A Dual Model for Selecting Technology and Technology Transfer Method Using a Combination of the Best-Worst Method (BWM) and Goal Programing

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Abstract

Supplier selection is vital in the supply chain, with significant effects on the chain structure. Three important factors contribute to this process, namely, product/technology selection, selection of the technology/product transfer method, and supplier selection. In this study, after defining the influential criteria for these factors, the best-worst method (BWM) was employed for measuring the weights. Next, the three factors were incorporated into goal programming (GP) to minimize the cost and failure and maximize the level of service and environmental compliance. The results of the GP indicated the level of demand allocation to the supplier(s). Overall, the gray analytical network process (GANP) is used as the best decision-making method, and over the past four years, BWM has been applied in decision-making processes. Therefore, the GANP method was used to measure the weights of criteria. These weights were also incorporated into GP for comparison with the proposed combination. The results showed the superiority of BWM-GP over GANP-GP, given the reduced cost and failure, besides the increased level of service and environmental compliance.

Keywords: Supplier selection, Technology selection, Best-worst method, Goal programming, Gray analytical network process

1. Introduction

One of the factors affecting economic growth is the productivity of production resources, which is influenced by several factors, such as knowledge and technology transfer (TT) [1]. New technologies have introduced more effective ways to evaluate new aspects of human activities. In other words, by using these new technologies, it is possible to increase the quality of services, improve efficiency, reduce the time required for entering new products into the market, and satisfy inexhaustible needs [2]. Developing countries have strengthened their technological foundations by transferring technologies from developed countries. Also, by creating appropriate economic infrastructures, they have improved their academic and research facilities [3]. However, few countries are self-sufficient in terms of technological demands. Therefore, TT is essential for bridging the technological gap between developing and developed countries.

The TT process is possible through various methods, depending on the position of the technology receiver and donor [4, 5]. The assessment of technology and its transfer methods is essential for any business enterprise and should be implemented at specific intervals. Various studies have been conducted around the world, including a study by Klintenberg et al. [6], which examined the success factors for TT from developed to developing countries.

In this study, we aimed to propose a novel and efficient method for TT with two simultaneous steps of technology selection and TT method selection. However, to the best of our knowledge, there is a scarcity of research, examining these two steps of TT, simultaneously. Besides, the proposed model was developed to control uncertainties in various situations, as they have been neglected in previous studies. The best-worst method (BWM) is recognized as the best method for determining the weights of effective criteria, as it presents optimal results. Also, the weights obtained by the gray analytical network process (GANP) are compared with BWM and used as a variable coefficient in mathematical modelling.

The remainder of this paper is structured as follows. Section 2 describes the research background; Section 3 provides a description of BWM, GANP, and mathematical modelling; Section 4 presents the results of a case study and data analysis; and Section 5 presents the conclusions.

2. Literature Review

A variety of decision-making methods have been employed for TT selection. In a previous study, the analytic network process (ANP) method was used to determine the priority of TT methods in the oil drilling industry [7]. Moreover, the decision-making trial and evaluation laboratory (DEMATEL) has been incorporated in ANP to select a building's light-emitting diodes [8]. Moreover, the ANP method has been utilized to determine a suitable technology for wastewater treatment in Malaysia [9]. Aliakbari Nouri et al. [10] employed a hybrid multi-criteria decision-making (MCDM) approach, according to the fuzzy technique for order preference by similarity to ideal situation (TOPSIS) and fuzzy ANP for technology selection. In another study, Lee et al. used the fuzzy ANP method, combined with the fuzzy Delphi method to select the best supplier in the transistor industry [11]. Moreover, to examine the green supplier development programs, Dou et al. [12] used a GANP-based model. Also, Tuzkaya and Yolver [13] used an integrated GANP method to measure the weights of criteria for selecting a research and development project. They also ranked projects, using the gray relational analysis (GRA) method.

TOPSIS is another MCDM method, which has been used along with fuzzy numbers, to select the best source of technology in different industries, including medical equipment [14–16]. In this regard, Sharawat and Dubey [17] used the TOPSIS method to rank the criteria for selecting technologies in health and treatment. Also, Kumar et al. [18] used the analytical hierarchy process (AHP), which is recognized as a simple and effective MCDM method, to determine the influential factors in the TT process and calculate the correlation coefficients. In the following year, Hu et al. [19] attempted to select an appropriate technology for wastewater treatment plants by adding fuzzy numbers and incorporating the preferential ranking technique to AHP. Moreover, Farshidi et al. [20] used the AHP method to design a decision support system for selecting a software technology. Also, Mokhtarzadeh et al. [21] used the structural hierarchy process to identify the influential criteria for selecting technology in the information technology industry. Rahimi et al. [22] employed the AHP technique for ranking technologies and selecting an appropriate location for a hospital. On the other hand,

Amirghodsi et al. [23] used a hybrid Delphi-DEMATEL-ELECTRE method on gray numbers to rank technology providers. Additionally, Sahin and Yip [24] conducted a case study to improve the structural hierarchy method of TT in the transportation industry after describing the Gaussian fuzzy analytic hierarchy process. Their results confirmed the appropriateness of this model for selecting the proper transportation technology. In another study, Mardani et al. [25] used the data envelopment analysis (DEA) to assess energy efficiency. Also, Goker and Karsak [26] aimed to improve the criterion weights by using the DEA technique.

Ren [27] employed a general MCDM model to classify ballast water treatment technology. The internal consistency method, the weighted objectives method and the BWM method were combined to calculate the weights. Moreover, Van De Kaa et al. [28] used BWM to calculate the relative importance (weight) of the evaluation criteria in the Netherlands. Next, to rank the best biomass thermochemical conversion technologies, the weights of the criteria were used. Also, Rezaei et al. [29] applied BWM and Service Quality (SERVQUAL) method to evaluate the quality of luggage loading systems. The SERVQUAL considers intangible performance aspects, whereas BWM allows us to determine the weights of service quality criteria. Additionally, Rezaei et al. [30] identified the most qualified supplier in the edible oil industry by using BWM. Setyono and Sarno [31] used BWM for weighing criteria, which were formerly examined and oriented to the company's business goals. They also compared multi-objective optimization based on ratio analysis (MOORA) and complex proportional assessment (COPRAS) approaches for the supplier assessment.

For ranking hydrogen production technologies with data uncertainties, Xu et al. [32] introduced a novel MCDM framework by combining the interval BWM (IBWM) method, interval best-worst projection (IBWP) method, and interval entropy technique (IET). Moreover, Jafarzadeh Ghoushchi et al. [33], in a case study in the oilseed industry, addressed sustainable supplier selection. For determining the weights of the supplier selection criteria, they used the fuzzy best-worst method (FBWM). Next, the suppliers were ranked, using a piecewise linear function. Also, Hendalianpour et al. [34] used the interval-valued fuzzy-rough number (IVFRN)-BWM method for ranking the suppliers. Overall, various MCDM methods, including DEMATEL, ANP, AHP, TOPSIS, and BWM, have been used in different studies. However, BWM yields more desirable results in comparison with the other methods.

