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ORIGINAL ARTICLE

A conceptual analytic network model for evaluating and selecting third-party reverse logistics providers

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Abstract Although the success of forward logistics depends on the performance of reverse logistics, some manufacturing companies are not able to manage their reverse logistics effectively and thus delegate this important process to third-party reverse logistics providers (3PRLPs). In such cases, the decision to evaluate and select an appropriate 3PRLP becomes highly significant. In this paper, we use the analytic network process (ANP) and propose an analytical framework to systematically model the complex nature of interactions among the selection factors. In this model, the factors determining the evaluation of 3PRLPs are initially valued using Likert scale questionnaires. Then, a screening process is implemented using the average alternative method. Finally, the factors selected are structured in a network framework following the ANP. We present a case study to demonstrate the applicability of the proposed framework and exhibit the efficacy of the procedures and algorithms. The results have important managerial implications for production managers and illustrate that, in our case study, quality is the most important factor when selecting a 3PRLP.

Keywords Third-party reverse logistics providers · Analytic network process · Average alternative method · Outsourcing

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1 Introduction

Reverse logistics is the process of moving a product in the opposite direction of the primary logistics flow to recapture value or ensure proper disposal [34]. The process of moving a product from its point of consumption to the point of origin is directly related to returned goods [8], the discharge of energy from resources, and the pollution from the waste disposal of products [54]. Reverse logistics can help achieving a proper balance between economic and environmental interests together with an efficient use of natural energy and resources [35]. Moreover, reverse logistics can be used as a competitive advantage in terms of customer needs [9]. For example, the trust of the customers in the company can increase if they know that faulty or impaired products are refundable. This can result in more consumer purchases thus benefiting the company and increasing its competitive advantage.

Due to resource restrictions, many manufacturing companies and retailers are not able to manage complicated reverse logistics processes efficiently. That is, the increase in the return of products experienced by companies or the growing environmental consciousness of consumers impose additional requirements that companies may not be initially ready to handle. The resulting competitive pressure is forcing companies to upgrade their logistics systems from in-house backroom to more efficient outsourced strategic boardroom functions [52, 64].

Outsourcing reverse logistics leads to the reduction of costs [52], increases in the proficiency of processes [52], and the improvement of services [39]. Sahay et al. [51] recommended the delegation of reverse logistic processes to third-party reverse logistics providers (3PRLPs) due to their many potential advantages. For this reason, evaluating and selecting 3PRLPs can play an important role in improving the performance of companies.

Moreover, since outsourcing is not always successful [16] and mistakes in evaluating and selecting 3PRLPs can be followed by irreparable damage; it is important to design decision-making models that can adequately represent the outsourcing process. In particular, the decision-making models should be designed in such a way so as to carefully consider all the possible interactions and dependencies between the various factors.

In this study, we present a model designed to evaluate and select 3PRLPs based on the analytic network process (ANP). A fundamental part of this research consists of determining the relationship between the multiple factors involved in the selection process of 3PRLPs. At the same time, given the requirements posed by the interrelated structure of the ANP, the current paper presents a case study that adjusts to each and every one of them.

In this regard, after an initial screening of criteria, the ANP is implemented while explaining a group of managers and engineers from a case company, whose answers determine the final ranking of the 3PRLPs, how each step of the process contributes to determining this ranking. This study extends previous analysis by including all the factors and interconnections considered to be essential by the decision makers of a company whose outsourcing of reverse logistic activities is embedded within a green supply chain environment.

The remainder of this paper is organized as follows. Section 2 provides a literature review on the topic of reverse logistics and the selection of 3PRLPs. Section 3 describes the analytical methodology of the model while Sect. 4 provides a case study. Section 5 concludes and suggests potential extensions of the current model.

2 Literature review

A supply chain is a network which includes all activities related to the flow and conversion of goods from raw materials to ultimate merchandise together with their backward flow of information [21]. Supply chain management is also synonymous with network sourcing, supply pipeline management, value chain management, and value stream management [6]. Logistics, as part of supply chain management, includes all activities of products flow and information from, to, and between supply chain members [3]. An acceptable definition of logistics was established by the Council of Logistics Management in 1986: “Logistics is the process of efficient, costly, and effective planning, implementing, and controlling in relation to the flow or maintenance of raw materials, goods being manufactured, produced goods, and relevant information from the origin to the end and its aim is to adapt with customer demands and needs.”

Contrary to this forward flow, reverse logistics considers all the activities of the supply chain process which take place in the reverse order. In general, reverse logistics can be defined as “The efficient and effective (in terms of costs) process of planning, implementing, and controlling the flow of raw materials, in-process inventory, finished goods and their information, from the consumption point to origin point aimed at recreation of value or proper disposal.” [44]. Note how this definition is directly related to recycling operations.

In this regard, Zikmund and Stanton [65] were the first scholars who discussed recycling management by introducing the term “reverse.” They described recycling as “Finding new methods to reuse the materials which were thrown away formerly in order to present a solution to arrange the cluttered environment.” Similarly, El-Ansary [14] described the various integrated concepts of marketing together with the difference between controllable and uncontrollable variables. He stated that the management of reverse distribution channels would be necessary as a marketing function in order to achieve a successful organizational change. Figure 1 uses the product life cycle to explain the mechanisms of reverse and forward logistics.

This figure illustrates how the forward and reverse logistics operations should be considered together. Forward logistics operations will be performed properly when the reverse logistics operations are managed correctly. In other words, reverse logistics play a key role in the success of organizations [17]. Numerous studies have been done on the topic of reverse logistics, especially on the outsourcing reverse logistic activities.

Ritchie et al.[43]) developed a reverse logistic system for the Manchester Royal Clinic to assist in the assessment and improvement of the recycling and disposal of pharmaceutical products. Autry et al. [2] investigated the effect of industry, sales volume, and the assignment of responsibility for movement on the performance of reverse logistics, customer satisfaction, and services. They found that the performance of reverse logistics is remarkably based on sales volume, while customer satisfaction is mainly affected by the characteristics of the environment. They concluded that neither the performance of reverse logistics nor the customer satisfaction was affected by delegating regulation responsibility.

Tibben-Lembke [57] highlighted the importance of reevaluating reverse logistics within the life cycle of

