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ORIGINAL ARTICLE

An analytic network process-based multicriteria decision making model for a reverse supply chain

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Abstract Reverse logistics has emerged as an important dimension for organizations to build their strategic advantage. Part of this effort relies on potentially outsourcing these activities. With this competitive issue in mind, this paper presents a multistep process to select a third-party reverse logistic provider (3PRLP). Criteria for evaluation are drawn from the literature and practical input from experts and decision makers within a case company. The process requires that an initial screening of criteria is completed through the analytical hierarchy process. The second stage of the process, 3PRLP selection, is completed using the analytic network process. An illustrative example is provided to demonstrate the solutions obtained by the proposed process within an automobile case company. A sensitivity analysis is also provided for a robustness check. The results obtained from the proposed model provide some interesting managerial implications to the case company and others wishing to apply the process.

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1 Introduction

In order to retain customers and gain new market share, companies seek an increased value for their products and services when compared to their competitors [8]. Increased competitive pressures have also caused organizations to find alternative and creative strategies and tactics such as outsourcing activities to increase organizational competitiveness. Even though outsourcing has been in practice since the beginnings of commerce, the recent literature and practice reveals that some core activities such as transportation, warehousing, inventory management, and logistics services are increasingly outsourced to third-party logistics (3PL) providers [32, 88].

Logistics plays an important strategic role for organizations that strive to keep pace with market changes and supply chain integration [51]. Companies, in response to these shifting market dynamics are upgrading their logistics systems from traditional backroom functions to strategic boardroom functions [68]. Organizations can use many approaches to efficiently and effectively manage their logistics activities [68]. They can:

- Provide the logistics service as an in-house service
- Own logistics subsidiaries through setting up or buying a logistics firm
- Outsource the logistics function and buy the service

From the current literature, we observe the growing interest in the outsourcing option [45, 47, 49, 70], i.e., outsourcing of logistics functions to third-party logistics service providers. Simultaneously, organizations are increasing allowances for free trial and return policies to improve their competitiveness. Given these return policies, in most situations, discarding of returned products is not economical nor environmentally sound [59]. In the past few years, changes in environmental regulations, increased environmental awareness amongst customers, and increased returns have forced companies to reexamine and improve their reverse logistics systems. In addition to forward logistics, organizations are increasingly pressured to consider how to manage their reverse logistics systems.

Reverse logistics management necessarily focuses on the decision to keep these functions in-house or outsource to other specialized organizations. This decision process, as is for most strategic organizational initiatives, is not a trivial process or decision. Significant complexities and issues arise that may influence the long-term strategic competitiveness of an organization. Thus, examination and development of decision models that can be utilized by organizational managers and executives for this strategic decision purpose must be completed with care. In this study, we seek to add to this important body of literature by presenting a two-staged decision process utilizing multi-attribute decision tools (analytic hierarchy process (AHP) and analytic network process (ANP)) for a real-world case study of a reverse logistics outsourcing decision. The modeling approach contributes to the literature by first accumulating a comprehensive set of factors that need to be considered in these evaluations. We then provide novel and creative ways of evaluating the results in a what-if sensitivity analysis that can prove useful for management. Insights from the practical case study also contribute to the body of knowledge through validation and extend research in this field. The analyses of the methodology and sensitivity results provide us with directions for future research.

We now introduce some background on issues and modeling of third-party reverse logistics provider (3PRLP) outsourcing.

2 Background on third-party reverse logistics provider outsourcing concerns and models

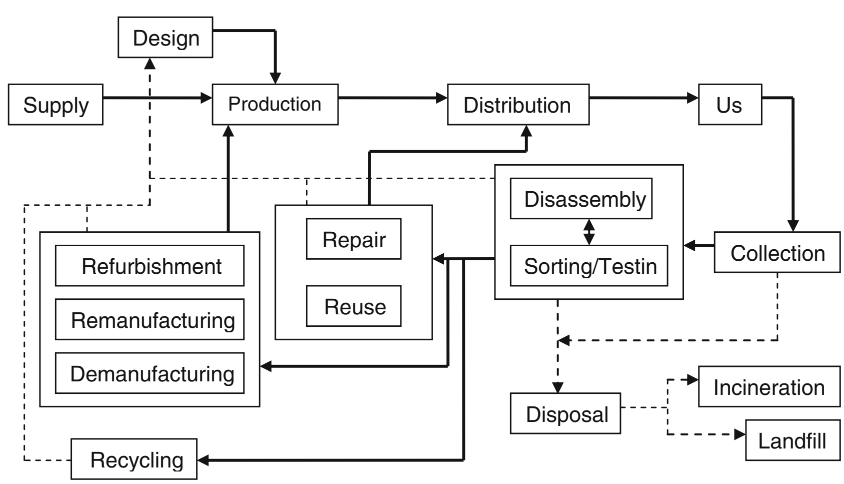
Broadly, forward logistics is defined as the flow of men, material, and information from suppliers to the customers in order to satisfy customer needs and also after-sale services. Reverse logistics is the process of moving goods from their typical final destination for the purpose of capturing value or proper disposal. Reverse logistics comprises all the activities involved in managing, processing, reducing, and disposing of hazardous or nonhazardous waste from production, packaging, and use of products, including the processes of reverse distribution [63, 64]. Reverse logistics is sometimes called "logistics backward" because flow of goods is just opposite to the flow in the conventional forward supply chain. It includes flow of goods and information that are necessary to collect used products, packaging materials, production scrap, and other residues and bring them to places where they can be reused, remanufactured, recycled, or disposed of properly [79]. A simple framework of forward and reverse logistics structure is shown in Fig. 1.

Various reasons have been postulated for the increased importance of reverse logistics including [62, 76]:

- Products are returned at a very high rate due to damage, expiration (obsolescence), seasonality, internet purchases, and poorly performing products.
- An end-of-life opportunity which utilizes the remanufacturing, refurbishing, or repairing process to extend the life of the product.
- Companies taking responsibility for the disposal of their products which contain hazardous waste.

Researchers have identified outsourcing as an important management strategy for the 3PRLP problem [35, 40, 66, 67]. Even though there exists some possibilities of using 3PRLP in industries such as pharmaceuticals, container reuse, cellular telephone reuse, electronics, and computers.

