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Evaluation of key performance indicators in engineering execution of gas distribution network projects using the fuzzy best-worst approach

Ammar Rostami Najafabadi[1], Mehrdad Nikbakht[1,*], Atefeh Amindoust[1] and Mahdi Karbasian[1]

[1]*Department of Industrial Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Iran.*

Abstract

Nowadays, the role of gas industry projects in the economic development cycle of a country is significant as one of the major sources of revenue and ensures important energy resources for optimal and purposeful management in the execution of gas distribution network projects. Given the importance of executing such projects, this study aims to evaluate the key engineering performance indicators in gas distribution network projects using a fuzzy multi-criteria approach. For this purpose, 36 experts and specialists in the gas industry were selected. The research methodology is descriptive, analytical, and survey-based, utilizing both library and field studies, with the tools including a researcher-made questionnaire, the lawshe method, the fuzzy best-worst (FBWM) multi-criteria decision-making method, and LINGO software. The results indicate that, out of 48 effective engineering execution indicators, 19 indicators were identified as key and influential based on the CVI index calculations. According to the findings, the fuzzy best-worst method revealed that the “quality of contractor's execution (competent and skilled contractor)” with a weight of 0.077 is identified as the best (most important) indicator, while the “duration of obtaining permits and completing legal and regulatory processes” with a weight of 0.014 is identified as the worst (least important) indicator.

Keywords: Natural gas, Gas distribution networks, key engineering execution indicators, Lawshe method, Fuzzy best-worst method (FBWM).

1-Introduction

The importance of addressing the issue of executing gas distribution network projects, as one of the main industries in the country, is self-evident. Access to energy resources and economic advantages, as one of the economic arteries in today’s competitive world, is of great significance in the gas industry. Proper and purposeful decision-making and planning in the execution of gas distribution network projects, by systematizing optimal project management, leads to

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[*] Corresponding Author

improvements in indicators related to the execution of each project in three main phases: engineering or design, equipment procurement, and construction. The oil and gas industry has two main activities: project execution and operation. However, the statistics indicate that a significant percentage of these projects face challenges in achieving goals and adhering to various execution constraints (Biuoseh et al, 2015; Fallah et al., 2021). These deviations and constraints can be attributed to factors such as: different design, execution, and operational methods, uncertainties like technical skills, design, management, and also the lack of attention to engineering indicators in project execution (Hatefi and Wahhabi, 2018; Ghahremani et al., 2024).

One of the key factors in executing gas distribution network projects is the engineering execution indicators. These indicators are determined based on the technical specifications and commissioning of gas distribution network projects and the type of gas project according to established procedures and execution methods. In these procedures, based on requirements, definitions, and technical standards related to gas distribution network projects, the work is divided into three sections: design, execution, and monitoring and commissioning. It includes a technical set of all stages such as route preparation, transportation, construction operations, welding, insulation, testing, and commissioning (Gas company standards and technology department, 2011; Movahed et al., 2023).

In general, the importance and necessity of conducting this research can be pointed out to appropriate, systematic, and targeted decision-making and planning in the implementation of gas distribution network projects for managers and interested experts in order to select effective key indicators of implementation engineering.

Therefore, in this article, considering the significance of the issue and evaluating the key engineering execution indicators in gas distribution network projects, no research has been conducted to date using the lawshe method and the fuzzy best-worst multi-criteria decision-making method. The structure of this research is as follows: In sections two and three, the literature review and research methodology are presented, while sections four and five are dedicated to the findings and results.

