Heliyon 10 (2024) e30664

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Application of the full consistency method (FUCOM) - Cosine similarity framework in 5G infrastructure investment planning: An approach for telecommunication quality improvements

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A R T I C L E I N F O

Keywords:
Full consistency method (FUCOM)
Cosine similarity
5G technology
Network planning
Data-driven decision making
Next-generation networks
Strategic planning
Telecommunications infrastructure

A B S T R A C T

In the rapidly evolving telecommunications landscape, the shift towards advanced communication technologies marks a critical milestone. This transition promises to revolutionize connectivity by enabling seamless data downloads, high-quality video streaming, and instant access to applications. However, adapting to these advanced technologies poses significant challenges for infrastructure expansion, requiring innovative investment and deployment strategies. These strategies aim not only to enhance service quality but also to ensure extensive network coverage. To address the need for systematic planning in infrastructure investment, this paper presents a novel methodology that combines the Full Consistency Method (FUCOM) with cosine similarity analysis. This integrated approach effectively prioritizes service areas for the deployment of 5G technology, emphasizing the importance of detailed planning in mobile strategy development. By leveraging FUCOM to determine the weights of various criteria and employing cosine similarity analysis to rank service areas, the methodology facilitates efficient resource allocation and service quality enhancements. Empirical validation using real data from a Turkish telecommunications company confirmed the effectiveness of the proposed algorithm. The results indicate that this integrated approach can significantly advance the telecommunications industry by providing essential insights for companies seeking to improve service quality amidst the transition to 5G and beyond. The successful implementation of the proposed algorithm demonstrates its effectiveness in addressing the challenges faced by telecommunications companies and underscores the importance of a data-driven approach in strategic decision-making and resource allocation. Furthermore, the findings suggest that the integrated FUCOM and cosine similarity analysis approach can offer a valuable tool for telecommunications companies worldwide, offering a

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https://doi.org/10.1016/j.heliyon.2024.e30664
Received 5 January 2024; Received in revised form 12 April 2024; Accepted 1 May 2024
Available online 6 May 2024

systematic method for prioritizing infrastructure investments and enhancing network performance.

1. Introduction

In the rapidly evolving technological landscape, the digital transformation is becoming increasingly pervasive across various sectors, including health, education, finance, and governance. This transformation is fundamentally altering the way people interact, work, and access services, leading to the emergence of smart cities, e-government services, telemedicine, and online education platforms. Consequently, there is a surge in data consumption, placing new demands on mobile communications technology. 5G, the next generation of communications technology, is poised to meet these demands and support the digitalization of society. The digital transformation extends to the manufacturing sector as well, exemplified by Industry 4.0, which is underpinned by technologies such as the Internet of Things (IoT), cyber-physical systems, and smart manufacturing. These technologies rely on high-speed, low-latency internet, which 5G mobile networks promise to provide through broadband, massive machine communication, and ultra-low latency communication services [1].

However, the transition to 5G technology is fraught with complex challenges spanning technical, strategic, and operational domains. A critical challenge is the strategic expansion of telecommunications infrastructure to support the dense network required for 5G's high-speed, low-latency connections. Through its innovative technologies, 5G has the potential to connect billions of devices and enable seamless collaboration, opening up advanced technological possibilities in society and industry. The main goal of future next-generation communication technologies is to meet increasing user demands and create more user-centric value. As a crucial milestone, 5G and beyond networks promise new technologies that will fundamentally change the way we connect and interact. Telecommunications companies play a vital role in ensuring that society and industry can reap these benefits without interruption [2,3].

Although the academic and industrial research communities have extensively explored the potential of 5G, focusing on its technological capabilities, potential applications, and societal benefits, there is a notable gap in the literature regarding the systematic and strategic planning required for the effective deployment of 5G networks [4]. While numerous studies have highlighted the challenges associated with 5G deployment, there is a lack of research offering concrete, methodological solutions to these challenges [5,6]. In particular, the strategic prioritization of service areas—a key aspect of network deployment that directly impacts service quality and network coverage—has not been adequately addressed [7].

To fill this gap, our study presents a new methodology that combines the Full Consistency Method (FUCOM) with cosine similarity analysis for strategic planning and prioritization of 5G network deployment. In this approach, FUCOM is used to determine the weights of the criteria, and cosine similarity is employed to rank the alternatives based on these weights. The innovative approach determines the criteria weights based on the opinions collected from five R&D experts working in a leading company in Turkey. Based on these weights, cosine similarity ranks the alternative sites. The results demonstrate its practical applicability and relevance through feedback from four site experts working in the same company. This dual-method framework provides a strategic approach to telecom planning to address the complexities of network deployment in the 5G and beyond era. By combining expert insight with quantitative analysis, the research highlights a path forward for using 5G technology as a catalyst for quality improvements in telecom services and marks an important step towards realizing the full potential of next-generation networks.

