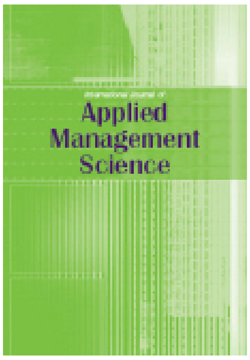

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An integrated ANP and Dempster–Shafer's theory (DST) model for distribution channel selection strategy

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Abstract: The purpose of this research is to investigate the distribution channel strategies adopted by original equipment manufacturers (OEMs) in the remanufacturing industry. The aim is to identify the best distribution channel alternative for OEMs based on various selection factors. The authors utilised the Analytic Network Process-based Dempster–Shafer's model as the main methodology for selecting the most suitable distribution channel for OEMs in remanufacturing. The approach involves analysing and evaluating eight distribution channel alternatives and considering multiple channel selection factors. The research findings demonstrated the effectiveness of the selected approach in identifying the optimal distribution channel for OEMs in the remanufacturing industry. The results also highlighted the robustness of the experimental findings. The utilisation of the Analytic Network Process-based Dempster–Shafer's model adds originality to the research. The identified optimal distribution channel may help OEMs effectively meet customers' demands and enhance their overall remanufacturing operations.

Keywords: distribution channel; remanufacturing; ANP; analytic network process; DST; Dempster–Shafer's theory.

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1 Introduction

1.1 Background of the study

The choice for selecting the accurate distribution channel for Original Equipment Manufacturers (OEMs) is a too critical decision-making process as it significantly impacts the overall success of their products and plays a major role in the productive process (Zhang et al., 2017). When selecting a distribution channel, OEMs need to consider factors such as the nature of the product or service, the target market, the competition and the company's resources. They also need to evaluate the strengths and weaknesses of each potential channel and determine which one will provide the most value to their customers. According to Lin (2004) OEM suppliers may increase the innovative adaptability of their network by choosing the appropriate distribution channels. The transfer of goods from manufacturers to end users or customers is greatly facilitated by the distribution channel. As a result, selecting the best distribution channels may have a big influence on a manufacturer's capacity to react to market changes, introduce new goods and maintain a competitive position in the global market. Further, Guru et al. (2023) approach that making efficient distribution channel selections requires adjusting to shifting customer tastes, comprehending possible disruptions and the profitability of various channel possibilities, and keeping up with technical developments. In remanufacturing distribution channel, there are also different types of factors that are applicable. The remanufacturers consider customer preferences, competition and the capabilities of potential distribution channels to make informed decisions (Michaud and Llerena, 2011). A decision maker is always responsible for making choices or selecting from among available options. They must consider various factors, analyse information, and evaluate the potential outcomes of their decisions. Zhou et al. (2023) suggested that channel selection in the context of remanufacturing is important in deciding the economic and environmental results for the OEM. For the purpose of maximising revenue and environmental performance, the OEM is able to strategically align its supply chain partners and operating procedures. Also, the distribution channel has a significant impact on the cost of remanufacturing, consumer perceptions and Willingness-to-Pay (WTP), OEM strategy choices and overall performance and welfare in a closed-loop supply chain (Qiao and Qin, 2021). It is essential for enhancing customer purchasing intent, obtaining benefits for OEMs and promoting environmental advantages. OEMs may successfully satisfy customer demands, improve operational efficiency and accomplish sustainability goals in the remanufacturing business by making educated judgements about the distribution channel (Gong et al., 2023). The Multi-Criteria Decision-Making (MCDM) process is extensively used to identify the optimal distribution channel that meets the desired criteria and objectives of the Original Equipment Manufacturers. MCDM serves as a systematic approach to support the decision-making process. Using a set of criteria, Đalić et al. (2020) used this technology to evaluate and compare various distribution channels. The organisation may make informed judgements by considering multiple factors simultaneously. Similarly, Liao et al. (2020) applied the MCDM technique which provides a structured decision-making process that helps decision-makers navigate the conflicts and trade-offs inherent in selecting distribution centres. In recent years, the Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) have gained more popularity as effective decision-making tools for selecting distribution channels. The Analytic Network Process (ANP) is the generalised form of the Analytic Hierarchy Process (AHP) used in Multi-Criteria Decision Analysis (MCDM). To assess the consumers' channel preferences Chiang and Li (2010) utilised the AHP methodology. This method allows for a certain amount of answer irregularity and enables respondents to express their opinions without making rigid assumptions. Utilising the AHP approach to assess consumer channel preferences adds uniqueness and value to the corpus of existing research in this field.

The concept of game strategy which investigates the mathematical representation of rational players' tactical exchanges has an extent influence in this concept. It can be applied in distribution channel selection to model the strategic interactions and decision-making of different players and identify the optimal distribution channel. Abedian et al. (2022) introduced Game theory as a decision-making tool in conflict situations, particularly in the context of planning optimal marketing strategies in dynamic competitive markets. The goal of game theory is to determine the optimum course of action and locate ideal solutions or stable results for marketing strategies via the examination of strategic interactions between various market players. The theory can help OEMs design a distribution channel that maximises their profits and market share and meets the needs of their customers and stakeholders. Similarly, the Dempster–Shafer (DS) theory is also a mathematical framework, used to model and analyse decision-making under uncertainty (Srivastava, 2011). DS theory can be applied in distribution channel selection to combine different pieces of uncertain information and form a more informed decision. The theory can be used to prioritise criteria, combine expert opinions and reason with incomplete information to help OEMs select an optimal distribution channel. The Dempster–Shafer theory is used by Bappy et al. (2019) to aggregate the knowledge obtained from many sources and experts. A more comprehensive evaluation of supply chain sustainability is possible because of the theory's mathematical framework for processing and combining uncertain and partial information. This DS theory is applicable in the AHP process. While Dempster–Shafer theory and AHP have different objectives, they can be used together in some applications to improve decision-making and reasoning under uncertainty. AHP can help in assigning weights to criteria or sources of information, which can then be used in Dempster–Shafer theory to combine evidence and form a more informed decision or belief. The Analytical Hierarchy Process (AHP) and Dempster–Shafer (DS) theory are combined by Chen and Deng (2018), where the AHP is used to establish the weight of sustainability criteria and DS theory integrates numerous sources of information and examines uncertainty by dividing evidence into belief levels. From today's point of view in every sector the term sustainability matters a lot. In recent years, there has been a growing awareness of the need for sustainable business practices, and OEMs are increasingly considering sustainability factors when selecting distribution channels. Sustainable distribution channels are those that are environmentally friendly, socially responsible and economically viable. Sustainable distribution channels can help OEMs to reduce their environmental impact, promote social responsibility and improve their overall profitability. The importance of aligning business practices with environmental and social responsibilities is discussed by Vafaei et al (2020) and formed a sustainable channel structure. The use of MCDM processes such as AHP and ANP can help OEMs to identify sustainable distribution channels that meet their desired criteria and objectives. Overall, the intension for doing this many efforts of the OEMs are the output of this process is a well-informed decision on which distribution channels to use that can effectively and efficiently deliver their products to their target customers. The selected distribution channel should align with the OEMs overall business strategy and goals and should enable them to maximise their sales and profits while minimising costs and risks.

