SELECTION OF REVERSE LOGISTICS SERVICE PROVIDER (RLSP) USING ANALYTICAL NETWORK PROCESS (ANP): A CASE STUDY OF AN AUTOMOTIVE COMPANY

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ABSTRACT

Activities in reverse logistics implementation are practiced extensively by lead acid battery manufacturing industries. One important problem faced by the management in the battery manufacturing industry is the regular supply of spent batteries/ lead from the end users in the supply chain management of battery production. The Analytic Network Process (ANP) based decision model presented in this work structures the problem related to options in selection of a reverse logistics service provider for supply of EOL lead acid batteries in a hierarchical form and links the determinants, dimensions, and enablers of the reverse logistics service provider with alternatives available to the decision maker. A reverse logistics service provider evaluation problem has been formulated that includes two primary tasks: preliminary screening of the RL service providers by a team of managers and an Analytic Network Process (ANP) based model for final selection. The proposed approach, therefore, links the financial and non-financial, tangible and intangible, internal and external factors, thus providing a holistic framework for the selection of an alternative for the reverse logistics operations for EOL batteries. The results of the present work indicate that acceptable cost between the user and the RL service provider companies is the most important determinant which influences the final selection process. This approach also enables the decision-makers to better understand the complex relationships of the relevant attributes in the decision making which may subsequently improve the reliability of the decision.

Keywords: Reverse logistics; Analytic Network Process; multi-criteria decision making; logistics outsourcing

1. Introduction

With rapid business growth in globalization, industries with relatively limited resources have to outsource some business functions or operations, and purchase raw materials or components/subcomponents from other small medium enterprises to establish an interrelated supply network. Consequently, if they would like to execute green programs

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to advance their environmental performance, they not only monitor their own operations, but also coordinate other partners in their supply networks, including reverse logistics activities, material suppliers, manufacturers, distributers, users and so on. Now-a-days supply chain managers ensure inclusion of traditional performance criteria as well as environmental criteria and this approach is known as green supply chain management. The outsourcing of reverse logistics activities to third party logistics service providers has now become a common practice. Reverse logistics encompasses the logistics involving activities all the way from used products no longer required by the user to products that may be usable again in the market. It is the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal (Stock et. al., 1998). The most intuitively related notion with such reverse activities involves the physical transportation of used products from the end user back to the producer. Reverse distribution activities involve the removal of defective and environmentally hazardous products from the hands of customers. This also includes products that have reached the end of their usable life. It is a process whereby companies can become more environmentally efficient through reusing and reducing the amount of materials used (Bhatnagar et al., 1999).

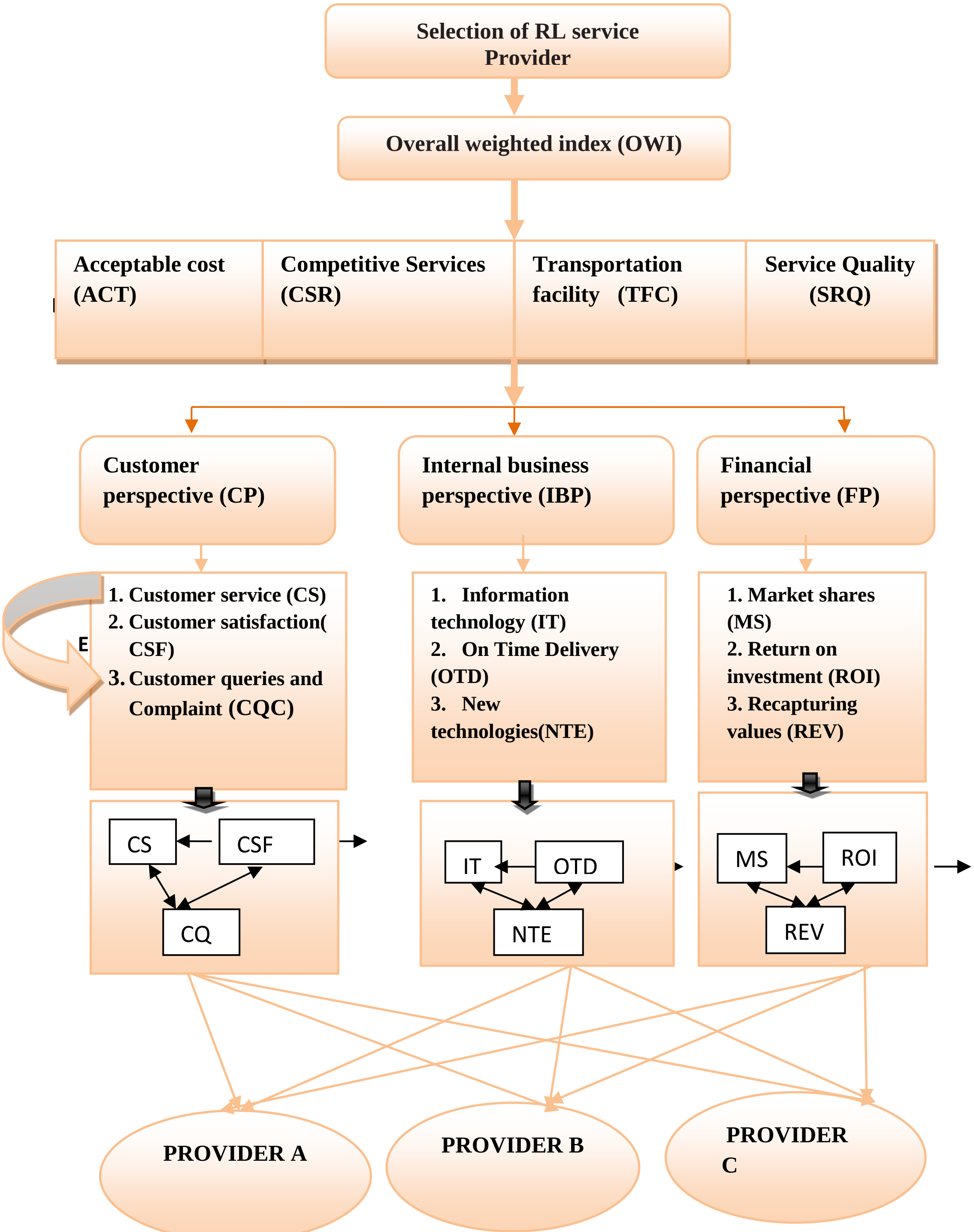

Figure 1. ANP model for selection of RL service provider

In recent years many Indian manufacturing firms have been forced to move to other states due to higher labor costs and fierce domestic competition. The North Indian market has become the most important investment market for Indian enterprises. Thus, Indian enterprises must find cheap resources that are available elsewhere in business environments, and the North Indian enterprises are recognized as a popular major investment location. However, the gradual transfer of investment to the Northern part of India results in a change in the supply chain which poses severe challenges for the enterprise's logistics capabilities. Due to changes in the business environment, the question of how to select the appropriate third-party logistics (3PL) provider for their own enterprise is becoming an important issue. Therefore, we propose a logistics service providers decision model, and focus on the lead acid battery manufacturing industry as the research object. We apply the Analytic Network Process (ANP) method to deal with dependent problems and evaluate the interdependence between criteria with a quantitative approach. After comprehensive evaluation, we can assist decision makers of XYZ limited in assessing the relative ranking of logistics service providers.

