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Integration of DEA (Data Envelopment Analysis) Approach for Supplier Selection with Hierarchical Analysis Process and Risk Considerations

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Abstract

Selecting a supplier is a critical issue that supply chain managers have faced for many years. Selecting a proper supplier is no longer as easy as selecting based on the price they offer. There are many quantitative and qualitative criteria that should be considered. Therefore, an approach is needed to cover these criteria. As supply chains become more important today, it is important to consider the risks of inadequate supply in evaluating suppliers. This paper provides an approach that focuses on data envelopment analysis to analyze and compare the relative efficiency of suppliers. Since data envelopment analysis can only cover quantitative properties, the Analytic Hierarchy Process (AHP) is used to help the qualitative analysis. Risks are also considered in the evaluation of suppliers. The purpose of the proposed approach was to provide a comprehensive approach to address the issue of supplier selection.

Keywords: Multi-Criteria Decision-making, AHP, Data Envelopment Analysis, Risk Considerations, Supplier Selection.

Introduction

Supply chain management is a phenomenon that conducts the coordinated management and control of all chain activities so that customers can receive reliable and fast service with quality products at the lowest cost. One of the most important activities for the success of the supply chain is effective and efficient purchasing. Purchasing has attracted attentions in supply chain management due to factors such as globalization, increased value-added in supply, and rapid technological change. The most important purchasing activity is selecting the proper supplier because it brings significant savings for organizations. External suppliers, like the traditional supply chain, are one of the important members of reverse logistic and closed-loop supply chain (CLSC) networks. One of the vital cases that should be considered when selecting a supplier is the risks that may threaten the supply chain and cause negative performance or even loss of the chain. Accordingly, risk management in the supply chain has been studied in several papers today, and various conceptual and mathematical models are being developed and presented to model it. Sustainable Supply Chain Management (SSCM) is defined as the management of materials, information, capital flows, and cooperation between organizations throughout the supply chain through which the goals of all three dimensions of sustainable development, including economic, social, and environmental, are met. The purpose of this research is to evaluate the productivity and effectiveness of suppliers of sustainable supply chain management. The generalities of the research will be examined in the following chapters.

Statement of the problem

Selecting a supplier is a common problem that many companies have faced over the years. Selecting a proper supplier can be a really difficult process because there are so many criteria that should be considered, and their evaluation is not easy. Selecting another supplier is not as simple as selecting a proper supplier based on the prices they offer. Moreover, the decision-maker may not be sure how to select an appropriate criterion for evaluating suppliers. Even if the decision-maker has the right criteria in mind, he or she may not be aware of the real tools to evaluate those criteria and select the proper supplier (Jasmine J. Lim; Allan N. Zhang, 2016).

Selecting a supplier is a process by which companies must first identify suppliers, then evaluate them, and finally communicate with them. This process usually requires a large amount of company financial resources and is therefore, a vital and important process. This process includes a general comparison of different suppliers using a set of criteria and indicators to evaluate their capabilities and skills. Moreover, it is impossible to produce low-cost, high-quality goods without the right choice of suppliers in today's highly competitive world. In fact, selecting a supplier is one of the most critical components in supply chain management, according to which the short-term and long-term success of companies strongly depends on the correct selection of suppliers. Hence, supplier selection plays an important role in ensuring company survival (Roh et al., 2013).

Today, supply chains activate more than ever in competitive and swinging environments. Accurate estimation of customer demand is one of the challenges due to the reduced lifespan of products and changing customer preferences despite recent advances in forecasting techniques. In addition to the unpredictability of customer demand, there are price uncertainty, supply volume (disruption risk), and the amount of returned products in the closed-loop supply chain.

Since the 1980s, many reputable companies have outsourced some or all of their outsourcing activities to foreign countries that could benefit from their competitive advantages due to access to raw materials as well as lower wage costs. After the successful operation of this type of outsourcing, other companies, including manufacturing or service, were encouraged to do this type of activity, and the scope of this outsourcing expanded unprecedentedly in the following years. The transfer of a company's production or service operations to a company located abroad leads to a complex network, which can result in greater risk, especially the risks in the supply chain. These risks can involve poor quality of products or services, less reliability, supply disruptions, logistics problems, natural disasters, and communication problems. In other words, the benefits of transferring activities abroad must be large enough to offset the risks to make these activities cost-effective. Although almost all companies face this type of risk in some way, risk assessment in the chain has become one of the most important issues. In this paper, a coherent and structured approach is presented to be able to assess supply chain risks related to overseas outsourcing decisions. This paper does not merely discuss manufacturing or purchasing decisions from other countries, but more precisely states the risks associated with these types of decisions and then considers outsourcing. There are several definitions of risk and risk management. For example, the British Standards Institution defines risk as to the probability or frequency of a particular risk. Related risks need to be identified before making an important decision, and appropriate programs should be adopted to reduce it or eliminate its adverse effects. One of these types of decisions that faces many risks is the decision to choose overseas suppliers. In these cases, it is necessary to compare the different decision-making options to make the best decision. For example, this type of decision-making can have the advantage of lowering the price of products, but at the same time, it may lead to a loss of control and buying advantages. In addition, supply chain risks increase exponentially when manufacturing or purchasing large parts from overseas due to the complexity of the chain network and its high uncertainties. Supply chain disruption can occur for a variety of reasons such as labor strikes, natural disasters, international terrorism, logistics failures, political instability, and so on. Therefore, identifying and paying attention to these risks, as well as applying risk reduction strategies, is an essential element for the competitive performance of the supply chain. These risks will become more important as the organization becomes more global. Therefore, conducting research that can identify these risks, and the result is the selection of an option that faces the least risk will be very important. Evaluation of the problem of selecting a supplier requires both quantitative and qualitative indicators to provide a more comprehensive evaluation of suppliers. Data Envelopment Analysis (DEA) is a common decision analysis method is able to measure the effectiveness and efficiency of suppliers. However, one of the weaknesses of the data envelopment analysis method is the need for quantitative data. In fact, data envelopment analysis does not use qualitative properties in its analysis (Paul SK, 2013).