The application of the FUCOM - cosine similarity framework in 5G Infrastructure Investment Planning is a relatively niche area that intersects several fields including multi-criteria decision making (MCDM), telecommunications, and infrastructure planning. The FUCOM is a remarkable MCDM technique that is effectively used in different decision-making scenarios, as demonstrated by Stević and Brković [8] in their study on the evaluation of human resources in a transport company. FUCOM allows obtaining credible and reliable weighting coefficients that contribute to rational judgment and to obtain convincing results in decision-making. This makes the method a valuable tool in determining the weights of criteria in decision-making processes [9]. On the other hand, cosine similarity is a widely used measure in information retrieval and text mining to assess the similarity between two vectors. It can be used to compare the similarity between different decision-making alternatives, as Zhang et al. [10] investigated the performance evaluation of financial logistics enterprises in the context of MCDM. Planning and allocation of resources for the development and deployment of 5G networks, known as 5G infrastructure investment planning, is a critical area of focus in the telecommunications industry. Ahamed and Faruque [5] discuss the challenges and strategies in investment and planning for 5G infrastructure from a cognitive perspective, emphasizing the importance of addressing uncertain processes in this context. There is no comprehensive literature on the individual components of the FUCOM - cosine similarity framework, nor is its specific integration into 5G infrastructure investment planning well documented. This presents an opportunity for future research to develop comprehensive frameworks that leverage the decision-making capabilities of FUCOM and the comparative analysis of cosine similarity to optimize 5G infrastructure investments for telecommunications quality improvement.

The remainder of this paper is structured as follows: Section 2 provides an overview of the theoretical background of the methods used in the study. Section 3 details the methodology employed in this research, encompassing the data collection process and the implementation of the similarity algorithm based on cosine similarity. Section 4 presents the results and analysis derived from applying the algorithm to telecommunication data. Section 5 discusses both the outcomes of the research and their broader implications, underscoring the significance of data-driven strategies in decision-making and resource allocation within the telecommunications realm. Lastly, Section 6 concludes by revisiting the key findings, addressing the study's limitations, and suggesting potential avenues for future work.

2. Theoretical background

The methodology employed in this study is rooted in the integration of the FUCOM and cosine similarity techniques. The rationale behind this choice is multifaceted:

1. In our research, we employed the FUCOM, a distinct approach that demonstrates minimal deviations from optimal values when determining the weights of criteria, as opposed to more subjective methods. This proximity of FUCOM to optimal values bolsters our capability to accurately define the similarity measure. An aptly defined similarity measure subsequently enhances the performance of various tasks, including but not limited to, classification, ranking, and clustering. FUCOM, known for its precision and adaptability, is instrumental in determining weights and ranking alternatives [11]. By utilizing pairwise comparisons, FUCOM permits decision-makers to calibrate and validate results, thereby ensuring that the resulting weights are both consistent and representative of the given criteria. This adaptability is paramount, especially in a field as dynamic and evolving as telecommunications, where decision-makers need tools that can be tailored to specific challenges and contexts.
2. Cosine similarity, renowned for its computational simplicity and efficacy, is adept at performing tasks like classification, clustering, and ranking. In the context of our study, it aids in identifying the similarity between vectors, which is pivotal for understanding the alignment between different deployment points in the telecommunications network [11]. Its widespread applicability ensures that results are both reliable and indicative of real-world scenarios.

By marrying the tailored flexibility of FUCOM with the computational robustness of cosine similarity, our methodology provides a comprehensive framework. This amalgamation ensures a more holistic approach to 5G infrastructure investment planning, emphasizing both the subjective judgments of decision-makers (via FUCOM) and the objective measures of deployment alignments (via cosine similarity). In this section, we first provide an overview of the 5G, FUCOM and cosine similarity methods.

2.1. Background of 5G

5G wireless communications technology represents a significant breakthrough for society and industries alike. Building upon the foundation laid by its predecessors, namely 2G, 3G, and 4G, 5G offers unparalleled advancements in terms of high-speed internet connectivity, data rates, and enhanced reliability. The transformative potential of 5G extends to various sectors, including industry 4.0, automotive and mobility, transportation, healthcare, energy, as well as the media and entertainment ecosystem [12] With significantly higher data transfer rates, reduced latency, increased network capacity, and improved energy efficiency, 5G is poised to meet the escalating demand for faster and more reliable connections. Consequently, the deployment of 5G infrastructure has become a strategic priority for countries striving to lead in technological innovation [13]. However, achieving this deployment goal is not without its challenges, and one of the key challenges is developing appropriate investment plans [13,14]. Therefore, this study focuses on investment planning for 5G infrastructure, which plays a pivotal role in shaping the future of communication networks and supporting economic growth in the digital age.

Recent studies have highlighted the importance of 5G in enabling smart cities, IoT applications, and the digital economy. For example, Lu et al. [15] discussed how 5G can revolutionize healthcare by enabling a three-dimensional and efficiently connected emergency medical management system. Similarly, Lei et al. [16] emphasized the role of 5G in facilitating seamless connectivity and real-time data processing, which are critical to the success of renewable energy initiatives. These studies underscore the diverse applications of 5G and the need for strategic investment planning to realize its full potential.

