Providing a model for evaluating and selecting suppliers of three-phase self-sustaining cables using the interactive approach of analytical hierarchical process and goal programming

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Abstract

Limited resources in the current competitive world have motivated the companies to use from technological tools in order to increase their productivity and efficiency. In this context, identification and selection of suppliers of raw materials and consumer and capital goods in production processes and services are a long step in achieving the goal of survival and excellence. On the other hand, organizations regard as a network of different companies in the supply chain that work together in order to create more added value for the final customer or consumer. Increasing added value by enhancing quality and reduces costs. Suppliers dramatically affect corporate performance in terms of price, quality, technology, and delivery. Therefore, in this study, practical criteria for the selection of suppliers in an Electricity Distribution Company are prioritized using an Analytical Hierarchical Process. An integration of the Analytical Hierarchy Process and Goal Programming use to goal restrictions in allocating an optimal order quantity to each supplier. In following, an integration of AHP and GP use in the case study to supply 500,000 m low-voltage three-phase self-sustaining cable ($3 \times 50 + 25 + 25$) to allocate an optimal order quantity to each supplier. The results indicated that a better solution could achieve using an interactive model. Overall, this study provided an appropriate model for using limited financial resources to provide better services to achieve a strategic and comparative advantage. Research results are also applicable in the following areas: 1. Provide appropriate solutions to increase the company's profitability by reducing supply costs. 2. Planning for investment and exploitation in the company's marketing department and supply of consumer goods. 3. Identify barriers in purchasing consumer goods and equipment and their impact on the proper marketing of the company. 4. Application of research in the supply of consumer goods in the electricity distribution company of Khorasan Razavi province and other large service and production companies and future researchers whose information is not accurate and whose criteria are diverse and vague.

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Keywords Analytical hierarchy process (AHP) · Goal programming (GP) · Evaluation and selection of suppliers · Supply chain management (SCM)

1 Introduction

Increased competition, globalization pressure, and market developments have changed methods of supplying various items and communication with customers and suppliers. In new circumstances, selection of suppliers and enhancement of sustainable partnership necessarily reduce costs and increase flexibility in terms of changes in the market. The increased importance of purchase has highlighted the significance of purchasing decisions. In most industries, the cost of raw materials and consumed components encompass a significant part of the cost of a product or service, which would be 70% in some cases [1–7]. More than 80% of the total cost covers purchased raw materials and services, even in high-tech companies [8]. Therefore, the decisions associated with purchasing strategies and operations play a crucial role in corporate profitability.

Selecting a supplier in the corporate supply chain is one critical multi-attribute decision-making (MADM) process. Because the selection of suppliers is an essential issue in the success of any organization in the current competitive environment [9]. Successful supply associated with the selection of the suitable suppliers, which directly depends on the management of long-term relationships with suppliers. Because the suppliers significantly affect corporate success or failure [10].

Selection of appropriate suppliers necessitates the evaluation of several criteria. Multi-attribute decision-making is an effective model for comparing of suppliers based on the evaluation of various criteria [11].

We know that, in most industries, the cost of raw materials and components of the product accounts for a large part of the cost of the product. With the increasing importance of procurement and purchase activities, purchasing decisions have become more critical, and as organizations today become more dependent on suppliers, the direct and indirect consequences of poor decision-making become worse. In such circumstances, the logistics sector can play a crucial role in the efficiency and effectiveness of the organization and have a direct impact on cost reduction, profitability, and flexibility of a company. Choosing the right set of suppliers to work is vital for the success of a company, and over the years, the selection of suppliers has emphasized.

Basically, in any decision-making process for how to select suppliers, there are two main tasks: how to evaluate, and the how to select. The evaluation process involves identifying indicators, characteristics, criteria, and factors related to the decision, and the selection process include the ranking of suppliers taking into account each of the indicators and criteria and the selection of a potential supplier. In this study, due to the importance of the issue and the selection of appropriate suppliers in the supply chain in the Khorasan Razavi Electricity Distribution Company, the need to collect evaluation criteria and select suppliers such as technical evaluation, price, quality evaluation, are vital factors in the success of the supply seems.