Fig. 1 A framework for forward and reverse supply chain [73]



The major issue in such systems is that the product providers, or original equipment manufacturers, are typically not prepared to effectively address these service needs due to the lack of reverse logistics knowledge [76, 83]. In order to earn customer loyalty, organizations are trying to concentrate on reverse logistics activities. This situation has made companies seriously consider outsourcing reverse logistics activities to 3PRLP [35, 39]. Yet, the determination of which 3PRLP to select is not always obvious or easy due to many criteria dependent on various environmental, industrial, and operational characteristics. Many of these relevant criteria for the selection of a 3PRLP are compiled and presented in Table 1 with appropriate referencing.

2.1 Models for outsourcing and supplier selection in a reverse logistics setting

Research in the area of supplier selection and outsourcing decisions has had a long and storied history. The decision models are derived from a variety of sources and include the breadth of techniques available to decision analysts. For example, supplier selection models range from simple scoring

Table 1 Summary of literature on the factor for the selection of a provider

S. No.	Selection factor	Selection subfactors	References
1	Competencies (CMP)	Quality management (QM)	[3, 9, 20, 42, 48, 50, 69, 78, 81]
		Cost of service (C.S)	
		Time of service (T.S)	
		Flexibility (FXL)	
		Capability under uncertainty (CAP)	
2	Operational performance (OP)	Take back policy (TBP)	[10, 18, 34, 54, 75, 80, 86]
		Packing (PAK)	
		Storage (STO)	
		Sorting (SOT)	
		Transitional process (T.P)	
		Delivery (DL)	
3	Organization role (OR)	Reclaim (RL)	[15, 18, 54, 75]
		Recycle (RC)	
		Remanufacture (RM)	
		Reuse (RU)	
		Disposal (DP)	
4	Technology innovation (TI)	Warehouse management (WM)	[3, 9, 13, 18, 22, 24, 43, 48, 57, 87]
		Transportation management (TM)	
		Inventory management (IM)	
		JIT philosophy (JIT)	
		Information technology (IT)	
		Demand forecasting (DF)	
5	Risk management (RM)	Complaint handling (CH)	[10, 11, 29, 33, 74, 89]
		Order management (OM)	
		Supply chain planning (SCP)	
		Shipment and tracking (SHTR)	
		Freight payment (FP)	
6	Financial performance (FP)	Market share (MS)	[3, 9, 27, 31, 50, 82]
		Profitability (PF)	
		Assets (ASS)	
		Reputation (REP)	
7	User satisfaction (US)	Effective communication (EC)	[6, 9, 23, 41, 46, 48, 50, 56, 58]
		Service improvement (SI)	
		Overall working relations (OWR)	
8	Geographical spread (GS)		[9]
9	Network size (N.S.)		[1]

models to advanced mathematical programming techniques that rely on the latest solution processes (e.g., see [2, 14, 28]).

One technique that has seen substantial application and growth in the determination of whether to outsource and who should be selected is the AHP and the ANP. The extant research in this area has relied primarily on the application of the technique from a conceptual perspective and has been used for a variety of supplier selection and outsourcing decisions (e.g., [54, 72]). Recent models have taken and applied fuzzy, grey, and rough set approaches intermingled with AHP/ANP approaches. Recently, Saen [67] summarized the solution methods used in the 3PL/3PRLP area. Also, there exists several other models which can be applied to similar kind of problems [16, 21, 36, 37, 52]. Reverse logistics evaluations and vendor selection has not been as broadly investigated as typical supplier selection [17, 35, 38, 40, 66, 73].

The recent literature reveals that there is an ample shift from the area of forward logistics-based outsourcing to reverse logistics-based outsourcing [5, 35, 38, 40, 44, 66]. An early conceptual model for the selection of 3PRLP using ANP [54] set the stage for some later models. The limitations of the early model are that it considers only four factors to evaluate the alternatives and also it is not validated by an actual application or rigorous simulated evaluation. Recently, more advanced models, such as a two-phase hybrid model based on artificial neural networks and fuzzy AHP have been applied to select the most appropriate 3PRLP [19]. Some specific industry examples exist such as a structured model to evaluate and select the best 3PRLP for a battery industry using fuzzy AHP [35], but the model considers only the initial evaluation process and its factors.

Recent literature in selecting 3PRLP has utilized additional techniques such as DEA [4, 66, 67], AHP [5, 7], and simplified fuzzy AHP [38]. The major limitation or disadvantages of these models is no consideration of either multiple factors or lack of consideration of the interdependency between the criteria and subcriteria. Although the literature has grown somewhat in this area over the past decade, limitations to the technique and a more complete analysis are missing.

Thus, there is ample room for further investigation utilizing formal modeling and application and insights from these applications. For example, many of the complexities of these latest models that incorporate fuzziness, algorithmic complexity, and other academic "niceties" cause greater confusion rather than clarity for decision makers and analysts. We provide a straight forward multistage process that is practically validated for this unique problem situation of an increasingly important issue facing the industry. Thus, this study overcomes some limitations and expands research in this field by proposing a multistep process to select the third-party reverse logistics provider using AHP and ANP.

We now introduce the multistage AHP/AHP approach and provide additional insights with a sensitivity analysis.

3 Solution methodology

In this work, the two-staged 3PRLP selection model utilizes AHP to identify the most prioritized factors and ANP to select the providers. The methodologies used in this work are now overviewed.

3.1 The analytic hierarchical process

AHP is a methodology for multicriteria decision making problems. AHP and its use of pairwise comparisons have inspired the creation of many other decision-making methods. The various applications of AHP in multicriteria decision making problems can be found in the literature [60, 77, 85].

Steps adopted for the AHP method in this work are as follows [65]:

1. Identify the factors for the study
2. Establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the elements.

3.1.1 Pairwise comparisons

Once the main factors are identified, the decision maker evaluates the various factors by comparing them to one another a pair of factors at a time. A numerical weight or priority is derived for each factor. The fundamental scale of pairwise comparisons is given in Table 2. A detailed exposition of the AHP methodology can be found in [25, 26]. Criteria that contain relative weights of more than 10 % of the maximum relative weight are selected for this study.

3.2 The analytic network process

The ANP technique is a general form of AHP. AHP can be used in unidirectional hierarchical models, whereas ANP can be used for more complicated decision problems primarily due to its ability to consider interdependent factor relationships [70]. The ANP approach is capable of handling interdependence among elements by obtaining the composite weights through the development of a "supermatrix" [55]. A detailed description of ANP can be found in [71]. The various applications of ANP in multicriteria decision making problems can be found in the literature [53, 60, 77] .

3.2.1 Steps in the ANP process

1. Develop a decision network hierarchy showing the relationships among decision factors.
2. Elicit pairwise comparisons among the factors influencing the decision, i.e., pairwise comparison for main and sub-attributes to determine their relative weights.

