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Optimizing Synthesis Gas Pipeline Network Using the TOPSIS Method with Interval Data

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Abstract

Pipelines play a crucial role in transporting natural gas across various process industries, particularly within the petrochemical and energy sectors, thanks to their cost-effectiveness. Optimising the design and operation of gas pipeline networks is vital for reliable, cost-effective gas delivery. This process requires balancing competing goals, including maximising flow rate, reducing energy consumption, and optimising line pack utilisation. This study investigates advanced optimisation strategies for gas pipeline networks by introducing a structured, multi-objective framework. We propose a novel approach that integrates the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) with Pareto-optimal solutions, enabling decision-makers to identify the most suitable design configurations for natural gas transport systems under uncertainty. To validate the effectiveness of this methodology, we present two case studies involving both branched and complex multi-input-multi-output networks. The outcomes demonstrate the proposed method's capability to yield more economical and operationally sound network configurations. Additionally, a cost analysis was performed across various gas transportation scenarios, offering practical insights for strategic planning and operational decision-making. Overall, our study highlights the advantages of the interval-based TOPSIS approach in improving both the economic and functional performance of natural gas pipeline systems.

Keywords: *Pipeline network; Multi-objective optimisation; TOPSIS approach with interval data; Mathematical modelling; Line pack; Power demand.*

1. Introduction

Pipelines generally fall into three primary categories: Gathering systems require effective collection of gas from multiple wells while minimising pressure losses; Transmission systems necessitate meticulous management of pressure and flow to ensure efficient gas transportation over long distances; and Distribution systems require a delicate balance between supply and demand, all the while sustaining consistent pressure levels for a variety of customer segments [1].

Three main types of network topologies are linear, tree, and cyclic. Each topology has its own advantages and disadvantages. For instance, a linear topology is simple to manage and maintain but may not be as efficient in terms of network capacity. A tree topology is more efficient but can be more complex to manage. A cyclic topology can be highly efficient but may be more prone to network issues [2].

Optimisation problems for gas transmission networks often focus on either the operational or design phase. Design optimisation concerns making suitable choices of layouts, materials and pipe dimensions. Conversely, operational optimisation concerns the enhancement of an existing network and station configurations [5].

The goal of pipeline operation optimization is to maximize natural gas delivery, maximize line pack, minimize energy consumption, or achieve a combination of these objectives simultaneously. Rios-Mercade and Borraz-Sanchez [3] provided a comprehensive review of various optimization objectives. Amir Hesham and Reza Molaei [5] present multi-objective approach to find optimum operating condition. Osiadacz and Isoli [6] present a bi-objective optimisation approach for high-pressure gas networks. Their algorithm balances minimising compressor running costs with maximising gas network capacity to ensure a secure supply. This bi-objective approach utilises gradient projection and hierarchical vector optimisation methods. Zhou *et al.* [7] present an optimisation model for minimising power consumption costs at compressor stations. Arya and Honwad [8] developed an ant colony optimisation approach for optimising pipeline systems.

El Garieb *et al.* [9] employed the VIKOR method to simultaneously maximize flow rate, maximize line pack, and minimize power. Amira *et al.* [10] utilizes fuzzy analogical gates to select optimal solutions. Their model aims to simultaneously increase delivery flow rate, reduce power consumption, and maximize line pack efficiency. This approach was applied to various network configurations, including branched and branched cyclic topologies

Hussein [11] presents a model that minimises fuel consumption in gas pipeline networks. This study introduces an innovative approach using the TOPSIS method with interval data to improve the design and planning of natural gas transmission networks. The primary research objectives focus on achieving multi-objective optimisation by prioritising increased flow rate, reduced power consumption, and maximised line pack efficiency within the network. The practical effectiveness of this approach is demonstrated through the solution of two case studies.