2.2. Background of FUCOM

One of the most significant challenges in decision-making processes is the determination of parameter weights, as they play a crucial role in shaping the overall results [17]. In addressing this challenge, the FUCOM offers a novel approach for weight determination. By applying FUCOM in decision-making, several advantages can be realized, including the reduction of required pairwise comparisons to a minimum (n-1 comparisons), the ability to validate outputs through quantifying variance from maximum accuracy, and the elimination of redundancy in pairwise comparisons of criteria for weight calculation [18].

By utilizing the FUCOM, decision-makers can effectively overcome the complexities and potential biases associated with traditional weight determination techniques. FUCOM provides a structured approach that allows for assessing the importance of criteria while minimizing the cognitive burden on decision-makers. The limited number of required pairwise comparisons in FUCOM simplifies the weight determination process and alleviates cognitive load [19].

Furthermore, the validation aspect of FUCOM empowers decision-makers to evaluate the accuracy of comparisons and ensure the reliability of the results. Through quantifying the variance from maximum accuracy, decision-makers can gain confidence in the derived weights and enhance the overall robustness of the decision-making process [18].

Given the aforementioned advantages, the FUCOM is the preferred choice in this study for determining parameter weights. The accurate and efficient weight determination facilitated by FUCOM contributes to more informed decision-making, providing a solid foundation for evaluating investment opportunities within the 5G infrastructure investment planning process.

Recent advancements in FUCOM have further enhanced its applicability in various decision-making contexts. For example, Kılıç and Erkayman [9] proposed a fuzzy logic-enhanced extension of FUCOM to address the uncertainty in deciding on production technology based on the critical characteristics of smart production systems. This extension has been applied successfully in fields such as supply chain management and environmental sustainability, demonstrating the versatility and potential of FUCOM in addressing complex decision-making challenges.

2.3. Background of cosine similarity

Cosine similarity is a widely adopted mathematical measure used to quantify the similarity between two vectors in a vector space. It calculates the numerical value as the cosine of the angle between the two vectors. The main advantages of this method lie in its simplicity and efficiency, making it a popular choice in various fields. One significant advantage of cosine similarity is its robustness to vector size variations. Unlike other similarity measures, cosine similarity focuses solely on the angle between the vectors, disregarding their magnitudes. It serves as an effective tool for analyzing relationships between items or entities. By representing items as vectors based on their features or characteristics, cosine similarity enables meaningful comparisons and helps identify similarities or dissimilarities [20,21]. In our research, we are exploring the potential application of cosine similarity in the context of ranking 5G alternatives. We are investigating whether this measure can effectively evaluate different alternatives in the 5G infrastructure investment planning process.

The use of cosine similarity in strategic planning processes is increasingly recognized in the literature. For instance, Guirao et al. [22] proposed a multi-criteria decision model that employs cosine similarity for the critical task of supplier selection in an investment company. Furthermore, Peng and Xiaonan [23] highlighted its significance by developing comparative algorithms that integrate multi-criteria decision making and cosine similarity to enhance both environmental sustainability and profitability in the coal supply chain. These applications underscore the versatility of cosine similarity across various domains. Consequently, this has motivated us to explore its potential contribution to the effective planning and deployment of 5G infrastructure.

2.4. Existing 5G infrastructure in Turkey

As investment decisions for 5G infrastructure have become a strategic priority, policymakers in many countries, particularly those with low- and medium-income economies, are grappling with the challenges of initiating 5G network investments. However, it is important to note that developing countries often face significant barriers in the adoption and deployment of 5G technology [24,25].

Fig. 1 depicts the current 5G coverage map of Turkey, highlighting the extent of 5G connectivity in the country. It is evident from the map that Turkey's 5G network is currently available in only a small geographical area. Given the immense potential and transformative power of 5G technology, effective planning is crucial to facilitate a more comprehensive and efficient transition process.

The limited 5G infrastructure in Turkey underscores the need for a well-defined investment strategy that accounts for the country's specific socio-economic conditions, technological capabilities, and regulatory framework. Policymakers and stakeholders must carefully assess the existing infrastructure gaps and develop targeted investment plans to expand 5G coverage nationwide.

Furthermore, it is essential to consider the unique challenges faced by developing countries in terms of financial resources, digital divide, and ensuring equitable access to 5G services. Investment planning should prioritize bridging these gaps and promoting inclusive growth, leveraging 5G technology as a catalyst for socioeconomic development.

We seek to contribute to the broader debate on 5G deployment and investment planning in Turkey and ultimately support the country's journey to embrace the full potential of 5G technology and reap its socio-economic benefits.

Fig. 1. Turkey's current 5 g map (Figure source https://www.nperf.com/tr/).

3. Methodology

Before presenting the detailed flowchart of our methodology, it's imperative to provide a brief overview to set the context. Our approach is meticulously designed to be both robust and adaptable, catering specifically to the dynamic landscape of telecommunications.

Central to our methodology's design is the involvement of R&D experts who have meticulously defined the input criteria. These experts conducted and evaluated the pairwise comparison matrices, lending their specialized knowledge to ensure a rigorous foundation for our methodological processes. After a thorough evaluation, the results derived from our methodology were reviewed by field experts. Their hands-on experience and insights were invaluable in gauging the practicality and applicability of our findings. It's worth noting that these field experts deemed the results not only accurate but also highly actionable within real-world contexts.