In the following, we explain more details for this selection. Khorasan Power Distribution Company was established in 1992 and in line with the policies of the Government of the Islamic Republic of Iran in the first five-year development plan of the country to change the structure of companies affiliated to the Ministry of Energy, under the name of Khorasan Power Distribution Company and in charge of all matters related to electricity was distributed in Khorasan province. The company's performance area at the time of its formation (1992) included all the cities of the vast province of Khorasan and the city of Mashhad, which amounted to 300,000 km (one-fifth of the total area of the country). First in 1994 Mashhad Electricity Distribution Company and then in 2001 South Khorasan Province Electricity Distribution Company (including Birjand, Tabas, Nehbandan, Ghaen, and Ferdows) and finally in 2002 North Khorasan Province Electricity Distribution Company (including Bojnourd, Shirvan, Esfarayen, Jajarm, Farooj, Ashkhaneh, Maneh and Semnqan) were separated from that company. Now in the whole level of Khorasan Razavi province (except Mashhad) in an area of 116,631 square kilometers, the duty of providing continuous and reliable Electricity is 1048185 subscribers. Electricity in residential, commercial, and industrial tariffs in 42 cities and 2697 villages covered by 665 official contract personnel and 750 contractors. Moreover, considering that so far the selection of suppliers has been done according to the needs of the company and to meet it based on the intuitive judgments of experts, and experts based on their judgments compared suppliers, and also due to the size of the company, the number many experienced and efficient managers, high cost of raw materials supply due to the large volume of materials needed and the importance of the organization to the optimal use of raw materials and equipment, and a leading service company in the industry that wants to provide its services with capabilities provide high reliability and quality per customer requirements. Because of the above explanation, this company selected as a case study of our research.

Nowadays, AHP used by both scholars and experts in order to solve the problem of evaluating supplier performance according to one criterion or the significance of multiple criteria with high precision [12]. AHP makes the possible hierarchical formulation of a problem and the inclusion of qualitative and quantitative criteria. AHP involves multiple alternatives in the decision-making process and makes possible sensitivity analysis for criteria and sub-criteria. Also, AHP based on paired comparisons, which facilitate judgment and calculations and show compatibility or incompatibility of decisions. One advantage of AHP lies in the available structure and framework for cooperation and collaboration in decision-making or problem solving [13].

On the other hand, AHP and GP include several objectives in order of priority set by the decision-maker. GP allows the decision-maker to formulate conflicting goals as a linear equation known as an objective function. GP also allows the decision-maker to formulate real constraints such as purchasing budget, production, as limitations of suppliers. Solving the problem determined the number of goods received from each supplier with the highest optimization level and an ideal goal [14]. A combination of these two techniques can provide a model, which simultaneously takes into account various criteria and different ideal goals.

Several studies have conducted on the selection of suppliers in the past. In this study, the quantity of order taken into account and both quantitative and qualitative criteria for the selection and allocation of orders to suppliers. A decision-making model provided to evaluate and rank suppliers of three-phase low-voltage self-sustaining cable in Khorasan Razavi Electricity Distribution Companies using a combination of AHP and GP methods and various restrictions. Then, a model proposed for the allocation of optimal order quantity to each selected supplier.

Selection and prioritization of appropriate solutions considered in the decision-making process. Multi-attribute decision-making methods have introduced, among which AHP used more than other management methods. AHP reflects normal behavior and human thought. AHP used in the decision-making process with multiple competitors and decision criteria. The proposed criteria could be either quantitative or qualitative. AHP based on paired comparisons. At first, the decision-maker organizes a hierarchical tree, which shows compared items and evaluates competitors and decision alternatives. Then, a series of paired comparisons carried out, which show the weight of each factor in evaluated competitors in the decision-making process. Finally, AHP logic integrates matrices of paired comparisons to deliver an optimal decision.

Also, GP is one decision-making method with multiple objectives in which the decision-maker determines an ideal goal. GP allows the decision-maker to formulate confounding objectives as a linear equation known as an objective function. GP also allows the decision-maker to formulate real constraints such as purchasing budget, capacity, as constraints in supplying materials. The model can determine the materials received from any supplier to provide the highest optimization level and an ideal goal.