On the other hand, the hierarchical analysis process can be used to attribute (assign) values (which are called weights) to qualitative characteristics. This causes qualitative characteristics to be converted into quantitative indicators, and quantitative indicators can be used in the data envelopment analysis model. The combination of hierarchical analysis and data envelopment analysis allows the decision-maker to compare the efficiency of suppliers based on quantitative and qualitative characteristics. Therefore, this research will examine the application of the hierarchical analysis - data envelopment analysis approach to solve the supplier selection problem.

Research literature

Internal Studies

Rafiei (2016) examined the alignment of purchasing strategy with commercial strategy as a factor in increasing the efficiency of supply chain management. This paper initially describes the major differences between corporate and consumer purchasing behavior. Then, it discusses the strategic role of purchasing and supply management in manufacturing companies and developing different strategies against suppliers to support overall product/market and commercial strategies while enumerating the success factors of the purchasing and supply chain.

Tavakoli et al. (2017) investigated the relationship between sustainable supply chain management with environmental and financial performance. The purpose of this research is to identify and explain the relationship between sustainable supply chain components with environmental and financial performance in chemical fertilizer companies in Alborz province. The present research is applied in terms of purpose, is descriptive-survey, and correlational in terms of the data collection method. The statistical population of the present research is all managers of companies producing chemical fertilizers in Alborz province. The data collection tool is a standard questionnaire whose validity was assessed by the convergent validity criterion of hidden research variables, which was also confirmed. The reliability of the questionnaires was determined using Cronbach's alpha test and composed reliability coefficient. The collected data were analyzed by structural equation method and SmartPLS software. The results of hypothesis testing showed that there is a significant relationship between the components of sustainable supply chain and environmental performance. There is a significant relationship between the components of a sustainable procurement and sustainable supply chain design, and financial performance. However, no significant relationship was observed between the components of sustainable distribution and the improvement of sustainable supply chain investment and financial performance.

Ahmadi and Jamali (2017) identified the factors of strategic orientations and sustainable supply chain initiatives based on reverse logistics (Case study: Dena Shiraz Rubber Industries Company). The purpose of this study was to identify the factors of strategic orientation and sustainable supply chain initiatives based on inverse logistics (Case study: Dena Shiraz Rubber Manufacturing Industries). For this purpose, the criteria of strategic orientation and sustainable supply chain initiatives were extracted and identified based on reverse logistics, including six main criteria and 26 sub-criteria based on the study of scientific texts and obtaining the opinion of rubber industry experts based on the study of scientific texts and obtaining the opinion of rubber industry experts.

Khozani (2018) identified and ranked the environmental dimension indicators of sustainable supply chain management. In this regard, seven environmental indicators were identified during the study in valid types of research and updated domestic and international references with a high scientific degrees. Then, seven indicators were scored and ranked with the help of ten academic and industry experts who were fully acquainted with the issues of sustainable supply chain management and the environment by the pairwise comparison matrix. In this ranking, the gas emission reduction index was ranked first, the energy efficiency and renewable energy index were ranked second, and the packaging improvement index was ranked last. This shows the importance of planning to control emissions and save energy and use renewable energy such as wind and solar energy and reduce the use of fossil fuel energy in the sustainability of supply chain management.

Azizi (2018) identified and prioritized the factors affecting the performance of the sustainable supply chain. In this research, the factors affecting its performance were identified after reviewing the theoretical foundations of a sustainable supply chain, and these factors became final after consulting experts. The statistical population of this research is the managers and employees of Shiraz Vegetable Oil Company. VIKOR technique has been used to analyze the data. The results showed that reducing operating costs among economic factors, environmental cooperation with suppliers and customers among environmental factors, and safety and health among social factors have the highest priority. On the other hand, factors related to the environmental dimension had a higher priority than indicators of both economic and social dimensions. This shows the importance of the environmental dimension in the sustainability of the supply chain of the edible oil industry.

Nazari et al. (2018) modeled and evaluated sustainable supply chain solutions using structural-interpretive modeling (ISM). First, the dimensions and indicators affecting the sustainable supply chain were identified to examine these gaps in this research by reviewing the literature on the sustainable supply chain. In the next step, the relationships between sustainable supply chain indicators were identified and analyzed in an integrated manner using a new methodology called interpretive structural modeling (ISM). The results show that indicators such as the brand of the organization and market share, and competitive advantage are at the highest level of priority over other factors.

Yazdanshenas (2018) evaluated the factors affecting the successful implementation of sustainable supply chain management with a multi-criteria decision approach. The purpose of this research is to identify the components affecting the successful implementation of sustainable supply chain management. For this purpose, the components affecting the sustainable supply chain have been identified, considering oil and gas industry experts, using interview tools. Then, the accuracy of these factors has been proved using the Delphi method. Three main criteria and 14 sub-criteria were identified, and finally, 5 options and solutions were introduced. First, these criteria were evaluated and weighted using a hierarchical method. Then, the best option and solution are identified using the AHP method. According to results, the option of creating innovation and up-to-date services for sustainable development is the highest priority.