1.2 Contribution of the study

The related study based on effective distribution channel selection for OEMs has been identified in the research work of Liu et al. (2018) and game strategy by Wu et al. (2021). The authors suggested dealing such distribution channel selection problem by selecting an effective distribution channel for OEMs, as it significantly impacts the success of their products and the overall productivity process. In our study, we suggested an ANP-based game strategy for distribution channel selection that considers the preferences of all stakeholders involved in the process, including customers, distributors and the OEM. This approach provides a comprehensive evaluation of different distribution channels, enabling OEMs to make informed decisions that optimise their revenue and profits. The overall goal of this study is to provide insights and guidance for decision-makers in the remanufacturing industry to improve their distribution channel selection process and ultimately optimise their productivity. Wen et al. (2021) reported that many OEMs are reluctant to remanufacturing due to proper recovery channel and in reality, independent remanufacturers retrieve used products from end users. Therefore, our study presented by choosing proper distribution channel how a manufacturer can also select the proper recovery channel.

After the introduction section, in Section 2, we discussed about existing literatures and the research gap for our study. In Section 3, we presented the preliminaries of the used methods. In Section 4, we identified distribution channel alternatives and significant criteria for selection strategy implementation. Later, in Section 5, we presented the data experiment and analysis and finally, Section 6 concludes this research work and Section 7 represents the future study.

2 Literature review

In adopting an ANP-based game approach, this section tries to examine the body of research that has already been done on OEM distribution channel selection. This review tries to identify the major concepts, methodology and discoveries in this field by analysing and synthesising pertinent academic works. The Analytic Hierarchy Process (AHP) and game theory are combined here to provide a thorough assessment of numerous aspects impacting distribution channel selection. Many researchers have used different approach to deal with the distribution channel selection problem. For example, Indap and Kocaoglu (2022) used a Linear Programming (LP) model to select the appropriate distribution channels. Analytic Hierarchy Process (AHP) and Data Envelopment Analysis (DEA) are both used in this framework to evaluate alternatives based on a hierarchy of criteria. Further, Liu et al. (2018) proposed a new methodology for supplier selection that addresses the limitations of existing techniques. To evaluate suppliers in uncertain circumstances, it coordinates ANP, entropy weight, DEMATEL, game theory and evidence theory. A complete and efficient solution for supplier management is provided by the technique, which integrates subjective and objective weights and modifies criteria weights. The necessity of supplier evaluation and selection is discussed by Kisly et al. (2016), who views it as a challenging undertaking including a number of factors. Weighted scoring, the Analytic Hierarchy Process (AHP), and goal programming models were used for the decision-making process to consider the buyer's competitive position as well as the economic effect. Wu et al. (2021) compared different distribution channel structures and their impact on the OEM's remanufacturing strategy selection. The results show that the OEM benefits from outsourcing remanufacturing. Designing a successful supply chain distribution network necessitates considering a variety of performance factors and product traits. A model based on AHP, MCDM techniques was created by Sharma et al. (2008) to investigate the connection between product attributes and optimising the architecture of supply chain delivery networks. Using the Analytic Hierarchy Process (AHP), Brezović et al. (2021) offered decision-makers an extensive structure to help them decide on the best channels for their needs. It is useful to comprehend the significance of taking into consideration a variety of factors and their varied degrees of relevance when assessing distribution channels. Serbest and Vayvay (2008) highlighted the significance of the supplier evaluation and selection system, where the use of a fuzzy Analytic Hierarchy Process (AHP) technique, which uses fuzzy logic to deal with different decision criteria including risk considerations, cost and quality, is discussed. Consuming various Multi-Criteria Decision Making (MCDM) techniques, Prabhuram et al. (2020) identified and assessed the performance of four different distribution network configurations within the Omni channel. The Omni Channel (OC) is a fulfilment process that aims to satisfy customer demands from various channels. The analytical hierarchy process, fuzzy analytical hierarchy process and order preference by resemblance to ideal solution methodology were some of these methods. For choosing distribution channels, Soltanmohammad et al. (2013) focused on identifying and prioritising elements that affect the marketing strategy and employs the Fuzzy Multiple Criteria Decision-Making (FMCDM) methods. The relative equilibrium decision approach, which Jing et al. (2019) presents, makes use of a fuzzy decision-making trial and evaluation laboratory-cooperative game model. Galankashi et al. (2016) introduced a novel approach, the Balanced Scorecard-Fuzzy Analytic Hierarchical Process (BSC-FAHP) model, for supplier selection process and based on the obtained parameters, the best supplier is chosen using the fuzzy Analytic Hierarchical Process (AHP) technique. For evaluating strategies and weighting criteria, Zolfani and Banihashemi (2014) used the MCDM structure, especially the SWARA technique to improve the selection process's effectiveness and efficiency. In this process Game Theory is used for the final evaluation of applications, considering their competitive interactions. MCDM approaches and game theory techniques together offer a potential approach to solving practical issues. İlbaş et al. (2023) combined the concept of Intuitionistic Fuzzy Preference Relation (IFPR) and Stochastic Multi-criteria

Acceptability Analysis (SMAA-2) for supplier selection in vehicle rental for armed forces, demonstrating effectiveness and reliability through sensitivity analysis. A system dynamic model is structured by Liu et al. (2023) for supplier selection that incorporates CSR practices, leading to improved profitability, customer satisfaction, and demand by reducing supplier distance and increasing their numbers. By providing an in-depth evaluation of the fusion of game theory and MCDM, Ibrahim et al. (2021) introduced a powerful decision-making framework which is applicable in various domains. Onari and Rezaee (2023) proposed Bargaining Game-based Fuzzy Cognitive Map (BG-FCM), and mixed-motive game approach enhances supplier selection in healthcare, improving supply chain quality and financial stability. Compared to traditional MCDM methods, it offers a more comprehensive decision-making model. It aids healthcare centres in selecting the best suppliers and mitigating potential risks. Deng et al. (2014) reviewed an evidential game theory framework for multi-criteria decision-making in competitive environments. It uses game theory to determine the best course of action and combines belief structures from Dempster–Shafer's theory to explain uncertain strategies. In supply chain management, choosing the right suppliers is essential. The analytic network process-based approaches now in use can manage the interdependence of decision qualities, but they may not perform as well when presented with ambiguous or lacking input data. The Dempster–Shafer evidence theory and the analytic network method are combined, according to Zhang et al. (2016), to overcome these uncertainties. For uncertain environment Dempster–Shafer Theory (DST) has been used for decision-making framework. Through implementing this idea Altieri et al. (2017) and Beynon (2002) work on DST and AHP which is known as DS-AHP for approaching a hybrid methodology and emphasising its benefits and prospective enhancements over conventional decision analysis techniques and talking about its most recent advancements and applications. By following this Utkin and Simanova (2012) introduced an extension to the DS-AHP method that addresses multi-criteria decision problems with multiple levels of criteria and considers imprecise and incomplete expert judgments. The expansion makes use of a computing approach that entails solving a finite set of linear programming problems in order to analyse and aggregate the imperfect knowledge concerning criteria and decision-making options. Askarifar et al. (2022) developed a supplier evaluation model in three stages: criteria selection, weighting and objective function integration. This model aims to optimise procurement for the largest seat belt manufacturer by considering criteria importance and operational constraints. It enhances supplier selection, a key factor in procurement success. The goal of Beynon et al. (2000) is to draw attention to the Dempster–Shafer Theory of evidence (DST) as a potential advancement over current methods of decision analysis. In the context of merging data from several sources, it has grown in prominence in the domains of Artificial Intelligence (AI) and Expert Systems. Combining the concepts of DS-AHP (Ganguly, 2014), game theory (Abedian et al., 2022) and ANP (Cheng et al., 2005) can provide a comprehensive framework for selecting the appropriate distribution channel with alternatives. Through an extensive literature review, we have compiled a diverse set of factors applied in different contexts, as summarised in Table 1.