Table 2 Relative importance measurement scale [25, 26]

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

3. Calculate relative weights by pairwise comparison matrices for interdependencies of sub-attributes and then evaluate providers by another pairwise comparison.
4. Form a supermatrix (i.e., a two-dimensional matrix composed from the relative–importance–weight vectors) and converged ("stable") weights from the supermatrix so that the numbers in every column sum to 1.
5 Calculate a desirability index (D_i), if needed.

The application of the two-staged approach is now illustrated through the development of a framework for application of a decision environment for 3PRLP.

4 Case illustration

An Indian automobile components manufacturing company is chosen for this study. This company produces components in three shifts and has approximately 1,500 employees per shift. The company supplies its products to most of the domestic and international automobile original equipment manufacturers. Currently, the company itself is managing its own reverse logistics (returned products) system. The company is interested in outsourcing its collection of returned products processes due to company expansion and uncertainties involved in returned products activities. In order to identify the best 3PRLP, the company approached the research team to aid them with this decision and suggest a transparent, simple, and adoptable methodology. In this regard, we suggested the four-step procedure for the 3PRLP selection process.

Using the 3PRLP partnership framework [54] as a foundation, the 3PRLP selection process was modified to a four-step procedure:

Step A Identification of necessary factors for provider (supplier) selection.
Step B Framing a conceptual selection model with academic and industrial expert aid.
Step C Generalized the sample questionnaire for evaluation of the model.
Step D Case study for validating the model.

In the initiation of this process, the company identified seven potential 3PRLPs. The potential providers are identified using a market survey and from the company's past record. The four step (steps A to D) procedure mentioned above is adopted for this study.

Table 3 Pairwise comparisons of the different main factors and their e-vectors

	CMP	O.P	R.M	T.I	U.S	F.P	N.S	GS	O.R	E-vector
CMP	1	2	6	4	5	7	8	9	3	0.303
O.P	0.5	1	5	3	4	6	7	8	2	0.220
R.M	0.166	0.2	1	0.333	0.5	2	3	4	0.333	0.051
T.I	0.25	0.333	3	1	2	4	5	6	0.25	0.099
U.S	0.2	0.25	2	0.5	1	3	4	5	0.2	0.069
F.P	0.142	0.166	0.5	0.25	0.333	1	2	3	0.1667	0.034
N.S	0.125	0.142	0.333	0.2	0.25	0.5	1	2	0.1428	0.024
GS	0.111	0.125	0.25	0.166	0.2	0.333	0.5	1	0.125	0.017
O.R	0.333	0.5	3	4	5	6	7	8	1	0.180

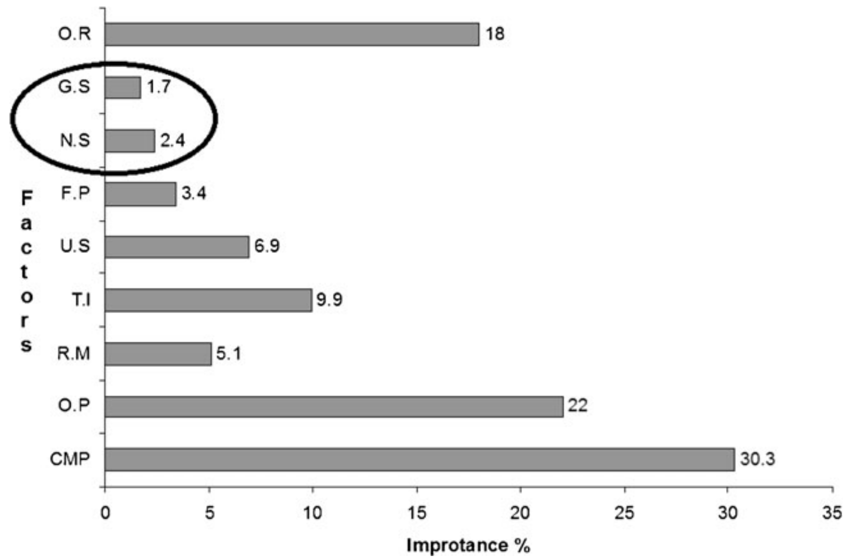


Fig. 2 Priorities of the factor

4.1 Step A: Identification of necessary factors for provider selection

In order to identify the important factors and subfactors for the case company, a research team composed of academicians' and industrial experts was formed. The team had significant industrial and academic knowledge of the 3PRLP problem. During the initial stage, the academicians reviewed the literature to determine a comprehensive listing of factors which will be used to select the 3PRLP. After completion of the review, the factors were categorized into nine main factor groupings with the help of the team. The major nine factor groups are shown in Table 1.

In this step, using AHP, we determine which factors have a relative weight of more than 10 % of the maximum relative weight. Those factors that meet this 10 % threshold will remain in the evaluation process. Table 3 provides the results of the pairwise comparisons and relative weights using inputs from the expert team.

The factor with the maximum relative importance weight is the "competencies" factor with a value of 0.303. Thus the cutoff threshold at 10 % will be a value of 0.0303. From Table 3 and Fig. 2, we see that two factors, "geographical spread" and "network structure" can be filtered from the remaining stages of this study and methodology.[1]

[1] If the final selection process of the alternatives shows a virtual tie between the alternatives, these secondary factors can be brought back into the analysis. The process of filtering is to help reduce the number of pairwise comparisons necessary for an analysis at later stages. A large number of factors can cause significantly (exponentially) more pairwise comparisons for both AHP and ANP approaches. Thus, eliminating less desirable or lower weighted factors can aid efficiency of the process reducing decision maker fatigue.

4.2 Step B: Framing a conceptual model with the help of academic and industrial experts

After eliminating the less important factors, factors and subfactors for further study were listed in Table 4. The conceptual model framed with the help of expert team is shown in Fig. 3. In Fig. 3, the interdependencies between main factors and subfactors are identified with the help of the expert team.

4.3 Step C: Generalized sample questionnaire for evaluation of the model built

In this step, a generalized sample questionnaire to populate the model is completed with the help of the expert team. The sample questionnaire for the main factors and alternatives are shown in Appendix A.

4.4 Step D: Case study for validating the model

In this study, seven providers are ranked, eventually determining the highest ranked 3PRLP. This step is completed using ANP.