The objective of this paper is to introduce a comprehensive decision methodology for the selection of a RL service provider that logistics managers and decision-makers can apply to their organization. The proposed methodology allows for evaluation of alternative providers in two steps: (i) initial screening of the providers by a team of managers, and (ii) ANP-based final selection. In this methodology, our focus is to demonstrate the application of ANP for the final selection of a logistics service provider. Therefore, an ANP-based model has been developed and illustrated for a battery manufacturing company.

After the introduction, the remainder of the paper is organized as follows. First, we review the literature on logistics outsourcing. The literature review includes the developments in logistics outsourcing, selection criteria for the provider, methods currently being used for the selection of a provider, and finally specific problems related to the selection of a provider. Next, we present the methodology for the selection of a provider. An ANP based approach for the final selection of a provider is a part of this comprehensive methodology. Our focus is on the development of an ANP model and its solution. For the purpose of model development, we have identified and named four major criteria as determinants. All these determinants are supported by four sub-criteria, named dimensions. Each dimension in this model is separately supported by some enablers as shown in Figure 1. Finally, the paper concludes with a discussion and managerial implications.

2. Literature review

The purpose of the literature review is to identify the criteria that need to be considered in logistics outsourcing partner selection. Other relevant issues such as the tools/techniques currently being used for the selection of a logistics service provider and specific problems related to the selection of a provider have also been captured. The outcome of the literature review, together with the inputs from industry and academia, have been used to (i) suggest a framework that may be used in short-listing the RL logistics providers, and (ii) develop an ANP-based model for the final selection of a RL logistics provider.

2.1 Logistics outsourcing& management

According to the Langley et al. (2002) 3PL survey, the most common outsourced activities are warehousing, outbound transportation, customs brokerage and inbound transportation. Keeping in view the growing trend of logistics outsourcing, many providers are now offering a variety of services. These services mainly involve business-to-business relationships, where the user is not only a critical stakeholder but his customers are also directly affected by the quality of service of the provider. Therefore, the user must identify exactly what it needs from the provider. The selection of a proper provider, which suits the needs of the outsourcing company (hereinafter called user), is not an easy task. The complexity of this task increases with an increase in the number of selection criteria.

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Table 1
Summary of literature on the criteria for the selection of a service provider

S.No.	**Selection Criteria**	**References**
1	Acceptable cost ACT	Lynch (2002), Langley *et al.* (2003), Boyson *et al.* (1999), Stock *et al.* (1998), Tam and Tummala (2001)
2	Competitive Services CSR	Bhatnagar *et al.* (1999), Lynch (2002), Langley *et al.* (2003), Boyson *et al.* (1999)
3	Transportation Facility TFC	Gibson *et al.* (2002), Murphy *et al.* (1992), Durvusula *et al.* (2002)
4	Service Quality SRQ	Razzaque and Sheng (1998), Langley *et al.* (2003), Stock *et al.* (1998), Thompson (1996)
5	Customer perspective CP	Lynch (2002), Stock *et al.* (1998)
6	Internal business perspective IBP	Lynch (2002), Andersson and Norrman (2002), Boyson *et al.* (1999), Bradley (1994)
7	Financial perspective FP	Andersson and Norrman (2002), Boyson *et al.* (1999), Gattorna and Walters (1996)
8	Customer service CS	Lynch (2002), Stock *et al.* (1998)
9	Customer satisfaction CSF	Lynch (2002), Stock *et al.* (1998), Thompson (1996)
10	Customer queries and Complaint CQC	Razzaque and Sheng (1998)
11	Information technology IT	Lynch (2002), Andersson and Norrman (2002), Langley *et al.* (2003), Boyson *et al.* (1999)
12	On Time Delivery OTD	Stock *et al.* (1998), Gattorna and Walters (1996)
13	New technologies NTE	Lynch (2002), Andersson and Norrman (2002), Boyson *et al.* (1999), Thompson (1996), Gattorna and Walters (1996)
14	Market shares MS	Thompson (1996
15	Return on investment ROI	Boyson *et al.* (1999), Bradley (1994), Maltz (1995)
16	Recapturing values REV	Lynch (2002), Langley *et al.* (2003), Boyson *et al.* (1999)

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Table 2
Criteria used in ANP model

S. No.	Selection Criteria	Descriptions
1	Acceptable cost (ACT)	It refers to the total cost of reverse logistics outsourcing, which should be minimal.
2	Competitive Services (CSR)	It refers to the ability of the user and the provider and their support systems to work together in close coordination to achieve success in competitive business environment. It may be classified in terms of the attributes of business process, technology capability, characteristics of other service providers of the user, etc.
3	Transportation Facility (TFC)	Transportation capability of the service provider must be very sound and effective to meet the set goals in the reverse logistics business.
4	Service Quality (SRQ)	Service quality of the provider includes many aspects such as on-time collection & delivery of used items, accuracy of order fulfillment, frequency and cost of loss and damage, promptness in attending customers' complaints etc.
5	Customer perspective (CP)	Customer perspective of the provider may not only provide good service to the user but may also foster a long-term relationship between the user and the provider.
6	Internal business perspective (IBP)	Provision of periodic evaluation of the performance of the provider enables the two parties to identify the gaps in service. On-time shipments, inventory accuracy, shipping errors, reduction in cash-to-cash cycle, logistics cost reduction, and reduction in customer's complaints may be used as the most important performance measures in reverse logistics outsourcing.
7	Financial perspective (FP)	A sound financial perspective of the provider ensures continuity of service and regular upgrading of the equipment and services, which are used in reverse logistics operations.
8	Customer service (CS)	A good performance towards customers of the provider is reflected by measures such as delivery performance, performance-monitoring capability, statistical data reporting to the user, fault diagnosis capability, detailed accounting information, system security, responsiveness, confidentiality of sensitive data, etc.
9	Customer satisfaction (CSF)	Level of customer satisfaction of reverse logistics service provider company in the business environment.
10	Customer queries and Complaint (CQC)	It refers to customer queries and complaint handling capacity of the service provider. It can be monitored by observing the past business performance of the company/service provider.
11	Information technology (IT)	The advanced IT capabilities of a provider help in reducing uncertainties and inventory level.
12	On Time Delivery (OTD)	Two dimensions of OTD, namely "speed" and "reliability", are important for the satisfaction of the user.
13	New technologies (NTE)	Mutual trust-based information sharing between the user and the provider is necessary not only for the continuance of the agreement but also for the continuous improvement of the service. It can be achieved by installing new business technologies like ERP, VMI, EDI and e-commerce etc.
14	Market shares (MS)	The market share of the provider reflects its financial performance, customer satisfaction, and reputation in the business market.
15	Return on investment (ROI)	Return on investment refers to development of required facilities for reverse logistics operations by case company and service provider and their chances to get sufficient profitability.
16	Recapturing values (REV)	Reverse logistics programs in addition to the various environmental and the cost benefits can proactively minimize the threat of government regulation and can improve the corporate image of the companies by development of RL facilities for the purpose of recapturing value or proper disposal of used /EOL products.