Safaei and Chaleshi (2018) conducted comparative research to identify barriers affecting sustainable supply chain management. The present research conducted a comparative study of experimental research in the field of identifying barriers affecting the sustainable supply chain and explaining the commonalities of the results of this research while defining the subject. It also mentioned obstacles such as lack of understanding of the concept of sustainability, imbalance of economic, social and environmental benefits, insufficient attention to theories and principles of supply chain research, difficulty in coordinating supply chain communication, lack of strategic planning, and managerial and operational resources were mentioned.

Foreign studies

Chun et al. (2016) examined the improvement of sustainable supply chain management using the DEMATEL-gray approach to a new hierarchy. The analytical method shows the proposed hierarchical structure and supplier selection that need to be justified in this gray-DEMATEL method with incomplete information. This analysis emphasizes the basic dimensions and criteria using exploratory factor analysis to construct a hierarchical structure that affects SSCM and benefits from a hierarchical structure for supplier selection decisions. Consequently, an analytical solution is recommended for efficient management under the internal relationships of hierarchical structure and incomplete information. If these dimensions and metrics can be improved in the supply chain network, the current SSCM can be improved. In addition, management should focus on improving the long-term prospects for addressing SSCM issues and improving performance, which can guide companies in recommending operational dimensions and criteria for selecting suppliers for future operations. Yinan et al. (2017) examined the effect of supply chain operations and strategies on integration and performance. This research renews the relationship between supply chain strategies and the winner/descriptor of the order. There are clear differences regarding the role of operations strategy in supply chain management, which shows that proper supply chain design is very important for companies to achieve the goals of their operations. This research helps to better understand the alignment between operations strategies and supply chain strategies and provides practical insights for investing in the development of supply chain integrity. Taliva et al. (2018) evaluated the supply chain sustainability by a DEA bidirectional boundary network, a big data approach. Today, evaluating the performance of sustainable supply chain management (SSCM) is an important issue for researchers and activists. Data Envelopment Analysis (DEA) is a suitable method to evaluate the performance of SSCM in the presence of large data. Network DEA (NDEA) can calculate the efficiency of multi-step processes. In this paper, the NDEA model is developed to calculate optimistic and pessimistic performance. The proposed model in this paper can integrate undesirable outputs. A case study has shown the productivity of the proposed model. Maxim et al. (2018) examined the improvement of supply chain performance for different distributions of delivery time. The delivery time on the expected price of the unexpected delivery has been investigated due to the changes in the distribution parameters. Some strategies are studied using the mean and variance of delivery time distribution, to distribute delivery time uniformly, demonstratively, and logistically to improve delivery performance when a supplier uses a timely delivery window to minimize the estimated costs of a failed delivery. Theoretical and managerial implications of the findings are discussed. Tseng et al. (2018) examined a framework for evaluating the performance management of sustainable supply chain services under uncertainty. The purpose of this study is to develop and evaluate the importance of SSSCM based on aspects of design, environmental design, environmental service operations design, and sustainable environmental design.

This paper created a hierarchical network for SSSCM in a closed hierarchical structure. Then, a minimum evaluation model based on the fuzzy Delphi method and analytical network process was used to consider both interdependencies between fuzzy measures and subjective measurements in SSSCM. The results show that the superior aspects are considered in the design of environmental service operations, and the above criteria are integrated reverse procurement in the service.

Research method

The research method can be divided into two parts, including methodologies and methods. The methodology includes the research approach and research strategy. Methods are tactics that must be used to achieve the research objectives. The data collection tools, their validation, analysis, and finally, model validation should be specified in the research method. As is common in survey research, a questionnaire is used in this research to collect a lot of data, especially in the field of risk. Other data will be collected with the help of library studies and available documents.

Multi-criteria decision-making approaches were used for modeling. The solution will be done with the help of MATLAB software. Finally, the final model was presented to check the validity of the model, the sensitivity analysis is performed.

Research population and statistical sample

The statistical population of this research is the heads and employees of the oil industry start-up and operation company.

The simple sampling method was used to sample the statistical population in the present study.

Data Analysis

Evaluation indicators

The indicator evaluation system of this problem is shown in Table (1). Table (1) shows that the index system has considered both input and output factor categories. The three categories of input indicators are considered as cost index categories (including operating costs, direct costs, and exchange costs), time index categories (including order logistic time), and human resources index categories (including the total number of employees). There are three categories of output indicators that are flexibility indicators (including product flexibility and delivery flexibility), financial indicators (including sales volume and net profit), and service level indicators (including order completion rate and on-time delivery percentage).

Table 1: Evaluation indicators considered for the problem

Factors	Measurement system	Index name	Index unit
Input	cost	Direct costs	$ 1000
		Operating costs	$ 1000
		Exchange costs	$ 1000
	time	Order preparation time	Day
	Human resource	Total number of employees	Individual
output	Flexibility	Product flexibility	Dimensionless
		Delivery flexibility	1/day
	Financial	Sales volume	$ 1000
		Net profit	$ 1000
	Service level	Order completion rate	%
		Percentage of timely delivery	%

The relationship of some of the indicators mentioned in Table (4-1) is as follows:

Machine costs + labor costs + raw material costs = direct costs

Financial expenses + administrative expenses = operating expenses

Information processing costs + marketing costs + purchase costs = exchange costs

Order Receipt Date - Order Completion Date = Order Preparation Time

$$\text{Order Completion Date} = (\text{Total volume of orders accepted}) / (\text{The total volume of orders reached}) \times 100\%$$

Percentage of timely delivery =
(Total volume of orders delivered on time)/
(The total volume of orders done) × 100%
.

It is impossible to measure all the indicators accurately and definitively in real-world problems. Here the cost index is considered fuzzy, and the other indicators are definite. It should be noted that the evaluation of the supply chain is done at the manufacturer level, and the measurement of each of the indicators is done for key companies, and in relation to suppliers and customers.