After identifying the potential providers, the problem is decomposed as a hierarchy of various levels into two categories. These categories are defined as determinants and dimensions [32]. In this model, the topmost level represents the factor which plays an important role and also dependent on the remaining factors. This level is termed determinants. The intermediate levels correspond to subfactors and are the dimensions. The last and the lowest level contains the decision alternatives. A schematic representation of the network hierarchy used in this study is shown in Fig. 4.

Table 4 Main factors and subfactors

Main factors	Subfactors
Competencies (CMP)	Quality management (QM)
	Cost of service (C.S)
	Time of service (T.S)
	Flexibility (FXL)
	Capability under uncertainty (CAP)
Operational performance (OP)	Take back policy (TBP)
	Packing (PAK)
	Storage (STO)
	Sorting (SOT)
	Transitional process (T.P)
	Delivery (DL)
Technology innovation (TI)	Warehouse management (WM)
	Transportation management (TM)
	Inventory management (IM)
	JIT philosophy (JIT)
	Information technology (IT)
	Demand forecasting (DF)
Organization role (OR)	Reclaim (RL)
	Recycle (RC)
	Remanufacture (RM)
	Reuse (RU)
	Disposal (DP)
Risk management (RM)	Complaint handling (CH)
	Order management (OM)
	Supply chain planning (SCP)
	Shipment and tracking (SHTR)
	Freight payment (FP)
User satisfaction (US)	Effective communication (EC)
	Service improvement (SI)
	Overall working relations (OWR)
Financial performance (FP)	Market share (MS)
	Profitability (PF)
	Assets (ASS)
	Reputation (REP)

Once the network hierarchy structure is completed, the pairwise comparison matrix for the factors is executed to find the relative importance (local priority vectors or eigenvectors or e-vectors) and one example is shown in Table 5.

The next step is forming a pairwise comparison matrix for dimensions to capture interdependencies among the subfactors. Table 6 presents an example result of one such interdependent relationship and pairwise comparison matrix. It is the result of a competencies (CMP) cluster with quality management (QM) as the controlling subfactor over the other subfactors.

In completing Table 6, a question asked to the decision maker may be: "when considering the QM factor with regard to increasing CMP, what is the relative impact of subfactor 1 when compared to subfactor 2?", i.e., "when considering QM with regard to increasing competencies, what is the relative impact of CS when compared to TS?". From Table 6, it is clear that CS (0.472) has the maximum impact on the competency criterion with QM as the control subfactors over others. Similarly, the pairwise comparisons to capture the other interdependencies among the other subfactors are completed as well.

The next step is the formation of the supermatrix. The supermatrix allows for a resolution of interdependencies that exist among the elements of an ANP system. A supermatrix is a partitioned matrix, where each submatrix is composed of a set of relationships between and within the levels as represented by the decision-makers model [70]. Table 7 presents the initial supermatrix, which is the result of the relative importance measures of the sub factors with their respective main factors.

The elements of the supermatrix are imported from pairwise comparison of matrices of factors and subfactors with their interdependencies (e.g., Table 6). In the supermatrix (Table 7), the columns are not column stochastic, which is required for supermatrix convergence to a stable set of weights. This next step is to make the values column stochastic by normalizing the summation of values in each column to one.

The supermatrix is made to converge to obtain a long-term stable set of weights. To converge the supermatrix, the supermatrix is raised to the power 2^{k+1}, where k is an arbitrarily large number [70]. In this paper, convergence, to the fourth significant decimal, is reached at k=63.

After determining the converged supermatrix, the next step is to find the relative weight of alternatives with respect to each subfactor (S_{ikj}). S_{ikj} denotes the relative impact of alternative i on dimension (subfactor) k of the determinant (main factor) j. This step can be completed by forming a pairwise comparison matrix for the performance of each alternative with respect to each subfactor. In our problem, there are 34 subfactors, so we need an additional pairwise comparison matrix for evaluating the alternatives. The values of S_{ikj} are shown in Table 8.

The selection of best alternative is determined by D_i. D_i is defined by [30, 32]:

$$D_i = \sum_{j=1}^{j} P_j A_{kj}^D A_{kj}^I S_{ikj} \quad (1)$$

In the above Eq. (1), P_j represents the relative importance of the determinant (main factor) j. A_{kj}^D denotes the relative importance of a dimension (subfactor) k of determinant (main factor) j for the dependency (D) relationships. A_{kja}^I is the stabilized importance weight of the dimension

