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# Comparing FAHP and FANP Methods in Locating Multi-storey Parking Sites Shiraz's CBD

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## ABSTRACT

*The substantial rise in automobile ownership and expansion of metropolitan areas in recent decades, especially in emerging nations, has resulted in a severe shortage of parking spaces. This problem not only causes significant traffic congestion and an increase in accidents but also places a considerable financial burden on individuals and worsens air pollution. Despite extensive research on addressing the parking issue, there is still a notable deficiency in effective approaches for selecting the best locations for multi-story parking structures, particularly in major cities in Iran. Hence, acknowledging the significance of effective parking management in addressing these problems, This study aimed to provide a comprehensive framework for choosing parking locations in Shiraz's business district. This study combined the Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) with a Geographic Information System to make fuzzy multi-criteria decisions. In determining acceptable locations, numerous aspects such as closeness to business hubs, distance from key roads, land prices, population density, and the feasibility of erecting multi-story parking structures were taken into account using these approaches. The findings revealed that districts 13, 14, 15, 16, 17, and 18 in Shiraz's core area had the most potential for the construction of multi-story parking facilities compared to the other 30 central districts. Additionally, the findings showed that accessibility to major roads, population density, and proximity to trip generators were the most relevant factors in deciding where parking facilities should be located in Shiraz. When the results of the two approaches were compared, it was found that while the models' results were basically similar, the AHP model's user-friendliness made it easier for urban managers and planners to understand and apply. Policymakers and urban planners can use the insights provided by the outcomes of these models to make well-informed decisions on parking infrastructure expenditures.*

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| **Highlights:** | **Contribution to the field statement:** |
|---|---|
| - Developed a comprehensive decision-making framework using AHP, ANP, and GIS for optimal parking site selection.<br>- Demonstrated the practical superiority of the AHP model for urban planning due to its user-friendly nature.<br>- Provided actionable insights for policymakers to enhance strategic investments in Shiraz's parking infrastructure, reducing congestion and pollution. | This study introduces a novel decision-making framework integrating AHP and ANP with GIS for optimal parking site selection, specifically targeting Shiraz, Iran. By addressing a critical gap in effective urban parking management, the research provides actionable insights for policymakers and urban planners, thereby enhancing strategic investments in parking infrastructure and contributing significantly to urban transportation planning literature. |

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## 1. Introduction

Parking problems in Central Business Districts (CBDs) have become a pressing urban challenge, characterized by high demand and limited supply of parking spaces. This imbalance leads to traffic congestion, reduced accessibility, and negative economic impacts on businesses (Agrawaal et al., 2024; Hussein, 2018; Kimpton et al., 2021; Ma & Mészáros, 2024). The issue stems from increasing vehicle ownership, limited space in city centers, and the attractiveness of CBDs for work and leisure activities (Dehghani et al., 2023; Louafi, 2019; Parmar et al., 2020). Resolving these issues is essential to preserving city centers' economic vibrancy and enhancing urban mobility. Cities must strike a balance between meeting immediate parking needs and promoting long-term sustainable urban development, often requiring innovative solutions and integrated urban planning strategies that consider both demand management and supply enhancement.

The supply side of parking solutions, particularly multi-story parking structures, is essential to solving the parking issues that CBDs encounter. (Aljohani et al., 2021; Chen et al., 2023). Multi-story car parks have emerged as an innovative and efficient solution to maximize parking capacity in limited urban spaces (Christiansen et al., 2017; Demir et al., 2021). These structures can accommodate a large number of vehicles vertically, significantly increasing the parking supply without consuming extensive horizontal land area (Kafrawy et al., 2022).

Locating suitable parking infrastructures has been an attractive topic for recent scholars. The growing interest in this topic among scholars and urban planners is driven by the increasing demand for efficient parking solutions in densely populated areas, particularly CBDs (Demir et al., 2021; Fard & Moghaddam, 2019). Multi-Criteria Decision Analysis (MCDA) combined with Geographic Information Systems (GIS) has become one of the most effective techniques for site selection. (Feyzi et al., 2019; Givi, 2015; Jonuzi et al., 2023; Kulinich & Lee, 2016). For instance, Jelokhani-Niaraki and Malczewski (2015) demonstrated the effectiveness of combining GIS with the Ordered Weighted Averaging (OWA) method to analyze multiple factors such as traffic load, land availability, and parking demand. This approach allows for a more nuanced evaluation of potential parking sites by visualizing spatial relationships and considering various weighted criteria simultaneously. Because fuzzy logic models can manage the inherent uncertainties in urban environments, they have become more and more popular in recent years. (Li et al., 2009; Mohammadzadeh et al., 2018; Noor et al., 2017; Wang et al., 2018). This method enhances the accuracy of site selection by accounting for the complex interplay between different urban variables. Optimization algorithms represent another significant strand of research in parking infrastructure location. The work of Choi and Lee (2023) on the Analytical Parking Planning Model (APPM) for Shared Autonomous Vehicles (SAVs) exemplifies this approach. Their model considers various planning scenarios to determine the optimal density and distribution of parking stations, taking into account both macroscopic urban characteristics and inter-zonal passenger trips. Advancements in technology have led to the increased use of predictive and responsive data in parking management. Enríquez et al. (2024) investigated the use of machine learning (ML) and artificial intelligence (AI) in processing real-time data from car sensors to forecast parking availability. This approach not only helps drivers find parking more efficiently but also provides valuable insights for urban planners in optimizing the location and management of parking infrastructures.