Problem Data

The index system introduced in the previous section was used from 6 companies under the Oil Industries Commissioning and Operation Company to evaluate the efficiency of the supply chain network. All data are extracted from the statistical data of these six companies in 2006. Table (3-4) shows the values of the cost indicators that are considered fuzzy. The fuzzy numbers considered as symmetric triangular. The first number in Table (2) indicates the center of the fuzzy number, and the second number indicates the distance from the sides of the symmetric triangular fuzzy number.

Table 2: Values for cost indicators for supply chains

	X_1	X_2	X_3
DMU_1	(160،1710)	(75،535)	(105،965)
DMU_2	(275،2165)	(75،580)	(65،795)
DMU_3	(240،1985)	(110،670)	(105،995)
DMU_4	(125،1790)	(40،720)	(80،895)
DMU_5	(190،2140)	(75،560)	(105،930)
DMU_6	(110،1985)	(80،645)	(160،1100)

Table (3) includes other indicators related to the evaluation of the supply chain of six Oil Industries Commissioning and Operation companies. All the numbers in Table (3) are definite numbers.

Given the evaluation index system of Table (2) and (3), X_1 is the direct cost, X_2 is the operating cost, X_3 is the exchange cost, X_4 shows the order preparation time, X_5 shows the total employees, Y_1 shows the product flexibility, Y_2 is the delivery flexibility, Y_3 is the sale volume, Y_4 is the net profit, Y_5 is the order completion rate, and Y_6 is the percentage of timely delivery.

Table 3: Data on non-cost indicators of supply chains

	X_4	X_5	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
DMU_1	25	1780	7	1/20	6790	2358	%96	%97
DMU_2	45	2096	9	1/25	8000	1947	%84	%85
DMU_3	40	1963	4	1/35	6550	1475	%93	%88
DMU_4	30	2040	3	1/25	5250	1865	%88	%90
DMU_5	45	1885	4	1/25	8260	2170	%85	%87
DMU_6	28	1768	3	1/40	6280	1540	%86	%85

AHP-DEA approach to select a supplier

A. Hierarchical analysis process

The process of hierarchical analysis was introduced as a powerful tool for decision-making. AHP allows decision-makers to compare options based on different criteria through their own judgment. These criteria may be quantifiable or non-quantifiable. Therefore, the decision-maker makes a pairwise comparison in a matrix based on the following introduced scale:

Table 4: Importance Intensity Scale

Importance Intensity	Definition	Explanation
1	Equal importance	The two activities have an equal share in the goal
3	Moderate importance	Experience and judgment are usually and slightly in favor of one activity over another
5	Strong importance	Experience and judgment are strongly in favor of one activity over another
7	Very strong importance	An activity is strongly desirable and its dominance is practically proven
9	Very important	The favorable evidence for one activity over another is very clear
2-4-6-8	Mean values between adjacent judgments	When compromise is needed
Reciprocal	If activity i has one of the above values compared to activity j, then j will have a bilateral value compared to i.	-

The corresponding pair comparison matrix (n in n) will be as follows:

$$\begin{pmatrix} 1 & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ 1/a_{n1} & \cdots & 1 \end{pmatrix}$$

In which

$a_{ii} = 1 \ for \ i = 1, \ldots, n$

And

$a_{ii} = 1/a_{ji} \ for \ i = 1, \ldots, n$ with $i \neq j$.

Since humans are able to make a perfect judgment a degree of instability in these comparisons may occur. There is a need for stability validation to ensure that judgments in the domain of stability are acceptable. The hourly stability index should first be calculated as follows.

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

In which

N is the matrix size, and λ_{max} is the real dominant special value.

The stability ratio can be written as follows using the stability index:

$$CR = \frac{CI \ of \ A}{RI \ for \ size \ n}$$

In which, RI is a random index, which can be calculated from Table (5).

Table 5: Random indicators for matrices of different sizes

Matrix size (n)	**Random Index (RI)**
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45

Experimentally, if the CR value is less than 0.1, which is equal to a 10% discrepancy.

B. Data Envelopment Analysis

Data envelopment analysis evaluates the efficiency of alternatives called decision units (36). Data envelopment analysis is a useful decision tool because it can analyze different types of data regardless of their measurement units. Measurement for efficiency is based on the concept of making an efficient boundary. Interested readers can refer to the Seford article for more information on boundary analysis in data envelopment analysis.

Efficiency is defined as weight output to weight input. The ratio of general efficiency for the decision unit to the experimental decision unit can be expressed as follows:

$$E_{ab} = \frac{\sum yO_{by}v_{ay}}{\sum xI_{bx}u_{ax}}$$

In which

E_{ab}: is the efficiency of a decision unit b using experimental DMUa weights

O_{by}: is the output of y for the output of y

v_{ay}: is Weight for DMU a test for Y output.

I_{bx}: is X input of DMU b.

u_{ax}: is the weight for experimental DMUa for x input.

The data envelopment analysis model was first introduced by Charnes, Cooper, and Rhodes (1978), which is called the CCR model. The model formulation for the decision unit is as follows.

$$maxE_{aa} = \frac{\sum_y O_{by}v_{ay}}{\sum_x I_{bx}u_{ax}}$$

So that

$$E_{ab} \leq 1 \forall b$$

$$u_{ax}, v_{ay} \geq 0$$

In which, E_{ab} is similar to Equation 3. The decision variables of the model are u_{ax}, v_{ay} .