Furthermore, Lee and Kim [35] used ANP and zero-one goal programming (GP) for interdependent information system project selection. A few years later, Yurdaklu [36] presented a combined AHP and GP model to select computer-integrated manufacturing technologies. Also, Feng et al. [37] used a linear mathematical model and the MCDM approach simultaneously to select and appraise the suppliers. Moreover, Kannan et al. [38] employed multi-criteria hybrid approaches for ranking the suppliers. In their study, the weights of criteria were measured, and the ranks were determined, using the fuzzy AHP method. After weighing the selected criteria, the fuzzy multi-objective linear programming was employed to define the optimal supplier order. Additionally, Li and Wan [39] introduced a mathematical model to determine the best supplier. They adopted a fuzzy GP approach to assess the predetermined criteria weights. Also, Hamurcu and Eren [40] incorporated the weights obtained by AHP into a GP model to identify the best alternative electric automobile technology. Also, Lin et al. [41] recently devised a new decision-making framework to solve the decision-making problem in selecting biorefineries under uncertainties.

Moreover, Vahidi et al. [42] introduced a randomized, probabilistic, two-step programming model for supplier selection to maximize stability, increase the supplier's flexibility, and minimize the total cost. Additionally, Sarkar et al. [43] integrated the multi-attribute decision making (MADM) approach and mathematical programming, along with quantitative and qualitative criteria, combined fuzzy ANP-based DEMATEL method, fuzzy TOPSIS method, and multi-segment goal programming (MSGP), for supplier selection. Also, Hendalianpour et al. [44] used zero-one mixed-integer programming, where the objective function minimized the cost of the distribution chain and enhanced customer satisfaction.

Previous studies have proposed various criteria for technology selection and transfer. In this regard, Mazdeh et al. [45] considered the influential factors in TT, including technology localization, complexity, willingness to learn, organizational distance, mutual trust, and learning culture. Also, Kharat et al. [46] addressed the criteria of purchase and consumption costs, environmental compatibility, efficiency, technological reliability, expertise requirements, and public acceptance. Moreover, Montazeri and NajartabarBisheh [47] described the criteria for technology localization, the benefits of technology, and the risks of replacing the existing technology with a new one.

A more precise look at the literature indicates that researchers have jointly used many evaluation criteria to assess appropriate technologies and different TT methods; this represents the close link between these two stages of the TT process. On the other hand, the literature review indicated that the uncertainty aspect, which is an undeniable part of selecting and transferring technology, has been less noted in previous studies, especially when it comes to solving this problem using gray numbers. Besides, none of the existing models address the selection of technology/technology provider and TT method simultaneously, and only one of these two steps is appraised in the TT process.

In the present study, we first attempted to examine, develop, define, and rank the criteria for selecting the technology, supplier, and TT method. Next, by applying a combined decision-making method, we proposed a systematic and understandable model to resolve the problem of selecting technology and the TT method simultaneously to meet the needs of different industries and organizations, including the petroleum industry.

3. Methodology

In this study, the proposed model consisted of two main parts, that is, BWM and GP. As mentioned earlier, the BWM method was used to weigh the criteria. Next, the technology suppliers and the extent of order allocation were determined, using multi-objective linear GP. The steps of this study are as follows:

- Extracting the important criteria for the selection of technology, technology supplier, and TT method: This was accomplished using an expert panel (decision-makers), who used different sources to prepare a list, based on the organization’s goals, requirements, and other influential factors.
- Using the BWM approach to prioritize and incorporating the weights of criteria, extracted in the previous step.
- Feeding the outputs of the previous step as the inputs of GP to obtain optimal results for selecting the suppliers and determining their order allocations.

Figure 1 displays the conceptual map of this study, which aimed to present a novel integrated model for the supplier selection problem by applying BWM and GP to find reliable solutions under uncertain circumstances.

Please insert Figure 1 about here

As presented in Figure 1, the extracted criteria were prioritized and weighed, using the priority matrix and BWM method. This process was repeated with the GANP method for comparisons with the BWM results. At the end of this process, each group of suppliers, technologies, and TT methods was weighed. Finally, the results of supplier selection and the amount of allocation were determined by transferring the obtained weights from each method separately to the GP model. A combination of MCDM and GP methods was used in the proposed model. The BMW method was considered the main decision-making model, while the GANP decision-making approach was employed for comparisons with the BWM method. The three stages in Figure 1 will be described in the following sections in detail.

Stage 1: Criteria extraction

By performing a comprehensive review of the literature and conducting open interviews with experts, a complete set of criteria, affecting the selection of technology, technology supplier, and TT method, was determined. Also, in this step, the TT methods, the main suppliers of drill bits in the oil industry, and the existing technologies for producing the drill bits were specified. The snowball sampling method was applied to select experts. At the beginning of the study, the interviewees were asked to introduce potential experts. The experts were chosen among managers and experts of the drill goods supply and purchase department of the Iranian Central Oil Fields Company. The experts cooperated with the authors in all steps of the study (e.g., decision matrix analysis). The demographic characteristics of the interviewed experts are presented in Table 1.

Please insert Table 1 about here

Stage 2: MCDM approach

In this section, the two main methods used in the present study are described. The BWM method was used as the main computing method, while the GANP method was employed for comparisons.

A. BWM method

BWM is the newest method of MCDM. Its advantages, compared to other MCDM models, include the reduced need for comparison and higher reliability [48]. For example, AHP is the most widely used MCDM method, which requires $(n(n-1))/2$ comparisons, while the BWM method requires $(2n-3)$ comparisons [49]. The steps of this method are presented in Figure 2 [30,48,50]:

Please insert Figure 2 about here

In the first step, the criteria influencing the decision-making process were identified. These criteria were assumed to be $\{c_1, c_2, \ldots, c_n\}$.

In the second step, the most important (best) and the least important (worst) criteria were specified. Next, the superiority of the best criterion over other criteria was determined. The best-to-others vector is as follows:

$$A_B = (a_{B1}, a_{B2}, ..., a_{Bn}), \qquad (1)$$

In this vector, a_{Bj} represents the preference of the best criterion B over criterion j $(a_{BB} = 1)$.

In the fourth step, the inferiority of the worst criterion to all other criteria was established. The others-to-worst vector is as follows:

$$A_W = (a_{1W}, a_{2W}, ..., a_{nW})^T. \qquad (2)$$

In this vector, a_{jW} represents the superiority of the criterion j over the worst criterion W $(a_{WW} = 1)$.

In the fifth step, the optimal weights $(w_1^*, w_2^*, ..., w_n^*)$ were determined, using Equation 3. To reach the optimal weights the maximum absolute differences $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_W} - a_{jW}\right|$ should be minimized for all j:

$$\min \max_j \left\{ \left|\frac{w_B}{w_j} - a_{Bj}\right|, \left|\frac{w_j}{w_W} - a_{jW}\right| \right\}$$

s.t.

$$\sum_j w_j = 1$$

$$w_j \geq 0, \text{ for all } j \qquad (3)$$

The min-max model in equation (3) was used to solve the problem below:

$$\min \ \xi$$

s.t.

