1^- = (1, 1, 1)$, thereafter each alternatives distance is calculated by using Eq. 4.6 and coefficient of the closeness is obtained by using Eq. (4.7) and according to descending order of CC_i values, final ranking of the solutions has been done, which is shown in the Table 20. This entire process has been done as per methodology discussed in phase III.

5. Results and discussion

It is very hard to say which barrier of RL adoption is more important than others, but prioritizing them by using this approach made it more logical and helpful for decision makers. The prioritization of the RL adoption barriers have been done by observing the highest weightage value which shows that legal barriers, market related barriers, management barriers, economic barriers, infrastructural barriers, technological barriers and organizational barriers are in descending order which is given in Table 5. It indicates that legal barriers are dominating barriers in implementation of RL operations. And the ranking of reported legal barrier sub-criteria in this study are LB1 > LB3 > LB4 > LB7 > LB5 > LB2 > LB6 (Table 9), which shows lack of law and directives for end of EoL products is the top most priority barrier in all legal barriers for RL adoption. Similarly in Market related barrier sub-criteria, MRB5 is the highest weightage barrier and MRB2 is the lowest weightage barrier, however other barriers rating are MRB4–MRB1–MRB3 (Table 12) in descending order. Management barriers rating are MB1 > MB4 > MB6 > MB2 > MB3 > MB5 > MB7 (Table 6), which

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declares Lack of Top management commitment is the highest ranking barrier for RL adoption in this category. Similarly ranking of economic barriers is EB2-EB1-EB3-EB4-EB5 (Table 8) in descending order which imply High initial & operating cost for RL adoption is highest ranking barrier among all these barriers. The rating of Infrastructural barriers are IB2 > IB3 > IB1 > IB4 (In Table 11) which depicts limited forecasting & planning has top position in this set. Technological barriers ranking are TB1-TB4-TB2-TB3-TB5 (Table 10) in descending order which indicates Lack of availability of technology & information system is first among them. Finally organizational barriers rating are OB4 > OB1 > OB2 > OB5 > OB3 (Table 7) which conclude that Lack of organization personnel resources is the top ranking barrier in RL adoption. Now in order to overcome these barriers, some solutions/strategies have been suggested and it is very difficult to say which solution of RL adoption to overcome its barrier is more important but prioritizing the solutions by using this integrated methodology made it more systematic and helpful for decision makers. The ranking of the solutions for RL adoption have been done by observing highest closeness coefficient value which shows solution 17, i.e. create, develop and invest in RL technology is the top most priority solution to overcome RL adoption barriers and solution 3, simplified and standardized processes for RL adoption is coming at the last. However other solutions ranking are S19-S15-S13-S9-S20-S16-S11-S5-S14-S2-S10-S6-S1-S8-S4-S12-S7-S18 in descending orders which are given in Table 20. Indian electronics industry should implement these solutions on the priority basis and in sequence as per the ranking.

By using this approach decision makers can evaluate and select appropriate set of solutions for RL adoption to overcome barriers.

5.1. Sensitivity analysis

The sensitivity analysis is performed to connote the effect on the evaluation process and ranking of the solution for RL adoption by variation in the priority weights. Twenty experiments were performed that could be seen in Table 21. This has been done by replacing the high weight for decision attributes while putting the other weights are constant. In the sensitivity analysis run 1, weight of the barriers MB1 (WMB1) = 0.55 and weights of all others 37 barriers i.e. WMB2–WMRB5 = 0.015, remains constant. Then CC_i scores are calculated by using FTOPSIS method. Again in the sensitivity analysis run 2, weight of the barriers MB2 (WMB2) = 0.55 and weights of all others 37 barriers i.e. WMB1, WMB3–WMRB5 = 0.015 remains constant and CC_i values are calculated to get final rank. Similar process is done till 19 runs. In the last run the weights of all barriers are assumed to be of equal importance and single value is assigned to each barrier i.e. WMB1–WMRB5 = 0.4 then CC_i values are calculated to get final rank which is shown in Table 21. The details of the experiments are given in Fig. 4. The results of the sensitivity analysis are shown in Table 21 and Fig. 4 shows that S17 has highest value in eight experiments out of 20 experiments (4–5, 8, 11–12, 14, 17, 20), S15 has highest score in three experiments (2–3, 16), S14 & S19 has highest score in two experiments (10, 18 & 7, 19 respectively) and S1, S4, S5, S16 and S20 has highest score in one experiment. It indicates that proposed framework is relatively sensitive to the criteria weights.