Recent urban planning literature has placed a great deal of emphasis on the use of the Fuzzy Analytic Hierarchy Process (FAHP) and Fuzzy Analytic Network Process (FANP) in the selection of parking sites. (Amari et al., 2023; Baseri et al., 2012; Darani et al., 2018; Dehghani & Soltani, 2023; Feyzi et al., 2019; Givi, 2015). These advanced decision-making methods incorporate fuzzy logic to address the inherent uncertainty and complexity in urban environments (Abdi & Soltani, 2022; Soltani & Marandi, 2011). FAHP extends the traditional Analytic Hierarchy Process by using fuzzy set theory to evaluate and prioritize potential parking locations based on multiple criteria, such as proximity to commercial areas, traffic density, and accessibility. It allows for a more nuanced evaluation of alternatives by accounting for the vagueness in expert judgments (Givi, 2015; Ishizaka, 2014; Jonuzi et al., 2023; Kubler et al., 2016). FANP, on the other hand, offers a more sophisticated approach by considering the interdependencies among decision criteria, capturing the complex relationships between various factors affecting parking location decisions (Mohammadzadeh et al., 2018; Wang et al., 2018). Both methods have been successfully integrated with Geographic Information Systems (GIS) to enhance spatial analysis and visualization of potential sites (Soltani et al., 2019). As urban areas continue to grapple with parking challenges, FAHP and FANP provide robust frameworks for urban planners to make more informed decisions about parking infrastructure placement, contributing to improved urban mobility and reduced traffic congestion.

The CBD of Shiraz in Iran faces significant parking challenges, characterized by high demand and limited supply of parking spaces (Soltani, 2017). This imbalance leads to traffic congestion, reduced accessibility, and negative economic impacts on businesses and residents. Despite the critical nature of this issue, there is a noticeable lack of comprehensive studies focused specifically on Shiraz's CBD parking problems (Dehghani & Soltani, 2023; Panahi et al., 2022; Sodagaran et al., 2016). Addressing these challenges requires a multifaceted approach that incorporates advanced decision-making methodologies, integrates emerging technologies, and considers environmental and economic factors. The lack of comprehensive, localized studies presents a significant research gap that needs to be filled to develop effective and sustainable parking solutions for Shiraz. To rectify this gap, this paper addresses the underutilization of the Spatial Decision Support System (SDSS) method despite the extensive research on parking site selection of Shiraz’s CBD.

The objective of this project is to integrate quantitative and geographical approaches for determining ideal parking site placements inside the Shiraz CBD in Iran. Specifically, this will be achieved through the integration of an MCDM approach with the FAHP and Fuzzy Analytic Network Process FANP. The use of trustworthy GIS data in combination with arbitrary expert judgments strengthens the study's robustness. Through the demonstration of a combined method that combines fuzzy MCDM techniques with spatial analytic capabilities, this study makes a substantial contribution to the body of literature by providing decision-makers with extensive information to support effective decision-making procedures.

The research objectives aim to tackle the existing parking demand in Shiraz’s CBD by developing a systematic approach to assessing the shortage of public parking spaces and devising an MCDM method to identify the optimal sites for constructing multi-story parking facilities.

The research aims to address multiple important inquiries:

- How can the integration of SDSS with MCDM approaches, specifically FAHP and FANP, improve the identification of optimal parking site locations in Shiraz's CBD?
- Where should multi-storey parking facilities be built in Shiraz's CBD using the proposed MCDM to determine the most suitable locations?
- Finally, how can the findings of this study inform policymaking and regulation to address parking challenges in Shiraz's CBD?

The structure of this document consists of the methodologies employed to compute the parking needs are described in Section 2, along with the strategy for employing fuzzy MCDM and GIS to identify the best places for multi-story parking. The case study area is introduced in Section 3, along with the locations of the parking spaces that are currently allocated within the traffic area zones. In Section 4, The techniques used to calculate the parking balance The methodologies employed to compute the parking balance and the MCDM technique are discussed in detail, and a map showcases the best locations for multi-story parking developments. The findings and their consequences for regulation and policymaking in resolving Shiraz's parking issues are explained in Section 5. In conclusion, Section 6 offers some final thoughts and suggests possible directions for further research.

## 2. Case Study

One of Iran's largest cities, Shiraz, faces considerable urban issues even though The percentage of automobiles owned in this country is smaller compared to affluent nations. Notably, there are a lot of accidents, Environmental contamination caused by the presence of harmful substances in the air, excessive sound levels, and traffic jams in the city. Shiraz's land size increased from 6,000 to 15,600 hectares and its population experienced growth from 0.85 million in 1986 to 1.8 million in 2016. The city has experienced significant growth, transitioning from a traditional bazaar-centered development to a contemporary metropolis characterized by extensive road networks (Dehghani & Soltani, 2023). the CBD of Shiraz, an area plagued by various traffic issues, notably exacerbated by on-street parking due to inadequate parking facilities. The CBD of Shiraz spans approximately 800 hectares, with 88 kilometres of roads comprising 5.5% of the total area, and encompasses 30 Traffic Analysis Zones (TAZs) (Damadam et al., 2022; Sodagaran et al., 2016). Nonetheless, the Shiraz CBD faces particular difficulties, such as constrained parking and road areas, stringent vertical zoning laws, and notable non-residential land uses including medical facilities and college campuses. The problem of parking scarcity is exacerbated by the lack of available land parcels, which calls for solutions like multi-story parking structures and enhanced public transportation. Ineffective public transportation systems also play a role in the prevalence of driving, which clogs roads even more as cars look for parking spots. Shiraz's TAZs and public parking locations are shown in Figure 1.