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \le \xi, \text{ for all j}$$

$$\left|\frac{w_j}{w_W} - a_{jW}\right| \le \xi, \text{ for all j}$$

$$\sum_j w_j = 1$$

$$w_j \ge 0, \text{ for all j} \tag{4}$$

The optimal weights $(w_1^*, w_2^*, ..., w_n^*)$ and ξ^* were determined in the abovementioned problem. It should be noted that ξ^* represents the comparison consistency. A larger ξ^* is associated with a higher consistency ratio and lower reliability of comparisons; therefore, reliability is greater when ξ^* is closer to zero. Overall, a consistent comparison can be made when $a_{Bj} \times a_{jW} = a_{BW}$ for all j. In this regard, Rezaei (2015) proposed a consistency index (CI), using the maximum possible $\xi(\max \xi)$ for $a_{BW} \in \{1, 2, ..., 9\}$, as presented in Table 2. According to the index in Table 2, Equation 5 can be used to measure the consistency ratio $\in [0,1]$ [48]:

$$\text{Consistency Ratio} = \frac{\xi^*}{\text{Consistency Index}} \tag{5}$$

Please insert Table 2 about here

It should be noted that for a not fully consistent problem ($\xi^* \succ 0$) with more than three influencing criteria, like the one we were facing, multiple optimal solutions exist. Therefore, we considered the optimal weight of each criterion as an interval. The lower and upper bounds of the weight of each criterion would be calculated by applying equations 6 and 7. We used the center of each interval as the weight of the criterion [51].

$\min\ w_j$

s.t.

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \le \xi^*, \text{ for all j}$$

$$\left|\frac{w_j}{w_W} - a_{jW}\right| \le \xi^*, \text{ for all j}$$

$$\sum_j w_j = 1$$

$$w_j \ge 0, \text{ for all j} \tag{6}$$

$$\max\ w_j$$

s.t.

$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \le \xi^*, \text{ for all j}$$

$$\left|\frac{w_j}{w_W} - a_{jW}\right| \le \xi^*, \text{ for all j}$$

$$\sum_j w_j = 1$$

$$w_j \ge 0, \text{ for all j} \tag{7}$$

B. GANP method

The ANP method, which was used as the basis of our comparisons, is derived from the AHP method. This method can model the correlations and feedback between different decision-making elements and integrate all internal effects in the decision-making process for computations [52]. Compared to simple scoring methods, ANP presents a more robust solution, without requiring complex mathematical modelling or computations [12,53]. Therefore, this method is distinct and superior to other decision-making processes. We also used the gray system theory to include incomplete and uncertain information. In the GANP method, gray numbers were also used. Despite the similarity of gray and fuzzy numbers, the exact value of gray numbers is unknown, while the span containing that number is clear. A fuzzy number is defined as a span, and the exact values of its left and right wings are unknown and follow a membership function [54].

B.1. Gray system theory

If there is incomplete or indeterminate information, the gray system theory can be used in system analysis, modelling, data processing, and decision-making to assess the outcomes [12,23,55]. We used the gray aggregation method in this study [56]. In the following equation, x represents a closed and bound set of real numbers, and $\otimes x$ (a gray number) is an interval with definite upper and lower limits, but indefinite distribution information for x [57]:

$$\otimes x = \left[\underline{\otimes} x, \overline{\otimes} x\right] = \left[x' \in x \mid \underline{\otimes} x \le x' \le \overline{\otimes} x\right] \tag{8}$$

where $\underline{\otimes} x$ and $\overline{\otimes} x$ denote the lower and upper limits of $\otimes x$, respectively. Some basic gray number mathematical operations are presented below:

$$\otimes x_1 + \otimes x_2 = \left[\underline{x}_1 + \underline{x}_2, \overline{x}_1 + \overline{x}_2\right] \tag{9}$$

$$\otimes x_1 - \otimes x_2 = \left[\underline{x}_1 - \overline{x}_2, \overline{x}_1 - \underline{x}_2\right] \tag{10}$$

$$\otimes x_1 \times \otimes x_2 = \left[\min(\underline{x}_1\underline{x}_2, \underline{x}_1\overline{x}_2, \overline{x}_1\underline{x}_2, \overline{x}_1\overline{x}_2), \max(\underline{x}_1\underline{x}_2, \underline{x}_1\overline{x}_2, \overline{x}_1\underline{x}_2, \overline{x}_1\overline{x}_2)\right] \tag{11}$$

$$\otimes x_1 \div \otimes x_2 = \left[\underline{x}_1, \overline{x}_1\right] \times \left[\frac{1}{\underline{x}_2}, \frac{1}{\overline{x}_2}\right] \tag{12}$$

The gray aggregation method, which is known as a variation of the Converting Fuzzy Data into Crisp Scores (CFCS) defuzzification method, was used to calculate the crisp values in a gray environment [56]. The gray number $\otimes x_{ij}^{k}$ was applied for the decision-maker k to assess the superiority of supplier i in TT method j. The lower and upper gray values, i.e., $\underline{\otimes} x_{ij}^{k}$ and $\overline{\otimes} x_{ij}^{k}$, were respectively used by the decision-maker k to estimate the relationship between supplier i and TT method j:

$$\underline{\otimes} x_{ij}^{k} = \left[\underline{\otimes} x_{ij}^{k}, \overline{\otimes} x_{ij}^{k}\right] \tag{13}$$

There are three steps in the modified-CFCS method:

Step 1: Normalization:

$$\underline{\otimes}x_{ij}^{k} = \left[\underline{\otimes}x_{ij}^{k} - \min_{j}\underline{\otimes}x_{ij}^{k}\right] \Big/ \Delta_{\min}^{\max} \quad (14)$$

$$\overline{\otimes}x_{ij}^{k} = \left[\overline{\otimes}x_{ij}^{k} - \min_{j}\overline{\otimes}x_{ij}^{k}\right] \Big/ \Delta_{\min}^{\max} \quad (15)$$

where $\Delta_{\min}^{\max} = \max_{j}\overline{\otimes}x_{ij}^{k} - \min_{j}\underline{\otimes}x_{ij}^{k}$ (16)

Step 2: Calculation of the total normalized crisp value:

$$Y_{ij}^{k} = \frac{\left(\underline{\otimes}x_{ij}^{k}\left(1-\underline{\otimes}x_{ij}^{k}\right)+\left(\overline{\otimes}x_{ij}^{k}\times\overline{\otimes}x_{ij}^{k}\right)\right)}{\left(1-\underline{\otimes}x_{ij}^{k}+\underline{\otimes}x_{ij}^{k}\right)} \quad (17)$$

Step 3: Calculation of crisp values:

$$Z_{ij}^{k} = \min_{j}\underline{\otimes}x_{ij}^{k} + Y_{ij}^{k}\Delta_{\min}^{\max} \quad (18)$$

B.2. ANP:

The ANP method is defined as follows:

B.2.1. Step 1: Constructing a decision network

To construct this network, it is essential to review previous studies and consult decision-makers. Some methods, including the interpretative structural modelling [58] and DEMATEL [59–61], can be applied for determining these structures. In this study, to develop a decision network, we used expert opinion.

B.2.2. Step 2: Extracting pairwise comparisons

We asked pairwise comparison questions to determine the relative significance of factors and clusters and develop an ANP decision network. The comparisons involved inter-factor and inter-cluster comparisons.

B.2.3. Step 3: Assessing the relative importance of factors

Different online software programs are used in decision analysis to calculate the relative importance of factors. In this study, we used MATLAB software for this purpose.

B.2.4. Step 4: Formulating a super-matrix from the weights

A super-matrix should be formulated when using the ANP method to determine the interdependence among clusters and factors. The Markov chain model and the concept of super-matrix resemble each other [62]. The relative weights, calculated in step 3, were integrated into a super-matrix, based on the effect of one cluster or factor on another. Four elements were incorporated to develop a super-matrix: (1) Identifying a matrix for all alternatives, unless they influence each other; (2) determining the relationship with the final objective; (3) comparison of alternative relationships with regard to the factors; and (4) comparisons among factors and clusters.