The above equation that justifies the performance of DMU a, is nonlinear. The following equation is equivalent in linear programming:

$$max \sum yO_{by}v_{ay}$$

In which

$$\sum_y O_{by}v_{ay} \leq \sum_x I_{bx}u_{ax} \forall b$$

$$\sum_{x} I_{bx} u_{ax} = 1$$

$$u_{ax}, v_{ay} \geq 0$$

This becomes a linear programming program by equating the denominator with a value of 1, with the constraint $\sum_x I_{bx} u_{ax} = 1$.

The optimal efficiency value obtained from the CCR model is equal to 1. This means that there is a possibility that a series of decision units with a maximum value of 1 are obtained. This occurs when decision-making units are on the optimal boundary and not dominated by other units. This issue prevents the decision-maker from choosing the most efficient decision unit.

Anderson and Patterson (1193) proposed a modification of the original CCR model, called the CCR model to overcome this problem.

$$max \sum y O_{by} v_{ay}$$

In which

$$\sum_{y} O_{by} v_{ay} \leq \sum_{x} I_{bx} u_{ax} \forall b\ , b \neq a$$

$$\sum_{x} I_{bx} u_{ax} = 1$$

$$u_{ax}, v_{ay} \geq 0$$

The recent presented models are not much different. The only difference is that the second constraint includes all decision units except the experimental decision unit (which in this case is DMU a). This model is one of the objectives of this research.

C. Proposed properties

Six effective quality criteria were identified regarding the selection of a supplier. These criteria are derived from resource reviews that can cover the needs of supply chain managers in supplier evaluation. The proposed criteria for selecting a supplier include quality, service, credibility, management, environment, and risk. The following table summarizes the meaning of each of the criteria:

Table 6: Summary of the meaning of each of the criteria

Criteria	Explanation
Quality	Standards including durability and compliance of produced goods by the supplier
Services	Sensitivity and responsiveness: The speed with which suppliers respond to questions and orders. This includes flexibility, which refers to the supplier's ability to anticipate changes such as abrupt changes in production capacity due to increased demand or to consider customizing product designs.
Credibility	Perceived reliability of the supplier and its strong position in the market. This is the basis for customer trust and the level of customer commitment to the supplier
Management	Organizational structure such as the number of employees and their level of technical skills and training and implementation in the company such as production planning system. In general, this is the effectiveness of supplier operations.
Environment	Efforts by suppliers to be green in product design to produce environmental friendly products by reducing pollution
Risk	Risks that can arise from supply chain disruption. Examples of these risks include logistics risk, order delivery risk, natural disasters, accidents, political instability, and so on.

The results showed that the criteria of quality, service, credibility, and management are important properties that are commonly used for evaluation. It was decided to add environmental and risk criteria as well, as they have attracted a lot of attention in recent years.

As global warming becomes more threatening due to the emission of pollutants and waste from production, it is important to take steps towards green measures and reduce greenhouse gas emissions. Supply chain managers should strive to consider environmental performance in evaluating suppliers as it encourages manufacturers to take greener action. As stated in Section 1, risk considerations are essential in evaluating suppliers. Considering the risks is important for the company's performance and competitiveness because supply disruptions are common today and come from all kinds of sources, including natural disasters, terrorism, and so on. AHP is also able to cover risks based on decision-maker tastes and risk assessment for the supply chain. Therefore, considering risks as a criterion in the approach presented in this research, allows the decision-maker to consider the issue of supply risks in supplier evaluation.

Evaluation of "risk" criteria in the AHP approach for suppliers is similar to the evaluation in which suppliers are paired with respect to their performance with respect to risks. For example, if supplier i is "much better" than supplier j in terms of performance in terms of "risks", supplier i scores 9 over supplier j.

These criteria listed in Table (6) in the AHP will be used for pairwise comparison. It should be noted that t these criteria are qualitative characteristics and therefore the application of AHP will be appropriate.

Three criteria, including price, waiting time and delivery costs were proposed in terms of quantitative characteristics. The table below summarizes the concepts and meanings of each criterion

Table (7): Inputs and their explanations

Input	Explanation
Price	The amount paid to the supplier by the customer for goods and services
Waiting time	Time between starting and completing the transaction. This includes the delivery time of the goods.
Delivery costs	Cost required for goods transferred from supplier to customer

D. Data Envelopment Analysis (DEA) Approach to Super Efficiency- AHP

AHP is applied to perform quality comparisons on supplier quality criteria. The weights extracted from the AHP for each criterion will be used as outputs for the DEA model. In other words, the criteria for supplier selection are in fact the outputs of the DEA model. The use of AHP quantifies these quality criteria so that they can be used for the DEA model.

It should be noted that the inputs of the data envelopment analysis model are quantitative criteria that are better when their values are smaller. For example, if the price of the product is lower, this is better for the customer. The reason for this feature for inputs is that having smaller input values actually leads to higher efficiency because efficiency is the input-to-output ratio. Similarly, the concept can be generalized to outputs so that the higher the AHP weights, the better the outputs. This shows why AHP weights are used as output in the model. In addition, the outputs and inputs are selected so that they are compatible in pairs to avoid double counting.

Objective values can be extracted from the DEA model with these inputs and outputs. The decision-maker is able to rank the supplier and select the most appropriate one based on the extracted objective values, which are performance values for each supplier.