The flowchart shown in Fig. 2 depicts each stage in our methodology, providing a visual guide to the processes and decision points that characterize our research approach.

3.1. Determination of weights by FUCOM

FUCOM, introduced to the literature by Pamucar et al. [19], is a criteria weighting method used to calculate the importance weights of criteria. This method follows the steps outlined below:

Step 1: Ranking the Criteria in Order of Importance

In the first step, the decision maker(s) rank the criteria in the decision problem from most important to least important. This ranking of criteria provides the expected values of the weight coefficients, as shown in Equation (1), which allows for the determination of the relative importance of each criterion.

$$C_{j(1)} > C_{j(2)} > \ldots > C_{j(k)} \tag{1}$$

Step 2: Determination of Comparative Priorities of Criteria

In this step, the mutual prioritization of the rankings proposed by the decision maker(s) in the first step is determined (Equation (2)).

$$\Phi = \varphi_{1/2} > \varphi_{2/3} \cdots > \varphi_{k/(k+1)} \tag{2}$$

here $\varphi_{k/(k+1)}$ indicates the advantage of criterion $C_{j(k)}$ over criterion $C_{j(k+1)}$.

Step 3: Calculation of Importance Weights of Criteria

In the third and final step, the final values of the weight coefficients of the criteria $(w_1, w_2, \cdots, w_n)^T$ are calculated. In order to

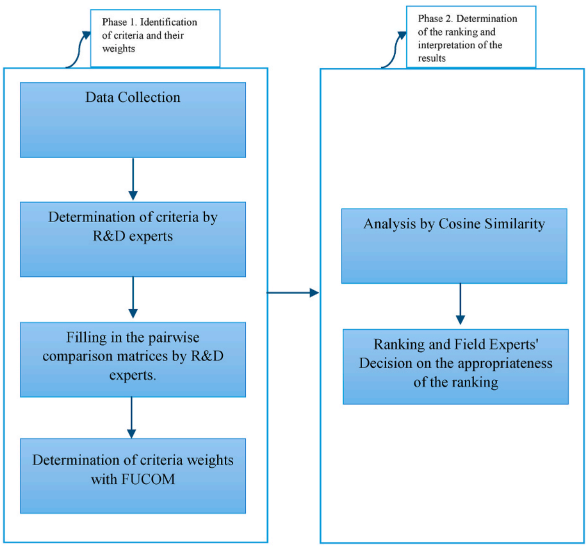

Fig. 2. Flowchart.

calculate these weights, the following two conditions must be met.

Condition 1. The ratio of the weight coefficients should be equal to the comparative priority values of the criteria as shown in Equation (3).

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \tag{3}$$

Condition 2: The final values of the weight coefficients must satisfy mathematical transitivity. Then $\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)}$. Since $\varphi_{k/(k+1)} = \frac{w_k}{w_{k+1}}$ and $\varphi_{(k+1)/(k+2)} = \frac{w_{k+1}}{w_{k+2}}$, that $\frac{w_k}{w_{k+1}} \otimes \frac{w_{k+1}}{w_{k+2}} = \frac{w_k}{w_{k+2}}$ is obtained. Thus, Equation (4) must be satisfied for the final values of the coefficients of the criteria weights.

$$\frac{w_k}{w_{k+2}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \tag{4}$$

Satisfying full consistency requires that the conditions shown in Equation (3) and Equation (4) are met. The existence of these equations means that the consistency condition is fulfilled. That is, the deviation from full consistency (DFC(χ)) is minimal. DFC is $\chi = 0$. The final importance of the criteria is calculated by solving the linear programming model shown in Equation (5).

Min χ

$$\begin{aligned} &\left| \frac{w_{j(k)}}{w_{j(k+1)}} - \varphi_{k/(k+1)} \right| \leq \chi, \forall j \\ &\left| \frac{w_{j(k)}}{w_{j(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \right| \leq \chi, \forall j \\ &\sum_{j=1}^{n} w_i = 1, \forall j \\ &w_j \geq 0, \forall j \end{aligned} \tag{5}$$

By solving model (5), the final importance weights $(w_1, w_2, \cdots, w_n)^T$ and DFC value of the criteria are calculated.

3.2. Ranking of alternatives by cosine similarity

Before proceeding with the cosine similarity method, the data needs to be normalized. Normalization can be done as shown in Equation (6). The ranking of alternatives using the weights obtained from FUCOM is performed using the cosine similarity method, as indicated by Equation (7). Since all criteria are required to be maximized, when using the cosine similarity method, a maximum artificial point is created by taking the maximum value of each criterion in the dataset and the distance of other alternatives to this artificial maximum is determined as shown in Equation (8). The values closest to this point are the best sites [23].