In this regard, the reasons for using Goal Programming in this research are: 1. Existence of non-collectible goals in the evaluation and selection of suppliers. 2. Change in goals over time and the possibility of considering it in the model. 3. The possibility of prioritizing goals and ideals in the model.

The process of selection of suppliers initiates with determining a set of criteria or indicators to characterize the supply function. Since evaluation is usually affected by multiple factors, most formal planning measures for supplier selection search for supplier performance in terms of quality, price, delivery, and services [15, 16]. According to library studies, a set of appropriate criteria subsequently selected for the case study.

However, Goal Programming is a powerful tool in terms of several factors in decision-making at the same time while taking into account systemic constraints. One of the things that should considered in this model is how to prioritize the ideal constraints (goals) or the penalty coefficient that we assign to each deviation. This planning alone is not able to do this aim. On the other hand, the use of qualitative and intangible factors or criteria is beyond the ability of this planning, so integration with AHP, a complementary tool that can cover the shortcomings of Goal Programming can be a good model for organizational decisions, including the allocation of the amount and provide optimal order to suppliers. It should note that the AHP approach cannot be a complete tool for decisions such as allocating the amount of the order to suppliers, the reason for this is not considering restrictions such as

budget, materials, in decision making and inability to choose or prioritize a large number of options. Therefore, using two tools (AHP and GP), these can cover each other's weaknesses and also use each other's strengths. This means, after weighing the criteria and options and identifying the limitations, the Goal Programming model can be developed to allocate the optimal amount of order to each supplier so that the importance of criteria in the supply chain as weights corresponding to apply decision-maker preferences to the model and assign purchase orders to suppliers accordingly.

2 Literature review about methodology

Due to the importance of supplier selection in the supply chain, there is a lot of research and material on this topic that combines different quantitative problem-solving methods such as data envelopment analysis, linear programming, ideal planning, hierarchical analysis, TOPSIS with the use of fuzzy logic. In this regard, following we review some literature about AHP and Goal Programming methods. Using the results of good articles that have already written in this field, we can get a better view of why these research methods chosen.

2.1 About AHP and goal programming

In 1999, Lee et al. presented a goal programming (GP) model which aids in allocating a healthcare system's information resources pertinent to strategic planning. This model is developed based on the data obtained from a significant healthcare system in the United States. The overall objective is to design and evaluate a model for effective information resource planning in a healthcare system. The proposed model: (1) utilizes a GP approach to reflect the multiple, conflicting goals of the healthcare system; (2) employs a GP solution process to reflect multi-dimensional aspects of the resource allocation planning; and (3) allows for some degree of flexibility of decision-making for resource allocation. The goals are decomposed and prioritized with respect to the corresponding criteria using the analytic hierarchy process (AHP). This GP model facilitates the decision-making planning process and managerial policy in healthcare information resources planning and similar planning settings [18].

Authors in [19] considered the collaborative production–distribution planning problems in supply chain systems. In this work, multi-objective linear programming model is developed, and in order to reflect the collaborative planning issues to the model and to provide a more realistic model structure, decision makers' imprecise aspiration levels for the goals are incorporated into the model using fuzzy goal programming approach. Also, to explore the viability of different fuzzy goal programming approaches for the collaborative production–distribution problem in different supply chain structures, i.e., centralized and decentralized, computational experiments are performed on a hypothetically constructed case problem.

In the following, in Sah et al. [20] studied identify and prioritized the barriers of drone logistics implementation based on their criticality by using the fuzzy Delphi method (FDM) and the analytic hierarchy process (AHP). They considered 34 barriers which identified through expert opinion and extensive literature review. Furthermore, relevant barriers finalized among all the barriers by using the FDM. Finally, prioritization of the barriers based on their criticality is done by the AHP technique. This study concluded that regulations and threats to privacy & security are the most critical barriers to the implement drones in the logistics sector.