The Analytic Hierarchy Process (Gattorna et al., 1996) is one of the widely used approaches to handle multi-criteria decision-making problems like this. However, a significant limitation of the AHP is the assumption of independency among various criteria of decision-making. The Analytic Network Process (ANP), on the other hand, captures interdependencies among the decision attributes and allows a more systematic analysis. It also allows inclusion of all the relevant criteria (tangible or intangible, objective or subjective, etc.) that have some bearing on arriving at the best decision. These criteria also have some interdependencies, which cannot be captured by the popular AHP method (Lawshe, 1975). Therefore, instead of using the commonly used AHP approach, we recommend the use of an ANP-based model for the selection of a service provider. Fifteen years ago, “logistics” had not yet been explored to a great extent. However today, with the development of information technology and increased customer demand, enterprises have to handle lots of thorny tasks to take care of service problems. Therefore, the area of “logistics” is getting considerable attention from enterprises. Logistics has evolved from a transportation focus based primarily on agricultural economics to the view that it is a diverse and key component of business strategy, differentiation, and a link to customers (Jharkharia & Shankar, 2007). With changing market conditions, logistics has become a part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customer’s requirements. Therefore, according to the definition, logistics includes the flow of goods, services and information related to movements of goods and services from the suppliers to a satisfied customer without waste, namely, the concept of integrated the logistics has also been portrayed in a positive light with its promises to bring higher customer service levels while decreasing distribution costs (Langley, 2003).

2.2 Third-party logistics

Third-party logistics (3PL) is also referred to as logistics outsourcing and is an emerging trend in the global market (Langley, 2002). According to Lieb (1992), third-party logistics (3PL) involves the use of external companies to perform logistics functions that have traditionally been performed within an organization. The functions performed by the third party can encompass the entire logistics process or selected activities within that process. Third-party logistics services are mostly focused on transportation and warehousing, etc, and the 3PL service providers must have professional experience in each service.

2.3 3PL provider selection criteria

It has become very difficult in a real business environment to select parameters for evaluation of service providers and to develop metrics to evaluate the selection criteria of a logistics service provider. In general, enterprises usually have a variety of different supplier characteristics; however, if the same methods are used to evaluate the different types of suppliers, the result will not represent the real situation. Hence, when we select the logistics service provider criteria, we also have to consider that the criteria of selection differ with different types of logistics service providers. In a related strain of research, we have organized some literature on logistics service provider selection criteria. Jharkharia and Shankar (2007) proposed a methodology that consists of two parts: (1) preliminary screening of the available providers, and (2) an ANP-based final approach for the final selection of the 3PL service providers. They organized the literature to select the appropriate criteria and form the basis for the development of an ANP model. Tam and Tummala (2001) applied the binary logistics model in high-tech industry for logistics service providers in Taiwan. They proposed that the service performance is the strongest criteria in the 3PL service provider selection, followed by service cost and added value. This research summarized some frequently used criteria from the literature which are listed in Table 1and brief description about the criteria used in the ANP model is also given in the Table 2.

3. Problem description

The company chosen for this study is a battery manufacturing industry located in the northern part of India. The main scope of this study is to evaluate logistics service providers in order to determine who to hire to collect and deliver the End-of-Life (EOL) lead-acid batteries back to the battery company for the purpose of reclaiming the lead from automotive batteries. In the forward supply chain, the major raw materials such as virgin lead, plastic, and sulphuric acid are procured from different suppliers for new battery production which is used in two wheelers, four wheelers, and for other industrial applications. Once the battery is produced in different plants it must be disseminated through distributors, wholesalers, retailers and then customers. After its end of life, the automobile owner leaves the used battery at the automobile service station (initial collection point) where it is replaced by a new one. The used batteries collected at the service stations should be quickly shipped to a centralized return center where returned products are inspected for quality failure and sorted for potential repair or recycling. After inspection, the useless batteries (those not able to be recycled) are disposed of and reusable batteries are transported to disassembly/recycling plants where they are crushed and separated into different components (lead, plastic, acid etc.). The remaining components, except the lead, are sold to the third party for other applications. Finally, the recycled lead is transported to the battery manufacturing plants where this secondary lead is used along with the virgin lead for new battery production.

A series of interviews and discussion sessions were held in the plant with company management, battery retailers and state pollution control boards officials during this project and the following problem areas were identified for improvement in a closed loop supply chain of lead acid batteries.

- Uncertainty involved in the supply of spent batteries to the recycling company; company is unable to forecast the quantity of collected EOL products.
- Presence of illegal lead smelting units in the state for unauthorized battery collection & lead recycling operation in business environment.
- Lack of any well-structured model of reverse logistics practice in the company.
- Underutilization of existing facilities for the battery closed loop supply chain.

To solve these problems and improve business performance, the battery manufacturing company is ready to assign the work of regular supply of End-of-Life (EOL) batteries to a logistics service provider. The team of managers must be capable of clearly defining the objectives and expectations they have for outsourcing the logistics services so that the provider understands exactly what their goals and objectives are. An accurate description

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of the service requirements would minimize the need for the provider to make assumptions, and ensure fewer surprises down the road. Service standards expected from the service providers should include both the present and projected service standards. The focus of this research is building a sound decision support methodology for evaluation and selection of the best reverse logistics service provider in the battery closed loop supply chain in order to minimize the total supply chain cost comprising procurement, production, distribution, inventory, collection, disposal, disassembly and recycling cost by making a responsive supply chain environment.

4. Decision support methodology for the selection of a logistics service provider

The proposed decision support methodology allows for the assessment of alternative logistics service providers in two steps: (i) initial screening of the providers by a team of concerned managers, and (ii) an ANP-based decision support system for the final evaluation of the service providers. Often, the initial screening of the service providers is an easy task, but the final selection from the list of short-listed providers is difficult. In this section, we present a methodology for the initial screening of the providers. Later, these short-listed providers will be ranked by the ANP-based approach.