2. Pipeline network model

2.1. Pipeline flowrate

As described in [10].

$$Q = 77.54\left(\frac{T_b}{P_b}\right)\left(\frac{P_1^2 - P_2^2}{G * T * Le * Z * f}\right) * D^{2.5} \qquad (1)$$

2.2. Power demand

The energy supplied by the compressors is represented as the "head" (H), which indicates the amount of energy delivered per unit mass of gas. The value of H can be calculated using Equation (2) [12].

$$H = ZRT\frac{K}{K-1}\left[\left(\frac{p_d}{P_S}\right)^{\frac{(K-1)}{K}} - 1\right] \qquad (2)$$

$$K = \frac{\sum C_{pi} MY_i}{\sum C_{pi} MY_i - R} \qquad (3)$$

Demissie [13] provides a method to Power equation

$$Power = \frac{Q.H}{\eta_{is}} \qquad (4)$$

2.3. Line pack

Line pack is calculated by equation, as presented by Menon [14].

$$LP = 7.885x10^{-7}\left(\frac{T_{SC}}{P_{SC}}\right)\left(\frac{P_{avg}}{Z * T}\right)(D^2 * L) \qquad (5)$$

2.4. Total cost

The total cost is calculated as the sum of operating and fixed costs [15].

$$Operating\ Cost = 100000 + (Power \times 850) \qquad (6)$$

$$Fixed\ Cost = (1495.4 \times Ln(Yr) - 11353) \times D \times 250 \times \frac{L}{1600} \qquad (7)$$

$$Total\ cost = operating\ cost + fixea\ cost \qquad (8)$$

3. Multiple criteria decision making

Optimizing natural gas transportation networks has become increasingly important due to the rising demand for this energy source. This work presents an innovative technique for the design and planning of such networks, employing the TOPSIS method for interval data to identify the most suitable option among multiple alternatives [16]. The core objective is multi-objective optimization, specifically aiming to enhance delivery flow rate, minimize power and fuel consumption, and maximize line pack. The technique's applicability is demonstrated through two cases with varying topologies and four parameters, along with an industrial case study. Suppose $\gamma_1, \gamma_2, \ldots\ldots, \gamma_m$ represent the mmm possible alternatives from which decision-makers must choose, and $\beta_1, \beta_2, \ldots\ldots, \beta_{1n}$ are the n criteria used to evaluate the performance of these alternatives. Let, λ_{ij} denote the performance rating of alternative γ_i with respect to criterion β_j Since the exact value of Since the exact value of λ_ij is not known, it is represented as an interval value such that,

$$\gamma_n\left[\quad \lambda_{ij}^L, \quad \lambda_{ij}^U \quad \cdots \quad [\lambda_{in}^L, \lambda_{jn}^U]\right].$$

$$\varphi = \begin{matrix} \gamma_n \\ \gamma_1 \\ \gamma_2 \\ \vdots \\ \vdots \\ \gamma_m \end{matrix} \begin{bmatrix} \beta_1 & \beta_2 & \cdots\cdots & \beta_n \\ [\lambda_{11}^L, \lambda_{11}^U] & [\lambda_{12j}^L, \lambda_{12}^U] & \cdots \cdots & [\lambda_{1n}^L, \lambda_{1n}^U] \\ [\lambda_{21}^L, \lambda_{21}^U] & [\lambda_{22}^L, \lambda_{22}^U] & \cdots \cdots & [\lambda_{2n}^L, \lambda_{2n}^U] \\ \vdots & \vdots & \cdots \cdots & \vdots \\ \vdots & \vdots & \cdots \cdots & \vdots \\ [\lambda_{m1}^L, \lambda_{m1}^U] & [\lambda_{m2}^L, \lambda_{m2}^U] & \cdots \cdots & [\lambda_{mn}^L, \lambda_{mn}^U] \end{bmatrix} \quad (9)$$

$\omega = [\omega_1, \omega_2, , \ldots\ldots\ldots, \omega_n]$, where ω is the weight of criterion.

4. Algorithmic method

This section presents a systematic approach to the TOPSIS method incorporating interval data.

