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A GIS–Analytic Network Process Framework for Fire Station Site Selection in Cities Experiencing Urban Sprawl

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Abstract

There is an interrelationship between community growth and the volume of emergency incidents. As the population increases, the chance of incidents rises as well. Urban sprawl reduces emergency accessibility and challenges equitable fire service coverage. Considering the fact that Mashhad and Calgary both are populated cities and are expanding in a fast-paced way, this expansion not only can heighten the response time for emergency services but also jeopardize the safety of the growing population. To prevent that, the proper placement of fire station is significant within these cities. In this study, the primary objective is to find the suitable sites for locating urban fire stations in Mashhad (Iran) and Calgary (Canada) which was achieved through the adaptation of GIS and ANP. Twelve sub-criteria were considered and categorized into four classes: "Service Area", "Accessibility", "Environment" and "Spatial Characteristics", also their weights were determined. Using the weight for each sub-criterion and ArcGIS PRO the optimal sites for fire stations were recognized. The final outcomes reveal that response time and distance from faults and rivers have the highest and the lowest weight respectively. 33% and 8% of city blocks are highly suitable for locating fire stations in Mashhad and Calgary respectively. The majority of the highly prioritized areas were centered in zones with higher response times obtaining the highest values in categories of spatial and environmental characteristics and accessibility. Moreover, 34% and 15% of existing fire stations in Mashhad and Calgary are located in highly prioritized blocks with values of 8 and 9. Therefore, generating optimal fire station site selection maps assists urban planners and decision-makers to keep more areas under cover and reduces the likelihood of dangers caused by a fire. The proposed framework provides a transferable decision-support tool for disaster risk reduction in rapidly growing cities.

Keywords: Fire stations, Spatial distribution, Analytic Network Process (ANP), Site selection, Mashhad (Iran), Calgary (Canada)

1. Introduction

As cities grow, not only will they undergo a transformation but also their constructions will become much larger and more functionally diverse. In city, urban construction and people's activities both have a close connection with the city's geographical attributes and are restricted by it. Indeed, urban fire risks are associated with high-rise and large-volume buildings, complex function, excessive use of new materials, products and a high population density which make uncontrollable factors of outbreaks of fires grow significantly (Dong et al. 2018; Han et al. 2021). Rapid urban expansion and urban sprawl have substantially increased the complexity of emergency service provision. As cities expand, longer travel distances, dispersed development, and uneven accessibility reduce the efficiency of fire emergency response, thereby increasing disaster risks and threatening public safety.

However, it must be remembered that the fire stations' services do not restrict to responding to fires, they also respond to other emergencies such as vehicle accidents or floods, ruptures/explosions, severe weather, and hazardous conditions. Moreover, they provide both community service (Home Safety program) and life safety education as well as offering less urgent missions such as eliminating wasp nests (Calgary Fire Department 2021; Chevalier et al. 2012). Consequently, Fire stations as a place to keep ready fire trucks and relief cars are important and vital service centers in the cities (Ghasemi and Babaeinesami 2020).

Providing fire safety is not only a multi-faceted context related to staff, vehicle and equipment, function, organization, technology, level of education and consciousness but also a high-priced measure. One of the important controllable variables to affect the level of expenditures for fire protection is the number of fire stations (Plane and Hendrick 1977); as a result, the major

concern of planners is adequately covering all service areas and the spatial arrangement of urban fire stations so that fires can be researched within a reasonable response time or distance; otherwise, extinguishing fire will be arduous and out of control (Shahparvari, Fadaki, and Chhetri 2020). Although numerous studies have applied Geographic Information Systems (GIS) and multi-criteria decision-making techniques to optimize fire station locations, most have focused on single-city case studies or specific local conditions. Consequently, relatively limited attention has been paid to evaluating whether such decision-support frameworks remain applicable across cities with different planning systems, urban forms, and levels of data availability. Moreover, in many developing countries, the lack of comprehensive fire service datasets, particularly response-time information, limits the application and validation of spatial optimization models. Addressing these challenges requires a methodology that is both transferable across different urban contexts and adaptable to data-constrained environments. Therefore, this study develops and evaluates an integrated GIS–Analytic Network Process (ANP) framework using two contrasting case studies, Mashhad (Iran) and Calgary (Canada), to examine its applicability under different urban planning and data conditions.