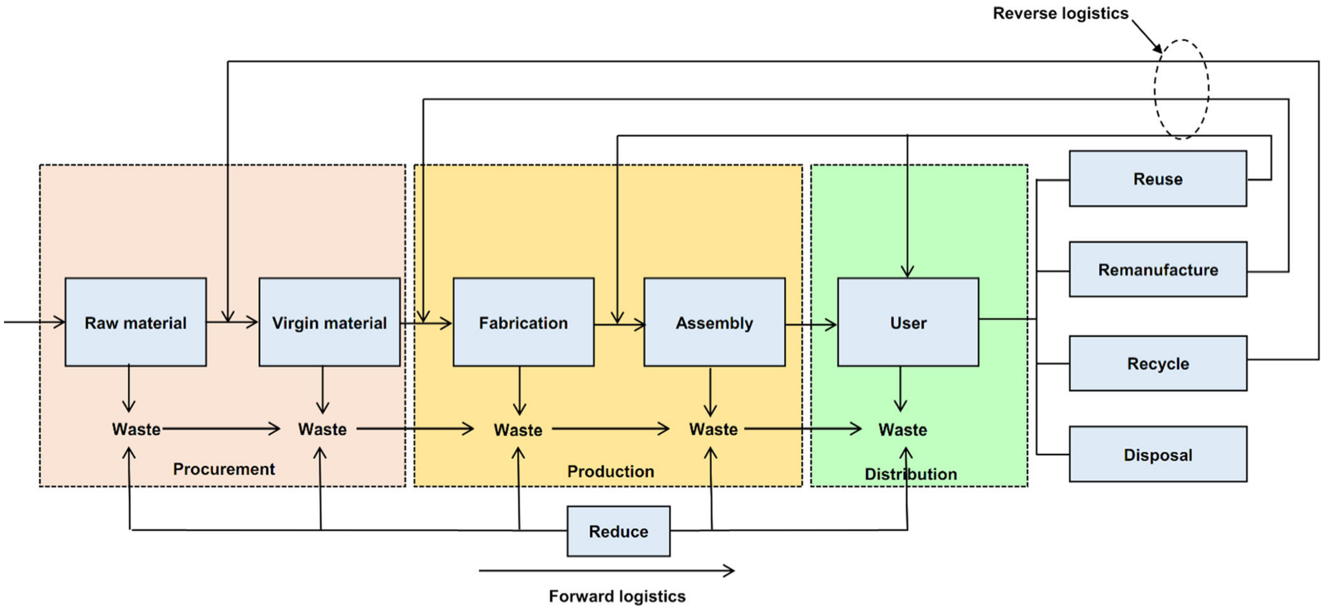

Fig. 1 Product life cycle and reverse logistics

products and determining how the reverse logistic process is influenced by it. The author performed several studies on the reverse logistic needs associated with three different shapes of the product life cycle using various models and classifications. He emphasized the importance of knowing the stage of production that should be undertaken so as to face the corresponding logistic challenges before moving to the next stage. Finally, a model of pricing decisions among competing retailers in a fuzzy closed-loop supply chain environment was presented by Wei and Zhao [60].

The number of qualitative models in the fields of reverse and forward logistics has increased gradually over time with a general focus on outsourcing activities. Particular emphasis has been placed on the development of decision-making models in green supply chain settings. For example, the Delphi method has been used to differentiate the criteria for evaluating traditional and green suppliers [31]. Efendigil et al. [13] introduced a hybrid model of neural networks and fuzzy analytic hierarchy process (AHP) for selecting 3PRLPs in the absence of certainty. Dat et al. [7] built a mathematical programming model to reduce the costs of electrical waste processing.

Recently, several fuzzy mathematical programming models were combined by Pishvaee et al. [41] to design green logistic networks. Yazdian and Shahanaghi [62] introduced a multi-objective possibilistic planning model to establish distribution centers and allocate customers' needs in the design of supply chain networks. Nikoofal et al. [38] designed a recovery system for disposal costs and dependent returns based on the expected effect that random returns have on the company's demand. Mirakhorli [36] optimized a fuzzy multi-objective model used to design a closed loop logistic network that aimed at minimizing total costs and delivery time.

A review of the literature indicates that most of the studies have evaluated and selected 3PRLPs based on fuzzy models and multiple criteria decision-making methods. For example, Farzipoor [15] defined a multiple dual-role factors model for selecting 3PRLPs. Recently, Govindan et al. [18] evaluated and selected 3PRLPs for an Indian automobile components manufacturing company using multi-criteria decision-making techniques. Kannan and Murugesan [27] used fuzzy extent analysis to evaluate and select 3PRLPs. Yin and Lu [63] suggested an AHP model based on gray systems theory for selecting 3PRLPs. Haq and Kannan [22] used fuzzy AHP to select vendors in supply chains.

It should be noted that the basic structure of the AHP cannot measure the value of the complex relationships existing among the factors involved in the selection of 3PRLPs [45]. Meade and Sarkis [34] and Govindan et al. [18] resolved this shortcoming to a large extent using the ANP method to evaluate and select 3PRLPs. However, these models did not consider all the factors available in the selection process of 3PRLPs. For example, Meade and Sarkis [34] do not consider prospective interconnections arising among different selection factors or the fact that the factors involved in supply chain risk can affect the existing relationships among other factors.

We must finally emphasize that very little attention has been paid to the design of reverse logistic processes for recycling or the management of outputs that are potentially hazardous and dangerous to the environment. Therefore, the current research attempts to determine and evaluate the existing relationships among all the factors involved in the selection of 3PRLPs and the necessity of defining appropriate decision-making models in this important area.

Table 1 Summary of the literature and current contribution

Reverse logistics setting	References	Solution method
Recycling	Zikmund and Stanton [65]	–
Product life cycle	Tibben-Lembke [57]	–
Green supply chain	Efendigil et al. [13], Mirakhorli [36]	Fuzzy AHP Fuzzy multi-objective optimization
Case study Multiple criteria decision	Meade and Sarkis [34], Govindan et al. [18]	ANP
Green supply chain Interactive case study	Current paper	Interactive ANP

2.1 Contribution to the literature

The main approaches to the different reverse logistics problems considered in the literature and presented above are summarized in Table 1, together with our contribution to the literature.

In short, we design an interactive ANP case study, where several decision makers within a company are taught the main mechanisms of the ANP and explained the way their subjective preferences and evaluations shape the final ranking obtained. In this regard, the closest paper to ours is that of Govindan et al. [18], who followed the same type of approach and applied it to an Indian automobile components manufacturing company. These authors consulted several experts, both academic and industrial, to identify the main decision criteria and then built the resulting ANP questionnaire. In our study, we requested the collaboration of the company experts throughout the entire process beforehand. The company experts helped constructing the model, defined the interactions among the different decision criteria, and evaluated the relations between each sub-criteria via pair-wise comparisons.

In detail, our approach consists of three main stages. The initial one aims at identifying all the potential criteria that influence the choice of a 3PRLP within our particular green supply chain setting. This has been done by asking a sufficiently large number of experts, both academicians, and company-related, to suggest and evaluate the corresponding criteria. After this initial selection process, we held a meeting with different managers and engineers from the company and explained them the structure of the ANP and how the pair-wise comparisons that they would be providing relate to the final ranking obtained. The information from the company experts was acquired in two separate stages. The first one consisted of a questionnaire used to identify the main relationships among all the decision criteria considered. After receiving the answers from several experts, the main ANP structure was built and a second questionnaire was provided to a larger set of experts, who defined the relative importance of each criteria and sub-criteria via pair-wise comparisons.

Our approach to the selection of 3PRLPs highlights one of the main constraints faced by this branch of the literature. That is, the interactions taking place between the 3PRLPs and the company at the supply chain level require the evaluation of (industry) experts who are familiar with the characteristics of the company's supply chain, the main characteristic of the potential 3PRLPs and how the latter are expected to interact with the company and affect the efficiency of its supply chain. This implies that the results obtained are highly dependent on the specific case being analyzed. Despite this fact, some general guidelines regarding the implementation of the ANP to this type of selection problems can be extracted from the current paper.