Step 1:

Calculate the normalized decision matrix using the following Equation (10). This equation is applied to each interval-valued element in the decision matrix [18].

$$[\eta_{ij}^L, \eta_{ij}^U] = \left[\frac{\lambda_{ij}^L}{\sum \lambda_{ij}^U}, \frac{\lambda_{ij}^U}{\sum \lambda_{ij}^L}\right] \quad i = 1, \ldots\ldots, n \ , j = 1, \ldots., m \quad (10)$$

Step 2:

Normalized interval decision matrix by its corresponding criterion weight as equations (11) and (12) [19].

$$v_{ij}^L = \omega_i \ \eta_{ij}^L \quad (11)$$

$$v_{ij}^U = \omega_i \eta_{ij}^U \quad (12)$$

Step 3:

The positive ideal solution (PIS) and negative ideal solution (NIS) by equations (13) and (14) respectively.

$$\alpha^+ = (A_1^+, \ldots, A_n^+) = \left\{\left(\max_j v_{ij}^U \in \Omega_1\right), \left(\min_j v_{ij}^L \in \Omega_2\right)\right\} \quad (13)$$

$$\alpha^- = (A^- \ldots, A_n^-) = \left\{\left(\min_j v_{ij}^L \in \Omega_1\right), \left(\max_j v_{ij}^U \Omega_2\right)\right\} \quad (14)$$

- Ω1: the set of benefit criteria, where higher values are preferred (e.g., delivery flow rate, line pack efficiency).
- Ω2: the set of cost criteria, where lower values are preferred (e.g., power consumption, operational cost).

Step 4:

Separation of each alternative from the (PIS) using the following formula:

$$d_j^+ = \left\{\sum_{i\epsilon\Omega_1}\left(v_{ij}^L - A_i^+\right)^2 + \sum_{i\epsilon\Omega_2}\left(v_{ij}^U - A_i^+\right)^2\right\}^{1/2} j = 1, \ldots m. \quad (15)$$

Calculate the separation of each alternative from using the following formula:

$$d_j^- = \left\{\sum_{i\epsilon\Omega_1}\left(v_{ij}^U - A_i^-\right)^2 + \sum_{i\epsilon\Omega_2}\left(v_{ij}^L - A_i^-\right)^2\right\}^{1/2} \quad j = 1, \ldots, m \qquad (16)$$

Step 5:
The relative closeness ψ_j is defined as:

$$\psi_j = \frac{d_j^-}{d_j^+ + d_j^-} \qquad j = 1, \ldots, \ldots, m \qquad (17)$$

Step6:
The alternative is ranking according to relative closeness in descending order. The alternatives that are top are the best solution. The analysis of two cases offers valuable guidelines for optimizing the operational performance of pipeline networks.

Case 1 featuring a tree topology, is used as a test bench for the proposed approach. Case 2 involves a more complex configuration, consisting of multiple loops, supply nodes, and delivery points, and is referred to as a multi-supply, multi-delivery transmission network.

5. Case studies

5.1. Case 1: Branch

Table 1 Data Specifications, Length and diameter for case1 as defined by [17]. The reference temperature of the given system is 520ºR and the pressure is 14.5 psia. In Figure 1 we can see the pipeline network layout. Table 3 presents the decision interval matrix for various scenarios.

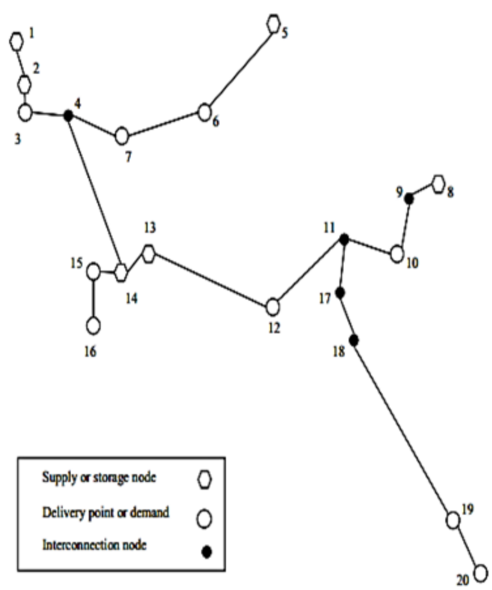

Figure1. Pipeline network layout for Case Study 1.