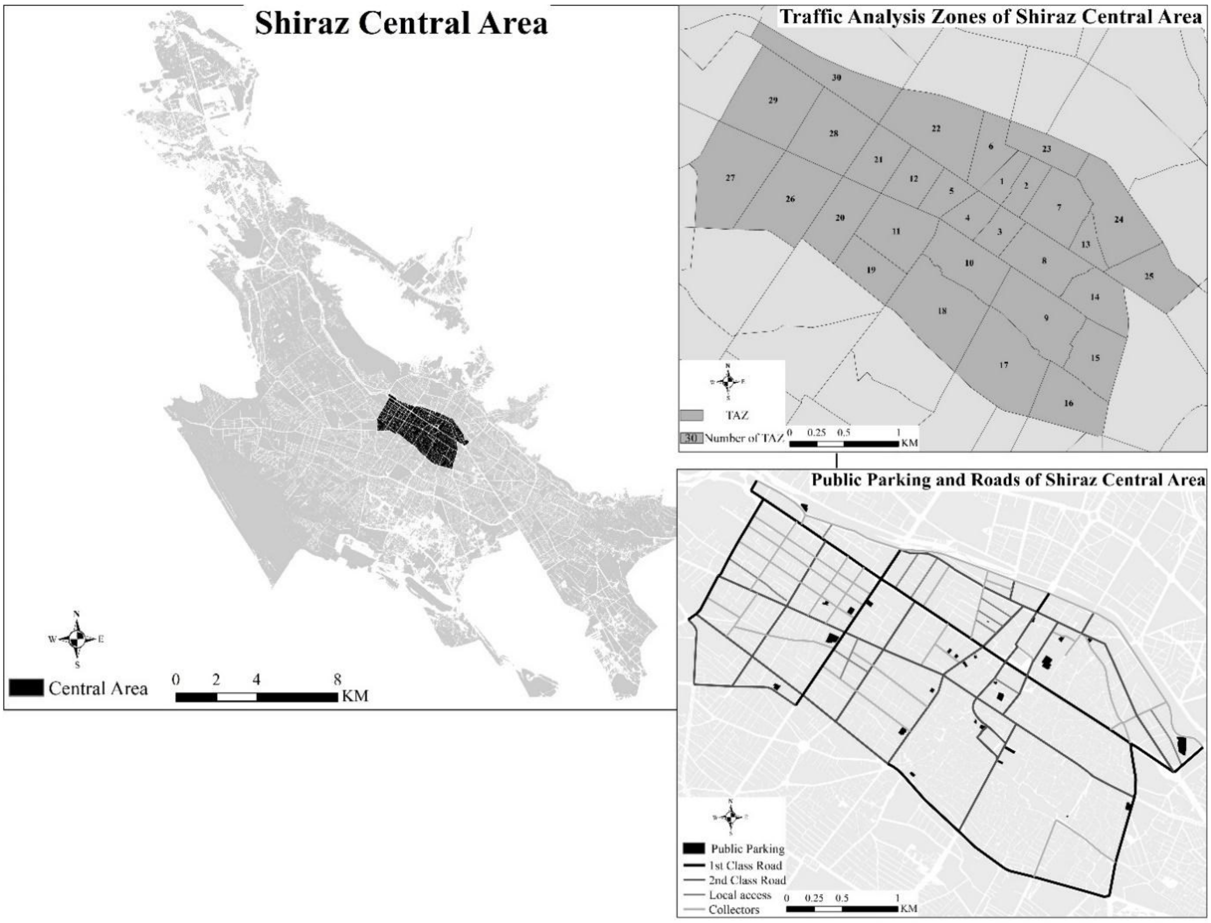

**Figure 1.** Location of TAZs and public parking in Shiraz central area.

## 3. Material and Methods

The research process (Figure 2) for finding optimal locations for multi-story parking facilities in Shiraz's CBD can be summarized in four steps:

*Data Collection:* This stage involves examining the current state of Shiraz's city centre, including traffic patterns, existing parking options (both on and off-street), and road slopes. Data is collected from official sources like the city's comprehensive plan and municipality maps.

*Identifying Suitability Factors:* Here, experts familiar with Shiraz identify factors that make a location suitable for a new parking facility. This data is likely gathered from sources like the Shiraz's comprehensive plan and municipality.

*Weighting Factors using FAHP and FANP:* In this stage, experts use two methods, FAHP and FANP, to determine the relative importance of each suitability factor.

*Mapping Suitable Locations:* Finally, GIS software (ArcMap) is used to combine the data collected in previous stages. This overlay method considers factors like weights and suitability and generates maps showing the most suitable locations for new parking facilities using both FAHP and FANP methods.

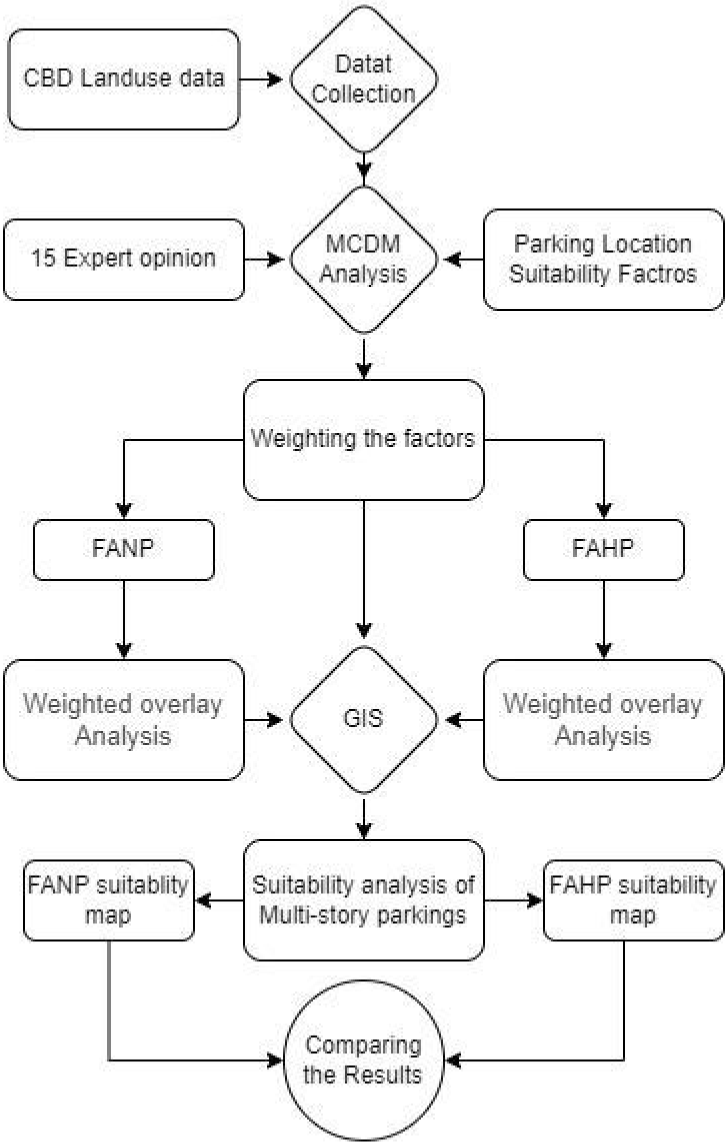

**Figure 2.** Research steps flowchart.

### 3.2. Factors affecting site selection of parking

A number of aspects that affect parking facilities' accessibility and efficacy are taken into account throughout the site selection process. Based on previous research and local expertise, five crucial elements were found (Table 1): the distance to roadways, the cost of the property, the population density, and the amount of land that can be used for multi-story parking (Amari et al., 2023; Demir et al., 2021).