Table 1 Summary of different evaluation factors selected in distribution channel selection studies

Authors	*Methodology used*	*Selected factors*
Kisly et al. (2016)	- Analytical Hierarchy Process (AHP) - Goal programming	*Criteria:* Hairiness, contamination, title, thick places, coef. of variation, thin places, neps, twist, unit price, availability of orders.
Serbest and Vayvay (2008)	- Fuzzy AHP	*Risk factors:* geographical location, terrorism, political stability, economy, climate. *Cost factors:* freight cost, tariffs and customers duties, technology cost, increased lead cost. *Quality factors:* on time transport, quality of transport place, non-damaged transport, performance history, acceptance rate of the product, response to changes
Prabhuram et al. (2020)	- AHP - Fuzzy AHP - TOPSIS	*Cost factors:* inventory cost, transportation cost, facilities cost, information cost. *Service factors:* response time, product variety, product availability, order visibility, returnability.
Soltanmohammad et al. (2013)	- Fuzzy Delphi analytic hierarchy process (FDAHP) - FTOPSIS	*Product:* variety, quality, brand, packing. *Price:* pricing, grant awards, payment period, *Place:* capillary distribution, coverage, products combination, transport, grant equipment. *Promotion:* advertising products, public relations, customer satisfactions.
Jing et al. (2019)	- Fuzzy DEMATEL - Cooperative game model	*Technical and Economic:* price, operational performance, reliability, cutting power, transmission ratio, cutting efficiency, adjustment height, cutting speed.
Galankashi et al. (2016)	- Balanced scorecard approach - Fuzzy AHP	*Financial:* price of product, quality of product, distance to manufacturer, economic value added. *Customer:* service & delivery, reputation, supply chain collaboration level, market share, rate of sales return. *Internal business:* technical capability, product capability, flexibility, inventory turnover, productivity. *Learning and growth:* competitiveness, employee satisfaction, knowledge sharing, health and safety issues level, standards consideration.
Zolfani and Banihashemi (2014)	- Game theory - Stepwise weight assessment ratio analysis (SWARA) method	*Strategies:* developing on government's (national) projects, concentrate on capital of Iran (Tehran), developing joint projects (specially international projects), developing in industries level, concentrate on industries in all around Iran, establishing some branches in metropolitan cities in Iran.

Table 1 Summary of different evaluation factors selected in distribution channel selection studies (continued)

Authors	*Methodology used*	*Selected factors*
İlbaş et al. (2023)	- intuitionistic fuzzy preference relation (IFPR) - stochastic multi-criteria acceptability analysis (SMAA-2)	*Criteria:* cost, technical specifications, supplier reliability, supportability, performance history, comm. system, mng. and org., delivery.
Onari and Rezaee (2023)	- Bargaining Game-based Fuzzy Cognitive Map (BG-FCM)	*Criteria:* product price, payment term, discount, product reliability, product conformity, consistency of product's quality, supply variety, packaging and transport quality, supplier replenishes defective lot, technology, personnel, supplier expedients emergency orders, efficiency of corrective action, tech. services: problem-solving, the supplier's background, consistency of delivered product.
Liu et al. (2018)	- Dempster–Shafer evidence theory - DEMATEL - ANP	*Business improvement:* reputation of industry, financial strength, managing ability, organisation customers. *Extent of fitness:* sharing of expertise, flexible practices, diversified customers. *Quality:* low defect rate, commitment to quality, improved process capacity. *Service:* on time delivery, quick responsiveness, supplier capacity. *Risks:* supply constraint, buyer-supplier constraint, supplier profile.

In general, DS-AHP enables the hierarchy-based prioritisation of criteria and options, and game theory can be used to examine and improve interactions between various distribution channel participants. The addition of ANP, is an extension of AHP, can enables more intricate decision-making scenarios including dependencies and feedback loops. ANP can capture the correlations between many criteria and alternatives when it comes to distribution channel selection.

2.1 Research gap for the present study

This section describes the gaps of our study that summarises the findings of the preceding subsections and obtain conceivable trends of decision-making strategy in distribution channel selection methodology.

- Despite the growing trend of OEMs collaborating with third-party remanufacturers and adopting various distribution channels to meet customer demands in remanufacturing, there is a lack of comprehensive studies that systematically analyse and identify the optimal distribution channel for OEMs. While the literature summarises the use of ANP and DS-AHP-based models (Zhang et al., 2016; Liu et al., 2018; Abedian et al., 2022) in decision making environment, there are a few works mentioned in the dimension of existing research or a comparative analysis of different distribution channel selection factors.

- Further research is needed to provide a comprehensive evaluation and recommendation framework for OEMs in selecting the most suitable distribution channel for their remanufactured products, considering relevant factors and industry-specific considerations (Liu et al., 2018).
- Therefore, this study fulfils the research gap in understanding the effectiveness, robustness and practical implications of different distribution channel alternatives for OEMs in the context of remanufacturing. For this study, we have selected eight distribution channel alternatives as referred to by Wu et al. (2021). Additionally, we evaluate the proposed effective criteria and factors put forth by Liu et al. (2018) using ANP approach to rectify the impact of appropriate factors in the selection of distribution channel strategies.

3 Methodology

In this section, the definition, and preliminary reviews of ANP, Game theory and Dempster–Shafer theory are briefly discussed.