3 Methods and procedures

3.1 Research plan

In this paper, we apply the proposed decision framework to Pipex,[1] a manufacturer of composite pipes in West Virginia (USA). Our research was conducted at Pipex headquarters in 2013. Pipex produces composite pipes. Composite wastes have high environmental durability and remain in the environment for a very long time [40]. Moreover, since many of these materials are hazardous to the environment, a proper plan should consider the disposal of these materials throughout the product life cycle. Recycling and collecting these materials plays an essential role in environmental protection terms and could also be profitable for Pipex if the company was able to transform the wastes into energy or recover products in their basic form. The company intended to delegate the recovery and recycling activities of its products to 3PRLPs.

It should be highlighted that the selection of this particular company as a subject of analysis was directly conditioned by the availability of several members of its management and

[1] The name has been changed to protect the anonymity of the manufacturing company.

engineering departments, who were willing to provide the required feedback following the guidelines of the ANP. Indeed, we were able to meet with several managers and engineers and explain them the fundamentals of the pair-wise comparison process together with its effect on the interconnected decision structure defining the ANP. This interactivity allowed us to integrate the human capital of the company as a fundamental element conditioning the implementation of our ANP-based decision model.

The present research consists of the following tasks:

1. Identifying the important factors involved in selecting 3PRLPs
2. Determining the relationships among these factors and creating a conceptual model based on the ANP
3. Forming pair-wise comparison matrices between the relevant factors

In order to perform the previous tasks, three different questionnaires were used throughout the research. The initial task was performed using an online questionnaire submitted to 72 academic and industrial experts, whose design was based on the Likert scale. The second questionnaire consisted of a matrix submitted to four company experts in order to determine how the different factors were related and affected each other. The design of the third questionnaire was directly based on the ANP model.

That is, the design of this latter questionnaire was based on pair-wise comparisons among those factors deemed to be sufficiently important. The relative importance of the different criteria was estimated using the numerical values obtained from the comparisons performed by eight company experts, which follow the basic principles of the AHP. We integrated the answers obtained from these experts to the third pair-wise questionnaire using their geometric means [42]. A standard compatibility test was performed in order to validate the reliability of the matrix of pair-wise comparisons.

It should be emphasized that during the distribution of the second and third questionnaires, any questions posed by the experts, i.e., managers and engineers, or problems in understanding the pair-wise evaluations were clarified. Moreover, as already emphasized, in order for the experts to better understand the ANP model and the way to answer the questions, a meeting was held with them for 60 min. The evolutionary process of the research has been illustrated in Fig. 2.

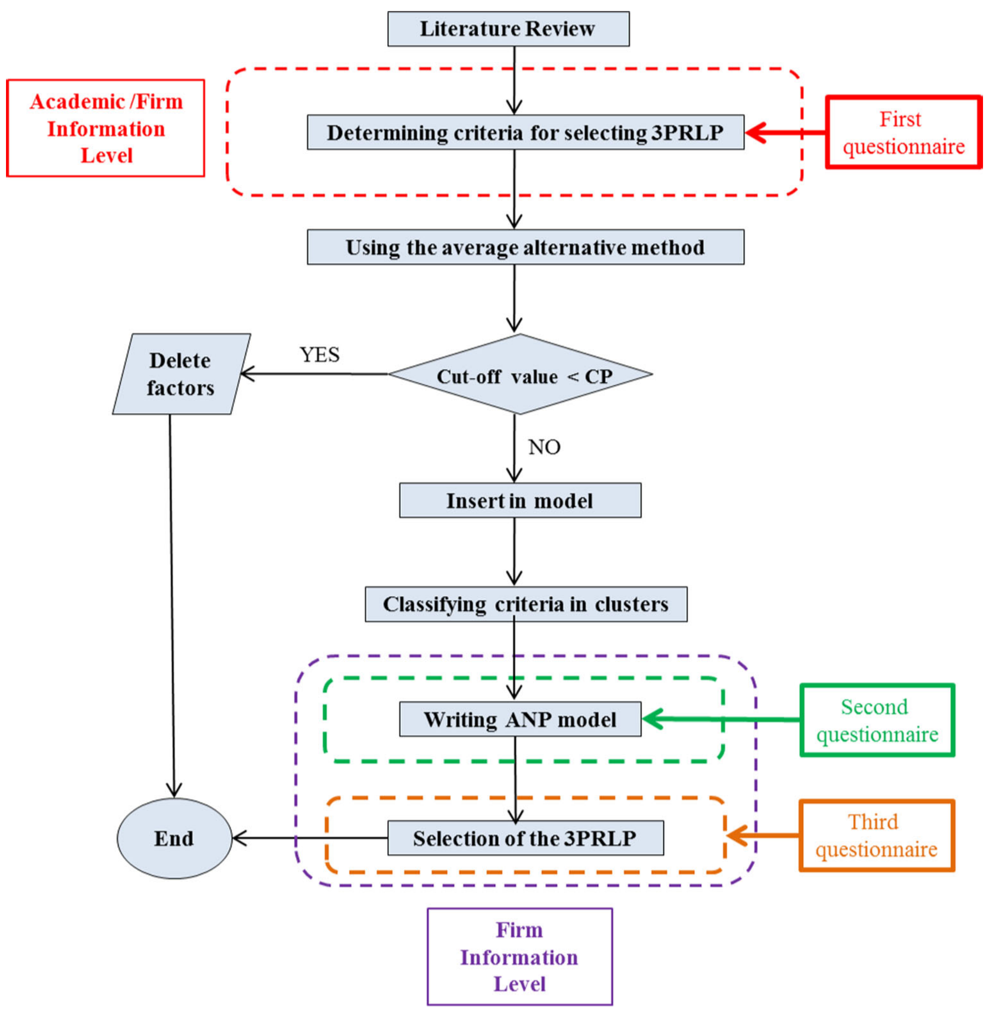

Fig. 2 Research evolutionary process

3.2 ANP methodology

According to the principles of AHP [46, 61], a hierarchical dependency should be top-bottom or bottom-up and linear. If the dependency among the factors is mutual, the model is not hierarchical anymore. In such a case, a nonlinear network or system, or a feedback system will be formed. The absence of a hierarchical linear structure implies that the rules and formulas of the AHP cannot be used to calculate the weights assigned to the alternatives. As a result, Saaty [48] introduced a network problem structure under the ANP, which is an expanded version of the AHP designed to account for nonhierarchical systems.

The network nodes defined in the ANP are equivalently used as objectives, criteria, and options. Directional vectors are used to connect the nodes, representing the direction of the effects that each node has on the others. Figure 3 illustrates the main differences between a network and a hierarchical structure.

The standard basic network consists of several clusters and the elements within them. When the elements of one cluster influence one or several elements from another cluster, a connection, which is called external dependency, is created between the two clusters. If the elements of one cluster influence one or several elements from their own cluster, this connection is called internal dependency. Both types of dependency are illustrated in Fig. 3. The edge connecting cluster C1 to C3 in Fig. 3a denotes external dependency, while the ring, which connects C2 to itself, indicates internal dependency [51]. If two clusters have mutual effects on each other, it is called feedback.