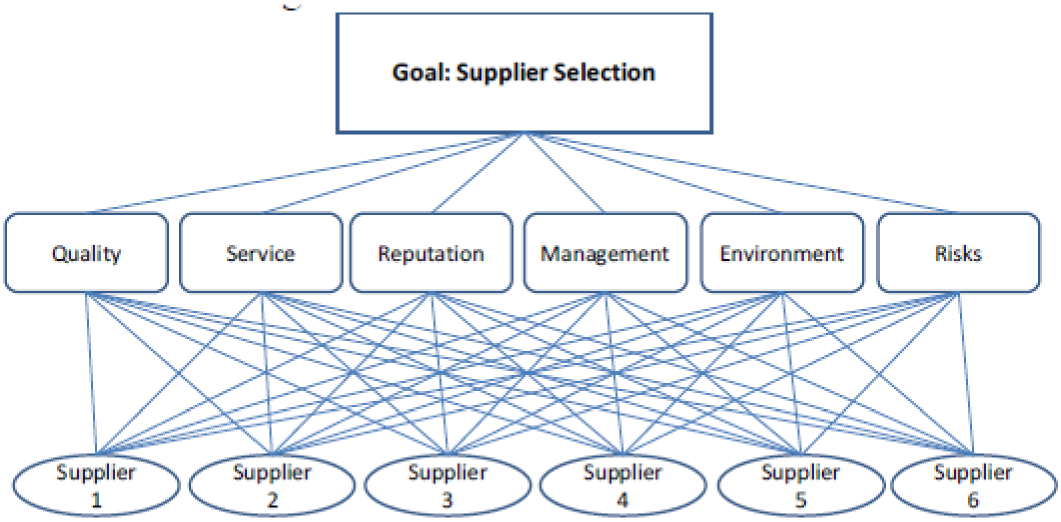
An example of this is provided in the next section to show how the DEA-Superior Performance (AHP) approach is used to select suppliers.

As shown in the resource review, both DEAHP and ANP-DEA are similar approaches to supplier selection. Ramanathan has developed a DEAHP approach that has an illustrative example to prove the comparison of alternatives. The ANP-DEA approach proposed by Hassan uses an illustrative case to illustrate how the approach works. Similarly, this paper presents an illustrative approach to illustrate how our approach to supplier selection works.

Suppose the desired company is a small manufacturing company that sources the parts needed to produce its products. A supply chain manager who is also a decision-maker is faced with the problem of selecting a supplier that includes 6 suppliers. Assume that S1-S2-S3-S3 = 4-S5-S6 are Supplier 1, Supplier 2, Supplier 3, Supplier 4, Supplier 5, and Supplier 6.

A: AHP and weights

The AHP hierarchy for these 6 suppliers is similar to the following:



Objective: Selecting a supplier					
Quality	Services	Credibility	Management	Environment	Risks
Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5	Supplier 6

Figure (1): AHP hierarchy for 6 suppliers

A pairwise comparison was performed among 6 suppliers for each criterion. The following is an example of a pairwise comparison for a quality criterion.

Quality

$$\begin{matrix} s1 \\ s2 \\ s3 \\ s4 \\ s5 \\ s6 \end{matrix}\begin{bmatrix} 1 & 2 & 4 & 1/3 & 1/2 & 2 \\ 1/2 & 1 & 2 & 1/6 & 1/3 & 1/2 \\ 1/4 & 1/2 & 1 & 1/5 & 1/4 & 1/2 \\ 3 & 6 & 5 & 1 & 2 & 4 \\ 2 & 3 & 4 & 1/2 & 1 & 3 \\ 1/2 & 2 & 2 & 1/4 & 1/3 & 1 \end{bmatrix}$$

The specific value for the matrix is 6.134 with a CI of 0.027 and a CR of 0.022. Hence, discontinuity in the 10% range is acceptable.

The corresponding weight is as follows:

$$\begin{matrix} s1 \\ s2 \\ s3 \\ s4 \\ s5 \\ s6 \end{matrix}\begin{pmatrix} 0.154 \\ 0.072 \\ 0.051 \\ 0.391 \\ 0.236 \\ 0.097 \end{pmatrix}$$

There is the following matrix that is used as an output for the data envelopment analysis model by collecting weights for 6 suppliers from 6 criteria.

$$\begin{matrix} Quality \\ service \\ cridibility \\ management \\ environment \\ risks \end{matrix}\begin{bmatrix} 0.154 & 0.072 & 0.051 & 0.391 & 0.236 & 0.097 \\ 0.032 & 0.427 & 0.047 & 0.099 & 0.283 & 0.113 \\ 0.144 & 0.048 & 0.049 & 0.450 & 0.226 & 0.082 \\ 0.034 & 0.126 & 0.104 & 0.457 & 0.242 & 0.036 \\ 0.038 & 0.229 & 0.421 & 0.046 & 0.093 & 0.172 \\ 0.101 & 0.050 & 0.179 & 0.032 & 0.380 & 0.258 \end{bmatrix}$$

B: DEA super efficiency model

Price, waiting time, and delivery cost for 6 suppliers are summarized in Table 6.

Table 8: Input data for 6 suppliers

Supplier/Feature (Unit)	S1	S2	S3	S4	S5	S6
Price (dollars per ordered unit)	1.45	1.20	0.95	1.55	1.65	1.35
Waiting time (days)	2	5	7	4.5	3	4
Delivery fee (dollars per ordered unit)	3.50	2.85	4.65	2.30	3.80	4.15

These data are used as input for the data envelopment analysis model. As mentioned, Model 6 will be a data envelopment analysis model. The data envelopment analysis model for the main supplier is as follows:

$$max \sum_{y} O_{my} v_{my}$$

In which

$$\sum_{y} O_{sy} v_{my} \leq \sum_{x} I_{sx} u_{mx} \forall s, s \neq m$$

$$\sum_{x} I_{mx} u_{mx} = 1$$

$$u_{mx}, v_{my} \geq 0$$

There are 6 criteria for output, and thus, y will be equal to 6. Similarly, there are three properties for input and x is equal to 3. Since there are 6 suppliers, there will be 6 data envelopment analysis models. Note that the O_{SY} output is as follows:

$$\begin{bmatrix} 0.154 & 0.072 & 0.051 & 0.391 & 0.236 & 0.097 \\ 0.032 & 0.427 & 0.047 & 0.099 & 0.283 & 0.113 \\ 0.144 & 0.048 & 0.049 & 0.450 & 0.226 & 0.082 \\ 0.034 & 0.126 & 0.104 & 0.457 & 0.242 & 0.036 \\ 0.038 & 0.229 & 0.421 & 0.046 & 0.093 & 0.172 \\ 0.101 & 0.050 & 0.179 & 0.032 & 0.380 & 0.258 \end{bmatrix}$$