5.2. Managerial implications

Managers have to understand the advantages in adopting flexible and responsive reverse logistics practices in the current time where they are dealing with resource scarcity, global take-back of EoL products, enforced legislations and environmental issues. India, which is looking to become a manufacturing hub, has not yet

Table 21
Sensitivity analysis.

Run	Experiments	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
1	WMB1 = 0.55, WMB2–WMRB5 = 0.015	0.991	0.990	0.984	0.992	0.990	0.990	0.991	0.992	0.992	0.991	0.992	0.989	0.990	0.990	0.992	0.992	0.991	0.992	0.990	0.990
2	WMB2 = 0.55, WMB1, WMB3–WMRB5 = 0.015	0.990	0.992	0.992	0.992	0.990	0.985	0.992	0.993	0.992	0.992	0.991	0.989	0.991	0.992	0.99	0.991	0.99	0.991	0.991	0.992
3	WMB3 = 0.55, WMB1, WMB2, WMB4–WMRB5 = 0.015	0.992	0.991	0.992	0.989	0.992	0.992	0.991	0.992	0.990	0.992	0.984	0.989	0.992	0.991	0.993	0.990	0.992	0.984	0.992	0.992
4	WMB4 = 0.55, WMB1–WMB3, WMB5–WMRB5 = 0.015	0.984	0.990	0.992	0.989	0.992	0.992	0.990	0.992	0.991	0.991	0.989	0.991	0.991	0.985	0.990	0.990	0.993	0.990	0.992	0.992
5	WMB5 = 0.55, WMB1–WMB4, WMB6–WMRB5 = 0.015	0.990	0.991	0.992	0.989	0.992	0.984	0.991	0.992	0.990	0.990	0.991	0.984	0.990	0.985	0.990	0.990	0.993	0.990	0.985	0.992
6	WMB6 = 0.55, WMB1–WMB5, WMB7–WMRB5 = 0.015	0.991	0.990	0.989	0.991	0.993	0.992	0.984	0.991	0.990	0.985	0.984	0.989	0.992	0.991	0.993	0.990	0.992	0.984	0.991	0.992
7	WMB7 = 0.55, WMB1WMB6, WOB1–WMRB5 = 0.015	0.984	0.984	0.984	0.989	0.990	0.991	0.984	0.989	0.985	0.990	0.989	0.991	0.991	0.985	0.990	0.990	0.993	0.990	0.993	0.992
8	WOB1 = 0.55, WMB1–WMB7, WOB2–WMRB5 = 0.015	0.991	0.990	0.989	0.992	0.993	0.992	0.992	0.992	0.992	0.991	0.990	0.991	0.993	0.991	0.985	0.991	0.993	0.990	0.992	0.991
9	WOB2 = 0.55, WMB1–WOB1, WOB3–WMRB5 = 0.015	0.992	0.990	0.992	0.991	0.992	0.992	0.991	0.991	0.990	0.984	0.991	0.992	0.992	0.991	0.992	0.990	0.991	0.989	0.990	0.993
10	WOB3 = 0.55, WMB1–WOB2, WOB4–WMRB5 = 0.015	0.990	0.991	0.992	0.989	0.992	0.984	0.991	0.992	0.990	0.990	0.992	0.992	0.992	0.993	0.992	0.990	0.992	0.991	0.991	0.992
11	WOB4 = 0.55, WMB1–WOB3, WOB5–WMRB = 0.015	0.990	0.991	0.989	0.989	0.992	0.991	0.991	0.992	0.991	0.992	0.991	0.991	0.990	0.992	0.985	0.990	0.993	0.990	0.992	0.985
12	WOB5 = 0.55, WMB1–WOB4, WEB1–WMRB5 = 0.015	0.990	0.991	0.992	0.991	0.992	0.990	0.992	0.984	0.990	0.992	0.991	0.992	0.990	0.991	0.992	0.991	0.993	0.989	0.990	0.992
13	WEB1 = 0.55, WMB1–WOB5, WEB2–WMRB5 = 0.015	0.990	0.992	0.991	0.992	0.990	0.990	0.991	0.984	0.989	0.985	0.991	0.989	0.991	0.984	0.990	0.985	0.991	0.989	0.992	0.991
14	WEB2 = 0.55, WMB1–WEB1, WEB3–WMRB5 = 0.015	0.990	0.984	0.990	0.992	0.992	0.992	0.992	0.993	0.992	0.992	0.989	0.984	0.985	0.990	0.992	0.991	0.993	0.989	0.992	0.985
15	WEB3 = 0.55, WMB1–WEB2, WEB4–WMRB5 = 0.015	0.992	0.990	0.991	0.992	0.992	0.991	0.992	0.991	0.991	0.990	0.992	0.989	0.990	0.992	0.992	0.985	0.991	0.989	0.992	0.991
16	WEB4 = 0.55, WMB1–WEB3, WEB5–WMRB5 = 0.015	0.990	0.991	0.989	0.990	0.990	0.991	0.984	0.991	0.992	0.990	0.991	0.991	0.990	0.992	0.993	0.991	0.991	0.990	0.992	0.991
17	WEB5 = 0.55, WMB1–WEB4, WLB1–WMRB5 = 0.015	0.990	0.984	0.984	0.985	0.990	0.992	0.991	0.991	0.992	0.991	0.992	0.989	0.992	0.992	0.993	0.991	0.993	0.989	0.990	0.990
18	WLB1 = 0.55, WMB1–WEB5, WLB2–WMRB5 = 0.015	0.992	0.992	0.991	0.992	0.990	0.991	0.990	0.991	0.992	0.991	0.992	0.984	0.992	0.993	0.992	0.992	0.992	0.989	0.992	0.992
19	WLB2 = 0.55, WMB1–WLB1, WLB3–WMRB5 = 0.015	0.990	0.990	0.992	0.991	0.985	0.990	0.989	0.985	0.990	0.990	0.991	0.984	0.990	0.991	0.992	0.990	0.992	0.991	0.993	0.992
20	WMB1–WMRB5 = 0.4	0.879	0.879	0.871	0.876	0.890	0.877	0.872	0.880	0.882	0.881	0.874	0.868	0.885	0.882	0.890	0.881	0.901	0.860	0.889	0.885