**Table 1:** Influencing factors and data sources.

| Factors | Data Sources |
|---|---|
| **Distance to travel attraction centres** | Derived from Shiraz municipality land use map |
| **Distance to roads** | Derived from Shiraz municipality traffic map |
| **Land price** | Derived from Shiraz master plan |
| **Population density** | Derived from Shiraz master plan |
| **Available land for multi-storey parking structures** | Derived from Shiraz municipality land use map |

**Distance to travel attraction centers**: This component recognizes the value of accessibility to a range of facilities and services, including places of business, government, religion, health care, education, culture, and recreation. Parking facilities must be close to these attractions in order to handle the large number of journeys that are made in these locations (Al Razib & Rahman, 2017; Baseri et al., 2012). An extensive inventory of travel attraction centers, including business, administrative, religious, medical, educational, cultural, and recreational amenities, was carried out in order to construct this layer. After that, point data was created by compiling and digitizing the geographic coordinates of these centers. The Euclidean distance between each grid cell in the research region and the closest attraction center was then determined using a distance analysis. Lower values indicate closer proximity to the nearest travel attraction center, and this is represented by the resulting raster layer. This layer is essential for determining how easily accessible and convenient potential parking facility locations are to different services and facilities, which in turn affects the site's overall acceptability.

**Distance to roads:** It is imperative to locate parking spaces close to collector and arterial highways in order to promote their use and adherence to parking laws. Increasing the quantity of parking spots close to these routes can reduce traffic jams and discourage vehicles from parked improperly (Bock & Sester, 2016; Christiansen et al., 2017). A distance to the roadways layer was made in order to evaluate this factor. Lower values indicate closer proximity. This layer computes the Euclidean distance between each grid cell and the closest road. It is feasible to discover locations that provide easy access to the road network by including this layer in the weighted overlay analysis, which enhances the parking facility's overall usefulness.

**Land price:** The selection of sites for multi-story parking lots is heavily influenced by the land's worth. Classifying land prices into low, medium, and high categories based on current market rates (Figure 3) helps determine feasible locations for parking development (Inci, 2015; Wang et al., 2020). This classification provides a qualitative assessment of land cost, enabling a preliminary evaluation of financial feasibility. Areas with lower land prices are generally more attractive for parking facility development due to reduced initial investment. However, it is essential to consider other factors beyond land cost, such as location, accessibility, and demand, when making final decisions.

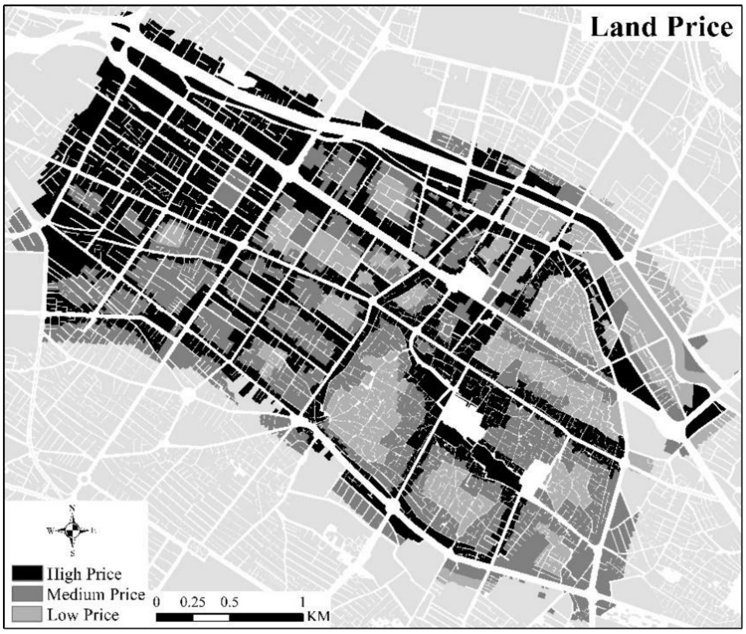

Figure 3. Land price classification map of Shiraz's CBD.

**Population density:** The main determinant of appropriate locations for multistory parking is population density. By analyzing demographic data and considering areas with varying population densities (Figure 4), planners can prioritize locations where parking demand is high and organize parking infrastructure accordingly (Liu et al., 2017; Scheiner et al., 2020). Initially, population data was sourced from authoritative demographic databases, ensuring data accuracy and reliability. This dataset was meticulously examined for inconsistencies, errors, and missing values, which were rectified to maintain data integrity. Subsequently, the population data was spatially referenced and converted into a raster format to align with the other geographic layers used in the analysis.