2- Literature Review

Due to the importance of the research topic, several studies related to the current research are referenced. For instance: Rahman and Hyeok Han (2024) in their research deal with multi-objective optimization based on linear scheduling method to evaluate the performance of a wood-frame wall panel production line project located in Canada. Paras et al. (2024) studied project scheduling optimization through time and cost trade-offs using linear programming. Elkliny et al. (2023) conducted a multi-objective optimization model for construction resource management using a genetic metaheuristic algorithm in their research in the field of construction projects. Son and Khoi (2023) in their article titled optimization time-cost-quality-work continuity in construction management using mutation–crossover slime mold algorithm It is done using the Slime Mold Algorithm. Eirgash et al. (2023) studied construction projects using a generalized version of the MDOLTLBO algorithm. Haghighi et al. (2023) in their study examined oil and gas projects under uncertainty conditions. This research developed a fuzzy ε - constraint method to produce optimal Pareto frontier solutions. Baghery et al. (2023) aimed to conduct a diagnosis of the performance evaluation system of employees and suggest solutions for Iran's oil pipeline and telecommunications company in the northeast region. This research used a one-sample T-test. The results of the study showed that the content of the employee performance evaluation system is appropriate, but the implementation of the system is not. Firoozbakht and Rezaian (2022) in their paper, titled "Designing and explaining the digital transformation model for project-oriented organizations in the Iranian oil and gas industry," discussed the critical role of these organizations in the fourth industrial revolution era. The study, based on the fuzzy Delphi method and structural equation modeling using partial least squares, found that digital transformation leads to value creation for project-based organizations in the oil and gas industry in Iran. It improves operational efficiency, project performance, team communication, strategic differentiation, competitive advantage, reliability, trust, client satisfaction, and enhances workplace safety and environmental protection. Nozari et al. (2025) aim to identify a strategic supplier in the supply chain of renewable energy, using the fuzzy best-worst method (FBWM), COPRAS, and WASPAS methods. In other studies, Celik and Gul (2021) in their paper addressed the identification, evaluation, analysis, and monitoring and control of risks associated with the safety of dam construction in order to optimize the use of water and hydroelectric power generation using the best-worst and MARCOS methods. Balali et al. (2021) used network analysis process and COPRAS methods to rank risks impacting human resource threats in natural gas supply projects in Shiraz. Ahmadvand and Eghbali (2021) aimed to identify and rank different types of risks in underground civil engineering projects, using the case study of Line 7 of the Tehran metro. This study applied hierarchical analysis. Moaveni and Sharitmadar (2021) in their study focused on identifying the primary causes of rework in construction projects in Iran. The research used a survey-based method via a researcher-designed questionnaire and fuzzy TOPSIS to rank criteria such as cost, time, quality, safety, and team satisfaction. The results showed that the main causes of rework were related to the client, construction phase, and design phase. Factors such as inefficient resource allocation, changes in client orders, financial delays, contract delivery issues, inadequate skills, and poor management were found to be the most significant detailed causes of rework. Nozari et al. (2024) proposed an integrated approach for selecting a suitable robot for specific industrial applications in an automated manufacturing environment, using two multi-criteria decision-making techniques: fuzzy best-worst and PROMETHEE.

A review of the relevant theoretical literature revealed that no research has been conducted regarding the impact of engineering execution indices in gas projects. Therefore, the current research aims to identify the most critical engineering execution indices in gas distribution network projects using the lawshe method and applying one of the newest fuzzy multi-criteria decision-making techniques, namely the fuzzy best-worst method.

3- Research Methodology

Given that the objective of this research is to evaluate the key engineering execution indices in gas distribution network projects, this study is applied in nature and follows a descriptive-analytical approach. It combines both library (documentary) and field studies, utilizing the opinions of experts and specialists relevant to the research topic. The research is conducted within the gas industry, and the sample size consists of 36 individuals. The non-random purposive sampling method has been employed in a census manner.

In this study, to assess the validity and reliability of the researcher-made questionnaire, both face and content validity were evaluated (with input from university professors and gas industry experts to clarify ambiguities and refine the questionnaire). To assess its reliability, Cronbach's alpha coefficient was used, which was calculated to be 0.86. Since this value is greater than 0.7, the reliability of the researcher-made questionnaire is confirmed.

In the present study, the researcher-made questionnaire, the lawshe method for analyzing the research findings, and the fuzzy best-worst method (BWM) for calculating the weights and evaluating the importance of the indices will be utilized. The mathematical model was solved using LINGO software.

3-1. Fuzzy Best-Worst Method (BWM)

The fuzzy best-worst method (BWM) is one of the most widely used multi-criteria decision-making techniques in fuzzy environments. it aims to address the ambiguities and drawbacks of other methods that rely on pairwise comparisons between each of the two criteria (best and worst) and other criteria. this technique formulates and solves a minimum-maximum problem to determine the weights of various criteria (Rezaei, 2015; Aliahmadi et al., 2016). Also, one of the features of this method compared to other fuzzy multi-criteria decision-making methods is that it provides more reliable and stable answers based on the information and data provided (Rezaei, 2016). The fuzzy best-worst method consists of five main steps, which are outlined below (Guo and Zhao, 2017):

Step 1: In this step, the set of criteria $\{C_1, C_2, ..., Cn\}$ that are to be used in the decision-making process is defined.

Step 2: In this phase, the decision-makers identify the best (most desirable and most important) and worst (least desirable and least important) criteria.