Mashhad and Calgary were intentionally selected because they represent two rapidly growing cities that share common challenges associated with urban sprawl and increasing demand for emergency services, while differing substantially in planning systems, governance structures, and data availability. Rather than comparing the performance of the two cities, the purpose of this comparative design is to evaluate the transferability and robustness of the proposed GIS–ANP framework across contrasting urban contexts. This approach enables the proposed methodology to be assessed beyond a single local case and provides evidence of its potential applicability to cities with different planning and operational environments.

The effectiveness of service coverage of the fire stations was determined by the locations, the number of fire stations and the distribution characteristics of fire-risk points (Liu et al. 2021). Prompt response to emergency calls, provision of rapid-fire rescue operations (Hou et al. 2021), shortening the distance between fire stations and accident sites in order to improve reaction time efficiency and minimizing overlap of fire station services so as to utilize efficiently fire station resources (Yang, Jones, and Yang 2007), mitigation of fire incidents and fire hazard, covering maximum demand and maximum coverage of the areas (Arifin 2011), decrease in property loss, improving public safety (Sufianto and Green 2012) are advantages of the optimal and proper distribution of fire stations.

2. Criteria for Fire Station Site Selection: A Review of Recent Studies

Recent studies (Table 1) have consistently identified accessibility, response time, and service coverage as the most influential criteria in fire station site selection. However, the reviewed literature also reveals considerable variation in the selection of environmental and socioeconomic factors depending on local planning contexts. Moreover, most existing studies focus on optimizing fire station locations within a single city, whereas comparatively limited attention has been devoted to evaluating whether the selected criteria and decision-making frameworks remain applicable across different urban environments. Existing studies suffer from two limitations: single-city analyses and lack of applicability in data-constrained cities. This study addresses both.

Table 1. Overview of the recent research.

Researchers	Case Study	Criteria
Dey, Heger and England (2022)	Victoria, USA	Incidents types, address of incident locations, date and time, response time, coverage area, fire service vehicle.
Kharaghani, Etemadfard and Salem Rafush (2022)	Mashhad, Iran	Distance from existing fire stations, medical centers, roads, administrative centers and training centers.
Han et al. (2021)	Nanjing city, China	The arrival of the firefighting task force, traffic jam.
Ming, Richard and Zhu (2021)	Hefei, China	Fire station size, vehicle quantity, vehicle type, response time, service reliability, and traffic condition.
Rodriguez, Fuente and Aguayo (2020)	Concepción province, Chile	Multiple regions, demand types, vehicle types, and region-dependent dispatching rules.
Shahparvari, Fadaki and Chhetri (2020)	Melbourne, Australia	Response time, fire station distance, fire incident locations, traffic light density, road density, street network density.
Xiang et al. (2020)	A mega project in Sichuan Province, China	Economy, time, distance and coverage rate, affecting factors of fire safety points.
Wang (2019)	Jiangsu, China	Transit time, scale cost, social service and environmental geography.
Yao, Zhang and Murray (2019)	Nanjing, China	Coverage area, demand areas.
Aldabbas et al. (2018)	Fribourg, Switzerland	Establishment costs, operating costs, technical criteria, administrative criteria, economic and social criteria, Professionalism, Effectiveness and Efficiency, Reliability, Stochasticity and Robustness, Sustainability.
Bolouri et al. (2018)	Tehran, Iran	Distance, time, coverage area.

Although previous studies have identified numerous criteria affecting fire station location, most have focused on optimizing station placement within a single urban context. Moreover, little attention has been devoted to evaluating the transferability of multi-criteria decision-making frameworks across cities with different planning systems and data availability. This limitation restricts the broader applicability of existing approaches.