Table 1. Data specifications, length and diameter for case1.

Arc	Diameter (in)	Length (mile)	Arc	Diameter (in)	Length (mile)
1-2	20	02.50	11-12	26	26.25
2-3	30	03.75	12-13	24	25.00
3-4	28	16.25	13-14	24	03.12
5-6	12	26.87	14-15	34	06.25
6-7	06	18.12	15-16	30	15.62
7-4	12	11.87	11-17	12	06.56
4-14	24	34.37	17-18	11	16.25
8-9	34	03.12	18-19	14	61.25
10-11	28	15.62	19-20	12	03.75
9-10	34	12.50			

Table 2. Physical properties of gas mixture.

Gas component	C_1	C_2	C_3
Mole fraction	0.700	0.250	0.050
Molecular mass(g/mole)	16.040	30.030	44.100
Lower heating value at 15^{0}C and 1bar (MJm^{-3})	37.706	66.067	93.936
Heat capacity at constant pressure (J mol^{-1},k)	35.663	52.848	74.916

Table 3. Interval decision matrix for Case 1.

Scenario	Flow rate (MMscf)		Power (hp)		Line pack (MMscf)	
	λ_{ij}^L	λ_{ij}^U	λ_{ij}^L	λ_{ij}^U	λ_{ij}^L	λ_{ij}^U
1	1522.668	1682.949	665.2238	735.2473	7445.550	8229.292
2	1556.245	1720.061	322.1059	356.0118	7714.691	8526.764
3	994.0943	1098.736	342.5093	378.5629	7822.270	8645.667
4	1502.198	1660.324	674.4364	745.4297	7201.936	7960.035
5	1010.139	1116.469	415.2959	459.0112	8161.938	9021.089

The results shown in Table 4 are based on the interval normalization of the decision matrix, as determined by applying equation (10). The results shown in Table 5 are based on the interval weighted normalization of the decision matrix, as determined by applying equations (11) and (12). The next step involves computing (PIS) and (NIS) calculated using Equations (15) and (16). The relative closeness for each scenario should first be calculated using equation (18), with these results being displayed in Table 7. Subsequently, the scenarios are to be ranked in descending order based on their relative closeness, and these final rankings are presented in Table 7. The second scenario is characterized by a relative closeness of 0.806158 and the lowest cost.

Table 4. Normalized decision interval matrix for Case 1.

Scenario	Flow rate (MMscf)		Power (hp)		Line pack (MMscf)	
	η_{ij}^L	η_{ij}^U	η_{ij}^L	η_{ij}^U	η_{ij}^L	η_{ij}^U
1	0.209200	0.255560	0.248750	0.303875	0.175674	0.214604
2	0.213813	0.261195	0.120447	0.147138	0.182024	0.222362
3	0.136579	0.166846	0.128076	0.156459	0.184562	0.225462
4	0.206387	0.252124	0.252195	0.308083	0.169926	0.207582
5	0.138783	0.169538	0.155294	0.189708	0.192576	0.235253

$W = [0.372671, 0.353238, 0.2740912]$

Table 5. Weighted normalized decision interval matrix for Case 1.

Scenario	Flow rate (MMscf)		Power (hp)		Line pack (MMscf)	
	ν_{ij}^L	ν_{ij}^U	ν_{ij}^L	ν_{ij}^U	ν_{ij}^L	ν_{ij}^U
1	0.077963	0.095240	0.087868	0.107340	0.048151	0.058821
2	0.079682	0.097340	0.042546	0.051975	0.049891	0.060947
3	0.050899	0.062179	0.452410	0.055267	0.050587	0.061797
4	0.050899	0.093959	0.089065	0.108827	0.046575	0.056896
5	0.051720	0.063182	0.054856	0.067012	0.052783	0.064481

$A^- = [0.050899, 108827, 0.046575]$; $A^{\mp} = [0.09734, 0.042546, 064481]$

Table 6 Distances from (PIS) and (NIS) for Case1.