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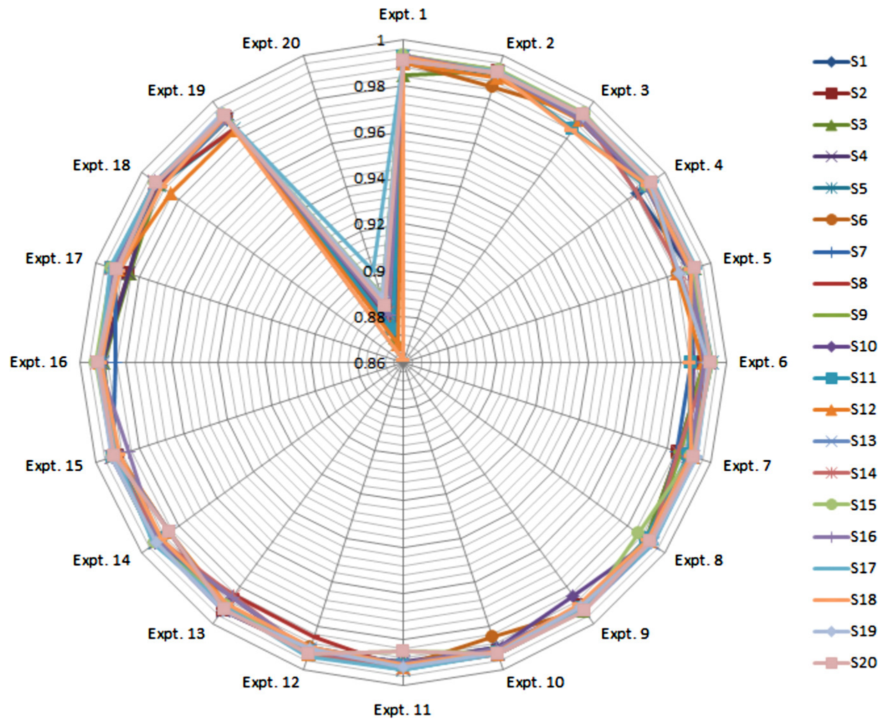