Recently authors in [21] also studied the consciousness of safety risk factors, and the emergence of WHO guidelines for the preparedness of health care workers have pushed the health care systems to take proactive decisions to maintain a safe and productive working environment during the COVID-19 outbreak. In order to provide this working environment, detailed identification and analysis of safety risk factors required. In this context, they proposed a hybrid fuzzy-based decision-making framework to rank the Indian hospitals based on the prevalence of safety risk factors among the health care workers. First, fifteen relevant safety risk factors identified with the help of the Fuzzy Delphi Method (FDM). Second, the weights of categories and their respective factors are computed and are ranked based on their criticality by the Fuzzy Analytic Hierarchy Process (FAHP). Finally, Indian Hospitals are ranked based on these factors using the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS).

Finally, in Ayag et al. [22] studied a selection process of a machine tool because the improper selection of a machine tool might cause many problems affecting negatively on productivity, precision, flexibility, and company's responsive manufacturing capabilities. On the other hand, selecting the best machine tool from its increasing number of existing alternatives in the market are a multiple-criteria decision making (MCDM) problems in the presence of many quantitative and qualitative attributes. Therefore, an analytic hierarchy process (AHP) used for machine tool selection problems because it has widely used in evaluating various kinds of MCDM problems in both academic kinds of research and practice. However, due to the vagueness and uncertainty on judgments of the decision-maker(s), the crisp pair-wise comparison in the conventional AHP seems insufficient and imprecise to capture the right judgments of decision-maker(s). That is why; fuzzy number logic is introduced in the pair-wise comparison of AHP to make up for this deficiency in the conventional AHP. In addition, this case study also presented to make this approach more understandable for a decision-maker(s).

3 Research methodology

This research is applied-developmental in terms of purpose and analytical-descriptive in terms of method. These explain in following steps:

(1) Data collection tools

In the first stage, by studying the library, searching reputable scientific sites, and reviewing existing scientific texts on criteria and indicators for evaluat-

ing and selecting suppliers, and ranking and selecting techniques for suppliers such as AHP and GP, collecting research requirements. Then, according to the research literature and reviewing the status of the company and suppliers and interviewing them, matrices of pairwise comparisons filled by the company's purchasing and logistics managers.

(2) Analysis tools

In this research, multi-criteria decision models such as AHP and ideal planning (GP) used to obtain the importance of criteria, evaluation, and selection, and allocate the optimal order amount to each supplier with the help of Expert Choice software. Expert Choice calculates the importance of criteria and final weight of suppliers. Thus potential and suitable suppliers for Khorasan Razavi Power Distribution Company ranked and selected, and finally, by solving the GP with the help of Lingo 11 software, The amount allocated to each supplier is specified.

In this regard, our research methodology can divided into two main phases: the first phase includes determining quantitative and qualitative criteria and using the technique of hierarchical analysis process in order to weight the criteria and options, in which case the importance of criteria and priority of suppliers through AHP is calculated by the opinions of company experts, and the second phase is to identify the ideal and systemic constraints and combine the results of the first phase with the GP model in order to assign the optimal order amount to each supplier.

4 The proposed model

In this study, an interactive model was developed for the evaluation and selection of the most suitable suppliers by simultaneously taking into account various criteria, and ideal goals. Product suppliers assessed by a model with an interactive AHP-GP methods and various restrictions (including idealistic and systematic restrictions). Finally, an optimal order quantity allocated to each supplier. Figure 1 shows development steps to AHP-GP interactive model.

In this model, a relative weight (W_j) given to deviations from each ideal goal in the GP objective function. The weights derived from the AHP technique could use to prioritize criteria in case of incompatible criteria. Several objectives simultaneously met. Accordingly, a particular necessary coefficient as the objective (ideal goal) determined, and an appropriate objective function formulated for each goal. A solution should find, which minimizes the total weight of each goal for the ideal determined each objective. The final solution should provide the possibility to achieve all the objectives [13].

4.1 Case study

Suppliers of three-phase low-voltage self-sustaining cable in Khorasan Razavi Electricity Distribution Company evaluated and selected using multi-attribute

Fig. 1 Steps to development of an interactive AHP-GP model

decision-making models to deliver a clear image of the structure of activities of purchasing managers, procurement, and supply of consumer goods in order to take a few short steps for improving and increasing economic performance in the company.