Step 3: In this section, the performance of the best criterion relative to the other criteria is determined. The vector of results from the comparisons of the best criterion with the other criteria is expressed as follows:

$$AB= AB= (\alpha_{B1}, \alpha_{B2}, \dots, \alpha_{Bn}) \qquad (1)$$

Step 4: In this phase, the performance of all criteria relative to the worst criterion is determined. The vector of results from the comparisons of all criteria with the worst criterion is expressed as follows:

$$AW= (\alpha 1w, \alpha 2w, \dots, \alpha nw) \qquad (2)$$

Step 5: In this step, the optimal weights for the criteria are determined. The optimal values for the criteria are unique, which will satisfy each pair of $\frac{\tilde{W}b}{\tilde{W}j}$ - $\tilde{\alpha}_{Bj}$ and $\frac{\tilde{W}j}{\tilde{W}w}$ - $\tilde{\alpha}_{JW}$. To satisfy these conditions for all j, a solution is found where the absolute difference $\left|\frac{\tilde{W}b}{\tilde{W}j} - \tilde{\alpha}_{Bj} - \tilde{\alpha}_{Bj}\right|$ and

$\left|\frac{\tilde{W}_j}{\tilde{W}_w} - \tilde{\alpha}_{jW}\right|$ is minimized. Since the weights are non-negative and summable, the problem is formulated as the following model under:

$$Min\ Max \left\{ \left| \frac{\tilde{W}_b}{\tilde{W}_j} - \tilde{\alpha}_{Bj} \right| and \left| \frac{\tilde{W}_j}{\tilde{W}_w} - \tilde{\alpha}_{jW} \right| \right\} \tag{3}$$

$$S.t \tag{4}$$

$$\sum_{i=1}^{n} R\ (\tilde{W}_j) = 1 \tag{5}$$

$$l_j^W \leq m_j^W \leq u_j^W \tag{6}$$

$$L_j^W \geq 1 \qquad\qquad j = 1, 2, \ldots, n \tag{7}$$

Next, model up is transformed into model under by defining and considering, where is the final model:

($\tilde{\alpha}_{jw} = (l_{jw}, m_{jw}, u_{jw})$, $\tilde{W}_w = (l_W^w, m_W^W, u_W^W)$, $\tilde{W}_J = (l_j^w, m_j^W, u_j^W)$, $\tilde{W}_B = (l_B^w, m_B^W, u_B^W)$, $\tilde{\alpha}_{BJ} = (l_{Bj}, m_{Bj}, u_{Bj})$) and ($\tilde{\xi} = (l\xi, m\xi, u\xi)$, $l\xi \leq m\xi \leq u\xi$, $\tilde{\xi}^* = (K^*, K^*, K^*)$, $K^* \leq l\xi$)

$$Min\ \xi \tag{8}$$

$$S.t \tag{9}$$

$$\left| \frac{(l_B^*, m_B^*, u_B^*)}{(l_j^*, m_j^*, u_j^*)} - (l_{Bj}, m_{Bj}, u_{Bj}) \right| \leq (K^*, K^*, K^*) \tag{10}$$

$$\left| \frac{(l_j^*, m_j^*, u_j^*)}{(l_{jw}^*, m_w^*, u_w^*)} - (l_{jW}, m_{jW}, u_{jW}) \right| \leq (K^*, K^*, K^*) \tag{11}$$

$$\sum_{i=1}^{n} R\ (\tilde{W}_j) = 1 \tag{12}$$

$$l_j^* \leq m_j^* \leq u_j^* \qquad\qquad j = 1, 2, \ldots, n \tag{13}$$

By solving model up, the optimal and final weights ($W1^*, W2^*, \ldots, Wn^*$) and the value ξ of, along with the consistency rate, will be obtained using expert opinions.

4- Research Findings

Using previous research and studies from credible sources, especially field studies and survey with experts in the gas industry and according to Table (1), 48 effective engineering performance indicators, categorized into three dimensions (indicator title), were identified and classified as key engineering performance indicators in gas distribution network projects. In the next step, a researcher-designed questionnaire was distributed among the stated statistical population, and after the participants answered the questions and completed the questionnaire, the importance of each indicator was assessed.

To calculate the content validity ratio (CVR) and the content validity index (CVI) for the research and using the Lawshe method, the CVR index was first calculated, followed by the CVI index with respect to the total number of participants. The CVR index should fall between 0.31 and 0.33. If the calculated value for any item is negative or less than 0.31, that item is discarded and removed from the questionnaire. Otherwise, the item remains in the questionnaire. Additionally, to calculate the CVI index, if the obtained value is less than 0.7, the item is removed; if it is between 0.7 and 0.79, a revision is necessary, and if it is greater than 0.79, the item is considered acceptable (Lawshe, 1975). Finally, the results obtained from the Lawshe method for evaluating the CVR and CVI indicators are shown in Table (1), and the final key engineering performance indicators for gas distribution network projects are listed in Table (2).