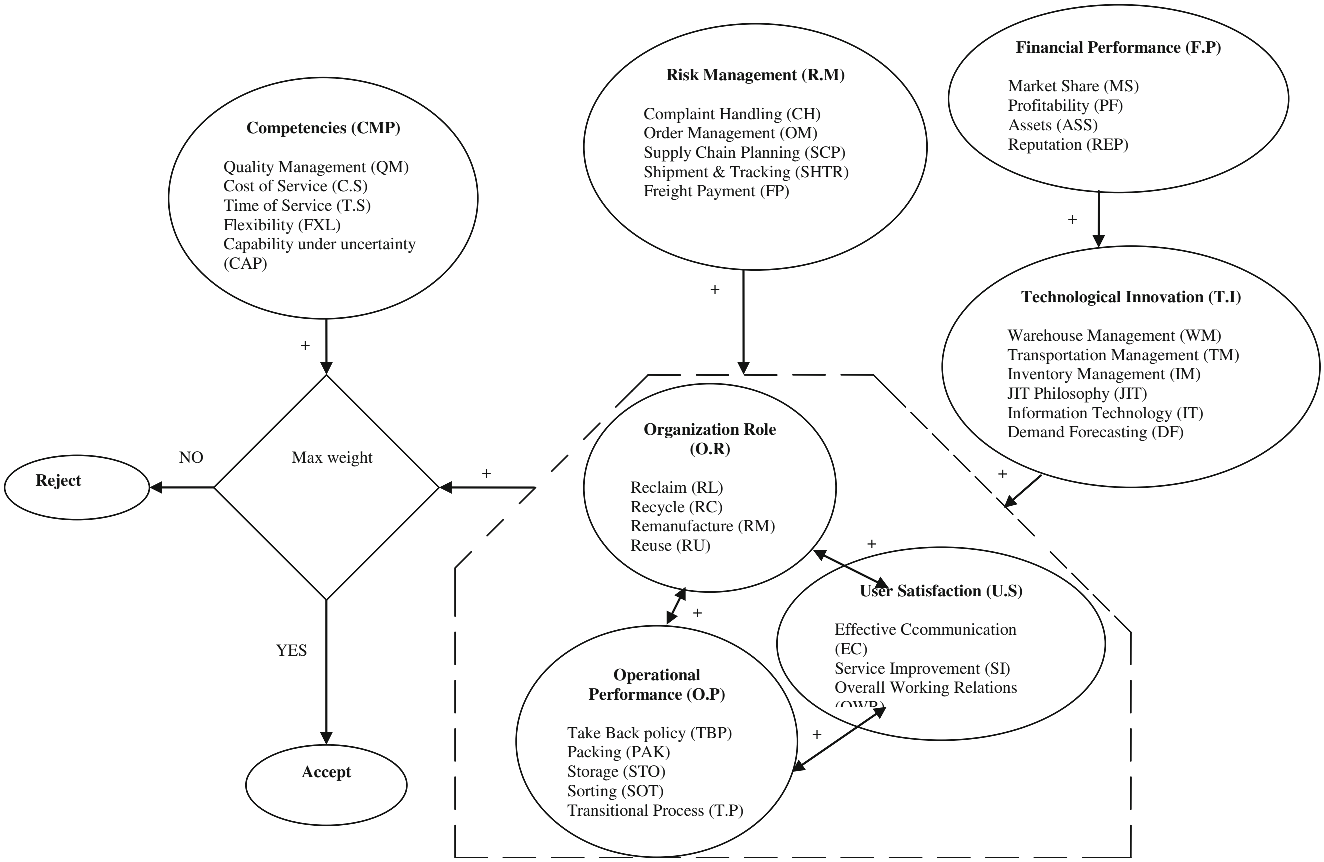


Fig. 3 Conceptual model for selection of third party reverse logistics provider

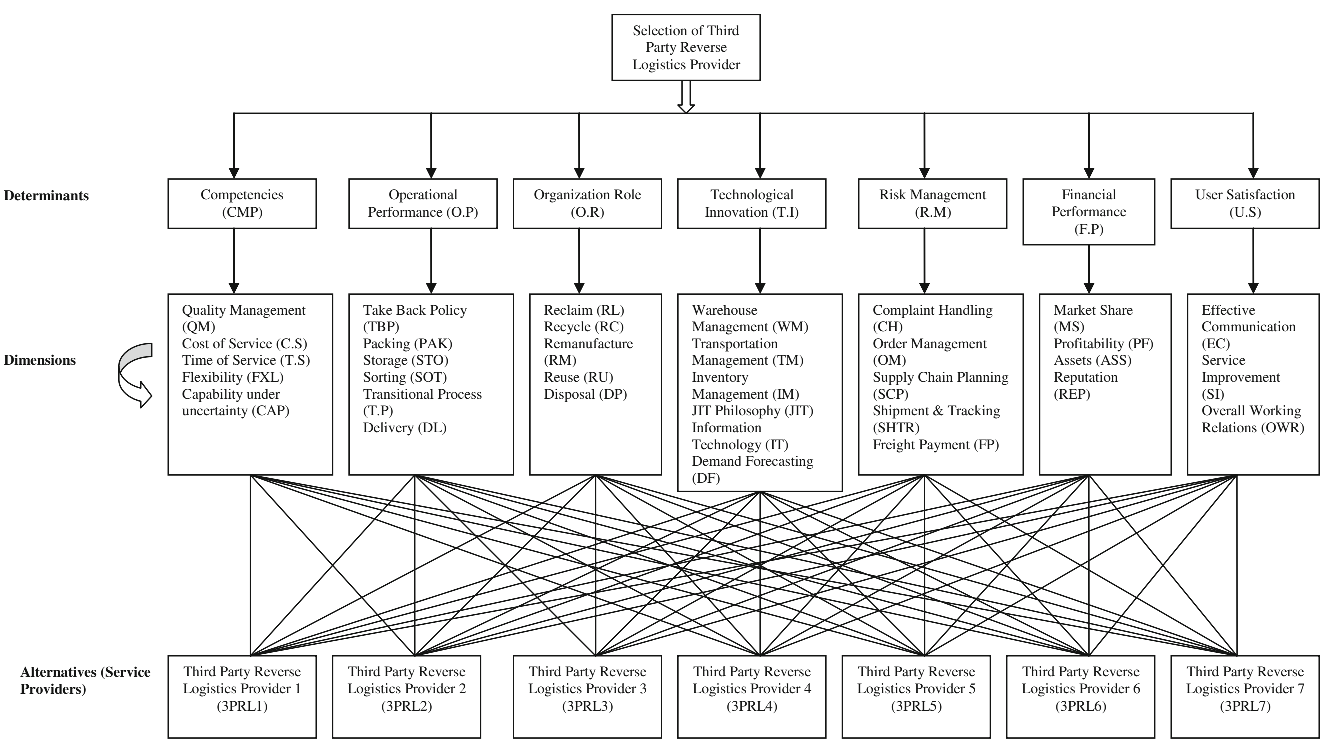


Fig. 4 Network hierarchy structure of the case study

Table 5 Pairwise comparison of main factors

	CMP	O.P	R.M	T.I	U.S	F.P	O.R	e-vectors
CMP	1	2	6	4	5	7	3	0.341
O.P	0.5	1	5	3	4	6	2	0.230
R.M	0.166	0.2	1	0.333	0.5	2	0.333	0.047
T.I	0.25	0.333	3	1	2	4	0.25	0.097
U.S	0.2	0.25	2	0.5	1	3	0.2	0.065
F.P	0.142	0.166	0.5	0.25	0.333	1	0.1667	0.030
O.R	0.333	0.5	3	4	5	6	1	0.189

(subfactor) k in the determinant (main factor) j with interdependency (I) relationships. These values are taken from the converged supermatrix. S_{ikj} denotes the relative impact of alternative i on dimension (subfactor) k of the determinant (main factor) j for goal. J is the index set for determinant (main factor).

Table 8 shows D_i. From Table 8, the alternative (the 3PRLP) with the highest desirability index (Table 8, last row) should be selected as the best option. For the given problem and based on the desirability index shown in Table 8, 3PRLP1 is the best alternative with a desirability index of 0.051.

5 Sensitivity analysis

Sensitivity analysis is important to determine the robustness of the solution, which may help to mitigate uncertainties in parameters and perceptions [12, 84]. The main aim of sensitivity analysis is to find the stability of the best solutions under some possible changes in parameters [61]. In this work, the sensitivity analysis is performed to find the changes in the ranking of alternatives with respect to changes in the weights of the main factors suggested by the expert team used in the study.