4.2 The first step: identification of suppliers

Consumer goods include many items. Each item requires a different type of application control. Standard methods of classification of inventories are as follows: (1) ABC Analysis, (2) VED (Vital Essential Desirable) Analysis, and (3) FNS (First Normal Slow Moving) Analysis [17].

Consumer goods in Khorasan Razavi Electricity Distribution Company classified in terms of importance and viability (based on VED) and based on their annual monetary value (inspired by the ABC method). Self-sustaining, three-phase, low-voltage cable ranked as the priority based on VED and ABC methods. Thus, the modeling process focused on the supply of goods.

At this stage, corporate technical and purchasing commissions provided a comprehensive list of available suppliers using various sources of information. In this regard, suppliers of three-phase, low-voltage, and self-sustaining cable in Khorasan Razavi Electricity Distribution Company identified, which included Bakhtar Wire and Cable Corporation, Forouzan Yazd Wire and Cable Corporation, Mashhad Wire and Cable Corporation, Pishro Rafsanjan Wire and Cable Corporation.

4.3 The second step: determining quantitative and qualitative criteria

A list of practical criteria for evaluating and selecting of suppliers in Electricity Distribution Company in Khorasan Razavi investigated. Finally, three main criteria of technical, price, and quality evaluation identified according to interviews with

experts in technical product commission and department of support and operation and dispatching. Technical evaluation criteria classified into the following sub-criteria: DC electric resistance, insulation thickness, conductive fiber diameter, cable marking quality, and weight per unit length. Qualitative evaluation criteria encompassed the following sub-criteria: financial power, evaluation of previous customers, the quality system governing the company, knowledge, and experience.

4.4 The third step: weighting criteria and alternatives using AHP

The hierarchy of criteria was determined. Then, decision-makers evaluated defined criteria by paired comparisons. Paired comparison process carried out in terms of significance, superiority, and similarity of two superior components. Finally, the criteria weighted and prioritized using Expert Choice Software as shown in Table 1 (for more details about the main criteria and sub-criteria weights of models, see appendix).

4.5 The fourth step: Identification of constraints

In this study, the proposed goal programming consisted of an objective function, ten goal constraints include: price optimization, DC electric resistance, insulation thickness, the diameter of conductive fibers, marking quality, weight per unit length, financial power, evaluation of previous customers, the quality system governing the company, knowledge and experience and six systematic limitations such as limited product demand, supplier capacity etc.

4.6 The fifth step: allocation of an optimal order quantity to each supplier by interactive AHP-GP model

Criteria and alternatives weighted, and constraints identified. Then, GP Model could developed in order to allocate an optimal order quantity to each supplier.

Table 1 Weight of criteria and sub-criteria for selecting suppliers of three-phase self-sustaining cable using AHP method

Criteria	Weight
Price	0.143
DC electric resistance	0.121
Insulation thickness	0.144
Diameter of conductive fibers	0.088
Marking quality	0.052
Weight per unit length	0.100
Financial power	0.046
Evaluation of previous customers	0.140
The quality system governing the company	0.038
Knowledge and experience	0.123

Information on the performance of each of the four suppliers and corporate demand for the supply of 500,000 m of self-sustaining cable in terms of different criteria shown in Table 2.

We should insist supplier indicators can be examined from different aspects, including: financial strength, management solution, globalization, technical capability, resources, and quality systems.

In the GP model, goal values for individual objectives are determined. Then, a solution with the minimized gap between objectives and criteria was determined. Due to specified limitations, the values listed in Table 3 are considered ideal for any objective.

The values specified for the ideal target in Table 3 are calculated on the basis that if we buy our total need for each ideal based on the production capacity of each supplier (their maximum production), then the minimum cost and deviation from ideals will be achieved (which is precisely the purpose of using the GP model).