Fig. 4. Result of sensitivity analysis (CC_i values).

implemented RL practices efficiently due to presence of barriers. This empirical analysis of Indian electronics industry identified RL adoption barriers with respect to management, organizational, economic, legal, infrastructural, technological and market related. This study indicates legal barriers are dominating barriers in adoption of RL practices in India, However MoEF (Ministry of Environmental & Forests) is responsible for rule and regulation dealing with e-waste but Indian government has to set a comprehensive and concrete efforts required to remove some of the barriers identified in this study. To overcome other barriers, set of solutions is proposed by industry experts. Hence it is suggested that to adopt RL practices, industry has to implement solutions on priority basis revealed in this study.

Industry associates are also confirmed the results and sensitivity analysis found in this paper to overcome the barriers of RL adoption. Managers should be motivated to implement such solutions on priority basis for future success of their organizations in RL operations.

6. Conclusion

In today's competitive scenario, pressure on companies for sustainable practices enforcing them to adopt RL practices. But due to the presence of barriers, make it difficult to get success in its. So there is a need to provide solutions to overcome these barriers. It is very hard to implement all solutions at a time therefore it is desirable to prioritize the solutions for proper implementation to overcome the barriers. This study presents a robust multi criteria decision making method for prioritizing the solutions to overcome barriers for RL adoption. This has been done through the identification of barriers based on literature, industry experts and industry associates and then linguistic ratings to the criteria is being assigned by decision making team. In this study 38 barriers have been identified. To overcome these barriers 20 solutions are presented through relevant literature and expert views. Then integrated Fuzzy AHP- TOPSIS is applied to get final rank. Fuzzy AHP is applied to get the relative weights of the barriers and fuzzy TOPSIS is applied to prioritize the solutions. The result exhibits create, develop and invest in RL technology is the highest ranked solutions in this case for RL adoption. The proposed framework is supported by an empirical case of Indian electronics industry to overcome its barriers of RL adoption. At last we work out on the sensitivity analysis to determine the effect on the decisions of the change in the barriers weights. Prioritization of the solutions supports organizations to make policy for solution implementation to overcome its barriers of RL adoption. This method considered the vagueness/impreciseness of expert opinions in the evaluation process that makes this method is a powerful tool in multi criteria decision making process. Several extensions of this study are possible by inculcating any number of quantitative and qualitative attributes. This study can also explore by using several approaches such as ANP, ELECTRE, PROMETHEE and rough set theory.

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Appendix A.