The various steps of the decision support methodology are as follows:

1. Form a team of competitive managers and a consultant
2. Make a decision regarding type of outsourcing service level required and collection objectives
3. Collect and identify functional specifications of the proposed task
4. Identify potential reverse logistics service providers
5. Evaluate request of RL logistics service providers (RLLSP)
6. Develop request for proposal offer from service providers
7. Evaluate service proposal offer supplied by the logistics service providers
8. Perform field visits and inspect facilities of the logistics service providers
9. Collect feedback from the existing customers of the service providers
10. Make final selection using the ANP approach and agreement for service

The ANP-based decision modeling methodology, which is discussed in the next section, is recommended for the final selection of a RL service provider. For any long term business relationship a business contract between two parties must address scope of work, damage types, individual status, responsibilities, risks and rewards, remedies, extra services, termination, agreement modification, liabilities, limitations, compensation, insurance, rate adjustments, service compensations, performance measurement issues, etc.

5. Analytic Network Process approach

Many decision problems cannot be built as a hierarchy because of dependencies (inner/outer) and influences between and within clusters (criteria, alternatives). The ANP is very useful for solving these kinds of problems. It provides a general framework to

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deal with decisions without making assumptions about the independence of higher-level elements from lower level elements, or about the independence of the elements within a level. In fact, ANP uses a network without the need to specify levels as in a hierarchy. AHP was first introduced by Saaty (1980), and is based on 1-9 scale. Saaty (1996) further developed this issue and suggested the usage of ANP to solve the problem of independence on alternatives or criteria and the usage of ANP to solve the problem of dependence among alternatives or criteria. The structural difference between AHP (hierarchy) and ANP (network) is also shown in Figure 2. The figure illustrates that a hierarchy is the simple and special case of a network.

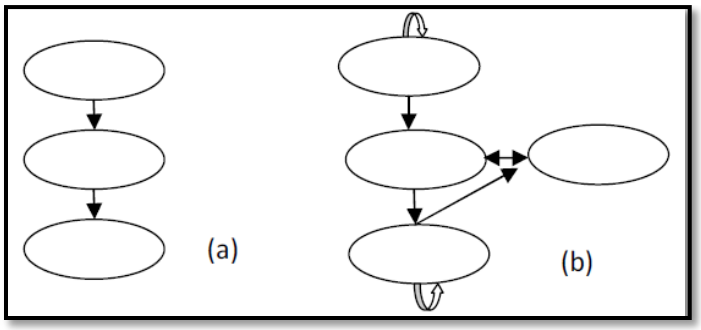

Figure 2. Structural difference between AHP (hierarchy) and ANP (network)

ANP is a combination of two parts:
1) Network of criteria and sub criteria that control the interactions
2) The network of influences of elements and clusters

A feedback system is represented by a network where nodes correspond to levels or components. The nodes in a cluster (level) may influence some or all the nodes in another cluster. Relationships in a network are represented by arcs and the direction of arcs signifies dependency. Interdependency between two clusters is shown in Figure 1 by two way arcs and inner dependencies are represented by loop arcs.

ANP is a multi-attribute, decision-making approach based on the reasoning, knowledge, and experience of the experts in the field. It can act as a valuable aid for decision making involving both tangible as well as intangible attributes that are associated with the model being studied. ANP relies on the process of eliciting managerial inputs, thus allowing for structured communication among decision makers. Thus, it can act as a qualitative tool for strategic decision-making problems.

Saaty (1980, 1996) proposed the following four main steps of the ANP:

Step 1: Model construction and problem structuring: The problem should be clearly stated and decomposed into a rational system, such as a network. The framework can be determined based on the decision maker's opinion through brainstorming or other appropriate methods.

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Step 2: Pair-wise comparison matrices and priority vectors: Similar to the AHP, pairs of the decision elements at each cluster are compared with respect to their importance towards their control criteria. The clusters themselves are also compared pair-wise with respect to their contribution to the objective. The decision maker is asked to respond to a series of pair-wise comparisons of two elements or two clusters to be evaluated in terms of their contribution to their particular upper level criteria. In addition, interdependencies among the elements of a cluster must also be examined pair-wise where the influence of each element on other elements can be represented by an eigenvector. The relative importance values are determined with Saaty's 1–9 scale, where a score of 1 represents equal importance between the two elements and a score of 9 indicates the extreme importance of one element (row cluster in the matrix) compared to the other one (column cluster in the matrix). A reciprocal value is assigned to the inverse comparison, i.e. $a_{ij} = 1/a_{ji}$, where a_{ij} denotes the importance of ith element over jth one. Like with the AHP, pair-wise comparison in the ANP is also performed in the framework of a matrix, and a local priority vector can be derived as an estimate of the relative importance associated with the elements (or clusters) being compared by solving the following equation

$$Aw=\boldsymbol{\lambda}_{max}w \qquad (1)$$

where A is the matrix of pair-wise comparison, W is the eigenvector and $\boldsymbol{\lambda}_{max}$ is the largest eigenvalue of A. If A denotes a consistency matrix, then the eigenvector X can be determined using the following expression:

$$(A-\boldsymbol{\lambda}_{max}I)X=0 \qquad (2)$$

Where I is an identity matrix, the consistency index (CI) and consistency ratio (CR) are used to verify the consistency of the pair wise comparison matrix [10]. The CI and CR values can be defined as below:

$$CI=\frac{\lambda max - n}{n-1} \qquad (3)$$

$$CR=CI/RI \qquad (4)$$

where n is the number of elements and RI denotes the average consistency index for numerous random entries of same-order reciprocal matrices. If CR≤0.1, then the pair wise comparison matrix is consistent; otherwise, a new comparison matrix is solicited until CR≤0.1.

From the pair-wise comparison matrix, using the normalized geometric mean (NGM) method [10], the relative priorities of the elements being compared with respect to their upper level criteria are estimated. Priority vectors must be determined for all the comparison matrices.

Step 3: Super-matrix formation: To obtain the global priorities in a system with interdependent influences, the local priority vectors are entered in the appropriate columns of a matrix. As a result, a super-matrix is formed which is actually a partitioned matrix, where each matrix segment represents a relationship between two clusters in a system. Let the clusters of a decision system be C_K; k=1, 2, 3, . . ., n and each cluster k

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has m_K elements, denoted by e_{K1}, e_{K2}, . . ., e_{Kmk}. The local priority vectors, obtained in step 2, are grouped and placed in the appropriate positions in a super-matrix based on the flow of influence from one cluster to another, or from a cluster to itself, as in the loop. A standard super-matrix is shown as below [10].