I_{sx} input is as follows:

$$\begin{bmatrix} 1.45 & 1.2 & 0.95 & 1.55 & 1.65 & 1.35 \\ 2 & 5 & 7 & 4.5 & 3 & 4 \\ 3.5 & 2.85 & 4.65 & 2.3 & 3.8 & 4.15 \end{bmatrix}$$

M of O_{my} output is the *mth* of the O_{sy} output column. M of I_{mx} input is the *mth* input column of I_{sx}, and u_{mx}, v_{my} includes the decision variables.

The target value was obtained for the data envelopment analysis model, which is the basis for supplier ratings. Since this model is a linear programming problem, it can be easily solved with a solver in Excel. Therefore, the extracted results were summarized in Table (4-10).

Table 9: Scores for six suppliers in the AHP-DEA approach

Supplier	Score (objective value extracted from the DEA super efficiency model) (superior efficiency)
1	0.895
2	2.321
3	2.508
4	3.284
5	2.712
6	0.913

According to the scores, suppliers can be ranked in descending order: supplier 4- supplier 5- supplier 3- supplier 3- supplier 2- supplier 6 - supplier 1.

A: Applying only AHP

Assume that Q-S-R-M-E-Rk represents quality, service, credibility, management, environment, and risk, respectively. If the decision-maker decides to use only AHP, he/she should compare pairs for six criteria. Assume that the decision-maker does this and the pairwise comparison matrix is as follows:

$$\begin{array}{c} \\ Q \\ S \\ R \\ M \\ E \\ Rk \end{array} \begin{array}{c} \begin{array}{cccccc} \text{Q} & \text{S} & \text{R} & \text{M} & \text{E} & \text{Rk} \end{array} \\ \begin{bmatrix} 1 & 3 & 7 & 5 & 3 & 2 \\ 1/3 & 1 & 3 & 6 & 1/3 & 1/3 \\ 1/7 & 1/3 & 1 & 1/2 & 1/4 & 1/5 \\ 1/5 & 1/6 & 2 & 1 & 1/7 & 1/6 \\ 1/3 & 3 & 4 & 7 & 1 & 1/4 \\ 1/2 & 3 & 5 & 6 & 4 & 1 \end{bmatrix} \end{array}$$

The specific value for the matrix is 6.604 with ci equal to 0.121 and CR equal to 0.097. Hence, the discontinuity is in the range of ten percent and is acceptable The corresponding weight is as follows:

$$\begin{array}{c} Q \\ S \\ R \\ M \\ E \\ Rk \end{array} \begin{pmatrix} 0.342 \\ 0.113 \\ 0.037 \\ 0.042 \\ 0.173 \\ 0.293 \end{pmatrix}$$

According to all extracted weights, the total scores for suppliers are as follows:

$$\begin{matrix} S1 \\ S2 \\ S3 \\ S4 \\ S5 \\ S6 \end{matrix} \begin{pmatrix} 0.099 \\ 0.134 \\ 0.154 \\ 0.198 \\ 0.259 \\ 0.156 \end{pmatrix}$$

Hence, the ratings for suppliers are in descending order: supplier 5, supplier 4, supplier 6, supplier 3, supplier 2 and supplier 1.

B: Integration of AHP with the only basic CCR model

If the decision-maker uses the initial CCR model for the data envelopment analysis section (Model 5 in Section 3), then the DEA model will be as follows

$$\max \sum_y O_{my} v_{my} \qquad (8)$$

In which

$$\sum_y O_{sy} v_{my} \leq \sum_x I_{sx} u_{mx} \ \forall s$$

$$\sum_x I_{mx} u_{mx} = 1$$

$$u_{mx}, v_{my} \geq 0$$

This model differs from the previous model only in terms of constraints. Again, the results summarized in Table 10 can be extracted using the solver in Excel.

Table 10: Scores for six suppliers using AHP with the basic DEA model

suppliers	Score (objective value extracted from the basic DEA model)
1	0.895
2	1.000
3	1.000
4	1.000
5	1.000
6	0.913

Suppliers 2-3-4-5 were in the first stage, followed by supplier 6 and finally supplier 1.

C. Comparison of the results of the three approaches

All results are summarized in Table 4-12.

Table 11: Summary results of three different approaches

	AHP	AHP-Basic DEA	AHP-Super Efficiency DEA
Supplier 1	0.099	0.895	0.895
Supplier 2	0.134	1.000	2.321
Supplier 3	0.154	1.000	2.508
Supplier 4	0.198	1.000	3.284
Supplier 5	0.259	1.000	2.712
Supplier 6	0.156	0.913	0.913

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Supplier 1 has the lowest score of all 6 suppliers in all three types of approaches. Since Supplier 1 has a relatively low AHP score and comparable inputs, the lowest rating should not be expected in both data envelopment analysis models. This suggests that Supplier 1 could be a dominant alternative.

Using AHP with basic data envelopment analysis leads to the creation of a group of suppliers with values of 1 because the maximum target value is limited to 1. However, there are no more constraints with the model of data envelopment analysis with super efficiency, and the relationships between these cases are eliminated. Therefore, the decision-maker can have a better choice of suppliers.