The Goal programming model is as follows:

$$\begin{aligned} \text{Min } A = & 0.141\beta_1^+ + 0.121\beta_2^+ + 0.144\beta_3^- + 0.088\beta_4^- + 0.052\beta_5^- \\ & + 0.100\beta_6^+ + 0.046\beta_7^- + 0.140\beta_8^- + 0.038\beta_9^- + 0.123\beta_{10}^- \end{aligned} \quad (1)$$

$$0.141X_1 + 0.141X_2 + 0.141X_3 + 0.141X_4 + \beta_1^- - \beta_1^+ = 38892800000 \quad (2)$$

$$0.388X_1 + 0.395X_2 + 0.388X_3 + 0.395X_4 + \beta_2^- - \beta_2^+ = 125940 \quad (3)$$

$$0.193X_1 + 0.166X_2 + 0.193X_3 + 0.193X_4 + \beta_3^- - \beta_3^+ = 129500 \quad (4)$$

$$0.085X_1 + 0.833X_2 + 0.825X_3 + 0.820X_4 + \beta_4^- - \beta_4^+ = 125680 \quad (5)$$

$$0.250X_1 + 0.250X_2 + 0.250X_3 + 0.250X_4 + \beta_5^- - \beta_5^+ = 125000 \quad (6)$$

$$0.254X_1 + 0.254X_2 + 0.273X_3 + 0.273X_4 + \beta_6^- - \beta_6^+ = 129500 \quad (7)$$

$$0.2643X_1 + 0.0925X_2 + 0.369X_3 + 0.171X_4 + \beta_7^- - \beta_7^+ = 191830 \quad (8)$$

$$0.105X_1 + 0.235X_2 + 0.568X_3 + 0.341X_4 + \beta_8^- - \beta_8^+ = 1 \quad (9)$$

$$0.014X_1 + 0.021X_2 + 0.102X_3 + 0.029X_4 + \beta_9^- - \beta_9^+ = 1 \quad (10)$$

$$0.0184X_1 + 0.0292X_2 + 0.1064X_3 + 0.460X_4 + \beta_{10}^- - \beta_{10}^+ = 1 \quad (11)$$

$$X_1 \leq 120000 \quad (12)$$

Table 2 Information on the performance of each supplier

	Price	DC electric resistance	Insulation thickness	Diameter of conductive fibers	Marking quality	Weight per unit length	Financial power	Evaluation of previous customers	Quality system governing the company	Experience and knowl- edge	Production capacity
The first sup- plier	0.941	0.388	0.192	0.085	0.250	0.254	0.0643	0.105	0.014	0.0184	120,000
The second supplier	0.929	0.395	0.166	0.0833	0.250	0.254	0.0925	0.235	0.021	0.0292	260,000
The third supplier	1.086	0.388	0.192	0.0825	0.250	0.273	0.269	0.568	0.102	0.1064	190,000
The fourth supplier	1.060	0.388	0.193	0.082	0.250	0.273	0.171	0.341	0.029	0.046	330,000

Table 3 Ideal value for each objective

Objective	Ideal of any objective (million Rials ^a)
Price	38,892
DC electric resistance	125,940
Insulation thickness	129,500
Marking quality	125,000
Weight per unit length	129,500
Financial power	191,830
Evaluation of previous customers	171,080
The quality system governing the company	170,220
Knowledge and experience	172,380

^aCurrency in Iran

$$X_1 \leq 360000 \quad (13)$$

$$X_1 \leq 190000 \quad (14)$$

$$X_1 \leq 330000 \quad (15)$$

$$X_1 + X_2 + X_3 + X_4 \geq 500000 \quad (16)$$

$$X_1 \geq 0, \beta_1^- - \beta_1^+ \geq 0 \quad (17)$$

where β_j^- and β_j^+ indicate the gap between objectives and goal values, x_i shows the purchase amount of self-sustaining three-phase low voltage cables from the i th supplier. Equation (1) denotes the objective function in which the gap between objectives and goal values minimized. Indeed, an optimal value of goal value of an objective determined, an increase in the ideal goal was not significant. Thus, negative criteria (such as price) show an increase in ideal goals, and positive criteria (such as financial power) indicate a decrease in ideal goals. Equations 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11 show goal functions, which maintain each objective close to ideal goals. Equations 12, 13, 14 and 15 guarantee that amount of purchase from each supplier does not exceed their capacity. Equation 16 shows the supply of demands, and Eq. 17 also guarantees non-negative variables.