Questionnaire form to facilitate the comparison of criteria with respect to goal (Similar types of questionnaire are used for sub-criteria w.r.t. each criterion) due to space constraint only 1 sub criteria are presented and other sub-criteria questionnaire is not given:

Criteria	MB Equal (1, 1, 1) Very Low (1, 2, 3) Low (2, 3, 4) Medium (3, 4, 5) High (4, 5, 6) Very high (5, 6, 7) Excellent (6, 7, 8)	OB Equal (1, 1, 1) Very Low (1, 2, 3) Low (2, 3, 4) Medium (3, 4, 5) High (4, 5, 6) Very high (5, 6, 7) Excellent (6, 7, 8)	EB Equal (1, 1, 1) Very Low (1, 2, 3) Low (2, 3, 4) Medium (3, 4, 5) High (4, 5, 6) Very high (5, 6, 7) Excellent (6, 7, 8)	LB Equal (1, 1, 1) Very Low (1, 2, 3) Low (2, 3, 4) Medium (3, 4, 5) High (4, 5, 6) Very high (5, 6, 7) Excellent (6, 7, 8)	IB Equal (1, 1, 1) Very Low (1, 2, 3) Low (2, 3, 4) Medium (3, 4, 5) High (4, 5, 6) Very high (5, 6, 7) Excellent (6, 7, 8)	TB Equal (1, 1, 1) Very Low (1, 2, 3) Low (2, 3, 4) Medium (3, 4, 5) High (4, 5, 6) Very high (5, 6, 7) Excellent (6, 7, 8)	MRB Equal (1, 1, 1) Very Low (1, 2, 3) Low (2, 3, 4) Medium (3, 4, 5) High (4, 5, 6) Very high (5, 6, 7) Excellent (6, 7, 8)
Management barriers (MB)	–						
Organizational barriers (OB)		–					
Economic barriers (EB)			–				
Legal barriers (LB)				–			
Technological barriers (TB)					–		
Infrastructural barriers (IB)						–	
Market related barriers (MRB)							–

Management barriers to RL adoption

Criteria code	Sub criteria	MB1 Equal (1, 1, 1) Very Low (1, 2, 3) Low (2, 3, 4) Medium (3, 4, 5) High (4, 5, 6) Very high (5, 6, 7) Excellent (6, 7, 8)	MB2 Equal (1, 1, 1) Very Low (1, 2, 3) Low (2, 3, 4) Medium (3, 4, 5) High (4, 5, 6) Very high (5, 6, 7) Excellent (6, 7, 8)	MB3 Equal (1, 1, 1) Very Low (1, 2, 3) Low (2, 3, 4) Medium (3, 4, 5) High (4, 5, 6) Very high (5, 6, 7) Excellent (6, 7, 8)	MB4 Equal (1, 1, 1) Very Low (1, 2, 3) Low (2, 3, 4) Medium (3, 4, 5) High (4, 5, 6) Very high (5, 6, 7) Excellent (6, 7, 8)	MB5 Equal (1, 1, 1) Very Low (1, 2, 3) Low (2, 3, 4) Medium (3, 4, 5) High (4, 5, 6) Very high (5, 6, 7) Excellent (6, 7, 8)	MB6 Equal (1, 1, 1) Very Low (1, 2, 3) Low (2, 3, 4) Medium (3, 4, 5) High (4, 5, 6) Very high (5, 6, 7) Excellent (6, 7, 8)	MB7 Equal (1, 1, 1) Very Low (1, 2, 3) Low (2, 3, 4) Medium (3, 4, 5) High (4, 5, 6) Very high (5, 6, 7) Excellent (6, 7, 8)
MB1	Lack of top management commitment	–						
MB2	Lack of awareness about RL		–					
MB3	Lack of strategic planning			–				
MB4	RL not integrated with SC business process				–			
MB5	Resistance to change					–		
MB6	Lack of waste management practice						–	
MB7	Company policies							–
MB8	Other (please specify)							

Appendix B.

Questionnaire form to facilitate the solutions for sub-criteria barriers due to space constraint only 1 sub- criteria are presented and other sub-criteria questionnaire is not given:

Set of solutions to for sub-criteria barrier MB1.

	Very Low (1, 2, 3)	Low (2, 3, 4)	Medium (3, 4, 5)	High (4, 5, 6)	Very high (5, 6, 7)	Excellent (6, 7, 8)
S1						
S2						
S3						
.						
.						
S18						
S19						
S20						

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