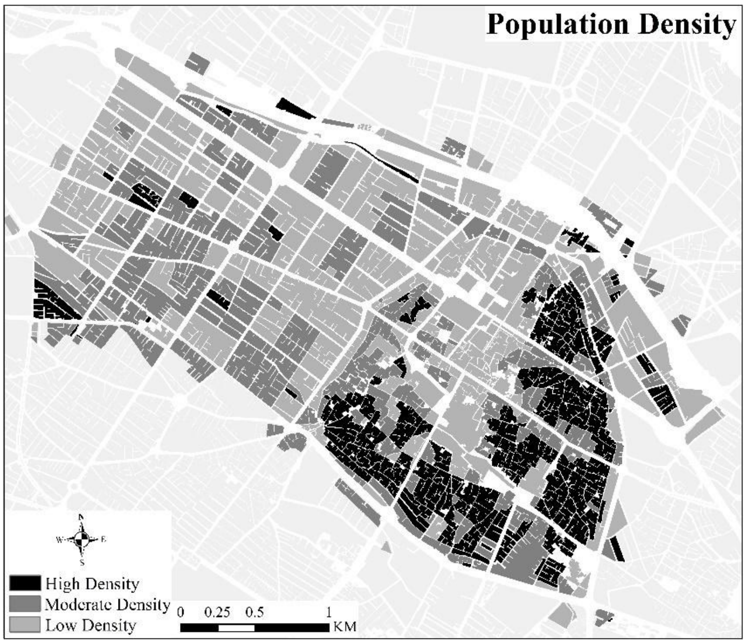

Figure 4. Population density classification map of Shiraz's CBD.

**Available land for multi-storey parking structures:** Urban growth and traffic management depend heavily on the availability of adequate space for the construction of multistory parking facilities (Figure

5). Analyzing various urban places, including abandoned buildings, garages, and wasteland, can assist find viable parking construction sites without negatively impacting other urban elements.

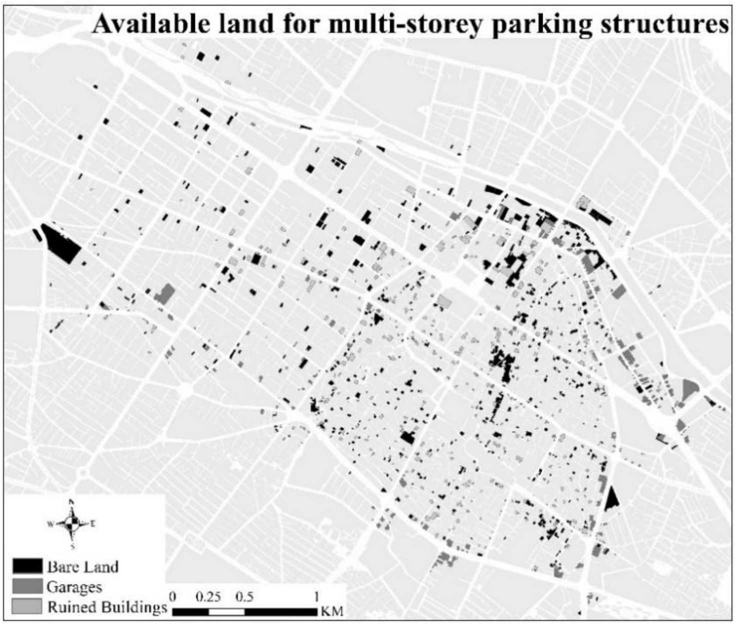

**Figure 5.** Available land for multi-storey parking construction in Shiraz's CBD.

### 3.3. Weighting with MCDM methods

The FAHP and Fuzzy Analytic Network Process (FANP) are sophisticated techniques utilized in multi-criteria decision-making processes, particularly in scenarios characterized by uncertainty and imprecision (Ishizaka, 2014). FAHP extends the traditional AHP by incorporating fuzzy logic to handle vague or ambiguous information, allowing for more nuanced decision-making in complex situations where precise numerical values may be challenging to obtain (Vinogradova-Zinkevič et al., 2021). Similarly, FANP extends ANP by integrating fuzzy logic, enabling the modelling of complex networks of criteria and their interdependencies in a fuzzy environment (Mohammadzadeh et al., 2018; Vinogradova-Zinkevič et al., 2021). These techniques have been widely employed in various studies to address decision-making challenges in metropolitan settings, offering robust methodologies to navigate uncertainties and complexities inherent in urban planning processes.

Fuzzy logic is incorporated into the FAHP, an extension of the AHP, to address ambiguity and uncertainty in the decision-making process. The FAHP uses triangular fuzzy numbers (TFNs) to translate language concepts into mathematical expressions. The steps involved in FAHP can be described mathematically as follows (Kubler et al., 2016; Noor et al., 2017):

1. **Building the Matrix of Fuzzy Comparisons:**
   A fuzzy comparison matrix is constructed using TFNs. For example, if we have a TFN represented as $(l,m,u)(l,m,u)$, where $ll$ is the lower limit, $mm$ is the most likely value, and $uu$ is the upper limit, the comparison matrix would consist of these TFNs for each pairwise comparison.
2. **Matrix Consistency Examination:**
   As with the crisp AHP approach, the consistency of the fuzzy comparison matrix is analyzed.
3. **Fuzzification and Defuzzification Processes:**
   To create a priority vector, the fuzzification procedure entails transforming crisp values into fuzzy numbers, which are then defuzzified back into crisp scores.
4. **Normalization of Weight Vector:**
   To ascertain the relative weights of the criteria or alternatives, the weight vector is normalized.

The mathematical expressions for operations on TFNs are as follows:

- **Addition:**
- $(l1,m1,u1)+(l2,m2,u2)=(l1+l2,m1+m2,u1+u2)(l1,m1,u1)+(l2,m2,u2)=(l1+l2,m1+m2,u1+u2)$
- **Scalar Multiplication:**
- $k\cdot(l,m,u)=(k\cdot l,k\cdot m,k\cdot u)k\cdot(l,m,u)=(k\cdot l,k\cdot m,k\cdot u)$
- **Multiplication:**
- $(l1,m1,u1)\cdot(l2,m2,u2)=(l1\cdot l2,m1\cdot m2,u1\cdot u2)(l1,m1,u1)\cdot(l2,m2,u2)=(l1\cdot l2,m1\cdot m2,u1\cdot u2)$
- **Inverse:**
- $(l,m,u)-1=(1/u,1/m,1/l)(l,m,u)-1=(1/u,1/m,1/l)$

The linguistic statements on the FAHP scale, which translate into matching TFNs for the comparison matrix, are "Equal importance," "Weak importance of one over another," "Essential or strong importance," "Very strong importance," and "Absolute importance." (Li et al., 2009).