3.1 ANP method

The Analytic Network Process (ANP) is a generalised form of the Analytic Hierarchy Process (AHP), which is generalised as a decision-making method used to prioritise decisions (Sipahi and Timor, 2010). It suggests quantifying criteria for evaluation, which makes it specific to different choice-making strategies. AHP structures a choice hassle right into a hierarchy with an intention, selection standards, and alternatives, at the same time as ANP systems it like a network. Both used the system of pairwise comparisons to gauge the weightings of the ingredients of the shape and eventually classify the alternatives within a choice. ANP has the ability to simulate intricate decision-making problems that cannot be adequately addressed by AHP models. The steps of ANP are discussed as follows (Liu et al., 2018):

- *Step 1:* Initially, Decision Experts (DEs) assess the proposed criteria pairwise without assuming any interdependence among them. The responses of DEs on questions such as 'which criteria should be emphasised more in determining the OEMs, and how much more?' are presented numerically and scaled according to Saaty's (1990) 1–9 scale, with a reciprocal value automatically assigned to the reverse comparison. The resulting pairwise comparisons are denoted as A. Once this step is completed, a relationship between the local weight vector u_0 and A is established, as shown in equation (1).

$$Au_0 = \lambda_{\max} u_0 \tag{1}$$

where $\lambda_{\max}$ represent the largest eigenvalue, which is an output of matrix A. The eigenvector of matrix A corresponding to the eigenvalue $\lambda_{\max}$ is u_0, and it can be easily calculated using mathematical methods. This vector is the weight vector and is normalised by dividing each of its values by the column total, resulting in the normalised local weight vector u_1

- *Step 2:* The second step involves resolving the effects of interdependence among the evaluation criteria. Decision makers assess the impact of each criterion on the others through pairwise comparisons, answering questions such as 'Which criterion has a greater impact on criterion 1: criterion, criterion 3, criterion 4 or criterion 5?' These comparisons are made while controlling for one criterion at a time. Once all pairwise comparisons have been made, a super matrix *S* is constructed from them. After the super matrix has converted to a stable state, relative importance measures for each attribute can be obtained, providing weights for each criterion. These weights are denoted as u_2.
- *Step 3:* The decision-makers look at the impact of all the criteria on each other with the aid of pairwise comparisons. Through this, the super matrix is formed, and all the weight values of each criterion can be evaluated. The overall output of this stage is

$$u_c = u_1 \times u_2 \tag{2}$$

3.2 Game theory

The Nash equilibrium (Nash, 1950) is a concept in game theory where the optimal outcome of a game is achieved when no player has an incentive to change their strategy after considering the choices of their opponents. In other words, a player receives no extra benefit from changing their actions, assuming that the other players keep their strategies constant.

Consider a game (*A*, *E*) with n players, where A_i is the strategy set for player *i*, *A* is the set of strategy profiles and $E(x) = E_1(x), E_2(x), \ldots, E_n(x)$ is the payoff function evaluated at $a \in \{1,2,\ldots,n\}$. Let σ_i be the strategy profile of player *i*, and σ_{-i} be the strategy profile of all players except for player *i*. If each player $a \in \{1,2,\ldots,n\}$ chooses strategy $\sigma_i = (a_1, a_2, \ldots, a_n)$, then player *i* obtains payoff $E_i(\sigma_i)$ (Liu et al., 2018). A strategy profile $\sigma^* \in A$ in *A* is a Nash equilibrium if no player can profit from a unilateral deviation in strategy, that is

$$E_i\left(\sigma_i^*, \sigma_{-i}^*\right) \geq E_i\left(\sigma_i, \sigma_{-i}^*\right), \ \forall i, \sigma_i \in A_i \tag{3}$$

3.3 Dempster–Shafer theory (DST)

At the same time regarded as a viable option to Bayesian principle (Souprayen et al., 2021), comparatively, Dempster–Shafer theory (DST) gives several advantages, inclusive of the ability to apply probability measures to focus elements additionally making an allowance for the attachment of chance to the body of discernment (Beynon, 2002; Utkin and Simanova, 2012). The DST method works based on the probability theory or the theory of belief. DST has an uncertain numerical measurement which is the cause of the overlapping of each set and their subsets. But there is a difference between probability and DST theory (Beynon et al., 2000)).

Let $\Theta = \{h_1, h_2, \ldots, h_n\}$ be a finite set of n hypotheses and the Basic Probability Assignment (BPA) is $m : 2^{\Theta} \rightarrow [0,1]$

$$\text{So, } m(\phi) = 0; \ 0 \leq m(x) \leq 1 \text{ and } \sum\nolimits_{x \in 2^{\Theta}} m(x) = 1 \tag{4}$$

The notation 2^{Θ} refers to the power set of Θ, which includes all subsets of the frame of discernment Θ. A focal element is any subset x of Θ for which $m(x)$ has a non-zero value, and it represents the exact belief in the proposition depicted by x. The sum of all assigned probabilities equals unity, and there is no belief in the empty set ϕ. The amount of uncertainty within the belief function $m(x)$ is indicated by the assigned probability to Θ, which is denoted as $m(\Theta)$. Various measures of confidence can be defined based on the belief function.

It is easy to elaborate the theory of DS-AHP from an example as mentioned by Beynon et al. (2000) that identifies a car buying problem, from a set of cars. As per example, they marge the DS-AHP accurately and mentioned the use of a frame of discernment (Zhang et al., 2016).

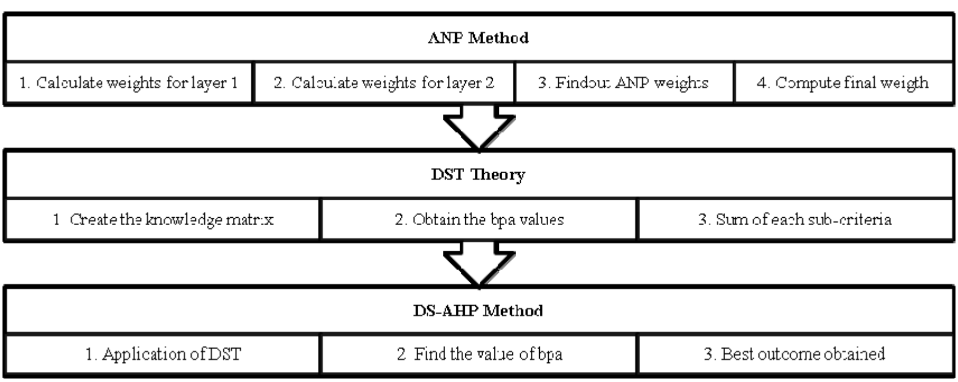
4 Problem solving procedure

In this paper, we use an objective evaluation method – ANP for decision making in distribution channel selection. Dempster–Shafter evidence theory combined with AHP method is used to deal with the uncertainties and to evaluate the final result.

4.1 Procedure for distribution channel selection

The stepwise procedure for remanufacturing distribution channel selection is shown in Figure 1.

Figure 1 Flow chart for remanufacturing distribution channel selection



- *Step 1:* Construct hierarchical structure for distribution channel selection by first identifying various criteria or dimensions to consider. Develop sub-criteria for each criterion to ensure a comprehensive evaluation of potential distribution channel.
- *Step 2:* Calculate the weight by using ANP method from equations (1) and (2).
- *Step 3:* Calculate the final weight from the modified equation as presented in equation (5).