Table (1): Evaluation of effective indicators of implementation engineering in gas distribution network projects

Index	**Effective indices of execution**	**CVR INDEX**	**CVI INDEX**	**Status** (results of acceptance / non- acceptance)
Time	Accurate estimation of the duration of the project's execution operations in accordance with the bill of quantities and project's resources and quantity list (package) for execution	0.226	---	Is removed.
	Duration for obtaining permits and completing legal and regulatory processes	0.677	0.83	Remain.
	Duration for conducting studies on gas distribution network projects and all study phases, including updating maps, marketing and etc	0.548	0.77	Remain.
	Duration for designing gas distribution network projects	0.484	0.74	Remain.
	Duration for conducting tests and experiments related to project execution	- 0.097	---	Is removed.
	Duration for gas injection	0.032	---	Is removed.
	Duration for performing Cathodic protection coating	0.161	---	Is removed.
	Total project execution time	0.548	0.77	Remain.
	Contentious monitoring time	0.548	0.77	Remain.
	Time loss due to project stoppage caused by weather factors	0.032	---	Is removed.
	Time loss due to human errors (knowledge, skill, and expertise) in conducting studies, calculations, designs, safety, execution, operation, and inadequate monitoring and control in the project	0.355	0.67	Is removed.
	Timely purchase of quality items, goods, and equipment for the project	0.613	0.81	Remain.
	Time loss due to the purchase of low-quality items, goods, and equipment and their replacement	0.613	0.81	Remain.
	Request for purchased goods or equipment	0.161	---	Is removed.
	Accuate estimation of gas consumption for proper marketing	- 0.032	---	Is removed.
	Considering the impact of local execution-related, social, economic, cultural, and political conditions on the project	- 0.032	---	Is removed.
	Timeline for temporary commissioning of the project	- 0.290	---	Is removed.

Continue table (1): Evaluation of effective indicators of implementation engineering in gas distribution network projects

Index	**Effective indices of execution**	**CVR INDEX**	**CVI INDEX**	**Status** (results of acceptance / non- acceptance)

Time	Initial appropriate estimation of the project's resources and quantity list(package) for execution	- 0.032	---	Is removed.
Cost	Appropriate initial estimate of the project (package) resources and quantities for implementation	0.484	0.74	Remain.
	Correct estimation of project execution tasks according to the official price list	- 0.290	---	Is removed.
	Costs incurred due to project delays caused by the lack of permits and the time required for legal and regulatory processes	0.484	0.74	Remain.
	Feasibility study for the establishment of the station	0.032	---	Is removed.
	Total project execution costs (direct and indirect)	0.677	0.83	Remain.
	Impact of the selected material prices by the design engineer on the design of the package	0.613	0.81	Remain.
	Costs of purchasing quality items, goods, and equipment for the project	0.613	0.81	Remain.
	Timely provision of financial resources for the project	0.419	0.71	Remain.
	Price fluctuations for purchasing items, goods, and equipment used in the project	0.749	0.87	Remain.
	Accurate estimate of gas consumption for proper marketing	0.032	---	Is removed.
	Costs incurred due to project delays caused by weather conditions	- 0.290	---	Is removed.
	Costs imposed due to human errors (knowledge, skills, and expertise) in conducting studies, calculations, designs, safety, execution, operation, and insufficient supervision and control in the project	0.161	---	Is removed.
	Temporary project startup costs	- 0.161	---	Is removed.
quality	Weather conditions and climate status	- 0.355	---	Is removed.
	Quality of contractor's execution (competent and skilled contractor)	0.806	0.90	Remain.
	Quality in the proper design of gas distribution network projects (status of city development and future considerations such as area, population, elevation and design)	0.677	0.84	Remain.
	Quality in the execution of gas distribution network projects (observing the depth of soil cover over the gas distribution pipelines, etc)	0.290	---	Is removed.
	Quality (performance evaluation and assessment) of the supervising authority	0.419	0.71	Remain.
	Inspection and quality assurance of supplied (purchased) items, goods and equipment	0.484	0.75	Remain.
	Quality of storage, transportation, and warehousing of items, goods and equipment used in the project	0.226	---	Is removed.
	Determining the suitable location for the construction of the station	0.032	---	Is removed.
	Quality of welding operations, execution and etc	0.806	0.90	Remain.
	Soil corrosion potential based on the type, resistance, and moisture content of the soil	0.161	---	Is removed.
	Physical quality of the soil to ensure maximum proper utilization of the project with minimal environmental damage	- 0.226	---	Is removed.