B.2.5. Step 5: Computation of stable weights from the super-matrix

To determine the stable weights of alternatives, the power of the super-matrix, determined in step 4, should be increased so that the weights converge and stabilize.

B.3. A gray ANP-based model:

The gray ANP-based approach is characterized by several steps: (a) Constructing a decision network; (b) making pairwise comparisons; (c) assessing the relative weights of criteria; (d) constructing a super-matrix from the weights; (e) evaluating the long-term weights for the super-matrix; (f) examining the supplier's priority for different TT methods; and (g) identifying the final ranks of suppliers.

Stage 3: Mathematical programming

In this section, optimal mathematical modelling was performed by applying the weights of the effective criteria for technology selection, TT method selection, and supplier selection. The allocation to each supplier was calculated, using the obtained weights from BWM and GANP methods for comparisons. For this purpose, first, the definitions of variables and parameters in the mathematical model were provided:

Sets

i Set of providers, $i = 1, 2, 3, ..., I$

j Set of technologies, $j = 1, 2, 3, ..., J$

k Set of TT methods, $k = 1, 2, 3, ..., K$

Parameters

$\tilde{X}_{ijk}$ The amount of demand from supplier i for technology j using TT method k

$\tilde{D}$ Total product demand

$\tilde{C}_{ijk}$ The capacity of supplier i for technology j using TT method k

$\mathrm{TS}_{\mathrm{ijk}}$ The final score of supplier i according to the technology selection criteria j and TT method k

$\tilde{L}_{ijk}$ The procurement time determined by the technology receiver for technology j from supplier i using TT method k

l_{ijk} The time needed to supply the demands for technology j by supplier i using TT method k

$\tilde{\tilde{C}}_{p}$ The required level of quality defined by the technology receiver

$\tilde{C}_{i}$ The quality level of the supply acquired from supplier i

$\tilde{q}_{ijk}$ The breakdown and maintenance rate of the acquisition process from supplier i for technology j using TT method k

$S\tilde{L}$ Customer's required service level

$\tilde{S}_{ijk}$ The required service level of supplier i for technology j using TT method k

F The desired price of the customer

Δ_{ijk} The proposed price by supplier i for technology j using TT method k

$\bar{C}_{ijk}$ The supply cost of supplier i for technology j using TT method k

C_{l} The minimum cost of technology

$\tilde{P}_1, \tilde{P}_2$
$\tilde{P}_3, \tilde{P}_4$ The obtained weight for each defined criterion in the target function

Y_{ijk} If demand is allocated to supplier i for technology j using TT method k, the binary variable will be equal to 1; otherwise, it will be 0.

E_{ijk} The degree of environmental compliance of supplier i, according to technology j

and TT method k

Z_i The degree of environmental compliance, specified by the technology receiver

$\tilde{H}_{ijk}$ The least commitment to the environmental issues of supplier i having technology j while using TT method k

B_i The allocated goal for supplier i

d^+ The upper limit of deviation from the goal

d^- The lower limit of deviation from the goal

Considering the weights obtained from BWM and GANP methods, as shown by $\tilde{P}_i$, the target functions (Equations 19-22) were developed, and finally, Equation 23 was obtained:

$$MinZ_1 = \sum_i \sum_j \sum_k \Delta_{ijk} \tilde{X}_{ijk} \quad (19)$$

$$MinZ_2 = \sum_i \sum_j \sum_k \tilde{q}_{ijk} \tilde{X}_{ijk} \quad (20)$$

$$MaxZ_3 = \sum_i \sum_j \sum_k \tilde{S}_{ijk} Y_{ijk} \quad (21)$$

$$MaxZ_4 = \sum_i \sum_j \sum_k E_{ijk} Y_{ijk} \quad (22)$$

Equation (19) represents the minimum supply cost, Equation (20) represents the minimum failure, Equation (21) represents the maximum level of service provided by the supplier, and Equation (20) represents the maximum compliance of the supplier with environmental issues. Equations (19) and (20) pertain to cost and failure minimization, and Equations (21) and (22) pertain to maximizing the service level and supplier's environmental compliance, respectively.

$$MinZ = \tilde{P}_1 Z_1 (d_1^-) + \tilde{P}_2 Z_2 (d_2^-) + \tilde{P}_3 Z_3 (d_3^+) + \tilde{P}_4 Z_4 (d_4^+) \quad (23)$$

$$\sum_{i=1} \sum_{j=1} \sum_{k=1} T\tilde{S}_{ijk} \tilde{X}_{ijk} + d_1^+ - d_1^- = B_i \qquad \forall_i \quad (24)$$

$$\sum_{i=1} \sum_{j=1} \sum_{k=1} E_{ijk} Y_{ijk} + d_2^+ - d_2^- \geq Z_i \quad (25)$$

$$\sum_{i=1}\sum_{j=1}\sum_{k=1} Z_i Y_{ijk} + d_2^+ - d_2^- \leq \tilde{H}_{ijk} \tag{26}$$

$$\sum_{i=1}\sum_{j=1}\sum_{k=1} \tilde{C}_i Y_{ijk} + d_3^+ - d_3^- \cong \bar{C}_p \sum_{i=1}\sum_{j=1}\sum_{k=1} Y_{ijk} \tag{27}$$

$$\sum_{i=1}\sum_{j=1}\sum_{k=1} \Delta_{ijk} Y_{ijk} + d_4^+ - d_4^- = F \sum_{i=1}\sum_{j=1}\sum_{k=1} Y_{ijk} \tag{28}$$

$$\sum_{i=1}\sum_{j=1}\sum_{k=1} \tilde{q}_{ijk} \tilde{x}_{ijk} + d_5^+ - d_5^- = 0 \tag{29}$$

$$\sum_{i=1}^{n}\sum_{j=1}\sum_{k=1} \tilde{S}_{ijk} Y_{ijk} + d_6^+ - d_6^- = SL \sum_{i=1}\sum_{j=1}\sum_{k=1} Y_{ijk} \tag{30}$$

$$\sum_{i=1}^{n}\sum_{j=1}\sum_{k=1} \bar{C}_{ijk} Y_{ijk} + d_7^+ - d_7^- \geq C_l \tag{31}$$

$$\tilde{l}_{ijk} \tilde{X}_{ijk} + d_8^+ - d_8^- = L_{ijk} \tag{32}$$

$$\sum_{i=1}^{n}\sum_{j=1}\sum_{k=1} \tilde{X}_{ijk} = \tilde{D} \tag{33}$$

$$\tilde{X}_{ijk} \leq \tilde{C}_{ijk} \tag{34}$$

Equation (23) is the target function, determining the amount of allocation to each supplier, based on the defined goals (Eq. 17 to 20). According to the capacity of each supplier, the highest amount of allocation was determined for each supplier to meet the four goals of the technology receiver.

Constraint (24) presents the final score of each supplier. The higher the supplier's score is, the more demand is allocated to the supplier. Constraints (25) and (26) indicate the supplier’s environmental compliance and the minimum supplier allocation, respectively. These relations represent the highest to the lowest environmental compliance of suppliers and the allocated amount to each supplier. Constraint (27) guarantees the minimum required quality for selecting a supplier. Constraint (28) specifies the price of the supplier to supply the demand. This constraint selects the supplier, which offers the lowest price. Constraint (29) indicates the amount of technology failure of each supplier. In other words, it chooses the supplier with the lowest failure rate.