$$x_{normalized} = \frac{\mathrm{x} - \min(\mathrm{x})}{\max(\mathrm{x}) - \min(\mathrm{x})} \tag{6}$$

$$\frac{\sum_i^n (x_{1i} w_i)(x_{2i} w_i)}{\sqrt{\sum_i^n (x_{1i} w_i)^2} \sqrt{\sum_i^n (x_{2i} w_i)^2}} \tag{7}$$

$$\boldsymbol{A}^* = \left\{ \left(\boldsymbol{max}_i \, \boldsymbol{x}_{ij} \right) \right\} \quad \boldsymbol{A}^* = \left\{ \boldsymbol{x}_1^*, \boldsymbol{x}_2^*, \ldots .\boldsymbol{x}_j^*, \ldots \ldots, \boldsymbol{x}_n^* \right\} \tag{8}$$

4. Case study

The study focuses on identifying the most suitable service areas for the deployment of 5G technology, taking into account the unique characteristics and challenges of the Turkish telecommunications environment. The research was conducted in collaboration with one of the leading telecommunications companies in Turkey, which was in the planning phase for 5G deployment. The study was completed with this company and its staff in November 2023, and the data from this period was used in the study.

The aim of the research was to analyze and prioritize service areas for 5G deployment within the company's network, considering factors such as population density, existing infrastructure, and estimated demand for 5G services. The telecommunications company selected for the research was chosen based on its market position, network coverage, and willingness to participate in the research. The company's network infrastructure and service areas were representative of the broader telecommunications landscape in Turkey, making it a suitable candidate for the study.

Additionally, the province of Mersin was chosen for the study because the company has strong data in this province, making it an ideal starting point. After selecting the telecom operator, the methodology described in Section 3 was applied to identify the most suitable service areas for 5G deployment. Five in-house R&D experts were consulted to identify and rank the criteria, which were then used to calculate the weights for each criterion.

The cosine similarity method was used to rank the service areas according to these weights, providing a data-driven approach to decision-making. The results of the research were validated with feedback from four in-house field experts who reviewed and validated the rankings obtained through the methodology. The study demonstrated the practical applicability and effectiveness of the proposed approach, highlighting its potential to support strategic decision-making in 5G network deployment. (For information on the R&D and field experts involved, see the Supporting Information Table −1).

4.1. Determination of criteria

The purpose of this paper is to investigate the prioritization process for a telecommunication company operating in Turkey in upgrading its existing service points to 5G quality. The study involves ranking all the station data that the company serves in a specific province, which amounts to a total of 576 service points. Table 1 presents the criteria used for ranking the alternatives, which were determined based on expert opinions considering the field experience required. Global and local weights are calculated using the methods described in section 3.1. The local weight values in the table indicate the extent to which each criterion meets the item at a higher level in the hierarchical structure. The global weight values indicate the extent to which each criterion meets the target at the top of the hierarchical structure. The final weight values, as shown in Table 1, are derived by multiplying the local and global weights. (The experts' assessments are shown in section 4.2.). The final weight values are subsequently employed when applying the cosine

Table 1
Local and global weights.

Main Criteria (Global Weights)	Sub-criteria	Local Weights	Unit	Final Weights
C.1. Data from sector counters (0.1761)	C.1.1. Bandwidth	0.0431	MHz	0.0076
	C.1.2. Downlink Physical Resource Block (PRB) utilization	0.0485	%	0.0085
	C.1.3. Voice traffic over 4G	0.1292	Erlang	0.0228
	C.1.4. Data traffic over 4.5G	0.1939	GB	0.0341
	C.1.5. Data traffic over sim card devices	0.3878	GB	0.0683
	C.1.6. Customers whose installation request was denied	0.0554	Number of Persons	0.0098
	C.1.7. Number of subscribers receiving service from sim card devices	0.0646	Number of Persons	0.0114
	C.1.8. Data download speed of 4.5G subscribers	0.0775	Mbps	0.0136
C.2. Data from user measurement reports (0.1320)	C.2.1. Reference Signal Received Power (RSRP)	0.24	dBm	0.0317
	C.2.2. Reference Signal Received Quality (RSRQ)	0.12	dB	0.0158
	C.2.3. Signal to Interference Plus Noise Ratio (SINR)	0.16	dB	0.0211
	C.2.4. Downlink Volume	0.48	MHz	0.0634
C.3. Data of users who are candidates to switch to 5G (0.5283)	C.3.1. Number of users who can replace their current terminal with a terminal that supports 5G	0.0915	Number of Persons	0.0483
	C.3.2. Traffic generated by users who are likely to replace their existing terminal with a terminal that supports 5G	0.1144	Downlink/ Uplink ratio	0.0604
	C.3.3. Number of users whose current terminal supports 5G	0.2287	Number of Persons	0.1208
	C.3.4. Traffic generated by users whose current terminal supports 5G	0.4574	Downlink/ Uplink ratio	0.2416
	C.3.5. Number of users whose current terminal does not support 5G and uses legacy terminals	0.0572	Number of Persons	0.0302
	C.3.6. Traffic generated by users whose current terminal does not support 5G and who use old-style terminals	0.0508	Downlink/ Uplink ratio	0.0268
C.4. Road features within the coverage area of the sector (0.0881)	C.4.1. Arterial roads	0.1767	Meter	0.0156
	C.4.2. Boulevards	0.1178	Meter	0.0104
	C.4.3. Streets	0.3535	Meter	0.0311
	C.4.4. State Roads	0.0505	Meter	0.0044
	C.4.5. Internal roads	0.0442	Meter	0.0039
	C.4.6. Province roads	0.0393	Meter	0.0035
	C.4.7. Motorways	0.0707	Meter	0.0062
	C.4.8. Motorways connection	0.0589	Meter	0.0052
	C.4.9. Avenues	0.0884	Meter	0.0078
C.5. Buildings within the coverage area of the sector (0.0755)	C.5.1. Shopping buildings	0.1178	Piece	0.009
	C.5.2. Entertain places	0.0442	Piece	0.003
	C.5.4. Financial institutions	0.0707	Piece	0.005
	C.5.4. Homes	0.0393	Piece	0.003
	C.5.5. Cultural facilities	0.0505	Piece	0.004
	C.5.6. Health institutions	0.0589	Piece	0.004
	C.5.7. Industry and production	0.0884	Piece	0.007
	C.5.8. commercial facilities	0.3535	Piece	0.027
	C.5.9. food and beverage facilities	0.1767	Piece	0.013