Scenario	Distances from (PIs) (d_j^+)	Distances from (NIs) (d_j^-)
1	0.083252	0.057380
2	0.025021	0.104058
3	0.061338	0.085363
4	0.085824	0.055021
5	0.064302	0.071917

Table 7. Rankings according to closeness coefficient value for Case 1.

Scenario	Pmin (psi)	Pmax (psi)	Relative closeness ψ_j	Rank	Cost (M$//Yr)
1	500	1109	0.408015	4	2.195
2	500	1139	0.806158	1	1.888
3	500	1168	0.581881	2	1.906
4	500	1083	0.390649	5	2.203
5	500	1197	0.577950	3	1.972

5.2. Case 2: Multi input –Multi output

Comprehensive information regarding the dimensions of length, internal diameter, for each pipe can be located in Table 8. The initial conditions prescribe a baseline temperature of 520 ^{0}R, a pressure of 14.5 psia and roughness 0.00001m. Figure 3 provides a schematic representation of the depicted transmission network, illustrating its intricate nature with numerous origins and destinations. The normalized decision matrix with interval data was formulated utilizing the outcomes derived from equation (2) with the complete data. Table 11 presents the results derived from the interval weighted normalized decision matrix, calculated using equations (3) and (4). The next phase of the process involves calculating both the (PIS) and (NIS) using Equations (7) and (8), respectively. Table 13 will present the relative closeness values for each scenario, as determined by equation (9) and cost. Following this, the scenarios will be ordered from highest to lowest relative closeness, and this descending ranking will be documented in Table 13. As shown in Table 13, scenario 4 is the optimal outcome, with the maximum relative closeness value 0.557843 and minimum cost.

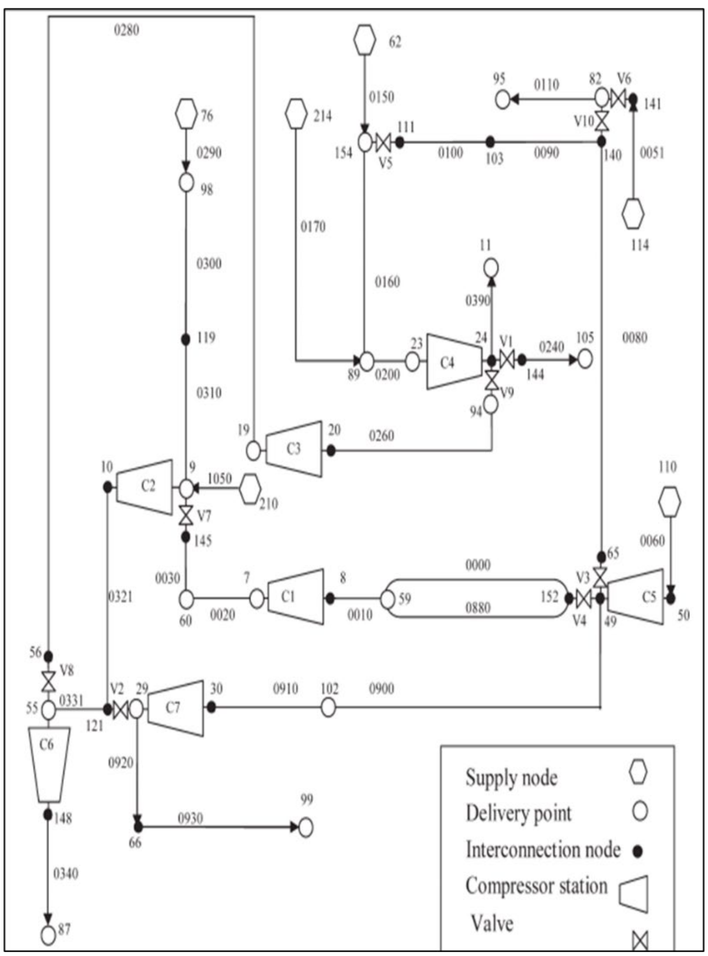

Figure 2. Pipeline network for case 2.

Table 8. Diameter and length of Case 2.