Due to the increasing importance of service satisfaction, constraint (30) represents the level of satisfaction with the supplier's services. Constraint (31) demonstrates the fixed price of technology (e.g., technology, transportation, and side costs) for each supplier. It is generally desirable to pay less for the desired technology. Constraint (32) shows the supplier's delivery time. Generally, time reduction is preferable for the receiving company. In other words, the shorter the delivery time is, the higher the supplier's allocation will be. Also, constraint (33) shows that selecting and assigning orders in a given period must be adequate, considering the technology receiver's demand. Constraint (34) considers each supplier's ability into account and ensures that orders do not exceed the capacity of the supplier.

4. Findings

As shown in the model presented in Figure 1, the results were analyzed, based on the finalized criteria, which were obtained by assessing the documents and open interviews with managers and experts of the drill goods supply and the purchasing department of Iranian Central Oil Fields Company. We developed and distributed pairwise comparison questionnaires among experts to meet our goals. Calculations were performed based on Equations 1 to 7. The weighing results, based on BWM, are presented in Table 3.

Please insert Table 3 about here

According to Table 3, "infrastructural issues" constituted the most important criterion in the category of technology selection. Also, in the category of TT method selection, "infrastructures" and "organizational affairs" were the most important criteria. Regarding the category of supplier selection, the product's state was the most important criterion. A general look at all 15 criteria showed that the "infrastructural issues" criterion was the first priority, followed by "organizational affairs" and "guarantee of success". As the amount of ξ^* calculated for the supplier category was zero, the obtained weights were completely reliable and consistent. The reliability and consistency of the TT category and technology selection were also established (ξ^* = 0.0831 and 0.157, respectively). The weights obtained for the criteria, using GANP, are shown in Table 4.

Please insert Table 4 about here

According to Table 4, the most important criteria in the selection and transfer of technology are “organizational affairs” and “technology”, respectively. Meanwhile, the least important criterion was “foresight”. It can be lengthy to present the weights of all constraining factors (e.g., cost, minimum failure, maximum service level, environmental compliance, technology supplier, and TT method) in a single table. Therefore, Table 1A, which presents the weights obtained by the BWM and GANP methods, is included in APPENDIX A. It should be noted that the top five suppliers were selected after determining the value and rank of 13 primary suppliers, according to the assessment criteria. Besides, after weighing the criteria and ranking the TT methods using the decision-making techniques, five transfer methods and three technologies were selected.

At this stage, after calculating the weights and by applying GAMS 24 software, the mathematical model was solved. GAMS 24 software was used to select the best supplier(s) and assign the optimal allocation to each supplier. The results of problem-solving, based on the defined criteria, are presented in Table 5. The lowest cost of supply was related to supplier 5 with 293 monetary units, followed by suppliers 2 and 4. Supplier 5 was selected as the optimal supplier, considering the negative impact of increased cost. On the other hand, the GANP method selected supplier 2 with 308 monetary units. According to the results of BWM, by integrating the other three factors in addition to the “supply cost”, supplier 5 was again selected as the first choice for optimal allocation and supply of demands, followed by suppliers 2 and 4, respectively. The optimal allocation to each supplier, based on the results of problem-solving in GAMS 24, is shown in Table 6.

Please insert Tables 5 and 6 about here

As shown in Table 6, the highest demand allocation was related to supplier 5 (3215 roller cone bits, 2453 polycrystalline diamond compacts, and 2864 core bits), which is in line with the results of BWM, as shown in Table 5. Therefore, supplier 5 was superior to the other two suppliers. Suppliers 2, 4, and 5 supplied all demands for bits.

Table 7 presents the optimal values of goals, according to the weights obtained by each method. This table indicates the optimal range of allocation for each product. It should be noted that the optimal values in this table were obtained according to the weights obtained by the BWM and GANP methods. The deviations from the optimal values are presented in Table 8, based on additional allocations.

Please insert Tables 7 and 8 about here

5. Conclusion

The selection of appropriate technology, TT method, and optimal supplier has a significant effect on organizations by reducing costs and environmental issues, increasing efficiency, using organizational and individual capabilities, risk control, and proper planning for the optimal use of time and resources. The GP method, along with BWM, was used in this study to select the best suppliers and allocate optimal demands. On the other hand, the GANP decision-making method was used to compare the results with those obtained by integrating the BWM method into GP. In this study, the goals of GP were as follows: 1) reduction of TT cost; 2) increase of quality; 3) promotion of service level; and 4) reduction of environmental damage (Eq. 17 to 20). This study primarily aimed to rank the criteria for technology and TT method selection. According to Table 3, the criterion of "infrastructural issues" was the most important criterion in the BWM method. Therefore, special attention must be paid to issues, such as the required hardware and software for product/technology transfer, organizational and cultural adaptability, and the required internal and international laws. According to the results of the GANP method presented in Table 4, the criterion of "organizational affairs" was the most important one. Despite the importance of this criterion in the TT process, even if all of its sub-criteria are considered, and the most compatible technology is selected, the TT process cannot be successful, unless the necessary infrastructures for technology transfer and utilization are available. From this point of view, the BWM method, as expected, yielded more accurate results than the GANP method. The selection of suppliers was dependent on the weights obtained by BWM and GANP methods used in the mathematical programming model. Finally, the demands were supplied using GP. The results of problem-solving in the mathematical model indicated the superiority of BWM. In future studies, other combinations, such as IVFRN-BWM, can be used along with GP.

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Figures' Captions

Figure Number	Caption
Figure 1	The conceptual model of the study
Figure 2	The BWM procedure

Tables' Captions

Table Number	Caption
Table 1	The demographic characteristics of the experts
Table 2	The consistency index (CI)
Table 3	The weights of criteria based on BWM
Table 4	The weights of the criteria based on the GANP method
Table 5	The optimal values for each supplier according to two different decision-making methods
Table 6	Demand allocation to each supplier
Table 7	The optimal values and sensitivity analysis of each product
Table 8	Deviations from the optimal values