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		C_1				C_2				…	C_N			
		e_{11}	e_{22}	…	e_{1n}	e_{21}	e_{22}	…	e_{2n}	…	e_{N1}	e_{N2}	…	e_N
C_1	e_{11}	W_{11}				W_{12}					W_{1N}			
	e_{22}													
	…													
	e_{1n}													
…	…	…				…				…	…			
C_N	e_{N1}	W_{N1}				W_{N2}					W_{NN}			
	e_{N2}													
	…													
	e_N													

Figure 3. Standard super-matrix

For example, the super matrix representation for a hierarchy with three levels, as shown in Figure 3 is represented as:

$$W_h = \begin{matrix} 0 & 0 & 0 \\ W21 & 0 & 0 \\ 0 & W32 & I \end{matrix} \qquad (5)$$

In this matrix, W21 is a vector, which represents the impact of the goal on the criteria, W32 is a matrix that represents the impact of the criteria on each of the alternatives, I is an identity matrix and zero entries correspond to those elements having no influence. For the given example, if the criteria are interrelated, the hierarchy is replaced with the network, as shown in Figure 1. The interdependency is exhibited by the presence of the matrix element W22 of the super matrix yielding the following matrix:

$$\mathrm{Wn} = \begin{matrix} 0 & 0 & 0 \\ W21 & W22 & 0 \\ 0 & W32 & I \end{matrix} \qquad (6)$$

Note that a matrix can replace any zero value in the super-matrix if there is an interrelationship of the elements within a cluster or between two clusters. Since there is usually interdependence among clusters in a network, the columns of a super-matrix may

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sum to more than one. However, the super-matrix must be modified so that each column of the matrix sums to unity [10].

Step 4: Selection of the best alternative: If the super-matrix formed in step 3 covers the whole network, the priority weights of the alternatives can be found in the column of alternatives in the normalized super-matrix. On the other hand, if the super-matrix only comprises clusters that are interrelated, additional calculations must be made to obtain the overall priorities of the alternatives. The alternative with the highest overall priority should be selected as the best choice. In any decision-making process, it is very important to consider the interdependent relationship among criteria that exists in many real life problems. However, the AHP is restricted to solving problems that have a linear uni-directional hierarchical relationship among criteria. The ANP does not require this strictly hierarchical structure and therefore, can treat problems having complex interrelationships among criteria (dependences and feedbacks) as is often encountered while making societal, governmental and corporate decisions. It can allow inclusion of criteria, both tangible and intangible, which have some bearing on making the best decision. The looser network structure of the ANP makes the representation of any decision problem possible without concern for what order the criteria are in as in a hierarchy. The ANP is unique in the sense that it provides synthetic scores, which is an indicator of the relative ranking of different alternatives available to the decision maker. Unfortunately, the ANP applications have been noticeably limited as compared to the AHP, due to its complexity and high computational time.

5.1 Advantages of ANP

- ANP is a comprehensive technique that allows for the inclusion of all the relevant criteria; tangible as well as intangible, which have some bearing on decision-making process (Saaty, 1996).

- AHP models a decision-making framework that assumes a uni-directional hierarchical relationship among decision levels, whereas ANP allows for more a complex relationship among the decision levels and attributes as it does not require a strict hierarchical structure.

- In decision-making problems, it is very important to consider the interdependent relationship among criteria because of the characteristics of interdependence that exist in real life problems. The ANP methodology allows for the consideration of interdependencies among and between levels of criteria, and thus is an attractive multi-criteria decision-making tool. This feature makes it superior to the AHP which fails to capture interdependencies among different enablers, criteria, and sub-criteria (Saaty, 1996).

- ANP methodology is beneficial in considering both qualitative as well as quantitative characteristics, as well as taking the non-linear interdependent relationship among the attributes into consideration.

- ANP is unique in the sense that it provides synthetic scores, which is an indicator of the relative ranking of different alternatives available to the decision maker.

5.2 Disadvantages of ANP

- Identifying the relevant attributes of the problem and determining their relative importance in the decision making process requires extensive discussion and brainstorming sessions. Also, data acquisition is a very time intensive process for the ANP methodology.
- ANP requires more calculations and formation of additional pair-wise comparison matrices than the AHP process. Thus, a careful track of matrices and pair-wise comparisons of attributes is necessary.
- The pair-wise comparison of attributes under consideration can only be subjectively performed, and hence the accuracy of the results depends on the user's expertise knowledge in the area concerned.

6. Application of Analytical Network Process (ANP)

Step 1: Model development and problem formulation: In this step, the decision problem is structured into its important components. The relevant criteria and alternatives are chosen on the basis of the review of literature and discussion with company management. The relevant criteria and alternatives are structured in the form of a control hierarchy where the criteria at the top level in the model have the highest strategic value. The top-level criteria in this model are acceptable cost (ACT), competitive services (CSR), transportation facility (TFC) and service quality (SRQ). These four criteria are called the determinants. In the second level of hierarchy, four sub-criteria called dimensions of the model are placed at the top level of the hierarchy which supports all the four determinants. These dimensions are customer perspective (CP), internal business perspective (IBP), and financial perspective (FP).In the proposed ANP model, each of the three dimensions has some enablers which help to achieve that particular dimension. For example, the dimension IBP is supported by the enablers IT, OTD and NTE. These enablers also have some interdependency with one another. For example, in the dimension IBP, enablers IT and NTE are interdependent as sincere deliveries on time would be necessary for procuring new technologies. The degree of interdependency may vary from case to case and will be captured in later steps. The strength of the ANP model is that the feedback and the network structure of the ANP makes representation of the decision problem possible without much concern for what comes first and what comes next in a hierarchy. The objective of this hierarchy is to select the best possible alternative that will meet the goals of conducting effective reverse logistics in a battery manufacturing industry. The developed ANP model is presented in Figure 1. The alternatives that the decision maker wishes to evaluate are shown at the bottom of the model. The opinion of the logistics manager of the company was sought in the comparisons of the relative importance of the criteria and the formation of pair-wise comparison matrices to be used in the ANP model. In this paper, mainly for the purpose of brevity, we present and illustrate only the results of the ACT determinant. The results of all four determinants would be used in the calculation of the logistics overall weighted index (LOWI) which indicates the score assigned to a logistics provider.

Step 2: Pair-wise comparison of four determinants: In this step, the decision maker is asked to respond to a series of pair-wise comparisons where two components at a time are compared with respect to an upper level 'control' criterion. These comparisons are made so as to establish the relative importance of determinants in achieving the case company's objectives. In such comparisons, a scale of 1–9 is used to compare two options (Saaty, 1980). A score of 1 indicates that the two options under comparison have equal importance, while a score of 9 indicates the overwhelming dominance of the component under consideration (row component) over the comparison component (column component) in a pair-wise comparison matrix. When a component has a weaker impact than its comparison component, the range of the scores will be from 1 to 1/9, where 1 indicates indifference and 1/9 represents an overwhelming dominance by a column element over the row element. For the reverse comparison between the components already compared, a reciprocal value is automatically assigned within the matrix, so that in a matrix $a_{ij}*a_{ji}=1$. The matrix showing pair-wise comparison of determinants along with the e-vectors of these determinants is shown in Table 3. The e-vectors (also referred to as local priority vector) are the weighted priorities of the determinants and are shown in the last column of the matrix. In this paper, a two-stage algorithm is used for computing the e-vector. For the computation of the e-vector, we first add the values in each column of the matrix, then, divide each entry in each column by the total of that column. The normalized matrix is obtained which permits the meaningful comparison among elements.