Arc	Diameter (in)	Length (mile)	Arc	Diameter (in)
G1(26,25)	40	40.06	G16(10-11)	30
G2(25-24)	28	63.50	G17(12-13)	30
G3(23-22)	28	50.25	G18(45-44)	36
G4(22-21)	26	16.94	G19(44-43)	48
G5(39-38)	48	107.94	G20(43-19)	36
G6(30-29)	48	3.06	G21(18-17)	36
G7(28-36)	48	76.38	G22(17-14)	36
G8(37-40)	36	50.81	G23(15-16)	32
G9(36-41)	48	26.00	G24(7-6)	20
G10(41-42)	42	17.75	G25(26-25)	42
G11(1-2)	36	13.50	G26(27-31)	42
G12(2-3)	42	8.88	G27(31-32)	42
G13(3-5)	42	27.06	G28(33-34)	36
G14(4-3)	24	29.25	G29(34-35)	36
G15(8-9)	24	17.44	G30(20-19)	42

Table 9. The interval decision matrix for Case 2.

Scenario	Flow rate (MMscf)		Power (hp)		Line pack (MMscf)	
	λ_{ij}^L	λ_{ij}^U	λ_{ij}^L	λ_{ij}^U	λ_{ij}^L	λ_{ij}^U
1	196132.8	216778.4	80635.59	89123.54	10746.92	11878.18
2	62828.88	69442.45	27448.71	30338.05	11589.51	12809.46
3	61981.39	68505.74	21355.32	23603.25	11818.96	13063.06
4	63076.31	69715.92	13055.3	14429.54	12235.59	13523.55
5	151164.6	167076.7	67867.82	75011.80	10563.66	11675.62

Table 10. Normalized decision matrix with interval data for Case 2.

Scenario	Flow rate (MMscf)		Power (hp)		Line pack (MMscf)	
	η_{ij}^L	η_{ij}^U	η_{ij}^L	η_{ij}^U	η_{ij}^L	η_{ij}^U
1	0. 331575	0.405054	0.34681	0.423666	0.170722	0.208555
2	0.106216	0.129754	0.118056	0.144218	0.184107	0.224906
3	0.1o4783	0.128004	0.091848	0.112203	0.187752	0.229359
4	0.1o6634	0.130265	0.05615	0.068594	0.19437	0.237444
5	0.255553	0.312185	0.291897	0.356583	0.167811	0.204999

$W = [0.34397, 0.342813, 0.31216]$

Table 11. The interval weighted normalised decision matrix for Case 2.

Scenario	Flow rate (MMscf)		Power (hp)		Line pack (MMscf)	
	ν_{ij}^L	ν_{ij}^U	ν_{ij}^L	ν_{ij}^U	ν_{ij}^L	ν_{ij}^U
1	0.114052	0.139326	0.118891	0.145238	0.053293	0.065103
2	0.036535	0.044632	0.040471	0.04944	0.057471	0.070207
3	0.036042	0.04403	0.031487	0.038465	0.058609	0.071597
4	0.036679	0.044807	0.0i9249	0.023515	0.060675	0.074121
5	0.087903	0.107382	0.100066	0.122241	0.053284	0.063992

$A^- = [0.036042, 0.145238 , 0.052384]$

$A^{\mp} = [0.139326, 0.019249, 074121]$

Table. 12 Distances from the positive ideal solution (PIS) and negative ideal solution (NIS) for Case 2.

Scenario	Distances from (PIs) (d_j^+)	Distances from (NIs) (d_j^-)
1	0.164182	0.132792
2	0.145559	0.143426
3	0.143231	0.157517
4	0.140247	0176942
5	0.146214	0.102387

Table 13. Rankings according to closeness coefficient value for Case 2.

Scenario	Pmin (psi)	Pmax (psi)	Relative Closeness ψ_j	Rank	Cost (M$//Yr)
1	650	1062	0.446983	4	5.980
2	670	1119	0.496309	3	3.704
3	650	1129	0.523751	2	3.270
4	650	1158	0.557843	1	3.128
5	650	1042	0.411851	5	6.656

6. Results and discussion

In this section, we shall elucidate outcomes derived from the conducted case studies. Building upon prior research in related areas, earlier studies focused on singular objectives or multi-objective optimization, this study introduces an innovative multi-objective optimization model.