Lingo11 software used to solve the programming model. As shown in Table 4, orders were allocated to the suppliers, so that the results of the entire purchase correspond with the preferences of the decision-maker.

According to Table 4, the buyer had purchased a self-sustaining, three-phase cable from the total production capacity of the third supplier. The rest of the buyer's demand purchased from the fourth supplier. This may be due to the weight of suppliers for selection criteria.

Table 4 The amounts allocated to each supplier

Supplier	Purchase amount (meters)
The first supplier	0
The second supplier	0
The third supplier	190,000
The fourth supplier	310,000

During the different stages of this research, new points discovered, and as the research progressed, more ambiguities created for the researcher, which due to the existing limitations. Thus, their study requires more research. For the future researchers who intend to work in this field, it is suggested: To increase accuracy and reduce uncertainty in prioritizing criteria and suppliers and assigning the optimal order amount to each supplier, also this model can combine with neural network models and genetic algorithms and compare with the results of this study.

5 Conclusion

Many manufacturing and service organizations depend on each other for the production or supply of goods and services. The continued success of any organization depends on reduced production costs and improved quality of the product. This could not achieved unless the supplier provided their products with superior quality. On the other hand, the supplier should be regarded as a partner because an appropriate supplier can significantly reduce procurement costs and increase corporate competitiveness. Furthermore, the right supplier can increase product quality and ultimately customer satisfaction. In recent years, procurement strategy has led to the enhancement of such issues as long-term partnerships, long-term unions, and the development of merit suppliers. According to the global approach of collaboration for individual capacities and capabilities, the suppliers should be selected according to specific principles and criteria in order to minimize the risk of outsourcing activities. As a result, the suppliers should identified, evaluated, and selected based on a scientific process. The proposed interactive model can determine evaluation procedures and the optimal amount of purchase order quantity to allocate an optimal quantity to selected suppliers with ideal limitations in many respects. The strengths of this model lie in the simultaneous evaluation of multiple criteria (quantitative and qualitative). This provides the possibility of achieving an accurate analysis.

However, this study started to evaluate and select suppliers of three-phase self-supporting cable and allocating the optimal order amount to each of them in Khorasan Razavi Power Distribution Company. The reason for the importance of this product and the complete focus on all quantitative and qualitative aspects of supplier selection, considered.

In this regard, five main questions asked:

- (1) What are the criteria affecting the evaluation and selection of raw material suppliers?
- (2) How to prioritize the criteria obtained from the AHP method?
- (3) What are the final weights of raw material suppliers?
- (4) How can the optimal order amount be allocated to suppliers using the GP method?
- (5) How can the combined approach of the Hierarchical Analysis Process and GP to analyze and select appropriate and potential suppliers?

The most important criteria for selecting three-phase self-supporting cable suppliers identified by reviewing the literature related to the subject and research conducted inside and outside the country, and consulting the experts of the technical, Operation and Dispatching, Support, and Commerce Commission of the company. In this regard, technical evaluation and quality evaluation criteria divided into sub-criteria.

Like any other research, conducting this research was faced with many obstacles and problems, some of which were eliminated, and others changed the direction of the research or limited the application of the results. These restrictions include:

- (1) Some of the contracts between the Khorasan Razavi Power Distribution Company and the suppliers of self-supporting three-phase cables are related to previous years, which makes the price and other influential factors of these suppliers with other suppliers.
- (2) Due to price fluctuations and market demand, it is possible to change its purchase volume. Therefore, the fluctuation may be different from the actual demand and capacity of the company.
- (3) Because the Khorasan Razavi Electricity Distribution Company considered a state-owned company, in some circumstances, it must comply with certain conditions. For example, according to the approvals of the parliament and the laws of the Program and Budget Organization and the Ministry of Energy, the company must supply the required goods from a series of suppliers with prices and other specific factors, which can affect the selection of suitable suppliers.
- (4) Due to the high scope of operations and the complexity of the model, other limitations of the model, such as operating costs, purchase budget, etc., may not considered in this study.
- (5) Some suppliers, due to some issues such as financial constraints, export of their products are not very willing to cooperate with the Khorasan Razavi Electricity Distribution Company. These lead to a problem and be influential in selecting a supplier by the Khorasan Razavi Electricity Distribution Company.