2.1.Coverage Area (Service Area)

To enhance urban firefighting efficiency, emergency response time is of paramount importance (Chen et al. 2020). Jaldell (2017), mentioned that the shorter the response time of emergency services, the more lives are saved. As stated in the NFPA-1710 (2020), response time is the time interval from the receipt of the alarm at the primary Public Safety Answering Point (PSAP) to when the first emergency response unit is initiating action or intervening to control the incident. The travel times for units responding to the first alarm are within 4 minutes and all units must arrive within 8 minutes. However, the total response time can alter, depending on different countries. In fact, the Canadian national fire standards target a response time of 6 minutes for medical calls, and 6 minutes and 20 seconds for fires 90 % of the time. In Iran, the standard response time differs from 3 minutes to 5 minutes (Iran's Institute of Industrial Standards and Research 2001).

Moreover, the time taken to get to a fire incident is necessarily dependent upon the distance to be travelled and upon the conditions experienced during the journey. The time that elapses between a brigade receiving an alarm and its arrival at the incident is directly affected by the location of the fire station (Hoggt 1968). Notably, if an area covered by a fire station is large, the distance would be longer to reach the incidents; accordingly, it heightens the response time

(Savsar 2014). In some cases, there are micro-level stations which are a subset of macro-level ones to reduce the total response time. Strictly speaking, the micro stations should attend the place and commence the operations until the backup firefighters with more equipment from large stations arrive at the place. Iran's standard for coverage areas comprises 2 km for micro-level stations, 4 km for mediocre-level stations and 6 km for macro-level ones (Iran's Institute of Industrial Standards and Research 2001).

2.2.Accessibility

Generally, accessibility is defined in terms of route and traffic volume. The shortness of the route does not necessarily mean quick access to the areas of fire incidents. Regardless of the length of the routes, the traffic load can make the fire rescue team linger. Dong et al., (2018) mentioned that two major aspects of traffic should be considered: (1) traffic management, including the driving direction, driving time and road traffic, (2) traffic capacity, denoting vehicle capacity and road congestion., so traffic volume is a key factor of locating fire stations. Under the context of fire rescue, fire engines reach the locations of incidents through the route of a street network, and in practical applications, the main attention of planners is also paid to the division of network segments for understanding the accessibility of fire emergency service. It is recommended to locate stations at points with quick access to a major arterial to avoid any traffic congestion (Hacioglu 2010;Habibi, Lotfi, and Koohsar 2008). The distance from intersections is another factor that should be paid attention to, when there is heavy traffic at the crossroads, there will be an obstacle for the fire engines to leave the station, so the fire stations should be located where there are at least 60 meters distance from the intersection to the location of fire stations (Iran's Institute of Industrial Standards and Research 2001).

2.3.Environmental Criteria

One of the measures that can be implemented to hinder the fire spread and put out fire is adequate water which should be provided by means of fire cisterns. Without sufficient water supply, fires tend to develop beyond control, and lead to serious losses of lives and property (Hou and Li 2021). Therefore, fire stations should be located in the areas that provide ready access to the water supply. Another indicator is distance from fault. In earthquake-prone areas, the urban system can also be subjected to fire following earthquake (FFE). Simultaneous ignitions following an earthquake and overwhelming demands for fire service can be particularly destructive (Uddin and Warnitchai 2020). Minimizing overlap of services provided by fire stations is the subsequent factor that should be taken heed of. The unbalanced workload of fire stations is affected by their inappropriate distribution and a disproportion between the workload and fire-prone areas in a city (Iran's Institute of Industrial Standards and Research 2001).

*2.4.*Population density and Fire incident density

The shift in the population often creates the need for new fire departments (Alberta office of the fire commissioner, n.d.). According to Taridala et al. (2017), The highest potency of collateral hazard is in urban area having high population density, land use complexity, urban population activity center, building materials and urban slump areas. National Fire Protection Association (NFPA) (2020) defines a dense urban area as an incorporated or unincorporated area with a population of over 200,000 people and/or a population density of over 3,000 people per square mile (1158 people per square kilometer). There is a positive relationship between the frequency of fire incidents and population density. Significantly, the overwhelming majority of the recorded incidents occurred in populated regions (Corcoran et al. 2007). Consequently, to minimize the high fire risk, not only the areas with high population density

but also the density of fire incidents must be considered to choose a location for fire stations with a maximum benefit of coverage areas.