In case 1, Table 4 presents the normalized results obtained using Equation (10). Subsequently, with the determination of the (PIS) and the (NIS by using equations 15 and 16 which was presented previously. As shown in Table 7, the TOPSIS method with interval data identified Scenario 2 is optimal, with the highest relative closeness value of 0.806158. This scenario is characterized by a pressure range of 500–1139 psi. and the lowest total cost of $1,888 million.

Table 9 presents scenarios in Case 2, including flow rate, power consumption, and line pack. The normalized interval decision matrix, derived using Equation (10), is shown in Table 10. As shown in Table 13, Scenario 4 is the optimal, with the highest relative closeness value of 0.557843, a pressure range of 650–1158 psi and the lowest total cost of $3.128 million.

7. Conclusion

This study introduces a novel methodology that integrates the TOPSIS technique with interval data to support multi-objective decision-making for the design of natural gas Pipeline networks. The method provides two major contributions. First, it establishes a robust and adaptable framework for addressing complex optimization problems in gas pipeline networks. Second, by incorporating the TOPSIS method with interval data, it enhances decision-making using similarity measures and the existing configuration knowledge approach is validated through two representative case studies: a tree topology and a multi-supply, multi-delivery network. These examples demonstrate the method's capacity to optimize performance under varying levels of network complexity. Results confirm the reliability and precision of the method, with total cost calculations reinforcing its robustness. Furthermore, the approach's scalability makes it applicable to a broad range of gas transmission scenarios. It equips decision-makers with a suite of Pareto-optimal solutions, facilitating the selection of more efficient and economically viable network designs when compared to conventional optimization techniques.

Nomenclature

p_b	*Base Pressure in psia.*
T_b	*base temperature in °r.*
P_1	*upstream pressure in psia.*
P_2	*downstream pressure in psia.*
T_f	*gas flowing temperature in °R.*

$\boldsymbol{\rho_g}$	*gas density in lb/ft^3.*
$\boldsymbol{\rho_{air}}$	*air density in lb/ft^3.*
D	*pipe inside diameter in inch.*
L	*equivalent length in mile.*
$\boldsymbol{M_{wt(avg.)}}$	*average molecular weight of gas.*
$\boldsymbol{P_{avg.}}$	*The pseudo critical pressure psi.*
T	*gas temperature in K.*
K	*specific heat ratio (cp/cv) assumes it to be 1.26.*
$\boldsymbol{T_1}$	*suction temperature in °R.*
MMscf	*Million standard cubic feet per day.*

References

[1] Arya AK, Jain R, Yadav S, Bisht S, and Gautam S. Recent trends in gas pipeline optimization. Materials Today: Proceedings, 2022; 57: 1455–1461. https://doi.org/10.1016/j.matpr.2021.11.232

[2] Li CJ, Jia WL, Liu EB, and Wu X. A multi-hierarchy grey relational analysis model for comprehensive evaluation of natural gas pipeline operation schemes. International Journal of Industrial Engineering: Theory, Applications and Practice, 2021; 19(6): 241–251. https://doi.org/10.1007/978-3-642-21402-8_40

[3] Ríos-Mercado RZ, and Borraz-Sánchez C. Optimization problems in natural gas transportation systems: A state-of-the-art review. Applied Energy, 2015; 147: 536–555. https://doi.org/10.1016/j.apenergy.2015.03.017

[4] Tabkhi F, Pibouleau L, Hernandez-Rodriguez G, Azzaro-Pantel C, and Domenech S. Improving the performance of natural gas pipeline networks: Fuel consumption minimization problems. AIChE Journal, 2010; 56(4): 946–964. https://doi.org/10.1002/aic.12011