- *Step 4:* Deal with the uncertainties using Dempster–Shafer theory. Construct the knowledge matrix and find out the BPA values.
- *Step 5:* Ranking all the suppliers and ought to select the best suppliers, which can be one or more.

4.2 Distribution channel alternative selection

The OEMs are working with independent remanufacturers, and they also go through the help of retailers for dealing with their new and remanufactured products. At times the OEMs deal with customers directly and sometimes they work through retailers for the selling process. In this paper, ANP and DS-AHP is applied to determine the effective and significant alternative among the eight selected distribution channels referred to by Wu et al. (2021). Table 2 highlighted the eight distribution channels with their description and alternatives.

Table 2 Description of distribution channel alternatives

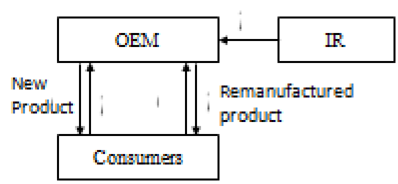
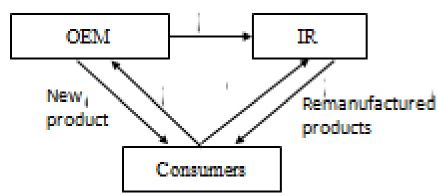
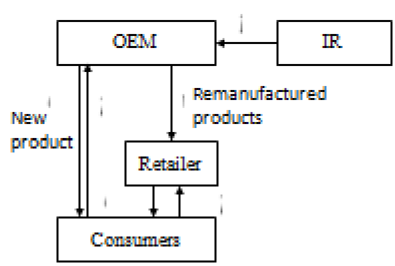
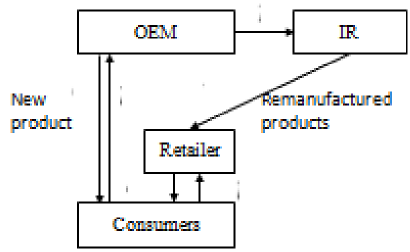
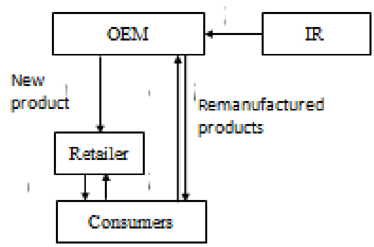
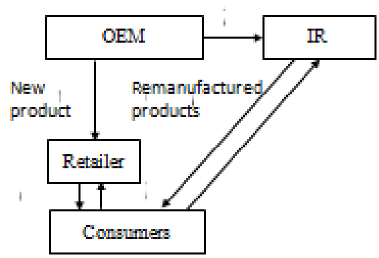
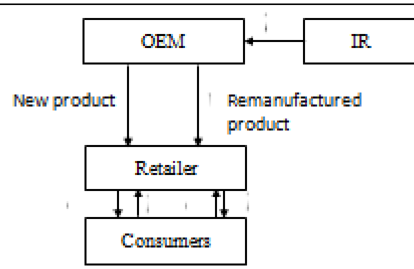
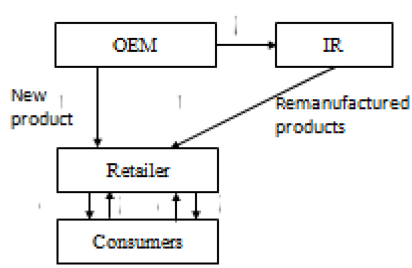
Distribution channel alternatives	*Description*	*Figure*
P	OEM outsources remanufacturing to IR. OEM directly sells new and remanufactured items to consumers.	
Q	OEM licences IR for remanufacturing and sells new products directly. IR sells remanufactured items directly to consumers.	
R	OEM sells new products directly to consumers and outsources remanufacturing to IR. Later OEM sells remanufactured products through retailer.	

Table 2 Description of distribution channel alternatives (continued)

Distribution channel alternatives	*Description*	*Figure*
S	OEM sells new products directly and licences IR to remanufacture and IR sells remanufactured products through retailer.	
T	OEM outsources remanufacturing to IR for indirect sales of new products through retailers and remanufactured products directly to consumers.	
U	OEM offers new products through retailers, while IR sells remanufactured products directly to consumers.	
V	Through retailers, OEM sells both new and remanufactured products.	
W	OEM sells new products directly to consumers, while IR sells remanufactured products through a retailer.	

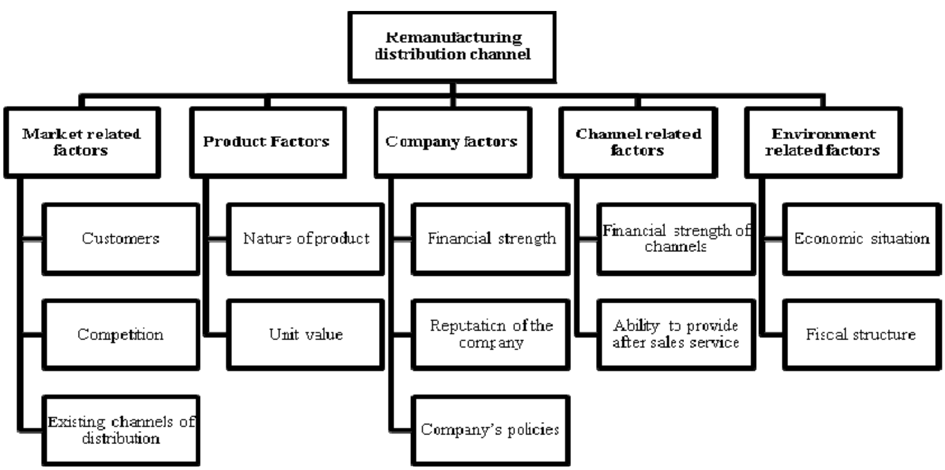
5 Data experiment and analysis

In this paper, we have presented eight distribution channels for obtaining the best distribution channel among them. Therefore, we have chosen five criteria that belong to layer 1 and each criterion has sub-criteria which are in layer 2.

5.1 Distribution channel selection framework

To access the performance of each OEMs, we need to identify and evaluate all relevant elements and factors. We demonstrate the hierarchical structure for remanufacturing distribution channel selection in Figure 2. In the figure, we have identified five criteria or dimension that will be used to evaluate potential OEM. These five criteria are Market Related Factors (MRF), it has three Sub-criteria Customers (CS), Competition (CM) and existing Channels of Distribution (CD); Product Factors (PF) has two sub-criteria Nature of Products (NP) and Unit Value (UV); Company Factors (CF), it has three sub-criteria Financial strength (F), the Reputation of the Company (RC) and Company's Policies (CP); Channel-Related Factors (CRF) has two sub-criteria Financial strength of Channels (FC) and ability to provide After-sales Service (AS); Environment-Related Factors (ERF) has also two sub-criteria Economic Situations (ES) and Fiscal Structure (FS). The concepts of these attributes and hierarchical structure are adopted from Liu et al. (2018).