For sensitivity ranges and changing the weights of main factors, we followed two procedures. First, the major influencing factor is identified from Table 4 and the weights of major influencing factor are varied from 0 to 1. From Table 4, we can conclude that the major influencing factor is CMP and by varying the weights of CMP from 0 to 1, we found the desirability index for various alternatives. Figure 5 shows the results of analyzing the impact of changing the weights of major influencing factor CMP from 0 to 1 towards the desirability index of the alternatives.

Table 6 Pairwise comparison matrix for subfactors under competencies and quality management

	C.S	T.S	FXL	CAP	e-vector
C.S	1	4	2	3	0.472
T.S	0.25	1	0.5	0.5	0.108
FXL	0.5	2	1	2	0.256
CAP	0.333	2	0.5	1	0.164

From Fig. 5, we can infer that the ranking of alternatives (desirability index) is affected by the change in the weights of the CMP factor. But the affect, overall, is only between the choice of two alternatives as the top alternatives (3PRLP1 and 3PRLP2). This means that the decision over the CMP range is mainly a tradeoff between these two alternatives. It looks like the breakpoint is about the 0.3 weight for CMP. Thus, if basic competencies and capabilities are most important or of greater importance by the decision makers, it is more likely that 3PRLP1 is the better choice. If the decision makers eventually feel that CMP is given too much importance, the shift would more likely occur to the second provider. The ranking of alternatives remains unchanged even though the weights of other main factors such as R.M, F.P, and U.S are changed. This shows that the alternative ranking mainly depends on the main factors such as CMP, O.P, and O.R.

A more specific sensitivity analysis can be completed with the direct comparison of factor shifts between two factors. As an example, we complete a sensitivity analysis of relative importance between two major factors, financial performance (FP) and CMP. Figure 6 indicates the effect of change in desirability index of alternatives due to the change in priority weight of CMP with respect to FP. In the current case study, the managerial opinion between CMP and FP is a 7 (CMP is viewed as much more important than FP). For this value, 3PRLP1 is selected as the best alternative. If the relative importance falls below 5 and above 0.5, then the best alternative changes from 3PRLP1 to 3PRLP2. Secondly, the alternative ranking does not change if the relative importance between CMP and FP is increased from 5 and decreased from 0.5. This indicates that even if managerial preferences and opinions increase and decrease the relative importance of CMP to FP, ranking of alternatives does not change. Thus, at this specific level, the solution is very robust with little change in eventual choice. Managers can be confident that 3PRLP1 is a better choice.

Table 7 Supermatrix before convergence

	QM	C.S	T.S	FXL	CAP	TBP	PAK	STO	SOT	TP	DL	RL	RC	RM	RU	DP	EC	SI	OWR
QM	0	0.411	0.272	0.412	0.241														
C.S	0.472	0	0.483	0.310	0.063														
T.S	0.108	0.265	0	0.098	0.096														
FXL	0.256	0.184	0.157	0	0.600														
CAP	0.164	0.140	0.088	0.180	0														
TBP						0	0.180	0.198	0.241	0.289	0.442								
PAK						0.154	0	0.395	0.293	0.098	0.158								
STO						0.396	0.360	0	0.078	0.164	0.062								
SOT						0.141	0.180	0.099	0	0.107	0.246								
TP						0.258	0.197	0.216	0.260	0	0.092								
DL						0.051	0.083	0.092	0.128	0.342	0								
RL												0	0.448	0.565	0.095	0.083			
RC												0.283	0	0.133	0.043	0.339			
RM												0.164	0.283	0	0.627	0.536			
RU												0.448	0.164	0.242	0	0.042			
DP												0.105	0.105	0.060	0.235	0			
EC																	0	0.858	0.900
SI																	0.900	0	0.100
OWR																	0.100	0.142	0

	WM	TM	IM	JIT	IT	DF	CH	OM	SCP	SHTR	FP	MS	PF	ASS	REP
WM	0	0.451	0.312	0.425	0.442	0.489									
TM	0.327	0	0.137	0.175	0.158	0.211									
IM	0.146	0.189	0	0.173	0.062	0.140									
JIT	0.135	0.150	0.111	0	0.246	0.090									
IT	0.089	0.156	0.130	0.160	0	0.070									
DF	0.303	0.054	0.310	0.067	0.092	0									
CH							0	0.109	0.579	0.574	0.283				
OM							0.654	0	0.110	0.239	0.164				
SCP							0.170	0.529	0	0.131	0.448				
SHTR							0.111	0.051	0.240	0	0.105				
FP							0.065	0.311	0.071	0.056	0				
MS												0	0.626	0.178	0.068
PF												0.084	0	0.070	0.682
ASS												0.705	0.238	0	0.250
REP												0.211	0.136	0.752	0