[5] Hesam A, and Molaei R. Techno-economical and environmental optimization of natural gas network operation. Energy, 2014; 92: 2106–2122. https://doi.org/10.1016/j.cherd.2014.02.006

[6] Osiadacz AJ, and Isoli N. Multi-objective optimization of gas pipeline networks. Energies, 2020; 13(19): 5141. https://doi.org/10.3390/en13195141

[7] Zhou J, Peng J, Liang G, Chen C, Zhou X, and Qin Y. Technical and economic optimization of natural gas transmission network operation to balance node delivery flowrate and operation cost. Journal of Intelligent & Fuzzy Systems, 2021; 40(3): 4345–4366. https://doi.org/10.3233/JIFS-201072

[8] Arya AK, and Honwad S. Modeling, simulation, and optimization of a high-pressure cross-country natural gas pipeline: Application of an ant colony optimization technique. Journal of Pipeline Systems Engineering and Practice, 2016; 7(1): 04015016. https://doi.org/10.1061/(ASCE)PS.1949-1204.0000206

[9] El-Ghareib N, Rawash YY, Aly S, Awad ME, and Hussein MH. Enhancing gas pipeline network efficiency through the VIKOR method. Decision Making: Applications in Management and Engineering, 2023; 6(2): 853–879. https://doi.org/10.1016/j.engappai.2023.106857

[10] Amira AH, Awad ME, Aly SM, and Hussein MH. Synthesis and design of natural gas transmission network through fuzzy analogical gates. Petroleum & Coal, 2024; 66(2): 665–675.

[11] Hussein MH. Simultaneous multi-objective framework of natural gas pipeline network operations. Chemical Industry and Chemical Engineering Quarterly, 2025; 31(1): 83–92. https://doi.org/10.2298/CICEQ231203016M

[12] Pambour KA, Bolado-Lavín R, and Dijkema GPJ. An integrated transient model for simulating the operation of natural gas transport systems. Journal of Natural Gas Science and Engineering, 2016; 28: 677–690. https://doi.org/10.1016/j.jngse.2015.11.036

[13] Demissie A, Zhu W, and Belachew CT. A multi-objective optimization model for gas pipeline operations. Computers & Chemical Engineering, 2017; 100: 94–103. https://doi.org/10.1016/j.compchemeng.2017.02.017

[14] Edgar TF, Himmelblau DM, and Lasdon LS. Optimization of chemical processes. New York: McGraw-Hill; 2001. https://doi.org/10.1002/aic.690490128

[15] Hwang CL, and Yoon K. Multiple attribute decision making: Methods and applications. Berlin: Springer; 1981. https://doi.org/10.1007/978-3-642-48318-9_3

[16] Jahanshahloo GR, Hosseinzadeh FL, and Izadikhah M. An algorithmic method to extend TOPSIS for decision-making problems with interval data. Applied Mathematics and Computation, 2006; 175: 1375–1384. https://doi.org/10.1016/j.amc.2005.08.048

[17] Tabkhi F, Pibouleau L, Azzaro-Pantel C, and Domenech S. Total cost minimization of high-pressure natural gas networks. Journal of Energy Resources Technology, 2009; 131(4): 042001. https://doi.org/10.1115/1.4000325

[18] Sui Y, and Wang Z. Discussion on normalization methods of interval weights. Science Journal of Applied Mathematics and Statistics, 2016; 4(5): 249–252. https://doi.org/10.11648/j.sjams.20160405.19

[19] Wang YM, and Elhag TMS. On the normalization of interval and fuzzy weights. Fuzzy Sets and Systems, 2006; 157: 2456–2471. https://doi.org/10.1016/j.fss.2006.06.008

[20] Coelho PM, and Pinho C. Considerations about equations for steady-state flow in natural gas pipelines. Journal of the Brazilian Society of Mechanical Sciences and Engineering, 2007; 29(3): 262–273. https://doi.org/10.1590/S1678-58782007000300005

[21] Mohitpour M, Golshan H, and Murray MA. Pipeline design & construction: A practical approach. New York: American Society of Mechanical Engineers; 2003. https://doi.org/10.1115/1.802574.ch7

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