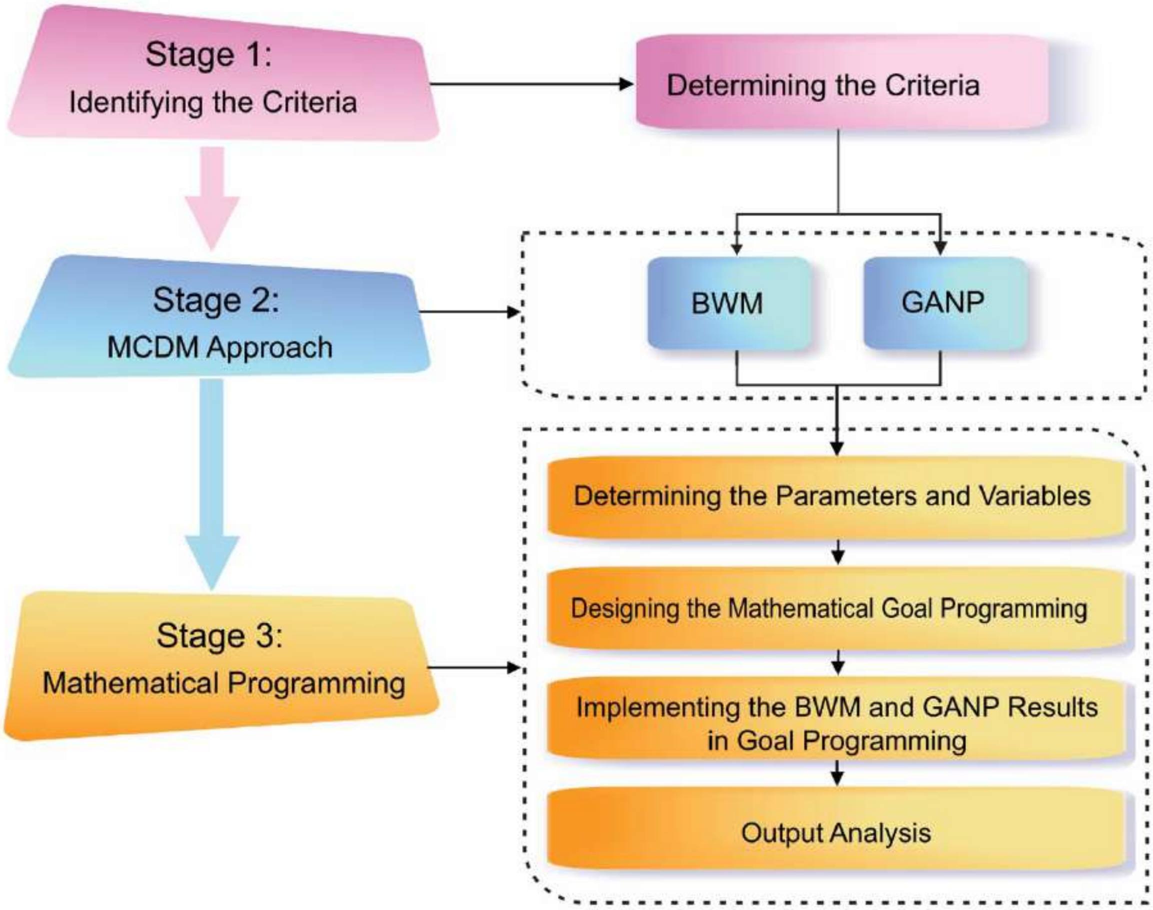

Figure 1: The conceptual model of the study

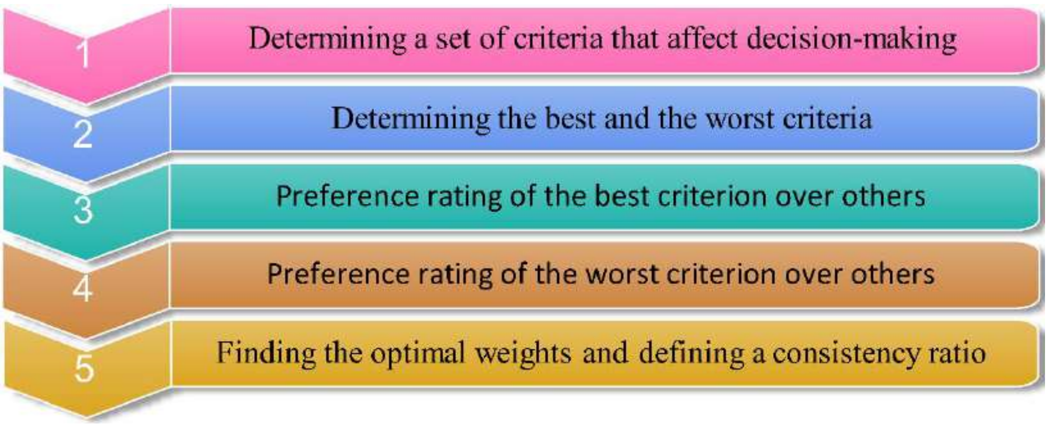

Figure 2: The BWM procedure

Table 1. The demographic characteristics of the experts

Gender		Educational level			Work experience in the building industry (years)		Age (years)			
Male	Female	Bachelor's degree	Master's degree	PhD	10-20	>21	30-40	41-50	51-60	>61
15	0	5	7	3	4	11	2	4	6	3
100%	0%	33.3%	46.6%	20%	26.7%	73.3%	13.3%	26.7%	40%	20%

Table 2. The consistency index (CI) [48]

a_{BW}	1	2	3	4	5	6	7	8	9
CI (max ξ)	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Table 3. The weights of criteria based on BWM

Row	Category	Category Weight	Factor	Factor weight	ξ^*	Compatibility level	The final weight of the factor	Final rank
1	Technology selection (T)	0.153	Technology	0.157	0.157	0.0318	0.024	8
2			Infrastructural issues	0.272			0.069	4
3			Foresight	0.175			0.027	7
4			Terms and Conditions	0.053			0.008	14
5			Risk	0.181			0.028	6
6			Recipient organization	0.162			0.025	9
7	TT method selection (E)	0.587	Guarantee of success	0.158	0.0831	0.0164	0.091	3
8			Infrastructure	0.614			0.360	1
9			Organizational affairs	0.172			0.101	2
10			Environmental issues	0.106			0.062	5
11	Supplier selection (G)	0.062	Recipient organization	0.157	0	0	0.009	13
12			Terms and Conditions	0.166			0.0103	12
13			Risk	0.277			0.017	11
14			Foresight	0.085			0.005	15
15			Product's state	0.315			0.019	10

Table 4. The weights of the criteria based on the GANP method

Factor	The final weight of the factor	Rank
Technology	0.122	2
Infrastructural issues	0.077	7
Foresight	0.058	9
Terms and Conditions	0.077	7
Risk	0.096	6
Recipient organization	0.071	8
Guarantee of success	0.146	3
Infrastructure	0.1	5
Organizational affairs	0.146	1
Environmental issues	0.108	4

Table 5. The optimal values for each supplier according to two different decision-making methods

Supplier (s)	BWM				GANP			
	Cost (in thou-sands of dollars)	Minimum failure	Compliance of supplier with environmental issues	Maximum service level	Cost (in thou-sands of dollars)	Minimum failure	Compliance of supplier with environmental issues	Maximum service level
	Minimum	Minimum	Maximum	Maximum	Minimum	Minimum	Maximum	Maximum
1	354	0.028	0.82	0.92	363	0.025	0.82	0.90
2	300	0.002	0.95	0.96	308	0.005	0.93	0.92
3	371	0.012	0.63	0.90	373	0.014	0.73	0.87
4	311	0.004	0.95	0.95	317	0.007	0.93	0.90
5	293	0.001	0.95	0.96	318	0.003	0.90	0.91

Table 6. Demand allocation to each supplier

Technology / Supplier	Roller Cone Bits	Polycrystalline Diamond Compacts	Core Bits
1	0	0	0
2	1558	1828	1567
3	0	0	0
4	1768	1836	1954
5	3215	2453	2864
Total	6541	6117	6385

Table 7. The optimal values and sensitivity analysis of each product

Technology	Via BWM weights			Via GANP weights		
	Upper bound	Amount	Lower bound	Upper bound	Amount	Lower bound
Roller Cone Bits	6562	6541	6538	6586	6541	6527
Polycrystalline Diamond Compact s	6120	6117	6112	6175	6117	6109
Core Bits	6391	6385	6380	6411	6385	6373