Table 3
Pair wise comparison of determinants

Determinants	**ACT**	**CSR**	**TFC**	**SRQ**	**e-vector**
ACT	1	5	9	7	0.6322
CSR	1/5	1	7	3	0.2268
TFC	1/9	1/7	1	1/3	0.0442
SRQ	1/7	1/3	3	1	0.0968
C.R	0.0770				

Table 4
Pair wise comparison matrix for dimension under acceptable cost

Pair wise comparison Matrix for dimension under Acceptable Cost				
	CP	IBP	FP	e-vector
CP	1	5	7	0.71
IBP	1/5	1	3	0.21
FP	1/7	1/3	1	0.08

Finally, averaging over the rows is performed to obtain the e-vectors. These e-vectors will be used in Table 11 for the calculation of logistics overall weighted index (LOWI) for alternatives.

Step 3: Pair-wise comparison of dimensions: In this step, a pair-wise comparison matrix is prepared for determining the relative importance of each of the dimensions of logistic providers (CP, IBP and FP) on the determinant of logistics providers. In the model, four such matrices would be formed, one for each of the determinant. The matrix for the

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acceptable cost determinant is shown in Table 4. The results of this comparison (e-vectors) are carried as P_{ja} in Table 10.

Step 4: Pair-wise comparison matrices between component/enablers levels: In this step, the decision maker is asked to respond to a series of pair-wise comparisons where two components will be compared at a time with respect to an upper level control criterion. The pair-wise comparisons of the elements at each level are conducted with respect to their relative influence towards their control criterion. In the case of interdependencies, components within the same level may be viewed as controlling components for each other, or levels may be interdependent on each other. For a determinant, pair-wise comparison is done between the applicable enablers within a given dimension cluster. All the pair-wise comparison matrices for the dimensions under each determinant are not shown here. For example, in Table 5, the relative importance of CQC when compared to CS with respect to CP, in achieving the acceptable cost, is 3. From Table 5 it is also observed that for the case company, the enabler CS has the maximum influence (0.58) on CP for the ACT. Similarly, CQC has the minimum influence (0.16) on CP under ACT. The number of such pair-wise comparison matrices depends on the number of determinants and the dimensions in the ANP model. In this model, 12 such pair-wise comparison matrices are formed. The e-vectors obtained from these matrices are imported as A^{D}_{kja}.

Table 5
Pair-wise comparison matrix for customer perspective under the acceptable cost determinant

Pair-wise comparison matrix for customer perspective under the acceptable cost determinant				
ACT/CP	CS	CSF	CQC	e-vector
CS	1	3	3	0.58
CSF	1/3	1	2	0.26
CQC	1/3	1/2	1	0.16
C.R	0.042			

Step 5: Pair-wise comparison matrices of interdependencies: Pair-wise comparisons are performed to consider the interdependencies among the enablers. From Table 6, it is observed that NTE (0.67) has the maximum impact on the IBP–CSR cluster with IT as the control enabler over others. It is also observed that the impact of OTD on IT in IBP–CSR cluster is minimal (0.33). Therefore, OTD is not a problem for the user company and it will have little impact on information technologies in the IBP–CSR cluster. For each determinant, there will be 12 such matrices at this level of relationship. The e-vectors from these matrices are used in the formation of super matrices. As there are four determinants, 48 such matrices will be formed. The e-vectors have been used in the sixth column of the super matrices.

Step 6: Evaluations of Alternatives: The final set of pair-wise comparisons is made for the relative impact of each of the alternatives, enablers in influencing the determinants. The number of such pair-wise comparison matrices is dependent on the number of

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enablers that are included in each of the determinants. In our present case, there are 9 enablers for each of the determinants, which lead to 36 such pair-wise matrices. All the pair-wise comparison matrices are not given here. Influence matrices with respect to ACT determinants are given in the Appendix. The e-vectors from this matrix are used in columns 7–9 of desirability indices matrices. The columns 7–9, correspond to Provider-A, Provider-B and Provider-C, respectively.

Table 6
Pair-wise comparison matrix for enablers

Pair-wise comparison matrix for enablers under competitive services, internal business perspective and information technology			
CSR/IBP IT	OTD	NTE	e-vector
OTD	1	1/2	0.33
NTE	2	1	0.67

Step 7: Super matrix formations: The super matrix allows for a resolution of the interdependencies that exist among the elements of a system. It is a partitioned matrix where each sub-matrix is composed of a set of relationships between and within the levels as represented by the decision maker's model. In this model, there are four super matrices for each of the four determinants of the reverse logistics service provider hierarchy network which need to be evaluated. All such super matrices 'M', are shown below. The results of the relative importance measures are presented for each of the enablers for the individual's determinant of the reverse logistics service provider. The values of the elements of the super matrix M have been imported from the pair-wise comparison matrices of interdependencies (for example, Table 6). As there are 9 such pair-wise comparison matrices, one for each of the interdependent enablers in the ACT, there will be 9 non-zero columns in this super matrix. Each of the non-zero values in the column is the relative importance weight associated with the interdependent pair-wise comparison matrices.

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Table 7
Super Matrix 'M' for acceptable cost before convergence

Super Matrix 'M' For acceptable cost before convergence:									
	CS	CSF	CQC	IT	OTD	NTE	MS	ROI	REV
CS	0	0.17	0.17						
CSF	0.91	0	0.83						
CQC	0.09	0.83	0						
IT				0	0.13	0.25			
OTD				0.75	0	0.75			
NTE				0.25	0.87	0			
MS							0	0.8	0.15
ROI							0.33	0	0.85
REV							0.67	0.2	0

In the next stage, the super matrix M is made to converge to obtain a long-term stable set of weights. For convergence to occur, the super matrix needs to be 'column stochastic', i.e. the sum total of each of the columns of the super matrix needs to be one. Raising the super matrix M to the power 2^{k+1}, where k is an arbitrarily large number, allows for the convergence of the interdependent relationships. Table 6 represents the super matrix before convergence for determinant Acceptable cost, and Table 8 represents a converged super matrix for determinant Acceptable cost. A similar super matrix will be regenerated for other determents in the analysis.