similarity method.

4.2. Determination of criteria weights by FUCOM

In order to evaluate the site ranking, the significance of the criteria must first be determined. For this purpose, the FUCOM is applied. In the first step, the ranking of the criteria is determined according to the actual needs of the company. Then, according to the preferences of the unanimous decision makers, the criteria are compared by applying the 1–9 scale shown in Table 2 [8].

To offer a brief insight into the intermediary steps: the methodology employed to deduce the main criteria is outlined below. Expert opinion led to the prioritization of the main criteria in the order C.3 > C.1 > C.2 > C.4 > C.5. These rankings, combined with the scores in Table 2, were subjected to calculations using the equations in Section 3.1, keeping the order C.3 > C.1 > C.2 > C.4 > C.5.

$$\varphi_{C_3/C_1} = 3/1 = 3;\ \ \varphi_{C_1/C_2} = 4/3 = 1.3;\ \ \varphi_{C_2/C_4} = 6/4 = 1.5;\ \varphi_{C_4/C_5} = 7/6 = 1.7$$

Two fundamental conditions must be met when finalizing the weight coefficient values:
Condition 1.

$$w_3 /\ w_1\ = 3;\ \ w_1/\ w_2\ = 1.33;\ \ \ w_2/\ w_4\ = 1.5;\ w_4/\ w_5\ = 1.67$$

Condition 2.

$$\varphi_{C_3/C_2} = 1 * 1.33 = 4;\ \ \varphi_{C_1/C_4} = 1.33\ *\ 1.5 = 2;\ \ \varphi_{C_2/C_5} = 1.5 * 1.67 = 1.75$$

Subsequent to these conditions being satisfied:

$$w_3 / w_2 = 4;\ \ w_1/\ w_4\ = 1.5;\ \ \ w_2/\ w_5\ = 1.75$$

The culmination of this process yields a comprehensive model derived from the evaluated criteria values:
Min χ.

$$s.t.\begin{cases} \left|\dfrac{w_3}{w_1} - 3\right| \le \chi, \left|\dfrac{w_1}{w_2} - 1.33\right| \le \chi, \left|\dfrac{w_2}{w_4} - 1.5\right| \le \chi, \left|\dfrac{w_4}{w_5} - 1.67\right| \le \chi, \left|\dfrac{w_3}{w_2} - 4\right| \le \chi, \\ \left|\dfrac{w_3}{w_2} - 4\right| \le \chi, \left|\dfrac{w_1}{w_4} - 1.5\right| \le \chi, \left|\dfrac{w_2}{w_5} - 1.75\right| \le \chi \\ \sum_{j=1}^{n} w_i = 1, w_j \ge 0, \forall j \end{cases}$$

The finalized weights for the criteria, as showcased in Table 2, are procured using the Lingo software.
In Fig. 3, we provide a visual representation of both the main criteria and their associated sub-criteria weights as detailed in Table 1.

4.3. Ranking of alternatives by cosine similarity

After utilizing the FUCOM to assign weights to our decision criteria, detailed in earlier sections, we turned our attention to ranking the alternatives using the cosine similarity method, as elaborated in Section 3.2.

The cosine similarity method serves as an instrumental metric in assessing the similarity between two entities. Through its

Table 2
Comparisons of criteria.