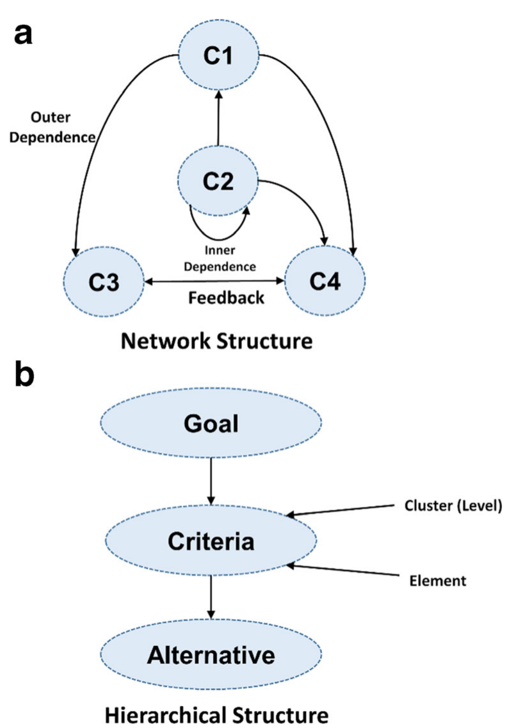

Fig. 3 Network and hierarchical structures

$$
w = \begin{array}{c} C_1 \\ \vdots \\ C_k \\ \vdots \\ C_N \end{array}
\overset{\begin{array}{ccc} C_1 & C_k & C_N \end{array}}{\begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1N} \\ W_{21} & W_{22} & \cdots & W_{2N} \\ \cdots & \cdots & \cdots & \cdots \\ W_{N1} & W_{N2} & \cdots & W_{NN} \end{bmatrix}}
$$

Fig. 4 General form of the super matrix

In order to understand how the main relations among the factors are obtained using the ANP, some notions of matrix algebra are required. Figure 4 shows a general super matrix. In this matrix, W_{ij} represents the relationship between cluster i and cluster j, denoted by C_i and C_j, respectively. Each one of these W_{ij} relationships consists of a matrix, which is further illustrated in Fig. 5. Each column of the W_{ij} matrix is a transient priority vector derived from pair-wise comparisons via the standard AHP method. In particular, the element of the eigenvector determining the weight of the relation between the n_ith factor of the ith cluster and the n_jth factor from the jth cluster is denoted by $W_{in_i}{}^{(jn_j)}$. When there is no relationship between the factors, the relevant matrix is a zero matrix [51]. Therefore, only the factors with positive dependencies are considered when performing the pair-wise comparison required to derive the priority vector.

After forming the primary super matrix, which is also referred to as the unweighted super matrix, the weighted or normalized super matrix is obtained by normalizing its columns. This normalization process consists of multiplying the value in each cell of the unweighted super matrix by the corresponding value of the element of the eigenvector determining the relative weights among the clusters. The weighted super matrix is raised to the $2k+1$ power, with k being a large number, in order to obtain the final or limit matrix. The columns composing the limit matrix are identical, with the values of each row defining the final weight of the corresponding factor [49]. The relevant calculations have been performed using the Super Decisions software.

3.3 Identifying the criteria

The selection process of an appropriate 3PRLP is determined by several main parameters such as the product life cycle, the

$$
W_{ij} = \begin{bmatrix} W_{i1}{}^{(j1)} & W_{i1}{}^{(j2)} & \cdots & W_{i1}{}^{(jn_j)} \\ W_{i2}{}^{(j1)} & W_{i2}{}^{(j2)} & \cdots & W_{i2}{}^{(jn_j)} \\ \cdots & \cdots & \cdots & \cdots \\ W_{in_i}{}^{(j_1)} & W_{in_i}{}^{(j_2)} & \cdots & W_{in_i}{}^{(in_j)} \end{bmatrix}
$$

Fig. 5 Super matrix detailed

type of operating process, the organizational role played by reverse logistics, the use of third-party logistics, and the potential application of information technology. We will consider several factors affecting the selection of 3PRLPs to create our decision-making model. Clearly, each 3PRLP has its own specific characteristics, and our model has been designed considering a particular set of parameters and factors, whose modification could result in a different choice of 3PRLPs.

In this initial stage of the process, the main factors considered for the selection of a 3PRLP have been determined through a review of the literature on systems theory and the help from several specialists. We have identified 38 factors as potentially critical in the selection of a suitable 3PRLP. These factors are described in Table 2.

In order to classify the selection criteria considered by the experts in terms of their importance, an online questionnaire was designed. This questionnaire, together with the remaining ones implemented at the company level of the decision process, is available in the Appendix section of the paper. The respondents were reverse logistics experts from both academic an industrial backgrounds. The questionnaire was composed by 38 items based on a five-point Likert scale consisting of the following evaluation criteria: “not important”=1, “moderately important”=2, “very important”=3, “highly important”=4, and “extremely important”=5. We contacted 72 experts in this phase of the research. We considered this to be a sufficiently large number to generate a reliable average relative to which we could discard unimportant criteria. This is the case since, similarly to Govindan et al. [18], the aim of this phase is simply to classify the criteria so that those deemed to be less important could be discarded.

In order to eliminate the problem caused by missing data, which increase the ambiguity and reduce the accuracy of the calculations, the responses obtained were analyzed using SPSS missing value analysis (MVA) software so as to adjust the sample size. Following Tabachnick and Fidell [56], when dealing with data with at least a 5 % missing rate, a t test should be performed to verify that the data missing do not have a significant effect on any of the criteria and that the distribution of missing values is sufficiently random. Table 3 describes the results obtained from SPSS MVA for the 18 criteria presenting missing values. Note that we have coded the criteria from A1 to A38, following the order presented in questionnaire 1 (please, refer to the Appendix section).

After verifying the significance of the available data, the average alternative method is used to obtain the missing data [56]. The resulting univariate descriptive statistics of the criteria initially considered by the experts are presented in Table 4 in mean descending order.

Most of the criteria were classified by the experts into two scales: very important and highly important. Thus, we decided to use a standard cutoff value approach in order to decrease the number of criteria analyzed and simplify the resulting calculations. Given the highest, 3.63, and the lowest mean value, 1.91,

Table 2 Criteria for selecting a third-party reverse logistics provider

Factors	
Logistical drivers	
Storage	Facilities
Warehouse management in logistics service	Facilities/sourcing
Warehouse management in IT	
Inventory replenishment	Inventory
Growth	Inventory/information/pricing
Maturity	
Introduction	
Collection	Transportation
Direct transportation services	
Shipment and tracking	
Transitional processing	
Delivery	
Shipment consolidation	
Cross-functional drivers	
Quality	Information
Time	
Flexibility	
Customer satisfaction	
Employee morale	
Supply chain planning using IT	
Effective communication	
Service improvement	
Overall working relations	
Packing	Sourcing
Carrier selection	
Recycle	
Frequent updating	
Remanufacture	
Disposal	
Sorting	
Order management	
Reuse	
Reclaim	
Service	
Decline	
Cost	Pricing
Freight payment in IT	
Cost saving	
Profitability	

The categorization of the decision criteria as logistical and cross-functional drivers follows from Chopra and Meindl [5]

Table 3 Criteria with missing data

Criteria		A1	A3	A4	A5	A8	A12	A15	A16	A22	A24	A26	A29	A32	A37	A35	A27	A28	A30
Number of answers		68	69	70	69	70	65	66	68	68	70	71	71	71	70	70	69	66	67
Missing data	#	4	3	2	3	2	5	6	4	4	2	1	1	1	2	2	3	6	5
	%	5.5	4.2	2.7	4.2	2.7	6.9	8.3	5.5	5.5	2.7	1.4	1.4	1.4	2.7	2.7	4.2	8.3	6.9

the average cutoff point (CP) equals 2.77. Given this value and those of the means presented in Table 4, we concluded that 22 criteria whose means were below the value of the cutoff point should be omitted from the analysis. This represents more than half of the criteria, whose omission would jeopardize our analysis from delivering its main research objective. As a result, we kept all 38 criteria in the subsequent phases of the research due also to the capacity of the ANP to handle problems consisting of a large number of factors and potential interactions.