Table 8 Desirability index matrix

Main factors	Subfactors	P_j	A_{kj}^D	A_{kj}^I	S_{ijk}						
					3prlp1	3prlp2	3prlp3	3prlp4	3prlp5	3prlp6	3prlp7
CMP	QM	0.341	0.451	0.263	0.392	0.192	0.104	0.101	0.064	0.07	0.073
	C.S	0.341	0.189	0.262	0.39	0.222	0.135	0.074	0.07	0.053	0.052
	T.S	0.341	0.150	0.131	0.386	0.175	0.122	0.108	0.076	0.073	0.056
	FXL	0.341	0.157	0.214	0.382	0.23	0.111	0.102	0.071	0.062	0.04
	CAP	0.341	0.054	0.129	0.028	0.031	0.079	0.08	0.156	0.208	0.415
O.P	TBP	0.230	0.328	0.204	0.19	0.373	0.134	0.111	0.076	0.06	0.052
	PAK	0.230	0.114	0.181	0.203	0.38	0.129	0.087	0.074	0.061	0.062
	STO	0.230	0.105	0.192	0.17	0.385	0.121	0.099	0.094	0.056	0.063
	SOT	0.230	0.069	0.128	0.193	0.372	0.151	0.071	0.088	0.055	0.066
	TP	0.230	0.192	0.174	0.21	0.398	0.143	0.09	0.056	0.055	0.045
	DL	0.230	0.191	0.119	0.203	0.403	0.113	0.091	0.071	0.058	0.058
O.R	RL	0.189	0.327	0.253	0.119	0.202	0.372	0.076	0.105	0.07	0.053
	RC	0.189	0.146	0.154	0.113	0.21	0.375	0.083	0.086	0.068	0.062
	RM	0.189	0.135	0.274	0.113	0.214	0.403	0.081	0.076	0.063	0.045
	RU	0.189	0.089	0.209	0.112	0.177	0.408	0.077	0.078	0.067	0.077
	DP	0.189	0.303	0.108	0.116	0.199	0.368	0.09	0.093	0.073	0.056
T.I	WM	0.097	0.040	0.299	0.178	0.41	0.092	0.098	0.081	0.07	0.067
	TM	0.097	0.045	0.186	0.214	0.401	0.116	0.079	0.073	0.06	0.053
	IM	0.097	0.083	0.128	0.192	0.39	0.116	0.087	0.07	0.062	0.079
	JIT	0.097	0.131	0.122	0.28	0.324	0.192	0.068	0.065	0.037	0.031
	IT	0.097	0.279	0.103	0.183	0.394	0.104	0.09	0.067	0.08	0.08
	DF	0.097	0.420	0.158	0.295	0.333	0.113	0.115	0.076	0.039	0.026
R.M	CH	0.047	0.080	0.269	0.156	0.183	0.341	0.12	0.12	0.049	0.027
	OM	0.047	0.160	0.250	0.105	0.248	0.368	0.087	0.068	0.065	0.055
	SCP	0.047	0.373	0.246	0.102	0.205	0.417	0.089	0.066	0.065	0.052
	SHTR	0.047	0.081	0.114	0.139	0.211	0.397	0.095	0.067	0.046	0.041
	FP	0.047	0.306	0.119	0.128	0.173	0.402	0.106	0.077	0.054	0.056
F.P	MS	0.030	0.572	0.212	0.404	0.21	0.13	0.09	0.086	0.038	0.038
	PF	0.030	0.158	0.230	0.407	0.214	0.103	0.079	0.073	0.06	0.061
	ASS	0.030	0.177	0.275	0.361	0.218	0.187	0.101	0.065	0.038	0.027
	REP	0.030	0.093	0.282	0.329	0.293	0.118	0.115	0.07	0.048	0.024
U.S	EC	0.065	0.091	0.464	0.108	0.232	0.394	0.103	0.062	0.049	0.049
	SI	0.065	0.514	0.428	0.114	0.195	0.399	0.095	0.071	0.067	0.055
	OWR	0.065	0.396	0.107	0.115	0.217	0.371	0.082	0.099	0.053	0.06
			Des indices (D_i)		0.051	0.051	0.042	0.019	0.015	0.013	0.012
			Ranking		1	2	3	4	5	6	7

6 Discussion and implications

The model, its results, and the sensitivity analysis were all important for management in helping to make decisions. But, like most practical applications of AHP and ANP, the decision process itself may be just as valuable as the ultimate quantitative ranking. That is, the development of factors, frameworks, and managerial thought process helps in structuring the decision environment to help make sense of the tradeoffs and factors that managers need to consider in a relatively new application area such as 3PRLP selection.

We did receive some feedback from management who were involved in this decision process. Managers felt the AHP process was easy to understand and straightforward. Given managerial confusion with the ANP complexity, management questioned the technique, preferring transparency to the complex technique's assumptions. But as the discussion and case analysis progressed with repeated, more

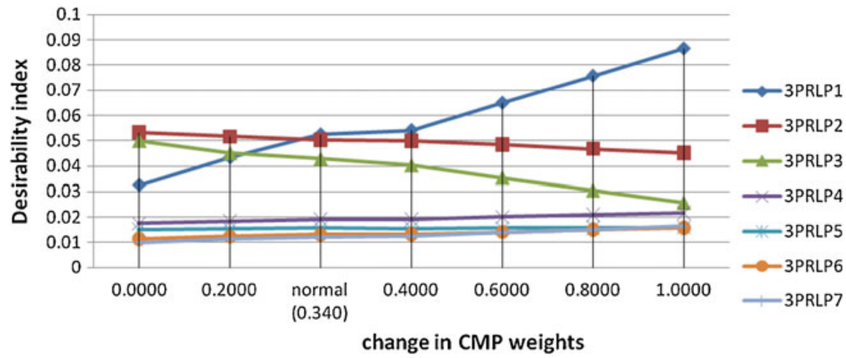


Fig. 5 Sensitivity analysis results of CMP from 0 to 1

detailed and practical explanations of the ANP approach, as well as the sensitivity analysis, results management became more convinced of the ANP results. This acceptance made trusting the results, and following up on the decision.

Part of the discussion with the managerial team revolved around the number of factors, subfactors, and alternatives. It was clearly explained that the level of effort would increase throughout all steps of the process, in some cases exponential increase in effort. This discussion allowed them to gain insight and appreciation for the two-staged approach that involved an initial filtering step and factor reduction for the evaluation.

After the evaluation and discussion, some of the poorly ranked and performing areas (or relative importance) were further investigated. For alternative company performance and evaluation relationships, feedback was provided to managers involved with some of the companies and in charge of various factors in the model. This was an unexpected, but valuable consideration in the structured decision process and how the results of the technique could be utilized for a broader range of managerial decision making and support.

7 Conclusion

The decision to outsource reverse logistics and the reverse logistics function is a common practice due to the lack of expertise and competitive advantages associated with operating a reverse logistics function. Outsourcing this function makes sense for significant strategic and competitive advantages. In this paper, we introduced a multistage AHP/ANP model for strategic third-party reverse logistics provider selection, when organizations seek to outsource all or some of their reverse logistics activities. A major contribution of this work lies in the refinement and extension of factors and

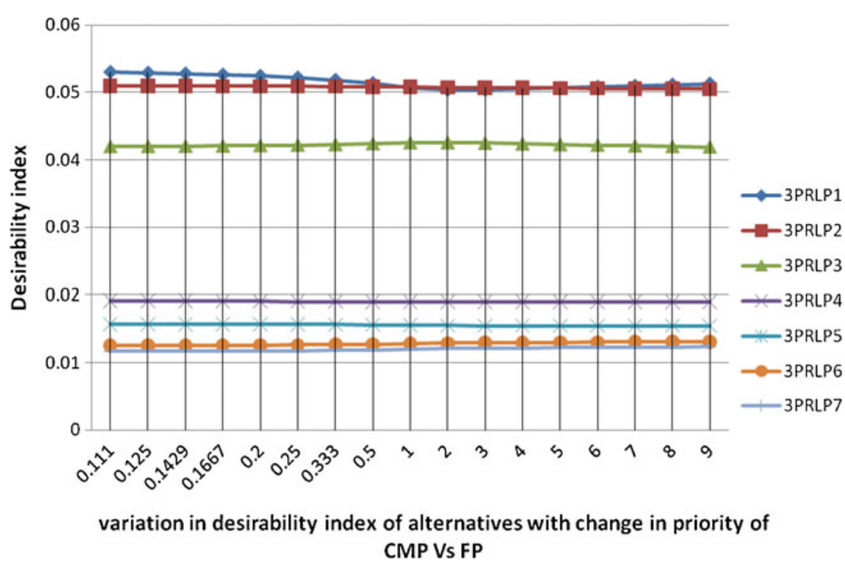


Fig. 6 Variation in ranking of alternatives with change in priority of CMP vs FP

subfactors used as a foundation for the decision framework, introduction of a multistep selection process through a robust methodology utilizing AHP and ANP, and an application and validation of the conceptual model using a practical case study. A sensitivity analysis for analyzing the robustness of the solution was also presented as part of the methodology.