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Table 8
Super Matrix 'M' For acceptable cost after convergence M^8

Super Matrix 'M' For acceptable cost after convergence: M^8									
	CS	CSF	CQC	IT	OTD	NTE	MS	ROI	REV
CS	0.1453	0.1453	0.1453						
CSF	0.4599	0.4599	0.4599						
CQC	0.3948	0.3948	0.3948						
IT				0.1589	0.1589	0.1589			
OTD				0.4286	0.4286	0.4286			
NTE				0.4126	0.4126	0.4126			
MS							0.3366	0.3366	0.3366
ROI							0.3648	0.3648	0.3648
REV							0.2985	0.2985	0.2985

Step 8: Selection of the best alternative for a determinant: The selection of the best alternative depends on the outcome of the 'desirability index'. The Desirability index, D_{ia}, for the alternative i and the determinant a is defined as (Jayant, 2012).

$$D_{ia} = \sum_{j=1}^{j} \sum_{k=1}^{Kja} P_{ja} A^{D}_{kja} A^{I}_{kja} S_{ikja}. \quad (7)$$

In this equation, P_{ja} is the relative importance of dimension j in influencing the determinant a. A^{D}_{kja} is the relative importance of an enabler k in influencing the determinant a through dimension j for the dependency (D) relationships. A^{I}_{kja} is the stabilized importance weight of the enabler k in the dimension j and determinant a cluster for interdependency (I) relationships. These values are taken from the converged super-matrix. S_{ikja} is the relative impact of alternative i on enabler k of dimension j for determinant a. K_{ja} is the index set of enablers for dimension j of determinant a, and J is the index set for dimension j. Table 10 presents the desirability indices for the acceptable cost determinant (Di ACT). It is based on the hierarchy using the relative weights obtained from the pair-wise comparison of alternatives, dimensions and weights of enablers from the converged super matrix. These weights are used to calculate a score for the determinants of logistics provider overall weighted index (LOWI) for each of the alternative being considered. In Table 10, the values of the third column are imported from Table 9, which are obtained by comparing the relative impact of the dimensions on the acceptable cost determinant. For example, in improving the acceptable cost, the role of customer perspective is found to be most important (0.71), which is followed by IBP(0.21), FP (0.08).In a similar pattern the desirability indices for all determinants have been generated in the analysis.

Table 9
Pair wise comparison matrix for dimension under acceptable cost

Pair wise comparison matrix for dimension under acceptable cost				
ACT	CP	IBP	FP	e-vector
CP	1	5	7	0.71
IBP	1/5	1	3	0.21
FP	1/7	1/3	1	0.08
C.R	0.061			

The values in the fifth column of Table 10 are the stable independent weights of enablers obtained through the converged super matrix (Table 8). The next three columns are from the pair-wise comparison matrices giving the relative impact of each of the alternatives on the enablers. The final three columns represent the weighted values of the alternatives ($P_{ja}*A^D_{kja}*A^I_{kja}*S_{ikja}$) for each of the enablers.

For the purpose of illustration, the value corresponding to provider A for CS is 0.047 (0.71*0.58*0.1453*0.80= 0.047). The summations of these results, for the acceptable cost of each of these alternatives, are presented in the final row of Table 10. These results indicate that the Provider A with a value of 0.162 has maximum influence on the acceptable cost. It is followed by Provider B (0.066) and Provider C (0.038). Similar analysis is carried out for the other three determinants. In the next step, an index would be calculated to capture the achievement of the overall goal of selecting an alternative.

Table 10
Acceptable cost desirability indices

Acceptable cost desirability Indices:											
ACT	ENABLERS	Pja	A^D_{kja}	A^I_{kja}	($Pja*A^D_{kja}*A^I_{kja}$)	S_{1kja}	S_{2kja}	S_{3kja}	Provider-A	Provider-B	Provider-C
		1	2	3	4=1*2*3	5	6	7	8=4*5	9=4*6	10=4*7
CP	CS	0.71	0.58	0.1453	0.059	0.80	0.13	0.07	0.047	0.007	0.004
CP	CSF	0.71	0.26	0.4599	0.084	0.72	0.20	0.08	0.060	0.016	0.006
CP	CQC	0.71	0.16	0.3948	0.044	0.10	0.61	0.29	0.004	0.026	0.012
IBP	IT	0.21	0.67	0.1589	0.022	0.72	0.20	0.08	0.015	0.004	0.001
IBP	OTD	0.21	0.23	0.4286	0.020	0.62	0.11	0.27	0.012	0.002	0.005
IBP	NTE	0.21	0.10	0.4126	0.008	0.10	0.73	0.17	0.008	0.005	0.001
FP	MS	0.08	0.49	0.3366	0.013	0.69	0.21	0.10	0.008	0.002	0.001
FP	ROI	0.08	0.20	0.3648	0.005	0.07	0.66	0.27	0.003	0.003	0.001
FP	REV	0.08	0.31	0.2985	0.007	0.74	0.16	0.10	0.005	0.001	0.007
									D11= 0.162	D12= 0.066	D13= 0.038

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Step 9: Calculation of logistic provider overall weighted index (OWI): The OWI for an alternative *i* (OWI_i) is the summation of the products of the normalized desirability indices (D_{iaN}) and the relative importance weights of the determinants (C_a). In the calculation of OWI the use of normalized values of D_{ia} ensures that the OWI values of the alternatives do not change with a large range of absolute values of D_{ia} for different determinants. In other words, it may be said that the values of OWI using normalized values of D_{ia} are unit invariant. The normalized values of desirability indices also ensure that the sum of OWI values is equal to 1.00.

OWI is mathematically represented as

OWI_i = DiaN C_a.

For example, OWI for A is calculated as:

OWI_A =[(0.6322*0.162)+(0.2268*0.11211)+(0.0442*0.10412)+(0.0968*0.21019)]
= 0.517499

These results are presented in Table 11. It is observed from Table 11 that Provider A is the most-suited logistics service provider. It is also observed that acceptable cost plays a major role in the selection of a service provider. It is further observed that Provider B (0.2878) is found to be more cost effective as compared to C (0.1946). This difference is probably due to the availability of supply chain visibility software availability and other advanced IT tools application in the business, which Provider A offers to its user in addition to the basic logistics services. If the user chooses Provider B or C for the basic logistics needs and separately procures SCM solutions and other advanced capability from other vendors, the costs of these services might be higher than what the user would pay to service Provider A. However, these results should be viewed in the light of the battery manufacturing company and the inputs provided by the decision-making team in the formation of pair wise comparison matrices. Table 11 also demonstrates that acceptable cost plays a major role in the conduct logistics operations as compared to other determinants like competitive services, transportation facility and service quality in the decision analysis.