3.4 Classifying criteria

The ANP model is formed by clusters, and its resulting weights are based on the relationships among the factors and criteria composing these clusters. Clusters make it possible to classify criteria with similar characteristics in the same group [50]. Given the results of questionnaire 1, the criteria were categorized in such a way that each cluster contains sub-criteria that were either comparable to each other or had no considerable differences in intensity of importance. That is, we did not categorize criteria with very low and very high relative importance in the same cluster. At the same time, the sub-criteria composing a cluster have to be related to the main criterion defining it.

The design of a proper and efficient model implies that there must not be more than nine criteria in one cluster. This restriction is imposed because it has been proved that the human brain cannot handle more than nine factors simultaneously, which could affect the accuracy of the results obtained [50]. Moreover, a substantial increase in the number of criteria would lead to unnecessarily complex calculations. We have coded all the clusters from A to H and described the relevant criteria and sub-criteria composing each cluster, together with the literature justifying their inclusion in our model, in Table 5.

Table 4 Descriptive statistics for survey results

Mean	Min	Max	Factors	Mean	Min	Max	Factors
2.62	2	4	Transportation services	3.63	3	5	Flexibility
2.53	1	4	Freight payment in IT	3.51	2	5	Cost
2.47	1	4	Reuse	3.40	1	5	Time
2.43	2	5	Growth	3.38	3	5	Quality
2.42	1	5	Frequent updating	3.35	2	5	Collection
2.40	2	5	Storage	3.27	3	5	Cost saving
2.40	2	5	Customer satisfaction	3.23	1	5	Effective communication
2.31	1	5	Packing	3.21	3	5	Profitability
2.30	1	5	Service improvement	3.07	2	5	Transitional processing
2.21	2	5	Inventory replenishment	3.07	1	5	Delivery
2.20	1	3	Employee morale	3.01	1	5	Remanufacture
2.17	1	3	Supply chain planning using IT	3.00	1	5	Recycle
2.01	1	4	Disposal	3.00	1	5	Overall working relations
1.99	1	4	Warehouse management in IT	2.99	2	5	Carrier selection
1.96	1	3	Sorting	2.90	1	5	Direct transportation services
1.95	1	3	Introduction	2.89	1	5	Warehouse management in logistics service
1.95	1	3	Reclaim	2.72	2	5	Shipment and tracking
1.93	1	3	Maturity	2.71	2	5	Order management
1.91	1	3	Decline	2.62	1	5	Shipment consolidation

Note that, after applying the corresponding adjustments to the missing data, the total number of observations per criterion equals 72

Table 5 Criteria for evaluating 3PRLPs and their supply chain process categorization

Criteria	Sub-criteria	References
IT applications (A) Process/Manufacturing	Warehouse management (A1), order management (A2), supply chain planning (A3), shipment and tracking (A4), and freight payment (A5)	Dowlatshahi [12], Van and Zijm [59], Jing et al. [25], Holguin-Veras [24], and Govindan et al. [17]
Impact of use of 3PL (B) Other	Customer satisfaction (B1), Profitability (B2), Frequent updating (B3), and Employee morale (B4)	Hendrik et al. [23], Lynch [33], Boyson et al. [4], and Govindan et al. [17]
Third party logistics services (C) Procurement	Inventory replenishment (C1), warehouse management (C2), shipment consolidation (C3), carrier selection (C4), and direct transportation services (C5)	Dowlatshahi [12], Van and Zijm [59], Kleinsorge et al. [29], Gunasekaran et al. [19], Davis and Gaither [10], Gupta and Bagchi [20], and Holguin-Veras [24], and Govindan et al. [17]
User satisfaction (D) Other	Effective communication (D1), cost saving (D2), service improvement (D3), and overall working relations (D4)	Mohr and Spekman [37], Lynch [33], Andersson and Norrman [1], Boyson et al. [4], Govindan et al. [17], and Govindan et al. [18]
Reverse logistics functions (E) Distribution	Delivery (E1), transitional processing (E2), storage (E3), sorting (E4), packing (E5), and collection (E6)	Schwartz [53], Dowlatshahi [12], Kaliampakos et al. [26], Van Dijck [58], and Govindan et al. [17]
Organizational performance criteria (F) Procurement	Flexibility (F1), service (F2), time (F3), cost (F4), and quality (F5)	Kim et al. [28], Kwang et al. [30], Andersson and Norrman [1], Lynch [33], Boyson et al. [4], Stock et al. [55], and Govindan et al. [17]
Organizational role (G) Process/manufacturing	Reclaim (G1), recycle (G2), remanufacture (G3), reuse (G4), and disposal (G5)	Meade and Sarkis [34], Dowlatshahi [12], Demir and Orhan [11], Schwartz [53], Govindan et al. [17], and Govindan et al. [18]
Product life cycle stages (H) Process/manufacturing	Introduction (H1), growth (H2), maturity (H3), and decline (H4)	Meade and Sarkis [34]

3.5 ANP model for selecting 3PRLPs

After classifying the main decision factors within their respective clusters, we asked four company experts to identify any relationship within the set of criteria. In particular, these company experts were presented with a matrix representing all the decision criteria and asked to identify any direct causal relations existing among them. This matrix and the corresponding guidelines provided to the experts composed the second questionnaire, which is presented in the Appendix section.

The information retrieved from the experts was inputted into the Super Decisions software, which uses vectors to