Continue table (1): Evaluation of effective indicators of implementation engineering in gas distribution network projects

Index	**Effective indices of execution**	**CVR INDEX**	**CVI INDEX**	**Status** (results of acceptance / non- acceptance)

quality	Impact of soil displacement, land movement and subsidence on project execution	0.290	**---**	Is removed.
	Social conditions of the region	- 0.548	**---**	Is removed.
	The government's foreign economic policies	- 0.419	**---**	Is removed.
	Urban and regional administrative services	- 0.226	**---**	Is removed.
	The level of culture of the people and the level of cooperation of the residents of the region	- 0.419	**---**	Is removed.
	Peace or war conditions in the project implementation area	- 0.226	**---**	Is removed.

Based on the findings from the calculation of the CVR index to evaluate the key performance indicators of execution engineering in gas distribution network projects, out of the 48 parameters considered, 20 indicators remain in the questionnaire, while 28 indicators are excluded and removed due to not meeting the required level of the index. Additionally, according to the results in Table 1, 19 of the 20 identified indicators remain based on the calculation of the CVI index, which are displayed as the final key performance indicators of execution engineering in Table 2, and will be used in subsequent stages.

Table (2): Final Key Engineering Performance Indicators in Gas Distribution Network Projects

Index	**Effective indices of execution**
Time	Duration for obtaining permits and completing legal and regulatory processes (W1)
	Duration for conducting studies on gas distribution network projects and all study phases, including updating maps, marketing and etc (W2)
	Duration for designing gas distribution network projects (W3)
	Total project execution time (W4)
	Contentious monitoring time (W5)
	Timely purchase of quality items, goods, and equipment for the project (W6)
	Time loss due to the purchase of low-quality items, goods, and equipment and their replacement (W7)
Cost	Appropriate initial estimate of the project (package) resources and quantities for implementation (W8)
	Costs incurred due to project delays caused by the lack of permits and the time required for legal and regulatory processes (W9)
	Total project execution costs (direct and indirect) (W10)
	Impact of the selected material prices by the design engineer on the design of the package (W11)
	Costs of purchasing quality items, goods, and equipment for the project (W12)
	Timely provision of financial resources for the project (W13)
	Price fluctuations for purchasing items, goods, and equipment used in the project (W14)
quality	Quality of contractor's execution (competent and skilled contractor) (W15)
	Quality in the proper design of gas distribution network projects (status of city development and future considerations such as area, population, elevation and design) (W16)
	Quality (performance evaluation and assessment) of the supervising authority (W17)
	Inspection and quality assurance of supplied (purchased) items, goods and equipment (W18)
	Quality of welding operations, execution and etc (W19)

After identifying and selecting the final key engineering performance indicators as shown in Table (2), the next step involves calculating the optimal and final weight for these indicators using the LINGO software and the fuzzy best-worst technique to determine the optimal weight and importance of these key performance indicators.

Following the five-step process of the fuzzy best-worst decision-making technique, triangular fuzzy numbers (l, m, u) are used to represent the largest, most likely, and smallest possible values in their respective sets. The steps include defuzzification, creating an initial decision matrix, evaluating the importance of the best and worst indicators relative to others, and finally calculating the optimal and final weights for these indicators of the key effective indicators of implementation engineering in the implementation of natural gas distribution network projects is carried out according to Table (2) and is shown in Tables (3) to (13) and Chart (1).

Based on the findings and evaluation presented in Table 1, index "quality of contractor's execution (competent and skilled contractor)" (W15) is considered the best (most desirable, most important), and the index "duration of obtaining permits and completing legal and regulatory processes" (W1) is regarded as the worst (least desirable, least important).

Table (3): Evaluation of the importance of the best indicator relative to others (normalized values) related to key performance indicators in the engineering execution of gas distribution network projects

Index	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Values I	6	8	6	1	2	2	6	2	1	2
Values m1	6.5	8.5	6.5	1	2.5	2.5	6.5	2.5	1	2.5
Values m2	7.5	9	7.5	1	3.5	3.5	7.5	3.5	1	3.5
Values u	8	9	8	1	4	4	8	4	1	4
Index	**W11**	**W12**	**W13**	**W14**	**W15**	**W16**	**W17**	**W18**	**W19**	
Values I	2	8	2	8	2	2	8	2	6	
Values m1	2.5	8.5	2.5	8.5	2.5	2.5	8.5	2.5	6.5	
Values m2	3.5	9	3.5	9	3.5	3.5	9	3.5	7.5	
Values u	4	9	4	9	4	4	9	4	8	