Figure 2 Criteria and sub-criteria of remanufacturing distribution channel selection



5.2 ANP method

It can be seen from Figure 2, that it is a two layered structure. So, before calculating the weight of the criteria at first, we need to modify equation (2) proposed by Liu et al. (2018).

$$u_c = u_1 \times u_2 \times u_3 \tag{5}$$

where u_1 represent the value of layer 1 weight and u_2 and u_3 stands for layer 2 weight. Because of interdependencies among the sub-criteria, it is necessary to calculate the u_3 for layer 2. Here, we take 10 experts' opinions to come into for a perfect outcome. Table 3 presents pairwise comparison matrix layer 1.

Table 3 Weight value for layer 1

	MRF	*PF*	*CF*	*CRF*	*ERF*	*Eigen vector (u_0)*	*Normalised eigen vector (u_1)*
MRF	1	3	5	7	4	0.497	0.5151
PF	1/3	1	6	5	8	0.641	0.6648
CF	1/5	1/6	1	4	3	0.294	0.3043
CRF	1/7	1/5	1/4	1	7	0.227	0.2351
ERF	1/4	1/8	1/3	1/7	1	0.37	0.3833

Firstly, Eigen vector, (u_0) is calculated based on equation (1) corresponding to the largest eigenvalue. Then the normalised Eigen vector, (u_1) of u_0 is obtained as

$$u_1 = (0.497, 0.641, 0.24, 0.227, 0.37)$$

Secondly, we evaluate the value of layer 2 for each criterion based on the pairwise comparison matrix of its sub-criteria. For example, Table 4 shows the obtained matrix for MRF and Table 5 demonstrates the pairwise comparison matrix for the sub criteria of MRF.

Table 4 Weight value for the sub-criteria of MRF (layer 2 weight)

MRF	*CS*	*CM*	*CD*	*Weight*
CS	1	5	6	0.65808
CM	1/5	1	7	0.26971
CD	1/6	1/7	1	0.07221

Table 5 Pairwise comparison for MRF's sub-criteria

CS (Controlling attribute)	*CM*	*CD*	*Weight (1)*
CM	1	7	0.875
CD	1/7	1	0.125
CM (Controlling attribute)	CS	CD	*Weight (2)*
CS	1	6	0.85714
CD	1/6	1	0.14286
CD (Controlling attribute)	CS	CM	*Weight (3)*
CS	1	5	0.83333
CM	1/5	1	0.16667

Similarly, we can obtain weigh value and pairwise comparison matrix for PF, CF, CRF and ERF. The detailed weight calculation for other criteria is demonstrated in Annexure section.

From the weighted value of each criterion (MRF, PF, CF, CRF and ERF) for layer 2 we get,

$$u_2 = (0.65808, 0.26971, 0.07221,$$
$$0.85714, 0.14286,$$
$$0.65837, 0.26182, 0.07981,$$
$$0.875, 0.125,$$
$$0.83333, 0.16667)$$

Then, the super matrix is formulated from each pairwise comparison matrix. The weight value of sub-criterion of MRF as calculated in Table 4 is presented here as an example under different controlling sub-criterion and obtained first part of the super matrix is presented as follow:

$$S_1 = \begin{bmatrix} 0 & 0.85714 & 0.83333 \\ 0.875 & 0 & 0.16667 \\ 0.125 & 0.14286 & 0 \end{bmatrix}$$

Similarly, if we calculate each of the super matrix for PF, CF, EF and CRF (presented in annexure section), we will get the final super matrix as follows:

$$S = \begin{bmatrix} S_1 & & & & \\ & S_2 & & & \\ & & S_3 & & \\ & & & S_4 & \\ & & & & S_5 \end{bmatrix}$$

After the convergence of super matrix, the u_3 for each sub-criterion is calculated and presented in Table 6 with results.

The results in Table 6 give insight into the relative value of each sub-criteria within its particular criterion. Consider the 'MRF' criteria as an illustration with the weight of 0.497, the sub-criteria 'CS' inside the 'MRF' criterion is given more weight than the other sub-criteria, showing its significance among others. Further emphasising its relevance in relation to the other sub-criteria is the normalised weight of 0.23551. Similarly, for the 'PF' criterion, the sub-criterion 'NP' carries a weight of 0.641, signifying its higher importance compared to other sub-criteria within 'PF'. The normalised weight of 0.23402 for NP reinforces its prominence. The same interpretation applies to the other criteria (CF, CRF, ERF) and their respective sub-criteria. The weights provide a relative measure of importance among the sub-criteria, and the normalised weights further highlight their relative significance. These findings can help decision-makers comprehend the relative weights assigned to various sub-criteria within each criterion. They offer useful information for setting priorities and making decisions based on the particulars of the choice problem at issue.

Table 6 Result of ANP

Criterion	*Sub-criterion*	u_1	u_2	u_3	*Weight*	*Normalise weight*
MRF	CS	0.497	0.65808	0.14087	0.04607	0.23551
	CM	0.497	0.26971	0.08681	0.01164	0.05948
	CD	0.497	0.07221	0.02232	0.0008	0.00409
PF	NP	0.641	0.85714	0.08333	0.04578	0.23402
	UV	0.641	0.14286	0.08333	0.00763	0.039
CF	FS	0.294	0.65837	0.1381	0.02673	0.13663
	RC	0.294	0.26182	0.08611	0.00663	0.03388
	CP	0.294	0.07981	0.02579	0.00061	0.00309
CRF	FC	0.227	0.875	0.08333	0.01655	0.0846
	SS	0.227	0.125	0.08333	0.00236	0.01209
ERF	ES	0.37	0.83333	0.08333	0.02569	0.13133
	FS	0.37	0.16667	0.08333	0.00514	0.02627

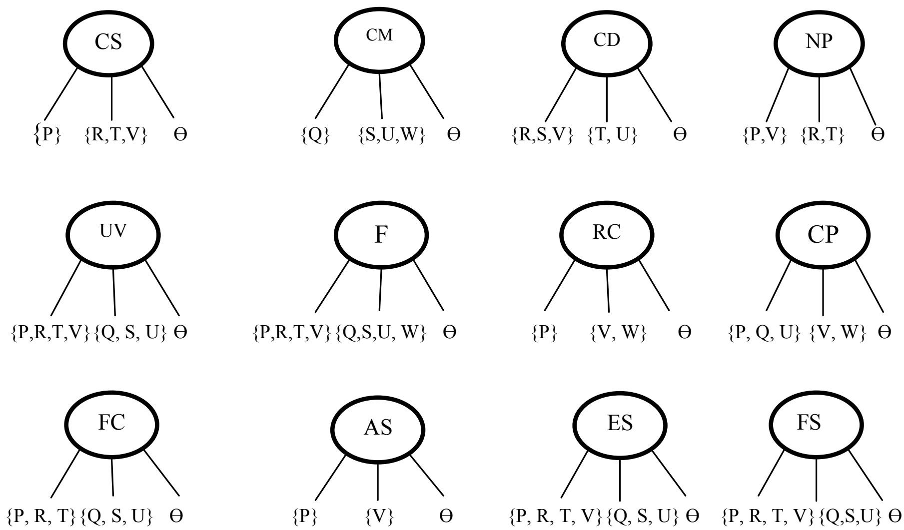
5.3 Application of DS-AHP method

In this section, we have presented a methodology that combines DST with AHP philosophy. The AHP is a well-known management tool created by Thomas L. Saaty to solve complex problems with multiple criteria, originally used in the Sudan transport study. It works by breaking down the problem into smaller parts and guiding the decision maker through a series of pairwise comparison judgments (Beynon et al., 2000; Saaty, 1990).