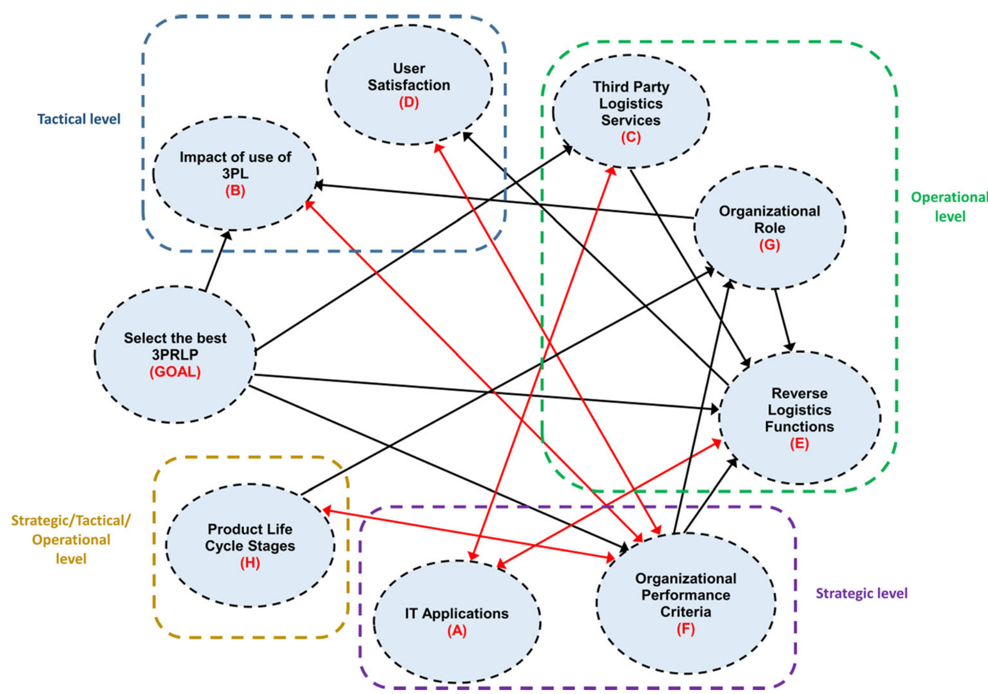

Fig. 6 Action and reaction interactions among the decision factors

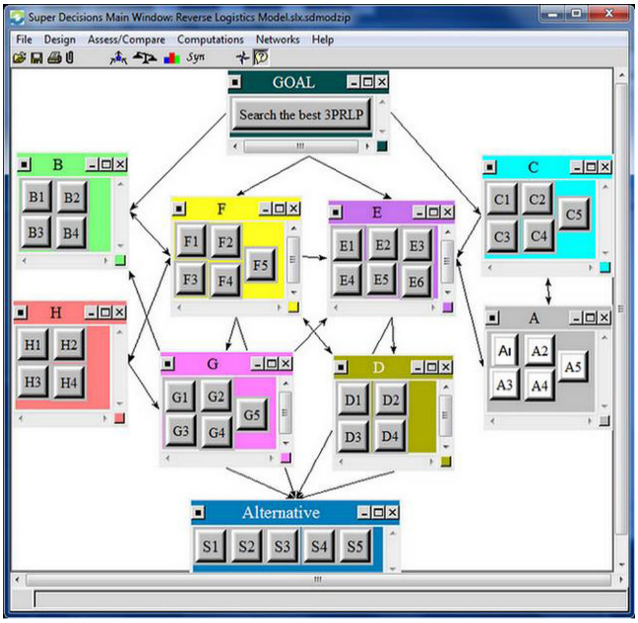

Fig. 7 ANP model for evaluating 3PRLPs

represent the relationships among the different elements composing the network. Each vector starts from a given element within the network and moves in the direction of (i.e., toward) the element which is affected by it [50].

We illustrate the main interactions defining our ANP conceptual model in Fig. 6, which displays the vectors describing the relationships among our main decision criteria based on the information retrieved from the second questionnaire. The Super Decisions Software can provide additional insight into the relationships among the decision factors since it can be used to build the network model, which is displayed in Fig. 7. Note that the network model presented in this latter figure corresponds to an interface of the software that describes the interactions illustrated in Fig. 6. Moreover, the notation employed in Fig. 7 is the same one used to define the criteria and sub-criteria in Table 5, with Si, $i=1,\ldots,5$, representing the 3PRLPs available as potential choices.

As can be observed in Fig. 6, bidirectional vectors are used to represent mutual external relationships among the elements of the clusters. A cluster is connected to another cluster when one of its elements is connected to at least two elements from the other cluster [50]. For instance, in our model, product life cycle and organizational performance criteria have a mutual external relationship. In this case, for example, product quality (F5) increases its importance at the growth stage (H2) and, as the product maturity (H3) is improved, its quality starts being affected by other factors.

3.6 Pair-wise comparisons

After building the ANP model, we collected data from a group of eight industry specialists performing pair-wise comparisons between the different criteria considered. Following Zareinejad and Javanmard [64], a group of experts ranging from 5 to 15 members is suggested for pair-wise analysis such as the one performed in the current study. Personal judgments were made based on a nine-point scale such as the one displayed in Table 6 [47].

It should be noted that pair-wise comparisons were performed among those elements which shared a positive relationship, independently of the causal direction of the relation. For example, the flexibility sub-criterion (F1) required a total of five pair-wise comparison matrices, one for each of the B, D, E, H, and G clusters related to the F one. Therefore, F1 must be compared to B1… B4, and all the elements composing the D, E, H, and G clusters. In total, 97 judgment matrices were defined, including 517 pair-wise comparison questions designed to account for all the network dependencies. The pair-wise comparison matrix determining the relative importance of the "Third Party Logistics Services (C)" sub-criteria for the selection of a 3PRLP and the corresponding guidelines provided to the experts are presented in the Appendix section.

Table 6 Scale of preference

Explanation	Definition	Preference weights
Two activities contribute equally to the objective	Equally preferred	1
Experience and judgment slightly favor one activity over the other	Moderately	3
Experience and judgment strongly or essentially favor one activity over the other	Strongly	5
An activity is strongly favored over the other and its dominance demonstrated in practice	Very strongly	7
The evidence favoring one activity over the other is of the highest degree possibility affirmation	Extremely	9
Used to represent compromise between the preferences listed above	Intermediate values	2,4,6,8
Reciprocals for inverse comparisons		Reciprocals

Table 7 Alternative comparison matrix with respect to *service improvement* sub-criterion

Eigenvector	S5	S4	S3	S2	S1	Service improvement
0.2556	2.96	3.90	1.56	0.34	1	3PRLP1 (S1)
0.3237	1.36	2.82	1.25	1	2.94	3PRLP2 (S2)
0.2233	2.58	3.12	1	0.80	0.64	3PRLP3 (S3)
0.0757	0.64	1	0.32	0.35	0.26	3PRLP4 (S4)
0.1215	1	1.56	0.39	0.74	0.34	3PRLP5 (S5)

CR=0.07926

3.7 Normalization of weights and compatibility test

After the experts performed the corresponding pair-wise comparisons among the criteria, the Super Decision software was used to calculate a relative preference vector for each comparison matrix. The elements of these vectors are actually the weights included as inputs in the primary super matrix. An example of such an aggregated comparison matrix is given in Table 7. This matrix compares 3PRLPs in terms of the service improvement sub-criterion (D3). Its corresponding vector of relative priorities is shown in the left column of the table.

Finally, a compatibility test must be performed on each pair-wise comparison matrix after the experts determine the relative importance of each criterion. This test is based on the consistency ratios (CRs) of the corresponding comparison matrices [49]. If the ratio is higher than 0.1, the comparison matrix is deemed to be incompatible and the corresponding set of pair-wise comparison must be repeated. As illustrated in Table 7, its CR< 0.10, and, consequently, the compatibility of this matrix is confirmed.

4 Analysis of results

We illustrate now the applicability of the conceptual model designed to evaluate and select 3PRLPs. Given the considerable importance of the pair-wise comparison matrices, we will describe some of them numerically throughout this section.

4.1 Pair-wise comparison for criteria

According to the values of the pair-wise comparisons performed by the experts within our applied ANP model, four main criteria are considered to directly affect the evaluation and selection of the 3PRLPs. The aggregated matrix of pair-wise comparisons that resulted from such an estimation process is presented in Table 8. Since the consistency rate of this matrix equals 0.01667, which is lower than 0.10, the estimation provided by the experts is consistent.

The results obtained show that from the experts' point of view, the Third Party Logistics Services (C) criterion has the strongest effect on the selection of 3PRLPs. That is, if a decision maker aims at enhancing the performance of the model when selecting 3PRLPs, then the 3PLS criterion should be given the highest priority.