Table 11
Logistics overall weighted index (LOWI) for alternatives

Logistics overall weighted index (LOWI) for alternatives:						
alternatives	ACT	CSR	TFC	SRQ	LOWI	Normalized values for LOWI
weights	0.6322	0.2268	0.0442	0.0968		
Provider A	0.162	0.11211	0.10412	0.21019	0.152791	***0.517499***
Provider B	0.066	0.14039	0.08333	0.07993	0.084986	0.287845
Provider C	0.038	0.10103	0.052514	0.084856	0.057472	0.194657

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7. Discussion and managerial implications

The proposed methodology provides for simplification of a complex multi-criteria decision-making problem. It may also be used to quantify many subjective judgments, which are necessary to evaluate different alternative providers. Another advantage of this methodology is that it not only supports group decision-making but also enables us to document the various considerations in the process of decision making. This documentation is useful if the results are to be communicated to various interest groups. In this study, the results indicate that RL service Provider A is the first choice of the battery manufacturing company. This may be attributed to its advanced IT, customer service, and change management capabilities. The expertise of Provider C in the framing of transportation and distribution policy also supports this result. It is pertinent to discuss the priority values of the determinants which influence this decision. From Table 3, it is observed that acceptable cost *(ACT* = 0.6322*)* is the most important determinant in the selection of a service provider. It is followed by competitive services (0.2268), service quality (0.0968) and transportation facility (0.0442). Although the proposed model ranked only three distinct alternative service providers, the method is capable of comparing more than three providers at the cost of complexity. It needs to be emphasized that despite using a sound algorithm for systematic decision-making, care must be taken in the application of the ANP approach. For example, in its application, the user has to compare the prospective providers on a number of pair wise comparison matrices. In these comparisons, the user must verify the capabilities of the providers and should not solely rely on the information given by the prospective providers. Experts recommend that the user companies should evaluate the providers by what they have done and not by what they plan to do. Although in this case the input to the pair wise comparison matrices is based on the responses to RLLSP and visits of groups of managers to the sites of the service provider companies, the bias of the decision maker towards a particular provider cannot be ruled out. Group decision-making help avoid this bias.

In future research, brainstorming and sharing of ideas and insights can often lead to a better understanding of the issues. Scenario building or the Delphi method may also be used for the initial screening of alternatives available to the company and pair-wise comparisons. In the case of a Delphi process, consensus may be reached by agreeing on the geometric means of individual judgments. In the absence of consensus, voting may also be conducted to arrive at a more acceptable value. Compared to low-level enablers, consensus is more desirable for determinants and dimension at the higher level of the ANP model. This is because of the higher global weights of determinants and dimensions in the ANP model for the calculation of OWI. A good number of software is available for ANP and decision support systems and may also reduce the complexities in implementing the group decision-making.

In light of the results obtained from this study, it may be noted that these results are valid only for the battery manufacturing company in its own decision environment, or for a similar type of industry and should not be generalized to establish the supremacy of one provider over others. Further, the application of the proposed methodology may require significant time and resources from managers and decision-makers. Yet, when seeking to invest in a long term logistics-outsourcing contract that can potentially reach billions of rupees, a structured analysis, which is provided by this methodology, may help to reduce the risk of poor investment decisions.

8. Summary and conclusions

The Analytic Network Process (ANP) framework serves as a tool for making a strategic decision as it is related to the selection of the best option out of a finite set of alternatives with the feedback consideration. In this paper, we proposed a decision support methodology to a battery manufacturing company for selection of a logistics service provider. In the current integrated supply chain environment, logistics needs consist of many distinct but interrelated services, each with its own set of requirements and constraints. The authors argued that the selection of logistics partner(s) should not be broken down into a set of stand-alone selections which is the approach traditionally pursued. The selection should be evaluated holistically at the integrated supply chain level, both strategically and tactically, thus requiring an approach that is capable of addressing many interdependent and intangible elements. The paper also provides for a review of the issues which influence the selection of a provider. The ANP approach, as a part of this methodology, not only leads to a logical result but also enables the decision-makers to visualize the impact of various criteria in the final result. The ANP approach is capable of taking into consideration both qualitative and quantitative criteria. Similar ANP-based models may also be developed in other contexts as well. But, as the development and evaluation of these models demand significant time and effort from the decision-makers in the formation of pair wise comparison matrices, these should only be used for long-term strategic decisions where the investments made in the lengthy and cumbersome process of decision making are recoverable. Further, though the technique is computationally intensive, the benefits of risk reduction will outweigh the cost and time. Using this formulation, decision makers can easily test a number of what-if scenarios.

For future research, it would be worthwhile to implement the ANP model with the Delphi approach for a set of decision makers. Such a research endeavor could be used to validate the effectiveness of the ANP model. More importantly, managerial implications can be empirically derived regarding the selection of logistics service providers. Such research should include a comprehensive sensitivity analysis to examine the significance of individual attributes to the selection decision. It is also worthwhile to compare the proposed ANP approach with other evaluation approaches. The ANP approach presented in this project has a few limitations as well. For example, the model result efficiency is dependent on the inputs provided by the group of managers in the XYZ limited company. The possibility of bias may not be ruled out in the decision-maker towards any particular provider while applying this model. Therefore, a team of concerned managers of the company should be constituted for making pair-wise comparison. Moreover, the formation of pair wise comparison matrices is a time-consuming and tedious task. Inconsistency and human error may be reduced by using software in calculating the pair wise comparison of matrices.

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APPENDIX

Influence matrices with respect to ACT determinants

Table 12

Pair-wise comparison matrix for enablers under acceptable cost, customer perspective and customer service			
ACT/CP CS	CSF	CQC	e-vector
CSF	1	9	0.91
CQC	1/9	1	0.09

Table 13

Pair-wise comparison matrix for enablers under acceptable cost, customer perspective and customer satisfaction			
ACT/CP CSF	CQC	CS	e-vector
CQC	1	5	0.83
CS	1/5	1	0.17

Table 14

Pair-wise comparison matrix for enablers under acceptable cost, customer perspective and customer queries and complaints			
ACT/CP CQC	CS	CSF	e-vector
CS	1	1/5	0.17
CSF	5	1	0.83

Table 15

Pair-wise comparison matrix for enablers under acceptable cost, internal business perspective and information technology			
ACT/IBP IT	OTD	NTE	E-VECTOR
OTD	1	3	0.75
NTE	1/3	1	0.25

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Table 16

Pair-wise comparison matrix for enablers under acceptable cost, internal business perspective and On time delivery			
ACT/IBP OTD	IT	NTE	E-VECTOR
IT	1	1/7	0.13
NTE	7	1	0.87

Table 17

Pair-wise comparison matrix for enablers under acceptable cost, internal business perspective and New technologies			
ACT/IBP NTE	IT	OTD	E-VECTOR
IT	1	1/3	0.25
OTD	3	1	0.75

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