Table 8. Deviations from the optimal values

Row	Goals	Negative deviation	Positive deviation
1	Cost (in thousands of dol-lars)	304	0
2	Minimum failure	0.002	0
3	Environmental compliance	0	0.93
4	Maximum service level	0	0.95

APPENDIX A

Table 1A. The weights of constraining factors in the mathematical model for each technology, TT method, and supplier

Suppliers	Technology	Technology transfer method	Constraint	Weights by BWM	Weights by GANP
Supplier 1	Roller Cone Bits	Licensing	Cost	0.27	0.24
			Minimum failure	0.14	0.17
			Maximum service level	0.32	0.31
			Environmental compliance	0.27	0.28
		Foreign investment	Cost	0.21	0.24
			Minimum failure	0.23	0.20
			Maximum service level	0.35	0.37
			Environmental compliance	0.21	0.19
		Contracting	Cost	0.30	0.21
			Minimum failure	0.17	0.19
			Maximum service level	0.31	0.30
			Environmental compliance	0.22	0.30
		Alliance	Cost	0.29	0.27
			Minimum failure	0.20	0.27
			Maximum service level	0.37	0.34
			Environmental compliance	0.14	0.12
		Supply of production equipment	Cost	0.35	0.32
			Minimum failure	0.11	0.14
			Maximum service level	0.38	0.32
			Environmental compliance	0.16	0.22
	Polycrystalline Diamond Compact	Licensing	Cost	0.22	0.20
			Minimum failure	0.11	0.14
			Maximum service level	0.30	0.27
			Environmental compliance	0.37	0.39
		Foreign investment	Cost	0.34	0.32
			Minimum failure	0.15	0.15
			Maximum service level	0.18	0.20
			Environmental compliance	0.33	0.33
		Contracting	Cost	0.41	0.38
			Minimum failure	0.20	0.24
			Maximum service level	0.30	0.32
			Environmental compliance	0.09	0.06
		Alliance	Cost	0.25	0.27
			Minimum failure	0.10	0.15
			Maximum service level	0.27	0.25
			Environmental compliance	0.38	0.33
		Supply of	Cost	0.28	0.27

		production equipment	Minimum failure	0.08	0.10
			Maximum service level	0.31	0.34
			Environmental compliance	0.33	0.29
	Core Bits	Licensing	Cost	0.34	0.32
			Minimum failure	0.09	0.10
			Maximum service level	0.21	0.20
			Environmental compliance	0.36	0.38
		Foreign investment	Cost	0.27	0.25
			Minimum failure	0.14	0.18
			Maximum service level	0.30	0.34
			Environmental compliance	0.29	0.23
		Contracting	Cost	0.31	0.30
			Minimum failure	0.14	0.17
			Maximum service level	0.28	0.30
			Environmental compliance	0.27	0.23
		Alliance	Cost	0.38	0.35
			Minimum failure	0.12	0.14
			Maximum service level	0.29	0.30
			Environmental compliance	0.21	0.21
		Supply of production equipment	Cost	0.25	0.22
			Minimum failure	0.16	0.18
			Maximum service level	0.32	0.35
			Environmental compliance	0.27	0.25
Supplier 2	Roller Cone Bits	Licensing	Cost	0.25	0.27
			Minimum failure	0.14	0.17
			Maximum service level	0.32	0.33
			Environmental compliance	0.29	0.23
		Foreign investment	Cost	0.23	0.20
			Minimum failure	0.16	0.19
			Maximum service level	0.31	0.30
			Environmental compliance	0.30	0.31
		Contracting	Cost	0.40	0.35
			Minimum failure	0.09	0.12
			Maximum service level	0.21	0.30
			Environmental compliance	0.30	0.23
		Alliance	Cost	0.22	0.20
			Minimum failure	0.18	0.22
			Maximum service level	0.38	0.41
			Environmental compli-	0.22	0.17

		ance		
	Supply of production equipment	Cost	0.29	0.27
		Minimum failure	0.24	0.26
		Maximum service level	0.27	0.25
		Environmental compliance	0.20	0.22
Polycrystalline Diamond Compact	Licensing	Cost	0.26	0.30
		Minimum failure	0.11	0.12
		Maximum service level	0.25	0.30
		Environmental compliance	0.38	0.28
	Foreign investment	Cost	0.28	0.30
		Minimum failure	0.10	0.12
		Maximum service level	0.25	0.28
		Environmental compliance	0.37	0.30
	Contracting	Cost	0.32	0.28
		Minimum failure	0.25	0.28
		Maximum service level	0.25	0.30
		Environmental compliance	0.18	0.14
	Alliance	Cost	0.36	0.32
		Minimum failure	0.21	0.20
		Maximum service level	0.18	0.18
		Environmental compliance	0.25	0.30
	Supply of production equipment	Cost	0.32	0.30
		Minimum failure	0.24	0.28
		Maximum service level	0.26	0.28
		Environmental compliance	0.18	0.14
Core Bits	Licensing	Cost	0.25	0.20
		Minimum failure	0.21	0.25
		Maximum service level	0.36	0.30
		Environmental compliance	0.18	0.25
	Foreign investment	Cost	0.39	0.32
		Minimum failure	0.07	0.12
		Maximum service level	0.30	0.31
		Environmental compliance	0.24	0.25
	Contracting	Cost	0.34	0.30
		Minimum failure	0.18	0.20
		Maximum service level	0.29	0.32
		Environmental compliance	0.19	0.18
	Alliance	Cost	0.25	0.28
		Minimum failure	0.22	0.27

			Maximum service level	0.35	0.31
			Environmental compliance	0.18	0.14
		Supply of production equipment	Cost	0.28	0.31
			Minimum failure	0.22	0.34
			Maximum service level	0.29	0.30
			Environmental compliance	0.21	0.05
Supplier 3	Roller Cone Bits	Licensing	Cost	0.29	0.28
			Minimum failure	0.20	0.22
			Maximum service level	0.36	0.37
			Environmental compliance	0.15	0.13
		Foreign investment	Cost	0.30	0.28
			Minimum failure	0.11	0.15
			Maximum service level	0.35	0.30
			Environmental compliance	0.24	0.27
		Contracting	Cost	0.30	0.28
			Minimum failure	0.11	0.15
			Maximum service level	0.38	0.32
			Environmental compliance	0.21	0.25
		Alliance	Cost	0.30	0.28
			Minimum failure	0.14	0.16
			Maximum service level	0.29	0.32
			Environmental compliance	0.27	0.24
		Supply of production equipment	Cost	0.27	0.28
			Minimum failure	0.14	0.14
			Maximum service level	0.34	0.34
			Environmental compliance	0.25	0.24
	Polycrystalline Diamond Compact	Licensing	Cost	0.25	0.30
			Minimum failure	0.17	0.30
			Maximum service level	0.33	0.17
			Environmental compliance	0.25	0.23
		Foreign investment	Cost	0.25	0.27
			Minimum failure	0.16	0.18
			Maximum service level	0.40	0.29
			Environmental compliance	0.19	0.26
		Contracting	Cost	0.26	0.28
			Minimum failure	0.14	0.15
			Maximum service level	0.34	0.32
			Environmental compliance	0.26	0.25