For this paper, we first developed the knowledge matrix for all criteria. Then, the decision tree is developed with the help of the DS-AHP methodology. It helps to find the best distribution channel. Here, we take eight alternatives, {P, Q, R, S, T, U, V, W}. As per experts' opinions, each criterion has a group of decision alternatives is shown in Figure 3.

From the Figure 3, it can be seen that customers (CS), competition (CM), existing channels of distribution (CD), nature of products (NP), unit value (UV), financial strength (F), the reputation of the company (RC), company's policies (CP), the financial strength of channels (FC), ability to provide after-sales service (AS); environment related factors (ERF) have also two sub-criteria economic situations (ES) and fiscal structure (FS) are shown with their alternatives.

Figure 3 Decision tree for alternatives



To evaluate the decision alternatives a 5-unit scale as proposed by Beynon et al. (2000) is utilised that incorporates both qualitative and quantitative data (adopted from AHP method). The AHP commonly uses a scale with nine units to convert the decision maker's preferences into numerical values. However, for the sake of simplicity, we have chosen to use a scale with five units. The knowledge scale for the proposed study is shown in Table 7.

Table 7 Knowledge scale

Opinion	*Numerical rating*
Extremely favourable	6
Strongly to extremely	5
Strongly favourable	4
Moderately to strongly	3
Moderately favourable	2

In the knowledge scale, we do not utilise the same preferred rating of 1as in the AHP method. The decision is based on the assessment of groups of decision alternatives in relation to the frame of discernment. The following Table 8 presents the initial knowledge matrix for each attribute.

In Table 8, the value of 'p' is 0.2159 which is sustained. By following the steps outlined by Beynon et al. (2000), the initial knowledge matrix is normalised for each attribute and best outcome of the overall process is presented in Table 9.

Table 8 Initial knowledge matrix for each attribute

CS	*{P}*	*{R, T, V}*	*Θ*	*CM*	*{Q}*	*{S, U, W}*	*Θ*	*NP*	*{P, V}*	*{R, T}*	*Θ*	*UV*	*{P, R, T, V}*	*{Q, S, U}*	*Θ*
{P}	1	0	5p	{Q}	1	0	6p	{P, V}	1	0	5p	{P, R, T, V}	1	0	4p
{R, T, V}	0	1	4p	{S, U, W}	0	1	5p	{R, T}	0	1	2p	{Q, S, U}	0	1	3p
Θ	1/5p	1/4p	1	Θ	1/6p	1/5p	1	Θ	1/5p	1/2p	1	Θ	1/4p	1/3p	1
F	{P, R, T, V}	{Q, S, U, W}	Θ	RC	{P}	{W, V}	Θ	CP	{P, Q, U}	{V, W}	Θ	FC	{P, R, T}	{Q, S, U}	Θ
{P, R, T, V}	1	0	6p	{P}	1	0	5p	{P, Q, U}	1	0	4p	{P, R, T}	1	0	5p
{Q, S, U, W}	0	1	4p	{W, V}	0	1	3p	{V, W}	0	1	3p	{Q, S, U}	0	1	3p
Θ	1/6p	1/4p	1	Θ	1/5p	1/3p	1	Θ	1/4p	1/3p	1	Θ	1/5p	1/3p	1
AS	{P}	{V}	Θ	ES	{P, R, T, V}	{Q, S, U}	Θ	FS	{P, R, T, V}	{Q, S, U}	Θ	CD	{R, S, V}	{T, U}	Θ
{P}	1	0	6p	{P, R, T, V}	1	0	5p	{P, R, T, V}	1	0	6p	{R, S, V}	1	0	5p
{V}	0	1	3p	{Q, S, U}	0	1	2p	{Q, S, U}	0	1	4p	{T, U}	0	1	2p
Θ	1/6p	1/3p	1	Θ	1/5p	1/2p	1	Θ	1/6p	1/4p	1	Θ	1/5p	1/2p	1

Table 9 Pairwise comparison matrix

CS	*{P}*	*{R, T, V}*	*Θ*	*CM*	*{Q}*	*{S, U, W}*	*Θ*	*NP*	*{P, V}*	*{R, T}*	*Θ*	*UV*	*{P, R, T, V}*	*{Q, S, U}*	*Θ*
{P}	1	0	1.08	{Q}	1	0	1.3	{P, V}	1	0	1.08	{P, R, T, V}	1	0	0.864
{R, T, V}	0	1	0.864	{S, U, W}	0	1	1.08	{R, T}	0	1	0.43	{Q, S, U}	0	1	0.648
Θ	0.926	1.158	1	Θ	0.77	0.926	1	Θ	0.93	2.32	1	Θ	1.158	1.544	1
F	{P, R, T, V}	{Q, S, U, W}	Θ	RC	{P}	{W, V}	Θ	CP	{P, Q, U}	{V, W}	Θ	FC	{P, R, T}	{Q, S, U}	Θ
{P, R, T, V}	1	0	1.295	{P}	1	0	1.08	{P, Q, U}	1	0	0.86	{P, R, T}	1	0	1.08
{Q, S, U, W}	0	1	0.864	{W, V}	0	1	0.65	{V, W}	0	1	0.65	{Q, S, U}	0	1	0.648
Θ	0.772	1.158	1	Θ	0.93	1.544	1	Θ	1.16	1.54	1	Θ	0.926	1.544	1
AS	{P}	{V}	Θ	ES	{P, R, T, V}	{Q, S, U}	Θ	FS	{P, R, T, V}	{Q, S, U}	Θ	CD	{R, S, V}	{T, U}	Θ
{P}	1	0	1.295	{P, R, T, V}	1	0	1.08	{P, R, T, V}	1	0	1.3	{R, S, V}	1	0	1.08
{V}	0	1	0.648	{Q, S, U}	0	1	0.43	{Q, S, U}	0	1	0.86	{T, U}	0	1	0.432
Θ	0.772	1.544	1	Θ	0.93	2.316	1	Θ	0.77	1.16	1	Θ	0.926	2.316	1

Based on the analysis of the pairwise comparison matrix presented in Table 9, the best distribution channel can be determined by considering the weights assigned to each alternative in each criterion. The alternative with the highest cumulative weight across all criteria would be considered the most favourable distribution channel.