Table (4): Evaluation and calculation of the normalized upper and lower bounds related to key performance indicators in the engineering execution of gas distribution network projects

Index	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Values I	0	0	0	0	0	0	0	0	0	0
Values m1	0.25	0.5	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Values m2	0.75	1	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Values u	1	1	1	1	1	1	1	1	1	1
Index	**W11**	**W12**	**W13**	**W14**	**W15**	**W16**	**W17**	**W18**	**W19**	
Values I	0	0	0	0	0	0	0	0	0	
Values m1	0.25	0.5	0.25	0.5	0.25	0.25	0.5	0.25	0.25	
Values m2	0.75	1	0.75	1	0.75	0.75	1	0.75	0.75	
Values u	1	1	1	1	1	1	1	1	1	

Table (5): Evaluation and calculation of the normalized upper and lower bounds related to the key performance indicators of execution engineering in gas production network projects

Index	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Values I	0.5	0.57	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Values u	0.66	0.8	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Index	**W11**	**W12**	**W13**	**W14**	**W15**	**W16**	**W17**	**W18**	**W19**	
Values I	0.5	0.57	0.5	0.57	0.5	0.5	0.57	0.5	0.5	
Values u	0.66	0.8	0.66	0.8	0.66	0.66	0.8	0.66	0.66	

Table (6): Evaluation and calculation of the total normalized values related to the key performance indicators of execution engineering in gas distribution network projects

Index	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Normalized definite values	0.595	0.720	0.595	0.595	0.595	0.595	0.595	0.595	0.595	0.595
Index	**W11**	**W12**	**W13**	**W14**	**W15**	**W16**	**W17**	**W18**	**W19**	
Normalized definite values	0.595	0.720	0.595	0.720	0.595	0.595	0.720	0.595	0.595	

Table (7): Evaluation and calculation of the definitive values related to the key performance indicators of execution engineering in gas distribution network projects

Index	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
definite values	7.19	8.72	7.19	3.19	3.19	3.19	7.19	3.19	3.19	3.19
Index	**W11**	**W12**	**W13**	**W14**	**W15**	**W16**	**W17**	**W18**	**W19**	
definite values	3.19	8.72	3.19	8.72	3.19	3.19	8.72	3.19	7.19	

Table (8): Evaluation of the importance of the worst indicator compared to other indicators (normalization of values) related to the key performance indicators of execution engineering in gas distribution network projects

Index	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Values I	6	2	8	6	2	6	6	2	2	6
Values m1	6.5	2.5	8.5	6.5	2.5	6.5	6.5	2.5	2.5	6.5
Values m2	7.5	3.5	9	7.5	3.5	7.5	7.5	3.5	3.5	7.5
Values u	8	4	9	8	4	8	8	4	4	8
Index	**W11**	**W12**	**W13**	**W14**	**W15**	**W16**	**W17**	**W18**	**W19**	
Values I	2	2	2	8	6	2	6	2	6	
Values m1	2.5	2.5	2.5	8.5	6.5	2.5	6.5	2.5	6.5	
Values m2	3.5	3.5	3.5	9	7.5	3.5	7.5	3.5	7.5	
Values u	4	4	4	9	8	4	8	4	8	

Table (9): Evaluation and calculation of the normalized upper and lower bounds related to the key performance indicators of execution engineering in gas distribution network projects

Index	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10
Values I	0	0	0	0	0	0	0	0	0	0
Values m1	0.25	0.25	0.5	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Values m2	0.75	0.75	1	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Values u	1	1	1	1	1	1	1	1	1	1
Index	**W11**	**W12**	**W13**	**W14**	**W15**	**W16**	**W17**	**W18**	**W19**	
Values I	0	0	0	0	0	0	0	0	0	
Values m1	0.25	0.25	0.25	0.5	0.25	0.25	0.25	0.25	0.25	
Values m2	0.75	0.75	0.75	1	0.75	0.75	0.75	0.75	0.75	
Values u	1	1	1	1	1	1	1	1	1	

Table (10): Evaluation and calculation of the normalized upper and lower bounds related to the key performance indicators of execution engineering in gas distribution network projects

Index	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**
Values I	0.5	0.5	0.57	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Values u	0.66	0.66	0.8	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Index	**W11**	**W12**	**W13**	**W14**	**W15**	**W16**	**W17**	**W18**	**W19**	
Values I	0.5	0.5	0.5	0.57	0.5	0.5	0.57	0.5	0.5	
Values u	0.66	0.66	0.66	0.8	0.66	0.66	0.66	0.66	0.66	