The methodology did have some advantages by helping management structure the decision process as well as arriving at a decision. The utilization of the two-stage approach helped to narrow down the factor set which made for a more parsimonious model while still providing real-world practical decision maker utility. It was advantageous, overall, by allowing for both greater flexibility, efficiency, and rigor in this decision making environment.

Even with practical advantages, the major limitation of the methodology is the requirement for the additional time and effort to determine the relationships in terms of pairwise comparison for the factor filtering process, in addition to the effective 3PRLP selection process. Although, the first stage-filtering process may involve fewer overall pairwise comparisons for the ANP selection stage. Further behavioral research involving multistage multiple criteria decision analysis that requires an initial filtration and data reduction step is needed. Advancing the technique by incorporating a non-interactive data reduction approach, such as rough set theory and other information theoretic approaches may be a fruitful direction for additional research. Additional development for the proposed methodology can include incorporating fuzzy values to overcome an uncertain decision environment, development of a optimization-based mathematical model to integrate this selection model into the allocation of order quantities, and other operational and design considerations.

We can see that as organizations become more sustainability focused and reverse logistics plays a larger role, the importance of tools such as these will only grow. Making the most effective and thoughtful decisions as a manager and owner of environmentally and socially sensitive organizations are critical for the benefits of all stakeholders.

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Appendix A

Greetings!

This is a research about “An analytic network process (ANP) based multicriteria decision making model for a reverse supply chain”. The purpose of this questionnaire is to explore the opinion about 3PRLP selection. This questionnaire uses ANP to model the 3PRLP selection. As an expert, your support will be very crucial to the successful completion of this research. We sincerely hope that you would spend some time to express your opinions to be taken as reference for this research.

Instructions for filling out the questionnaire

In order to express your opinion, the pairwise comparison scale proposed by Saaty (refer below table) can be utilized.

Saaty relative importance measurement scale [25, 26]

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

Method for filling out

Please mark (X) or circle the relative importance levels in terms of pairs of the main factors used in the study.

For example, we used the factors [competencies (CMP) and operational performance (OP)] to explain the method for filling out the questionnaire.

If you mark or circle "6" in the following question, means that "CMP" is six times more important than the "OP"

1	Competencies (CMP)	9	8	7	(6)	5	4	3	2	1	2	3	4	5	6	7	8	9	Operational performance (OP)

If you mark or circle "1" in the following question, means that "CMP" is equally preferred as "OP"

2	Competencies (CMP)	9	8	7	6	5	4	3	2	(1)	2	3	4	5	6	7	8	9	Operational performance (OP)

If you mark or circle "4" in the following question, means that "OP" is four times more important than the "CMP"

3	Competencies (CMP)	9	8	7	6	5	4	3	2	1	2	3	(4)	5	6	7	8	9	Operational performance (OP)

Sample question related to the main factors

Please mark (X) or circle the relative importance levels in terms of pairs of the main factors used in the study.

1	Competencies (CMP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Operational Performance (OP)
2	Competencies (CMP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization Role (OR)
3	Competencies (CMP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technology Innovation (TI)
4	Competencies (CMP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Risk Management (RM)
5	Competencies (CMP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Financial Performance (FP)
6	Competencies (CMP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	User Satisfaction (US)
7	Competencies (CMP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Geographical Spread (GS)
8	Competencies (CMP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Network Size (N.S)
9	Operational performance (OP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Organization Role (OR)
10	Operational performance (OP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technology Innovation (TI)
11	Operational performance (OP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Risk Management (RM)
12	Operational performance (OP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Financial Performance (FP)
13	Operational performance (OP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	User Satisfaction (US)
14	Operational performance (OP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Geographical Spread (GS)
15	Operational performance (OP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Network Size (N.S)
16	Organization role (OR)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Technology Innovation (TI)
17	Organization role (OR)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Risk Management (RM)
18	Organization role (OR)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Financial Performance (FP)
19	Organization role (OR)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	User Satisfaction (US)
20	Organization role (OR)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Geographical Spread (GS)
21	Organization role (OR)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Network Size (N.S)
22	Technology innovation (TI)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Risk Management (RM)
23	Technology Innovation (TI)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Financial Performance (FP)
24	Technology innovation (TI)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	User Satisfaction (US)
25	Technology innovation (TI)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Geographical Spread (GS)
26	Technology innovation (TI)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Network Size (N.S)
27	Risk management (RM)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Financial Performance (FP)
28	Risk management (RM)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	User Satisfaction (US)
29	Risk management (RM)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Geographical Spread (GS)
30	Risk management (RM)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Network Size (N.S)
31	Financial performance (FP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	User Satisfaction (US)
32	Financial performance (FP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Geographical Spread (GS)
33	Financial performance (FP)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Network Size (N.S)
34	User satisfaction (US)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Geographical Spread (GS)
35	User satisfaction (US)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Network Size (N.S)
36	Geographical spread (GS)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Network Size (N.S)

Sample question related to the alternatives

Please mark (X) or circle the relative importance levels in terms of pairs of the alternatives with respect to sub-factor "Quality management (QM)" under the main factor of "Competencies (CMP)" used in the study.

1	3PRLP1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP2
2	3PRLP1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP3
3	3PRLP1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP4
4	3PRLP1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP5
5	3PRLP1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP6
6	3PRLP1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP7
7	3PRLP2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP3
8	3PRLP2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP4
9	3PRLP2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP5
10	3PRLP2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP6
11	3PRLP2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP7
12	3PRLP3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP4
13	3PRLP3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP5
14	3PRLP3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP6
15	3PRLP3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP7
16	3PRLP4	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP5
17	3PRLP4	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP6
18	3PRLP4	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP7
19	3PRLP5	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP6
20	3PRLP5	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP7
21	3PRLP6	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	3PRLP7

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