A paradigm for making decisions called FANP expands the FAHP to networks in which components may be interdependent (Feyzi et al., 2019; Mohammadzadeh et al., 2018). The FANP involves the following steps:

1. **Building Pairwise Comparison Matrices**: To depict the relative importance of criteria or sub-criteria, fuzzy numbers are used in the construction of pairwise comparison matrices.
2. **Creating the Supermatrix**: Inner dependence matrices are created for each criterion, and a supermatrix is created to illustrate the interdependencies between the criteria.
3. **Computing Global Weights**: The local weights of the subcriteria and the interdependent weights of the associated criteria are multiplied to determine the global weights of the subcriteria.
4. **Fuzzy Inverse Matrix Derivation**: Various techniques, including Basaran's Method, ε-Inverse Method, Rohn's Scheme, and Zadeh's Extension Principle, are employed to derive the fuzzy inverse matrix.
5. **Weight Normalization**: To guarantee that the total weight is equal to one, the weights are normalized.

The mathematical formulation for deriving the fuzzy weights in FANP can be represented as follows (Wang et al., 2018):

- **Weight Normalization:** If $tt$ and $uu$ are any vectors such that $t=u\cdot W\ t=u\cdot W$ and $WW$ is a weight matrix, then the normalized weight $PP$ can be derived based on the equation
- $P=t/\sum tiP=t/\sum ti$.

The steps in FANP can be diagrammatically represented as a flowchart, starting from the construction of pairwise comparison matrices, forming the supermatrix, calculating global weights, deriving the fuzzy inverse matrix, and finally normalizing the weights to obtain the final decision matrix.

The key differences between the FAHP and the FANP lie in their respective application domains and the complexity of decision-making scenarios they address. FAHP is primarily used for hierarchical decision-making structures, where criteria are organized hierarchically with clear top-down relationships. It is effective for evaluating alternatives against multiple criteria with varying levels of importance (Table 2). Conversely, FANP extends beyond hierarchical structures to model decision scenarios with interconnected criteria and feedback loops. It is suited for more complex decision networks where criteria influence each other directly or indirectly. While FAHP is suitable for simpler structures, FANP is designed to handle higher levels of complexity in decision-making processes.

**Table 2:** Analysis of triangular fuzzy numbers and subjective expression within five distinct groups:

| The quality | triangular fuzzy numbers | Inverse triangular fuzzy numbers |
|---|---|---|
| **Equivalent** | (1, 1, 1) | (1,1,1) |
| **Approximately equivalent** | (1, 2, 3) | (1/3, 1/2, 1) |
| **Excellent** | (3, 4, 5) | (1/5, 1/4, 1/3) |
| **Extremely superior** | (5, 6, 7) | (1/7, 1/6, 1/5) |
| **Supreme** | (7, 8, 9) | (1/9, 1/8, 1/7) |

Fifteen professionals with backgrounds in civil engineering, traffic engineering, landscape architecture, urban planning, project management, and both the public and private sectors were given a questionnaire designed to gather expert opinions. The weights, FAHP, and FANP were computed with MATLAB. Expert opinions were represented by triangular fuzzy numbers. The weights of the criteria and sub-criteria were then calculated using the arithmetic mean of expert judgments. The center of gravity method was used to normalize and make these fuzzy weights non-fuzzy before they were finally assigned to the GIS layers. We used the FAHP, more especially Buckley's geometric mean technique, to rank and weight each criterion and sub-criteria.

Despite their strengths, FAHP and FANP possess inherent limitations. Both methods rely heavily on expert judgment, which can introduce subjectivity and inconsistency into the decision-making process. Additionally, defining clear and exhaustive criteria can be challenging, as it requires a deep understanding of the problem domain. Furthermore, the computational complexity of FANP, especially for larger-scale problems, can be a significant drawback. Both methods assume a static environment, neglecting potential dynamic changes in the factors influencing the decision.

### 3.4. Suitability analysis by Weighted overlay analysis (WOA)

Weighted Overlay Analysis (WOA) is a powerful geospatial technique employed to determine the optimal location for a specific purpose by evaluating multiple factors. It involves the integration of various thematic layers into a single output layer representing overall suitability. The core principle of WOA is the assignment of weights to each input layer, reflecting its relative importance in the decision-making process. These weights are numerical values that quantify the influence of each factor on the final suitability assessment. After weights are assigned, each raster layer's cell values are multiplied by the weight that corresponds to it. Subsequently, these weighted values are summed for each location to produce a composite suitability index. The resulting suitability map provides a visual representation of the study area, with higher values indicating locations that more closely align with the desired criteria. This method effectively integrates diverse and often conflicting factors, enabling a comprehensive evaluation of potential sites. WOA is frequently used to determine the best places for infrastructure, conservation areas, or agricultural land, among other things, in a variety of domains, including urban planning, environmental impact assessment, and natural resource management. In this study, we calculated suitability maps using the weights derived from both the FAHP and the FANP in ArcGIS pro-environment. By taking into account the intricate linkages between the evaluation criteria, we hoped to improve the appropriateness assessment's accuracy and reliability by implementing these multi-criteria decision-making procedures.

### 3.5. Locating possible, effective places with GIS

The criterion weights were linked to the layers using ArcMap, which allowed AHP and GIS to find possibly appropriate parking spots. Using GIS, each criterion was processed to provide maps, weights, and rating scales based on the FAHP and FANP methodologies. The map of possible parking locations was subjected to an overlay analysis, and weights and rating scales for the sub-criteria were determined using the AHP technique. When assessing possible sites, it is necessary to take into account a few limitations, such as giving priority to lots that score the highest in each zone even if they are not historically or culturally significant and making sure that the geometric dimensions—such as length and breadth—are appropriate and that the total area is at least 1,200 m². The Natural Break method can be used to categorize a continuous weight and score into five groups: not appropriate (less than 0.25), less appropriate (0.25 to 0.35), somewhat appropriate (0.40 to 0.45), highly appropriate (0.45 to 0.50), and the most appropriate (more than 0.5). ArcMap made it easier to overlay criterion layers with varying weights.