Finally, the selection of suppliers made according to the needs of the company and in order to satisfy it, based on the judgments of the experts, we suggest selecting suppliers in this company and other similar companies, be according the result of this research systematically.

Appendix

The Analytic Hierarchy Process (AHP) is one of the most comprehensive systems designed for decision-making with multiple criteria because this technique allows the problem to formulate hierarchically and the possibility of considering different quantitative and qualitative criteria in the problem. This process involves different options in decision-making and allows the analysis of sensitivity to criteria and sub-criteria. In addition, it based on pairwise comparisons that facilitate judgments and calculations, and the degree of consistency and incompatibility of the decision. One of the advantages of the hierarchical analysis process is that it provides a structure and framework for collaboration and group participation in decision-making or problem-solving. In the following, we present the main criteria and sub- criteria weights for the AHP implementation section:

First, three main criteria include: 1. Technical evaluation. 2. Price 3. Qualitative evaluations, compared in pairs, and the data entered into Expert Chose software, and the weights of each criterion obtained as shown below. As shown the below table, in this pairwise comparison (two by two), the highest weight is related to the technical evaluation criterion with a value of 0.508, followed by a quality evaluation criterion with a weight of 0.349 and a price criterion with weight 0.143 are in the following priorities. In this decision matrix, the incompatibility rate is 0.01, which is less than 0.1, so the incompatibility of the indicators is acceptable and indicates that the views on the relative importance of the main criteria are consistent.

The following technical evaluation criteria, which include DC electrical resistance, cable insulation shell thickness, cable conductor diameter, marking quality and insertion of specifications on the cable, and unit weight of length, were compared in pairs. According to the results obtained from Expert Choice software, insulation shell thickness criteria with relative weight 0.285, DC electrical resistance with relative weight 0.240, unit length–weight with relative weight 0.198, conductor string diameter with relative weight 0.174, and marking quality on the cable with a relative weight of 0.104 are in the first to fifth priority. The incompatibility rate of this set is 0.01, which indicates the compatibility of opinions.

It is noteworthy that the source of information about the status of each supplier in the technical evaluation items based on the documents available in the Energy Research Institute (which is the only reference laboratory approved by the Ministry of Energy in the country) and information provided by suppliers to attend in the tenders of Khorasan Razavi Electricity Company.

Following the sub-criteria of quality evaluation, include: financial ability, evaluation of previous customers, the quality system governing the company, and having knowledge and experience in the field, compared in pairs. According to the results obtained with Expert Choice software, sub-criteria for evaluating previous customers with a relative weight of 0.403 in the first priority and having knowledge and experience with a relative weight of 0.354, financial power with a relative weight of 0.134, and quality system governing the company with a relative weight 0.109 is in the following priorities. The incompatibility rate of this set is 0.02, which indicates the almost complete compatibility of the comments.

Table 5 Prioritize the main criteria using the AHP method

Priority	Criteria	Weight
1	Technical evaluation	0.508
2	Qualitative evaluation	0.349
3	Price	0.143

Table 6 Final prioritization of criteria in Khorasan Razavi Power Distribution Company using AHP method

Priority	Criteria	Weight
1	Insulation shell thickness	0.144
2	Price	0.143
3	Evaluation of previous customers	0.140
4	Having knowledge and experience	0.123
5	DC electrical resistance	0.121
6	Unit weight length	0.100
7	Conductor string diameter	0.088
8	Marking quality	0.052
9	Financial power	0.046
10	Quality system governing the company	0.038

Finally, the general priorities of the selection criteria for three-phase self-supporting cable suppliers in Khorasan Razavi Power Distribution Company shown in the next table. Accordingly, the criterion of insulation shell thickness with a relative weight of 0.144 is the most important, and the criterion of the quality system governing the company with a relative weight of 0.038 is the least important in selecting the supplier. See Tables 5 and 6

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Declarations

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