The results obtained from performing pair-wise comparisons on the entire set of clusters are presented in Table 9 below. This table/matrix shows that, from the perspective of the experts, the effect of 3PLS (C) on IT applications (A) and vice versa, are the most important ones among all the pair-wise relationships that can be defined between the main criteria. Moreover, the effect of the organizational performance criteria (F) on the product life cycle (H) constitutes the next priority. These results imply that the 3PLS, IT, and OPC criteria should be the most important ones for selecting the appropriate 3PRLP.

4.2 Pair-wise comparisons between important sub-criteria and formation of super matrix

Table 10 presents the pair-wise comparison matrix between the set of sub-criteria composing cluster C, that is, third party logistics services, and the sub-criterion of warehouse management (A1), which is one of the elements of the IT cluster. The numerical results in this matrix show that inventory replenishment (C1) has the highest priority value, i.e., 0.3433, when warehouse management is considered.

The eigenvector values obtained from the different pair-wise comparison matrices provide the weights of each one of the respective sub-criteria selected to evaluate the 3PRLPs. These weights are the input numbers of the primary or unweighted super matrix. The unweighted matrix has to be normalized, since it does not initially comply with the required

Table 8 Pair-wise comparison matrix of criteria with respect to goal

Eigenvector	F	E	C	B	Goal
0.2971	2	1.98	0.621	1	Impact of use of 3PL (B)
0.3625	1.910	1.792	1	1.600	Third party logistics services (C)
0.1829	1.301	1	0.562	0.510	Reverse logistics functions (E)
0.1574	1	0.770	0.520	0.501	Organizational performance criteria (F)

CR=0.01667

Table 9 Pair-wise comparison matrix on the entire set of clusters

	A	S	B	C	D	E	F	G	GOAL	H
A				0.571367		0.396278				
S					0.500000	0.221787	0.202548	0.482192		
B							0.221394	0.249701	0.297106	
C	0.653907								0.362503	
A = D						0.381935	0.210460			
E	0.346093			0.428633			0.128148	0.268107	0.182912	
F					0.500000				0.157479	0.571367
G							0.125904			0.428633
GOAL										
H							0.111546			

limitations in the column distribution, i.e., the total sum of the column values must be equal to 1 [32]. The normalization of the primary super matrix is achieved by multiplying the unweighted super matrix by the values of the eigenvectors obtained when performing the pair-wise comparison of clusters.

After performing the relevant calculations, it is necessary to convert the weighted or normalized super matrix into the limit super matrix, which provides the limit weights illustrating the relative importance of each sub-criterion in determining the choice of a 3PRLP. As already stated in Sect. 3.2, all the columns of the limit super matrix are identical and the sum of the values in each column equals one.

Table 11 compares the normal and limit weights obtained for each sub-criterion. The resulting limit vector shows that, according to the experts' opinion, the quality criterion (F5), with a final priority value of 6.69 %, is the most important criterion when selecting third-party reverse logistics providers. It is followed by cost saving (D2=4.11 %), service improvement (D3=4.08 %), service (F2=3.99 %), delivery and receipt (E1=3.64 %), warehouse management in IT applications (A1=3.45 %), warehouse management (C1=3.44 %), and transitional processing (E2=3.07 %).

Given the numerical results presented in Table 11, it should be noted that, even though the Frequent Updating sub-criterion has the highest normal weight (B3=41.11 %), it does not have a top priority in the limit matrix. This divergence between rankings is due to the combined effect of the weights obtained for each sub-criterion within a cluster and those of the clusters themselves when generating the respective rankings [49].

4.3 Main implications and shortcomings

The managers of companies seeking to outsource their reverse logistics and those of the potential contractor organizations can make use of the information obtained in our case study relative to the selection of 3PRLPs. In this regard, the results derived from the model *in the setting under analysis* imply that the managers of the outsourcing company are suggested to pay special attention to factors such as quality (F5), cost saving (D2), and service improvement (D3) when selecting 3PRLPs. At the same time, third-party contractors must also acknowledge that these three factors are vital for successfully contracting with large corporations. Clearly, the results obtained contain valuable information for the current and future managers of the organization that has been analyzed.

As already stated, the results obtained from the ANP-based decision model designed in this paper are determined by the subjective evaluations of the company experts. Thus, performing sensitivity analysis would certainly modify the results obtained, which are specific to the case being studied. This variability in the resulting rankings constitutes the main shortcoming of this type of research, which requires specific knowledge of the expected consequences derived from the

Table 10 Comparison matrix of the 3PLSs with respect to *warehouse management* (A1)

Eigenvector	C5	C4	C3	C2	C1	Warehouse management
0.3433	1.607	2.364	2.949	3.033	1	Inventory replenishment (C1)
0.1277	0.374	1.945	0.530	1	0.329	Warehouse management (C2)
0.1155	0.337	0.402	1	1.883	0.339	Shipment consolidation (C3)
0.1467	0.542	1	2.485	0.514	0.423	Carrier selection (C4)
0.2666	1	1.845	2.967	2.669	0.622	Direct transportation services (C5)

CR=0.08493

Table 11 Normal and limit weights of criteria

Factors	Normal weights	Limit weights	Factors	Normal weights	Limit weights
A1	0.29110	0.034559	E2	0.21908	0.030749
A2	0.21978	0.026092	E3	0.09737	0.013667
A3	0.10746	0.012758	E4	0.18316	0.025708
A4	0.20346	0.024154	E5	0.10729	0.015059
A5	0.17820	0.021156	E6	0.13393	0.018798
B1	0.25119	0.017320	F1	0.14138	0.026392
B2	0.23104	0.015931	F2	0.21405	0.039957
B3	0.41111	0.028347	F3	0.13092	0.024439
B4	0.10667	0.007355	F4	0.15527	0.028985
C1	0.32772	0.034459	F5	0.35838	0.066900
C2	0.14248	0.014982	G1	0.08978	0.004125
C3	0.11573	0.012169	G2	0.20063	0.009218
C4	0.11442	0.012031	G3	0.26932	0.012374
C5	0.29965	0.031508	G4	0.21153	0.009719
D1	0.12962	0.015330	G5	0.22875	0.010510
D2	0.34834	0.041198	H1	0.38181	0.010728
D3	0.34522	0.040830	H2	0.11965	0.003362
D4	0.17682	0.020913	H3	0.17991	0.005055
E1	0.25916	0.036375	H4	0.31863	0.008953

potential interactions of the outsourcing company with other companies. In this regard, considering a team composed exclusively by academic experts would probably lead to different interactions and weights being defined among the decision variables, which would modify the ranking obtained.

However, the analysis performed in this paper delivers a set of guidelines illustrating how the ANP can be implemented within the green supply chain setting considered. The set of criteria and sub-criteria identified and categorized provide an important reference framework for this type of analysis. In this regard, the paper also shows how it is possible to interact directly with a company within a structured evaluation process where company experts relate and compare different decision criteria while being aware of the evaluation structure underlying the ANP.

5 Conclusion

The current paper has designed a conceptual model based on the ANP for evaluating and selecting 3PRLPs. The ANP has helped us maintaining a hierarchical structure while processing a network environment, so that we could model the heterogeneous interactions existing among the different decision factors considered. Moreover, when designing the ANP-based decision model, we have interacted with several industry specialists whose opinions were later used to determine the final ranking of the alternatives.