## 4. Results

The results obtained from both the FAHP and the FANP provide valuable insights into the prioritization of criteria for site selection of multi-storey parking facilities (Figure 6).

In both methods, "Distance to travel attraction centers" emerges as the most influential criterion, highlighting the importance of proximity to key destinations such as administrative, commercial, religious, health, educational, cultural, and recreational centers. However, there is a slight variation in the weights assigned by FAHP (0.307) and FANP (0.254), indicating a nuanced difference in their prioritization. Similarly, "Distance to roads" and "Land price" are identified as significant factors in both approaches, albeit with some differences in the weights assigned. FAHP assigns higher importance to "Distance to roads" (0.188) compared to FANP (0.172), whereas FANP assigns higher importance to "Land price" (0.193) compared to FAHP (0.162). These differences may stem from the inherent characteristics of each method and the specificities of the decision-making context.

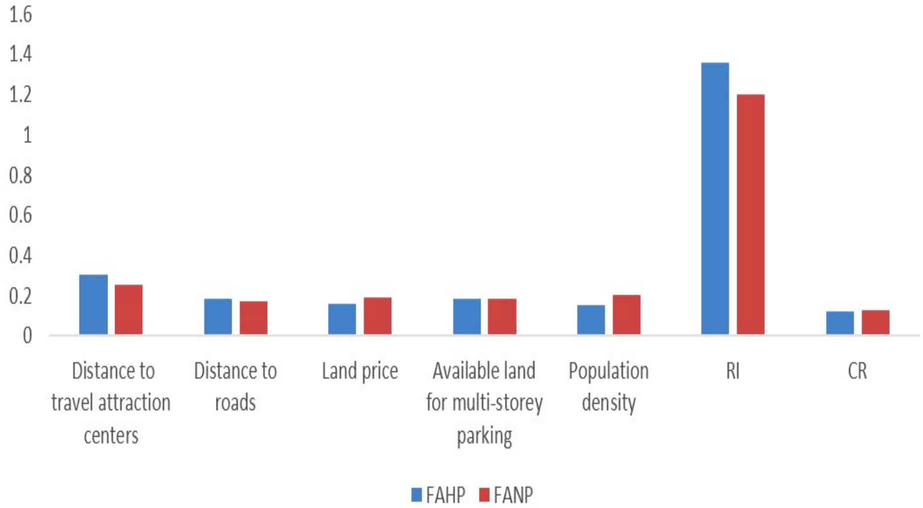

**Figure 6.** Weighting results of Factors.

Moreover, "Available land for multi-storey parking" and "Population density" also play crucial roles in both FAHP and FANP, although their relative importance varies slightly between the two methods. FAHP assigns a higher weight to "Available land for multi-storey parking" (0.185) compared to FANP (0.187), while FANP assigns a higher weight to "Population density" (0.203) compared to FAHP (0.155). This suggests that while both criteria are considered essential, their prioritization differs based on the method employed. Overall, the consistency ratios (CR) for FAHP (0.12) and FANP (0.13) indicate a satisfactory level of consistency in the decision-making process for both methods. However, the nuanced differences in the weights assigned to each criterion highlight the importance of considering multiple decision-making techniques and their respective outputs when making complex decisions such as site selection for multi-storey parking facilities.

Figures 7 offer detailed spatial insights into the assessment of prospective sites for parking infrastructure deployment. A comprehensive comparison of the findings derived from these two figures reveals a striking similarity in the outcomes produced by the respective methodologies. This alignment underscores the robustness and reliability of the analytical approaches utilized, affirming the consistency of the results across different evaluation techniques. Notably, Region 13 emerges as a standout candidate for the establishment of new parking facilities in both analyses, underscoring its strategic significance and optimal suitability for such development. Subsequently, regions 14, 18, 17, and 16 emerge as strong contenders for parking construction, demonstrating considerable potential for accommodating additional parking capacity. Moreover, a noteworthy pattern that emerges from the data is the strong inclination towards the southern areas of the research zone regarding their rating and appropriateness for the implementation of parking facilities. This spatial pattern suggests a compelling rationale for prioritizing parking development initiatives in the southern zones, potentially addressing localized parking demands more effectively while optimizing overall urban mobility and accessibility.

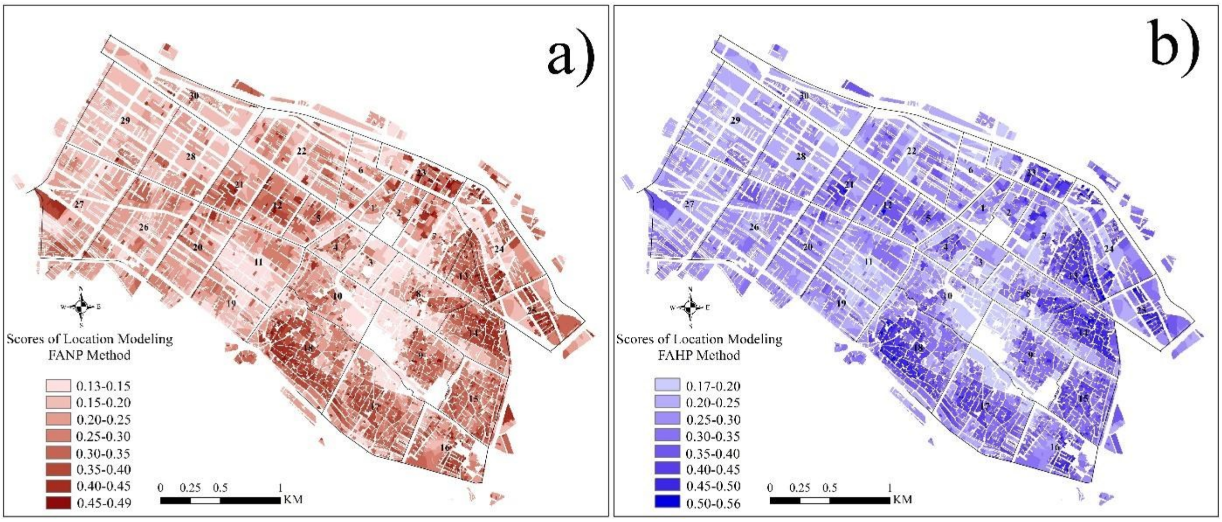

**Figure 7.** Final Suitability maps for (a) FANP and (b) FAHP results.

## 5. Discussion

Parking is a difficult and varied issue in highly populated city centers, like Shiraz, Iran's CBD. The results of this study make a substantial contribution to the corpus of knowledge already available on urban parking management and multi-story parking facility site selection. We have offered a thorough analysis of parking demand and supply dynamics in Shiraz's CBD by utilizing a combination of quantitative and geographical models, particularly a GIS-based Fuzzy MCDM framework.