6 Conclusions

In today's market, perfect distribution channel selection is a difficult task. Here we have used the integrated ANP and DS-AHP approach, which is a very effective method to find out the best results. DS-AHP depends on ANP methods. Through the probability concept that is used in Dempster–Shafer's theory, the value of Basic Probability Assignment (BPA) is obtained. In remanufacturing parts, OEMs are sometimes faced with some obstructions. This is why OEMs tend to work with independent remanufacturers. Sometimes retailers also join in this process of dealing with customers. This method can help overcome undertrained situations. DS-AHP is a flexible and efficient tool for selecting the best distribution channel.

It can be seen from our results that the alternatives 'Q' and 'R' provide the best outcomes concerning all criteria. For alternative 'Q', OEM and IR (OEM outsources the remanufacturing activity to IR) sell directly new and remanufactured items to consumers. Hence, consumers' preferences and purchasing behaviour can lead both OEM and IR to adopt operational strategies for collecting used products, controlling the production level of new and remanufactured products, and deciding pricing strategies for new and remanufactured products. Further, in the case of distribution channel 'R', OEM, retailer and IR are involved in the remanufacturing activity. The retailer is the nearest distribution channel entity to end consumers. The retailer provides information regarding consumers' preferences about remanufactured products to outsourced IR. However, the presence of retailers in the distribution channel may impact the sales price of remanufactured products. Whereas, in the case of alternatives 'Q', remanufacturing units (OEM and outsourced IR) can reduce the cost of remanufactured products to attract consumers' attention as well as collect more accurate information about used product collection, after-sales service and demand for remanufactured products than alternatives 'R'.

This study has outlined several advantages, as follows:

- *Integration of Subjective and Objective Methods:* By combining the strengths of subjective and objective methods, our approach yields more reasonable results. This integration mitigates the risk of overvaluation that may occur when relying solely on subjective expert opinions.
- *ANP for Optimising Game Theory:* We employ the Analytic Network Process (ANP) method to enhance game theory. This approach prioritises criteria with high prominence, which plays a pivotal role in achieving Nash equilibrium. Consequently, our method yields more justifiable and comprehensive weights.
- *Dempster–Shafer Theory for Handling Uncertainties:* To handle the inherent uncertainties in input data, we incorporate Dempster–Shafer theory. This inclusion enables our proposed method to be applicable in diverse circumstances, enhancing its versatility and robustness.

Leveraging the aforementioned advantages, our approach is well-equipped to harness the potential of big data for efficient and rational supplier evaluation and analysis. While we have validated our model on a small-scale case featuring eight distinct decision alternatives and twelve attributes, it is adaptable to more intricate challenges. Given access to extensive big data, we can confidently assert that the methodology presented in this paper holds the potential to mitigate the risks associated with making suboptimal investment decisions in complex supplier networks.

7 Limitations of the study and future work

However, our research has identified certain limitations, and we suggest potential areas for further investigation. The following considerations can be explored:

- Extending the ANP method by incorporating fuzzy set theory to handle the uncertainty inherent more effectively in expert-provided comparison matrices.
- Evaluating the use of D-number theory, an extension of evidence theory, as an alternative to Dempster–Shafer theory for supplier selection in uncertain environments.
- Similar applications of this model can be further evaluated in various contexts, extending beyond the current criteria and industries.

For future research, the present work may be extended by using the DEMATEL approach, and the stochastic nature of the demand and used product collection can be captured in the distribution channel selection process.

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Annexure:

Table A.1 Weight value for the sub-criteria of PF (layer 2 weight)

PF	*NP*	*UV*	*Weight*
NP	1	6	0.85714
UV	1/6	1	0.14286

The pairwise comparison matrix for both sub-criteria of PF under different controlling criteria is 1, i.e., a (1×1) matrix for each.

Table A.2 Weight value for the sub-criteria of CF (layer 2 weight)

CF	*FS*	*RC*	*CP*	*Weight*
FS	1	4	6	0.65837
RC	1/4	1	5	0.26182
CP	1/6	1/5	1	0.07981

Table A.3 Pairwise comparison for CF's sub-criteria

FS (Controlling attribute)	*RC*	*CP*	*Weight (1)*
RC	1	5	0.83333
CP	1/5	1	0.16667
RC (Controlling attribute)	FS	CP	*Weight (2)*
FS	1	6	0.85714
CP	1/6	1	0.14286
CP (Controlling attribute)	FS	RC	*Weight (3)*
FS	1	4	0.8
RC	1/4	1	0.2

Table A.4 Weight value for the sub-criteria of CRF (layer 2 weight)

CRF	*FC*	*SS*	*Weight*
FC	1	7	0.875
SS	1/7	1	0.125

The pairwise comparison matrix for both sub-criteria of CRF under different controlling criteria is 1, i.e., a (1×1) matrix for each.

Table A.5 Weight value for the sub-criteria of CRF (layer 2 weight)

ERF	*ES*	*FS*	*Weight*
ES	1	5	0.83333
FS	1/5	1	0.16667

The pairwise comparison matrix for both sub-criteria of CRF under different controlling criteria is 1, i.e., a (1×1) matrix for each.

The super matrices formulated from each pairwise comparison matrices are given below:

$$S_2 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

$$S_3 = \begin{bmatrix} 0 & 0.85714 & 0.8 \\ 0.83333 & 0 & 0.2 \\ 0.16667 & 0.14286 & 0 \end{bmatrix}$$

$$S_4 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

$$S_5 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

Therefore, the final super matrix will be as follow:

$$S = \begin{bmatrix} 0 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 0 \end{bmatrix}_{12\times 12}$$

The matrix values are presented in table below:

Table A.6 Final super matrix and layer 3 weight value

	CS	*CM*	*CD*	*NP*	*UV*	*FS*	*RC*	*CP*	*FC*	*SS*	*ES*	*FS*	*Weight*
CS	0	0.85714	0.83333	0	0	0	0	0	0	0	0	0	0.14087
CM	0.875	0	0.16667	0	0	0	0	0	0	0	0	0	0.08681
CD	0.125	0.14286	0	0	0	0	0	0	0	0	0	0	0.02232
NP	0	0	0	0	1	0	0	0	0	0	0	0	0.08333
UV	0	0	0	1	0	0	0	0	0	0	0	0	0.08333
FS	0	0	0	0	0	0	0.85714	0.8	0	0	0	0	0.13810
RC	0	0	0	0	0	0.83333	0	0.2	0	0	0	0	0.08611
CP	0	0	0	0	0	0.16667	0.14286	0	0	0	0	0	0.02579
FC	0	0	0	0	0	0	0	0	0	1	0	0	0.08333
SS	0	0	0	0	0	0	0	0	1	0	0	0	0.08333
ES	0	0	0	0	0	0	0	0	0	0	0	1	0.08333
FS	0	0	0	0	0	0	0	0	0	0	1	0	0.08333