Main Criteria	Comparisons								
C.3>C.1>C.2>C.4>C.5	C.1 3	C.2 4	C.3 1	C.4 6	C.5 7				
Sub-criteria	**Comparisons**								
C.1.5>C.1.4>C.1.3>C.1.7>C.1.8>C.1.6>C.1.2>C.1.1	C.1.1 9	C.1.2 8	C.1.3 3	C.1.4 2	C.1.5 1	C.1.6 7	C.1.7 6	C.1.8 5	
C.2.4>C.2.1>C.2.3>C.2.2	C.2.1 2	C.2.2 4	C.2.3 3	C.2.4 1					
C.3.4>C.3.3>C.3.2>C.3.1> C.3.5>C.3.6	C.3.1 5	C.3.2 4	C.3.3 2	C.3.4 1	C.3.5 8	C.3.6 9			
C.4.3>C.4.1>C.4.2>C.4.9> C.4.7>C.4.8>C.4.4>C4.5> C.4.6	C.4.1 2	C.4.2 3	C4.3 1	C.4.4 7	C.4.5 8	C.4.6 9	C.4.7 5	C.4.8 6	C.4.9 4
C.5.8>C.5.9>C.5.1> C.5.7>C.5.3>C.5.6> C.5.5>C.5.2>C.5.4	C.5.1 3	C.5.2 8	C.5.3 5	C.5.4 9	C.5.5 7	C.5.6 6	C.5.7 4	C.5.8 1	C.5.9 2

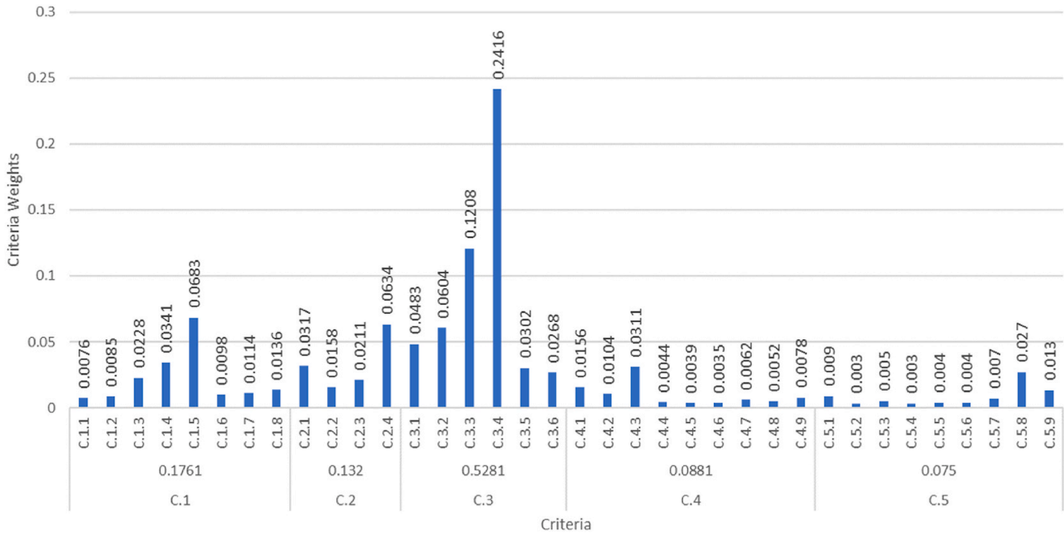

Fig. 3. Chart representing the main criteria and their respective sub-criteria weights.

application, we discern the relative closeness or distance of an alternative to the ideal solution in our decision-making context. Essentially, this method measures the cosine of the angle between two vectors in a multi-dimensional space.

The outcomes of this ranking are visually represented in Table 3. A key point to understand is that a higher ranking indicates an alternative that aligns more closely with the ideal solution, making it a preferable choice given the criteria and weights.

Table 3 uses data bars to visually depict the cosine similarity scores. Considering the vastness of the dataset, comprising 576 rows, a comprehensive visual portrayal of every data point is impractical. Therefore, the table provides a condensed perspective, emphasizing values that highlight the distribution and span of the cosine similarity scores. The representation is especially useful for rapidly understanding variations in similarity scores.

5. Results and managerial implications

In this research conducted in Mersin, Turkey, we have delved deep into the nuanced challenge of determining decision-makers' foremost motivations when opting for a specific site for a telecommunications company's deployment decision. Given the inherent subjectivity of this process, coupled with its many uncertainties, it was imperative to define criteria and assign corresponding weights through the insights of industry experts.

Our pioneering approach has seamlessly merged two distinct methodologies: FUCOM, employed to determine criteria weights, and cosine similarity, utilized for ranking alternatives. The amalgamation of these techniques has borne results that are viewed as

Table 3
Cosine similarity scores and rankings of alternatives.

Ranking	Station	Similarity
1	Site312	0.999999999749134
2	Site225	0.999993297868434
3	Site278	0.999988896469804
…	…	…
287	Site468	0.993042234358963
288	Site509	0.993030437320133
289	Site29	0.992951384885449
…	…	…
574	Site157	0.567156285698435
575	Site149	0.506190695586132
576	Site153	0.500035328716164

consistent by domain experts, thereby underscoring the robustness inherent in our methodology. Additionally, the inherent simplicity and adaptability of the mathematical model accentuate its potential application across a vast range of MCDM problems.

Going beyond its mathematical design, the versatility of our model is evident in its adaptability to an array of scenarios. It stands poised to aid decisions spanning diverse technological investments, strategic undertakings, or site allocations. The ramifications of our research on the telecommunication realm are substantial. By grounding site selection in a rigorous mathematical foundation, decision-makers are empowered to hone their choices, catalyzing enhanced operational results.