Table (11): Evaluation and calculation of the total normalized values related to the key performance indicators of execution engineering in gas distribution network projects

Index	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**
Normalized definite values	0.595	0.720	0.595	0.595	0.595	0.595	0.595	0.595	0.595	0.595
Index	**W11**	**W12**	**W13**	**W14**	**W15**	**W16**	**W17**	**W18**	**W19**	
Normalized definite values	0.595	0.595	0.595	0.720	0.595	0.595	0.595	0.595	0.595	

Table (12): Evaluation and calculation of the definitive values related to the key performance indicators of execution engineering in gas distribution network projects

Index	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**
definite values	7.19	3.19	8.75	7.19	3.19	7.19	7.19	3.19	3.19	3.19
Index	**W11**	**W12**	**W13**	**W14**	**W15**	**W16**	**W17**	**W18**	**W19**	
definite values	3.19	3.19	3.19	8.72	7.19	3.19	7.19	3.19	7.19	

Then, based on model 2 in the fuzzy best-worst method, the optimization problem is extended, and by calculating the upper and lower bounds of the normalized values and definitive values for the best and worst indicators compared to other indicators, the results of the calculations are presented in the form of model 3.

Min ξ (3)

S.t.

w1 - 8.72* w2<=a; w1 - 8.72* w2>=-a;
w1 - 7.19*w3<=a; w1 - 7.19*w3>=-a;
w2 - 3.19* w9<=a; w2 - 3.19* w9>=-a;
w3 - 8.72*w9<=a; w3 - 8.72* w9>=-a;

```
 w1 - 3.19* w4<=a;   w1 - 3.19* w4>=-a;              w4 - 7.19* w9<=a;   w4 - 8.19* w9>=-a;
 w1 - 3.19* w5<=a;   w1 - 3.19*w5>=-a;               w5 - 3.19* w9<=a;   w5 - 3.19* w9>=-a;
 w1 - 3.19*w6<=a;   w1 - 3.19* w6>=-a;               w6 - 7.19*w9<=a;   w6 - 7.19* w9>=-a;
 w1 - 7.19*w7<=a;   w1 - 7.19* w7>=-a;               w7 - 7.19*w9<=a;   w7 - 7.19* w9>=-a;
 w1 - 3.19* w8<=a;   w1 - 3.19* w8>=-a;              w8 - 3.19* w9<=a;   w8 - 3.19* w9>=-a;
 w1 - 3.19*w9<=a;   w1 - 3.19* w9>=-a;               w10 - 7.19* w9<=a;   w10 - 7.19* w9>=-a;
 w1 - 3.19* w10<=a;   w1 - 3.19* w10>=-a;            w11 - 4.8* w9<=a;   w11 - 4.8*w9>=-a;
 w1 - 3.19* w11<=a;   w1 - 3.19* w11>=-a;            w12 - 3.19*w9<=a;   w12 - 3.19* w9>=-a;
 w1 - 8.72* w12<=a;   w1 - 8.72* w12>=-a;            w13 - 3.19* w9<=a;   w13 - 3.19* w9>=-a;
 w1 - 3.19* w13<=a;   w1 - 3.19* w13>=-a;            w14 - 8.72* w9<=a;   w14 - 8.72*w9>=-a;
 w1 - 8.72* w14<=a;   w1 - 8.72*w14>=-a;             w15- 7.19* w9<=a;   w15- 7.19* w9>=-a;
 w1 - 3.19* w15<=a;   w1 - 3.19* w15>=-a;            w16 - 3.19* w9<=a;   w16 - 3.19* w9>=-a;
 w1 - 3.19* w16<=a;  w1 - 3.19* w16>=-a;             w17 - 7.19* w9<=a;   w17 - 7.19* w9>=-a;
 w1 - 8.72*w17<=a;   w1 - 8.72*w17>=-a;              w18 - 3.19* w9<=a;   w18 - 3.19* w9>=-a;
 w1 - 3.19* w18<=a;   w1 - 3.19*w18>=-a;             w19 - 7.19*w9<=a;   w19 - 7.19*w9>=-a;
 w1 - 7.19* w19<=a;   w1 - 7.19* w19>=-a;
w1+ w2+ w3 + w4+ w5+ w6+ w7 + w8+ w9+ w10+ w11 + w12+ w13+w14+ w15+ w16 + w17+ w18+ w19 =1;

 @bnd(0,W1,1);                @bnd(0,W8,1);                @bnd(0,w15,1);
 @bnd(0,W2,1);                @bnd(0,W9,1);                @bnd(0,w16,1);
 @bnd(0,W3,1);                @bnd(0,W10,1);               @bnd(0,w17,1);
 @bnd(0,W4,1);                @bnd(0,W11,1);               @bnd(0,w18,1);
 @bnd(0,W5,1);                @bnd(0,W12,1);               @bnd(0,w19,1);
 @bnd(0,W6,1);                @bnd(0,W13,1);
 @bnd(0,W7,1);                @bnd(0,w14,1);
END
```

Finally, by aggregating the criteria, which must result in a single value, the optimal and final weights of the key performance indicators of execution engineering in natural gas distribution network projects, along with the consistency rate and value is shown in the table and chart below.