		Alliance	Cost	0.24	0.25
			Minimum failure	0.11	0.15
			Maximum service level	0.35	0.32
			Environmental compliance	0.30	0.28
		Supply of production equipment	Cost	0.28	0.25
			Minimum failure	0.17	0.22
			Maximum service level	0.36	0.32
			Environmental compliance	0.19	0.21
	Core Bits	Licensing	Cost	0.32	0.30
			Minimum failure	0.09	0.14
			Maximum service level	0.37	0.31
			Environmental compliance	0.22	0.25
		Foreign investment	Cost	0.33	0.30
			Minimum failure	0.09	0.14
			Maximum service level	0.36	0.34
			Environmental compliance	0.78	0.22
		Contracting	Cost	0.33	0.36
			Minimum failure	0.09	0.14
			Maximum service level	0.32	0.29
			Environmental compliance	0.26	0.21
		Alliance	Cost	0.28	0.32
			Minimum failure	0.10	0.18
			Maximum service level	0.34	0.37
			Environmental compliance	0.28	0.13
		Supply of production equipment	Cost	0.24	0.28
			Minimum failure	0.10	0.14
			Maximum service level	0.31	0.30
			Environmental compliance	0.35	0.28
Supplier 4	Roller Cone Bits	Licensing	Cost	0.29	0.24
			Minimum failure	0.09	0.16
			Maximum service level	0.36	0.31
			Environmental compliance	0.26	0.29
		Foreign investment	Cost	0.27	0.28
			Minimum failure	0.12	0.16
			Maximum service level	0.32	0.30
			Environmental compliance	0.29	0.26
		Contracting	Cost	0.27	0.27
			Minimum failure	0.12	0.13
			Maximum service level	0.34	0.30

		Environmental compliance	0.27	0.30
	Alliance	Cost	0.25	0.24
		Minimum failure	0.12	0.12
		Maximum service level	0.35	0.37
		Environmental compliance	0.28	0.27
	Supply of production equipment	Cost	0.36	0.32
		Minimum failure	0.09	0.12
		Maximum service level	0.27	0.30
		Environmental compliance	0.28	0.26
Polycrystalline Diamond Compact	Licensing	Cost	0.34	0.31
		Minimum failure	0.08	0.14
		Maximum service level	0.29	0.31
		Environmental compliance	0.29	0.24
	Foreign investment	Cost	0.27	0.30
		Minimum failure	0.14	0.18
		Maximum service level	0.34	0.32
		Environmental compliance	0.25	0.20
	Contracting	Cost	0.26	0.25
		Minimum failure	0.17	0.20
		Maximum service level	0.36	0.31
		Environmental compliance	0.21	0.24
	Alliance	Cost	0.27	0.28
		Minimum failure	0.14	0.14
		Maximum service level	0.34	0.32
		Environmental compliance	0.25	0.26
	Supply of production equipment	Cost	0.30	0.31
		Minimum failure	0.14	0.14
		Maximum service level	0.36	0.30
		Environmental compliance	0.20	0.25
Core Bits	Licensing	Cost	0.30	0.34
		Minimum failure	0.11	0.14
		Maximum service level	0.28	0.30
		Environmental compliance	0.31	0.22
	Foreign investment	Cost	0.30	0.31
		Minimum failure	0.10	0.11
		Maximum service level	0.37	0.32
		Environmental compliance	0.23	0.26
	Contracting	Cost	0.36	0.30

			Minimum failure	0.08	0.16
			Maximum service level	0.34	0.32
			Environmental compliance	0.22	0.22
		Alliance	Cost	0.35	0.35
			Minimum failure	0.08	0.10
			Maximum service level	0.30	0.30
			Environmental compliance	0.27	0.25
		Supply of production equipment	Cost	0.35	0.32
			Minimum failure	0.07	0.09
			Maximum service level	0.31	0.28
			Environmental compliance	0.27	0.31
Supplier 5	Roller Cone Bits	Licensing	Cost	0.36	0.36
			Minimum failure	0.07	0.08
			Maximum service level	0.34	0.30
			Environmental compliance	0.23	0.26
		Foreign investment	Cost	0.38	0.30
			Minimum failure	0.07	0.09
			Maximum service level	0.32	0.27
			Environmental compliance	0.23	0.34
		Contracting	Cost	0.39	0.32
			Minimum failure	0.06	0.10
			Maximum service level	0.29	0.25
			Environmental compliance	0.26	0.33
		Alliance	Cost	0.28	0.24
			Minimum failure	0.16	0.17
			Maximum service level	0.34	0.33
			Environmental compliance	0.22	0.26
		Supply of production equipment	Cost	0.27	0.24
			Minimum failure	0.16	0.18
			Maximum service level	0.32	0.30
			Environmental compliance	0.25	0.28
	Polycrystalline Diamond Compact	Licensing	Cost	0.28	0.27
			Minimum failure	0.18	0.22
			Maximum service level	0.33	0.38
			Environmental compliance	0.21	0.13
		Foreign investment	Cost	0.30	0.33
			Minimum failure	0.12	0.13
			Maximum service level	0.33	0.30
			Environmental compli-	0.25	0.14

		Environmental compliance		
	Contracting	Cost	0.30	0.28
		Minimum failure	0.12	0.15
		Maximum service level	0.32	0.30
		Environmental compliance	0.26	0.27
	Alliance	Cost	0.34	0.35
		Minimum failure	0.10	0.12
		Maximum service level	0.32	0.33
		Environmental compliance	0.24	0.20
	Supply of production equipment	Cost	0.31	0.32
		Minimum failure	0.16	0.17
		Maximum service level	0.37	0.38
		Environmental compliance	0.16	0.13
Core Bits	Licensing	Cost	0.35	0.33
		Minimum failure	0.08	0.12
		Maximum service level	0.36	0.37
		Environmental compliance	0.21	0.18
	Foreign investment	Cost	0.34	0.35
		Minimum failure	0.07	0.09
		Maximum service level	0.32	0.32
		Environmental compliance	0.27	0.26
	Contracting	Cost	0.27	0.27
		Minimum failure	0.17	0.19
		Maximum service level	0.31	0.30
		Environmental compliance	0.25	0.24
	Alliance	Cost	0.28	0.29
		Minimum failure	0.18	0.19
		Maximum service level	0.32	0.30
		Environmental compliance	0.22	0.22
	Supply of production equipment	Cost	0.29	0.30
		Minimum failure	0.18	0.20
		Maximum service level	0.32	0.36
		Environmental compliance	0.21	0.14

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Sirous Amirghodsi received the B.S. degree in civil engineering from Khajeh Nasir Toosi University, Tehran, Iran, in 1995, and the MBA degree in executive master of business administration from Iran University of Science and Technology (IUST), Tehran, in 2014. He recently finished the Ph.D. degree in technology management with the Progress Engineering Department, IUST. He was recognized as one of the Premier Researchers in 2019. His research interests include technology transfer, multi-criteria decision making, and knowledge management of engineering projects.

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Ahmad Makui received the bachelor's, MBA, and doctoral degrees in industrial engineering from the Iran University of Science and Technology (IUST), Tehran, Iran, in 1985, 1991, and 1994, respectively. He is currently a Professor with the Department of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran. He has published four books in the field of operation research, production planning, and MCDM. His research interests include operation research, production planning, multi-criteria decision making, and technology transfer. Mr. Makui is the Editor-in-Chief of the Journal of Industrial and Systems Engineering.