Our results demonstrate that the integration of FAHP and FANP with GIS can lead to more rational, inclusive, and efficient decisions in parking site selection. Interestingly, both FAHP and FANP models yielded similar results in our case study. This finding aligns with the work of Jonuzi et al. (2023) who highlighted the trade-offs between simplicity and complexity in decision-making models. The similarity in results suggests that for this specific case, FAHP's faster processing and simpler structure might have been sufficient. This has important implications for decision-makers, as it indicates that in some cases, a simpler model can provide equally valuable insights with less computational complexity.

However, it is crucial to note that the choice between FAHP and FANP should be context-dependent. While FAHP offers advantages in terms of simplicity and computation speed, FANP remains valuable for more complex situations where interdependencies among criteria are significant. This finding contributes to the ongoing debate in the literature about the most appropriate MCDM methods for urban planning decisions (Jelokhani-Niaraki & Malczewski, 2015). Our study also highlights the potential of multi-storey parking structures as a viable solution to parking scarcity in urban centres. This aligns with the findings of Darvazeh et al. (2018), who emphasized the economic viability of developing parking infrastructure in congested areas due to economies of scale. However, our research goes further by providing a methodological framework for identifying optimal locations for these structures, considering multiple stakeholders with varying priorities.

The implications of our findings for urban planning and policy are significant. The GIS-based Fuzzy MCDM framework we employed allows for a comprehensive analysis of potential parking facility locations, which can inform more effective urban planning strategies. This approach can help policymakers balance the need for parking spaces with other urban development goals, such as reducing traffic congestion and promoting sustainable transportation options. It's crucial to recognize our study's limitations, though. Only planners and transportation experts participated in the decision-making process, which may have excluded important input from users and customers. This limitation aligns with critiques in the literature about the need for more inclusive decision-making processes in urban planning (Kubler et al., 2016). Additionally, our focus on traditional supply and demand metrics may not fully capture emerging trends in urban mobility and sustainability.

The potential impact of our findings on urban mobility and infrastructure is substantial but requires further exploration. For instance, the strategic placement of park-and-ride (P&R) systems, as suggested by our results, could significantly reduce traffic congestion by encouraging commuters to use public transportation. This aligns with the work of Mei et al. (2020) who emphasized the importance of integrating parking solutions with broader urban mobility strategies. Furthermore, our study opens up several avenues for future research. The incorporation of additional data sources, such as Points of Interest (POI), could provide a more comprehensive understanding of parking utilization patterns. The application of optimization methods could further refine the identification of promising locations for parking facilities. Moreover, future studies should consider emerging concepts like carbon-zero cities, which suggest allocating parking based on vehicle emissions (Abdi & Soltani, 2022; Dehghani & Soltani, 2023).

## 6. Conclusion

In conclusion, this study makes several significant contributions to the field of urban parking management and site selection for parking facilities. Firstly, we have demonstrated the effectiveness of integrating GIS with Fuzzy MCDM methodologies for parking site selection in dense urban environments. This approach provides a robust, data-driven framework that can support more informed decision-making in urban planning. Secondly, our comparison of FAHP and FANP models provides valuable insights into the trade-offs between simplicity and complexity in decision-making tools. This finding can guide future researchers and practitioners in selecting appropriate methodologies for similar urban planning challenges. Thirdly, our study highlights the potential of multi-storey parking structures as a solution to parking scarcity in urban centres, while also providing a methodological framework for identifying optimal locations for these structures. It's crucial to recognize our study's limitations, though. Our analysis's breadth may have been restricted by the decision-making process's omission of user and customer viewpoints. Additionally, our focus on traditional supply and demand metrics may not fully capture emerging trends in urban mobility and sustainability. For policymakers and urban planners, our study provides several actionable insights:

- The use of GIS-based Fuzzy MCDM frameworks can significantly enhance the decision-making process for parking site selection.
- Multi-storey parking structures, when strategically located, can be an effective solution to parking scarcity in dense urban areas.
- The integration of parking solutions with broader urban mobility strategies, such as park-and-ride systems, can yield significant benefits in terms of traffic congestion reduction.
- A more holistic approach to parking management, incorporating environmental, social, and economic considerations, is crucial for developing sustainable urban mobility solutions.
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Future research should build on these findings by:

- Incorporating a broader range of stakeholder perspectives, including consumers and users, in the decision-making process.
- Investigating the application of optimization methods to further refine parking site selection.
- Examining the potential impacts of emerging trends, such as autonomous vehicles and carbon-zero city initiatives, on parking demand and infrastructure requirements.
- Exploring the environmental impacts of parking infrastructure, such as urban heat island effects, and developing strategies to mitigate these impacts.

By addressing these areas, future research can continue to advance our understanding of urban parking challenges and contribute to the development of more efficient, sustainable, and user-friendly urban mobility solutions.

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## Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

## Data availability statement

Any additional data related to this study are available from the corresponding author upon reasonable request.

## CRediT author statement:

Alireza Dehghani: Conceptualization; Data curation; Formal analysis; Methodology; Software; Visualization; Roles/Writing - original draft. Ali Soltani: Conceptualization; Writing - review & editing; Investigation; Supervision; Validation; Project administration. All authors have reviewed and approved the final version of the manuscript.

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