Our research offers consequential insights beneficial to the managerial stratum of the telecommunications industry. Armed with this data-driven framework for site selection, leaders can make more informed, strategic decisions. By leveraging this model, companies are better positioned to prioritize sites that not only promise significant ROI but also resonate with their broader business objectives.

By embedding the insights from our study into their strategic paradigm, telecommunication entities can project their commitment to innovation and data-led decision-making. Such a stance augments their standing in a competitive marketplace, emphasizing a dedication to harnessing research for superior operational outcomes.

Looking ahead, we envision an expansive utilization of our model, one that could span national boundaries or even be adopted across diverse countries. Such an extension would instill a mathematical precision into the deliberations of policymakers at a grander scale, fortifying the effectiveness of their resolutions.

6. Conclusion and limitations

Our research conducted in Mersin, Turkey, introduces a novel approach to understanding the intricate motivations behind telecommunications site selection. By integrating the FUCOM for criteria weighting with cosine similarity for ranking, we have developed a model that not only aligns with expert opinions but also demonstrates the robustness and versatility of our methodology. This methodology shows promise for addressing a wide range of MCDM challenges.

The results of our study are significant, as they provide a systematic and data-driven framework for selecting optimal sites for 5G deployment. By employing the FUCOM, we were able to determine criteria weights that accurately reflect the priorities and considerations of decision-makers in the telecommunications industry. The subsequent application of cosine similarity for ranking the service areas based on these weights yielded a prioritized list that was validated by domain experts. This validation underscores the practical applicability and effectiveness of our approach, highlighting its potential to support strategic decision-making in 5G network deployment.

Despite these strengths, our study has limitations that warrant consideration. Firstly, our geographic scope is limited to Mersin, Turkey, which may restrict the generalizability of our findings to other regions. Additionally, while the cosine similarity framework is effective for ranking alternatives based on criteria weights, it may not be universally applicable. Limitations include sensitivity to data dimensionality, the need for data normalization, challenges in interpreting results, and scalability issues for large datasets. These constraints should be carefully weighed when applying the cosine similarity framework in different contexts.

Furthermore, our reliance on expert opinions for determining criteria and weights introduces potential biases. The perspectives or knowledge limitations of the chosen experts could influence the outcomes. Although our integration of the FUCOM with cosine similarity offers novelty and consistency, there is a possibility that other mathematical frameworks or combinations could yield more insightful or accurate results.

Looking ahead, there are several promising avenues for further exploration. Testing our model in diverse geographic regions would enhance its adaptability and validate its utility on a broader scale. Diversifying our pool of experts, potentially including perspectives from other countries or specialties, could provide more comprehensive insights. Additionally, refining our model or integrating other mathematical approaches could improve accuracy. Exploring the model's relevance and adaptability to industries beyond telecommunications, such as logistics or healthcare, would further demonstrate its wide-ranging applicability.

In conclusion, our study not only contributes to the field of telecommunications site selection but also demonstrates a novel approach that can be applied to various decision-making processes. The results achieved highlight the importance of systematic planning and innovative methodologies in addressing complex challenges in network deployment. Future research can build upon our findings to further refine and validate the proposed approach, ultimately enhancing the effectiveness and efficiency of decision-making processes in the telecommunications industry.

Data availability statement

The authors declare that no data associated with our study have been deposited in a publicly accessible repository due to the confidential nature of the company's data. The data is being withheld to maintain competitive advantage and privacy in accordance with company policy.

CRediT authorship contribution statement

Sadrettin Çodur: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Burak Erkayman:** Writing – review & editing, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Saliha Sezgin Alp:** Project administration, Funding acquisition, Data curation. **Omar Özenir:** Project administration, Funding acquisition, Data curation.

Dragan Pamucar: Writing – review & editing, Writing – original draft, Conceptualization. **Gökhan Yıldız:** Validation, Project administration, Funding acquisition, Data curation. **Ali Gemalmaz:** Validation, Project administration, Funding acquisition, Data curation. **Arsal Dikel:** Validation, Project administration, Funding acquisition, Data curation. **Vladimir Simic:** Writing – review & editing, Writing – original draft, Conceptualization. **Hamza Akın:** Validation, Project administration, Funding acquisition, Data curation. **Yüksel Yılmaz:** Validation, Project administration, Funding acquisition, Data curation. **Yeşim Türk:** Validation, Project administration, Funding acquisition, Data curation. **Semih Aktaş:** Validation, Project administration, Funding acquisition, Data curation.

Declaration of AI and AI-assisted technologies in the Writing process

During the preparation of this work, the authors used ChatGPT 4.0 in order to enhance the readability and language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:Burak Erkayman reports article publishing charges was provided by Turkcell. Sadrettin Codur reports article publishing charges was provided by Turkcell. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work was supported by The Scientific and Technological Research Council of Turkey (TUBITAK) through the 1515 Frontier Research and Development Laboratories Support Program under Project 5229901 - 6GEN. Lab: 6G and Artificial Intelligence Laboratory. It was also supported by Atatürk University Scientific Research Projects with project number FDK-2022-10716.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e30664.

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