The comparison of the AHP approach with the DEA super-efficiency approach – AHP showed that the ranking of suppliers is changed. For example, Supplier 4 was replaced by Supplier 5 in the DEA super-efficiency-AHP approach, despite Supplier 5 with the higher AHP rating. In other words, having a higher AHP does not guarantee a higher DEA score. The DEA rating is still dependent on both the corresponding outputs and inputs.

However, it should be noted that the AHP approach can only be generalized to 6 qualitative criteria. If applied to all criteria (6 quality criteria and three quantitative criteria), the scores will be different. This way can provide a fair comparison with the AHP-DEA or the DEA super-efficiency approach-AHP. Since the scores obtained by applying AHP on qualitative and quantitative criteria are not applicable in this approach, the AHP analysis was not performed.

Conclusion

DEA super-efficiency approach-AHP, along with the proposed quantitative and qualitative criteria, provides a comprehensive approach for the decision-maker to select the best supplier. Model inputs and outputs should be small to make the data envelopment analysis effective. This limitation of data envelopment analysis can be solved by using AHP to quantify these qualitative factors through the allocation of weights in the analysis process.

Moreover, criteria were defined and proposed for pairwise comparison of the hierarchical analysis process. Outputs and inputs that should be included in the data envelopment analysis model were also suggested. An illustrative example of the proposed approach is provided in this paper so that readers can gain a better understanding of how the DEA super-efficiency approach-AHP works. The results of AHP, AHP-basic DEA and DEA-super-efficiency-AHP were also shown and discussed. The results showed that the DEA-super-efficiency-AHP approach could be the most appropriate supplier selection method. Limitations to this approach were also discussed, and possible modifications were proposed for future work. In addition, a large number of suppliers with high computing power are required to address this proposed approach. The DEA super-efficiency approach-AHP helps decision-makers rank more efficiently for suppliers and select the most appropriate supplier for their company together with the proposed quantitative and qualitative criteria.

Discussion

Bhagwat and Sharma developed a balanced scorecard approach to supply chain management that measures and evaluates business operations on a daily basis from four financial, customer, internal business process, and learning and growth perspectives. This research has also used the fuzzy data envelopment analysis model in addition to the balanced scorecard, which has succeeded in evaluating the performance in uncertain environments by using this model.

Xu et al. (2009) developed an uneven data envelopment analysis model to evaluate supply chain performance. In this study, the balanced scorecard model has also been used in addition to using the model used in the research of Xu et al. (2009). Based on this model, the indicators are designed in the form of a questionnaire in four financial approaches, including approaches, the organization's internal processes, the customer and the growth and learning approach.

Easton et al. (2002) investigated the evaluation of the performance of the purchasing sector in the supply chain. They attributed this difficulty to the lack of acceptable measurement criteria and appropriate methods for integrating these criteria and providing an overall performance noting that it is very difficult to measure the performance of the purchasing department and compare that performance with other purchasing departments. They developed a DEA model to evaluate purchasing performance in the petrochemical industry. Only a part of the supply chain has been studied in the research of Easton et al., while in the current research, all supply chain processes have been studied and evaluated. In this research, the balanced scorecard model has also been used to select indicators.

Gunaskaran et al. (2004) pointed out that performance measurement and supply chain-related criteria have not received enough attention in research and practical work. They developed a framework to better understand the importance of evaluating supply chain performance and its criteria. They prepared a questionnaire and sent it to 150 large companies in various industries in the United Kingdom to determine their evaluation criteria and importance. These criteria are categorized into four main supply chain processes, including planning, sourcing, manufacturing (manufacturing/assembly), and delivery. They categorized the indicators into three general categories: strategic, technical, and operational management aft receiving the questionnaires and determining the importance of each indicator to determine the appropriate level of management to have authority and responsibility for each criterion. The strategic level shows the performance of senior management. The technical level deals with resource allocation and performance measurement compared to predetermined goals. Performance measurement in this section provides good feedback on the decisions of middle managers. Measurements at the operational level require accurate data and show the results of low-level managers' decisions. The full results of this research are presented in Appendix (b).

The indicators of the questionnaire in the current research have been determined based on the balanced scorecard in comparison with the research of Gunaskaran et al. (2004), which has a higher accuracy. Wong and Wong (2007) used a classical data envelopment analysis model to evaluate the performance of 22 supply chains. They use criteria such as profit, on-time delivery and cost. The problem with this model was that the model could not be presented in the real world, but the researcher in this study has succeeded in solving this problem by using a fuzzy model so that it can be implemented in the real world. Stamp et al. (2010) provided a framework to attempt to analyze supply chain performance evaluation models. This analysis has been conducted by specifying the specific features and capabilities of each model in different fields. They have also tried to break down the models analytically into seven smaller layers to help managers choose the right model proportional to their needs. DEA cannot visualize data in the real world in an uneven set. This research in fuzzy format has succeeded in solving the mentioned problem.

Applied research recommendations

1. The basis for calculating the weight of indicators in most types of research in the field of supply chain performance evaluation is the personal opinions of individuals, which leads to the approximate weight of these indicators. It is recommended to consider quantitative models to increase the accuracy of the indicators and qualitative models to consider market changes. As a result, hybrid models can be a good option for such research.
2. It is recommended to use non-parametric methods such as the method used in this research (data envelopment analysis) to reduce errors in the weight of indicators.
3. This model specifies costs that have a significant effect on chain performance. Companies are recommended to consider all their costs accurately o have a significant effect on their performance. This model also considers costs, especially small costs in the real (fuzzy) world.

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