Thus, the results derived from this research are helpful to both the producer and the contractor of third-party logistics when considering the type decision setting analyzed in the paper. This case-specificity property of the model constitutes also its main shortcoming. That is, the results derived from the model are highly dependent on the case being analyzed and the capacity of the researchers to interact with the experts before retrieving the information that will be inputted into the ANP structure.

In this regard, and despite the substantial advantages inherent to the model presented, some limitations allowing for potential improvements should be highlighted. First, all the specialists are required to have some working knowledge regarding pair-wise comparisons and the way relationships are determined among the decision factors within the ANP. Second, performing pair-wise comparisons is very time-consuming and company experts may be reticent to provide detailed or precise evaluations. Third, the decision criteria considered are specific to the industry being studied.

Among its main advantages, we should note that the current model can be easily extended to analyze the behavior of other industries. Moreover, fuzzy logic and gray systems can be easily incorporated into the model so that it can deal with the uncertainty arising from the subjective linguistic evaluations generally provided by the experts. This is particularly important when the company experts are not fully aware of the decision structure implemented via the ANP and provide approximate answers to the corresponding questionnaires.

Appendix: Samples from the three questionnaires

Questionnaire 1: Evaluation of decision criteria

Selection of 3PRLP

This survey has been designed to identify relevant criteria for the selection of a third party reverse logistics provider required to perform waste disposal services for an outsourcing company. Please assess the degree of importance of each selection criterion using the following 5-point scale:

Not important	1
Moderately important	2
Very important	3
Highly important	4
Extremely important	5

If you are not familiar with any of the criteria, kindly skip it without marking.

		1	2	3	4	5
1	Inventory Replenishment	□	□	□	□	□
2	Warehouse Management	□	□	□	□	□
3	Shipment Consolidation	□	□	□	□	□
4	Carrier Selection	□	□	□	□	□
5	Direct Transportation Services	□	□	□	□	□
6	Collection	□	□	□	□	□
7	Packing	□	□	□	□	□
8	Storage	□	□	□	□	□
9	Sorting	□	□	□	□	□
10	Transitional processing	□	□	□	□	□
11	Delivery	□	□	□	□	□
12	Reclaim	□	□	□	□	□
13	Recycle	□	□	□	□	□
14	Remanufacture	□	□	□	□	□
15	Reuse	□	□	□	□	□
16	Disposal	□	□	□	□	□
17	Effective Communication	□	□	□	□	□
18	Service Improvement	□	□	□	□	□
18	Service Management	□	□	□	□	□
20	Overall Working Relations	□	□	□	□	□
21	Customer Satisfaction	□	□	□	□	□
22	Frequent Updating	□	□	□	□	□
23	Profitability	□	□	□	□	□
24	Employee Moral	□	□	□	□	□
25	Quality	□	□	□	□	□
26	Cost	□	□	□	□	□
27	Time	□	□	□	□	□
28	Flexibility	□	□	□	□	□
29	Service	□	□	□	□	□
30	Warehouse Management	□	□	□	□	□
31	Order Management	□	□	□	□	□
32	Supply Chain Planning	□	□	□	□	□
33	Shipment and Tracking	□	□	□	□	□
34	Freight Payment	□	□	□	□	□
35	Introduction	□	□	□	□	□
36	Growth	□	□	□	□	□
37	Maturity	□	□	□	□	□
38	Decline	□	□	□	□	□

Questionnaire 2: Relationships between the criteria

Specify any direct relation between the criteria composing each row and column using the scoring pattern which is shown in the questionnaire. In order to avoid any confusion regarding the causality defining the relation between two different criteria, the following example was given to the experts along with the questionnaire.
Example: Consider the criteria warehouse management (A1) and order management (A2):
1. If there is no relationship between (A1) and (A2), write "A1A2" in the corresponding matrix entrance.
2. If only (A1) is related to (A2), write "1" in the corresponding matrix entrance.
3. If only (A2) is related to (A1), write "2" in the corresponding matrix entrance.
4. If both criteria (A1) and (A2) are interdependent, write "3" in the corresponding matrix entrance.

Sub-Criteria	A1	A2	A3	A4	A5	B1	B2	B3	B4	C1	C2	C3	C4	C5	D1	D2	D3	D4	E1	E2	E3	E4	E5	E6	F1	F2	F3	F4	F5	G1	G2	G3	G4	G5	H1	H2	H3	H4
Warehouse Management (A1)																																						
Order Management (A2)																																						
Supply chain planning (A3)																																						
Shipment and Tracking (A4)																																						
Freight Payment (A5)																																						
Customer Satisfaction (B1)																																						
Profitability B2																																						
Frequent Updating (B3)																																						
Employee Morale (B4)																																						
Inventory Replenishment (C1)																																						
Warehouse Management (C2)																																						
Shipment Consolidation (C3)																																						
Carrier Selection(C4)																																						
Direct Transportation Services (C5)																																						
Effective Communication (D1)																																						
Cost Saving (D2)																																						
Service Improvement (D3)																																						
Overall Working Relations (D4)																																						
Delivery (E1)																																						
Transitional Processing (E2)																																						
Storage (E3)																																						
Sorting (E4)																																						
Packing E5																																						
Collection (E6)																																						
Flexibility (F1)																																						
Service (F2)																																						
Time (F3)																																						
Cost (F4)																																						
Quality (F5)																																						
Reclaim (G1)																																						
Recycle (G2)																																						
Remanufacture (G3)																																						
Reuse (G4)																																						
Disposal (G5)																																						
Introduction (H1)																																						
Growth (H2)																																						
Maturity (H3)																																						
Decline (H4)																																						
SCORING PAT No dependency=0; Dependency exist=1; Inverted Dependency=2; Mutual Dependency=3																																						

Questionnaire 3. Pair-wise comparisons

This questionnaire was divided in several separate sections and pair-wise comparisons were performed through each one of them. For example, in the section below, the following question was asked:
Which one of the sub-criteria from the "Third Party Logistics Services (C)" criterion has more influence on the selection of a 3PRLP?
Please, consider the following table (Table 6 in the paper) when performing pair-wise comparisons between sub-criteria.

		A-Importance - or B?				Equal	How much more?						
						1	2	3	4	6	7	8	9
1	□	Inventory Replenishment (C1)	or	□	Warehouse Management (C2)	□	□	□	□	□	□	□	□
2	□	Inventory Replenishment (C1)	or	□	Shipment Consolidation (C3)	□	□	□	□	□	□	□	□
3	□	Inventory Replenishment (C1)	or	□	Carrier Selection (C4)	□	□	□	□	□	□	□	□
4	□	Inventory Replenishment (C1)	or	□	Direct Transportation Services (C5)	□	□	□	□	□	□	□	□
5	□	Warehouse Management (C2)	or	□	Shipment Consolidation (C3)	□	□	□	□	□	□	□	□
6	□	Warehouse Management (C2)	or	□	Carrier Selection (C4)	□	□	□	□	□	□	□	□
7	□	Warehouse Management (C2)	or	□	Direct Transportation Services (C5)	□	□	□	□	□	□	□	□
8	□	Shipment Consolidation (C3)	or	□	Carrier Selection (C4)	□	□	□	□	□	□	□	□
9	□	Shipment Consolidation (C3)	or	□	Direct Transportation Services (C5)	□	□	□	□	□	□	□	□
10	□	Carrier Selection (C4)	or	□	Direct Transportation Services (C5)	□	□	□	□	□	□	□	□

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