Table (13): Evaluation and calculation of the final optimal weights of key performance indicators of execution engineering in gas distribution network projects using the fuzzy best-worst method

Index	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**
Final optimal weight	0.14	0.026	0.032	0.077	0.077	0.077	0.032	0.077	0.016	0.077
Index	**W11**	**W12**	**W13**	**W14**	**W15**	**W16**	**W17**	**W18**	**W19**	
Final optimal weight	0.077	0.026	0.077	0.026	0.077	0.077	0.026	0.077	0.032	
Total weights	1.00	**values ξ**		0.087						

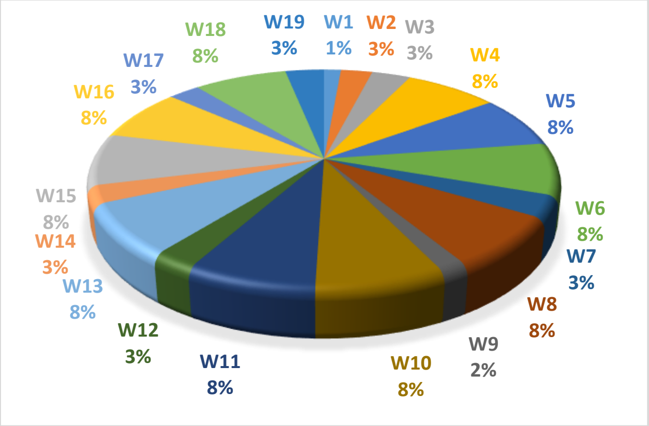

Figure 1: Final optimal weights of key performance indicators of execution engineering in gas distribution network projects using the fuzzy best-worst method

Based on the findings and evaluation conducted, according to Table 13 and Figure 1, the contractor's execution quality index (a capable and strong contractor) with a weight of 0.077 is considered the best (most desirable, most important), while the index of the time taken to obtain permits and go through legal and regulatory processes, with a weight of 0.0014 is considered the worst (least desirable, least important).

5- Discussion and Conclusion

Given the necessity of executing successful gas distribution network projects in any organization, this can only be achieved if due attention is paid to its structure and procedures. The aim of evaluating the engineering indicators affecting the execution of gas projects is to help service-oriented organizations identify these indicators and, with the necessary managerial measures under different time conditions and overall policies, develop a method for measuring and evaluating them for continuous improvement.

This research, based on the opinions of experts and specialists in the gas industry, initially identified the engineering indicators affecting the execution of gas distribution network projects using library and field research methods, including interviews and surveys with industry experts. Then, using the lawshe method, the key engineering indicators were determined. Finally, by utilizing the fuzzy best-worst method (BWM) multi-criteria decision-making technique, the final and definitive weights of the key engineering indicators affecting the execution of gas distribution network projects were evaluated, yielding significant results.

According to the findings presented in the research findings section, out of 48 engineering indicators, 19 were identified as key and influential based on the CVI index calculation. Furthermore, the evaluation of final weights for these key indicators, using the fuzzy best-worst method (BWM), showed that the "quality of contractor's execution (competent and skilled contractor)" with a weight of 0.077 was identified as the best (most desirable, most important), and "duration of obtaining permits and completing legal and regulatory processes" with a weight of 0.014 was identified as the worst (least desirable, least important).

Therefore, based on the findings from the case study in this research, it seems that to avoid conflicts and challenges, and to increase effectiveness and optimize management in the execution of gas industry projects, serious actions should be taken, such as: thorough and precise supervision over operational and executional sections, comprehensive and technical project design considering all execution details in the maps, the presence of the designer engineer on-site for project visits, identifying project issues before the design phase (preventing design changes), adhering to requirements to avoid repeated changes during project execution, and implementing a proper sustainability model in the quality of services to enhance consumer satisfaction with the execution of gas distribution network projects.

As for future research suggestions, it is recommended that future studies utilize other multi-criteria decision-making approaches such as fuzzy SWARA and fuzzy ARAS, and compare the results obtained with the current research in the studied industry.

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