In addition to the mentioned factors, there are some influential reasons that not only can cause a fire but also have an impact on locating fire stations: the conditions of a building and the type of activity. Indeed, the worn-out urban texture and dilapidated old buildings are on the verge of fire incidents so the stations should have maximum coverage of these areas. In addition, some activities which deal with flammable materials such as weaving, textile industry, gas and oil products, etc., can contribute as an influential factor in site selection. Based on the reviewed literature and relevant standards (NFPA and Iran's Institute of Standards and Industrial Research), twelve evaluation criteria were selected and organized into four major categories: Service Area, Accessibility, Environmental Characteristics, and Spatial Characteristics. These criteria constitute the basis of the GIS–ANP framework developed in this study to identify optimal locations for future fire stations in Mashhad and Calgary. Finally, this study will answer the following questions: How adequately do the existing fire stations cover the urban areas of Mashhad and Calgary? Which urban locations have the highest priority for future fire station development based on GIS–ANP analysis?

3. Materials and Method

This study not only assesses the whole locations of existing urban fire stations, but also locates the new areas for future fire stations in refers to two cities: Mashhad (Iran) and Calgary (Canada). Owing to the fact that locating urban fire stations is a decision-making process which is subject to a wide scope of significant factors, it would necessitate using Multicriteria Decision Making (MCDM) methods (Mu and Pereyra-Rojas 2018). Two of the most important methods of Multi Criteria Decision Making (MCDM) are the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP which is an extension of AHP) presented by Thomas Saaty (Nedjati and Izbirak 2013). ANP was selected because, unlike AHP, it allows interdependencies and feedback among decision criteria, making it suitable for complex urban planning problems where spatial, environmental, and accessibility factors interact. Since accessibility, service coverage, environmental characteristics, and spatial attributes influence one another in urban fire station planning, ANP provides a more realistic representation of the decision-making process.

The ANP is a general theory of relative measurement used to derive composite priority ratio scales from individual ratio scales that represent relative measurements of the influence of elements that interact with respect to control criteria. The ANP captures the outcome of dependence and feedback within and between clusters of elements (Figueira, Greco, and Ehrgott 2005). In other words, the criteria and sub-criteria will be compared to each other in this method. The ANP structure looks more like a network, with cycles connecting its components of elements, and with loops that connect a component to itself (Figure 1) (Saaty and Vargas 2006). Indeed, constructing a network structure capturing the goal, criteria, sub-criteria and their relationships is the first phase of the ANP process on Super Decision v3.2.0 which is the latest version of the software package developed for the analysis, synthesis, and justification of complex decisions (Mu and Pereyra-Rojas 2018).

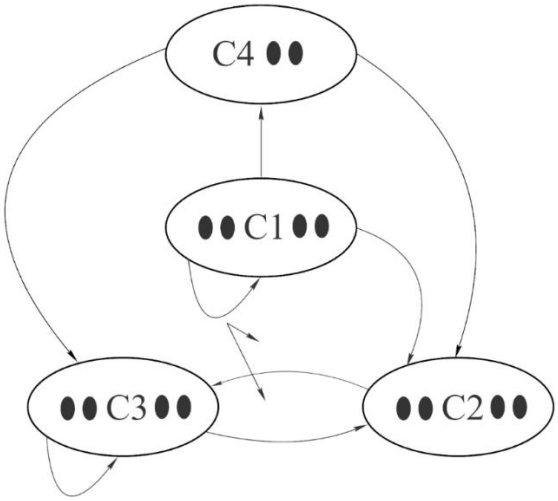


Fig. 1. Inner and outer dependence among the components of the ANP network (Source: Saaty and Vargas 2006).

Therefore, the criteria and sub-criteria for locating fire stations were gathered. Next, the pairwise matrices judgments were obtained from a panel of experts including urban planners, GIS specialists, and fire department professionals. generating a pairwise comparison matrix will help to recognize the priorities of elements by judging them in pairs for their relative importance. Afterward, the software formed the unweighted and weighted super matrices. The weights derived from the previous step were the weighs of sub-criteria used to populate the columns of the unweighted super matrix (Figure 2). The unweighted super matrix was then multiplied by the priority weights from the clusters, yielding the weighted super matrix. This is done because the resulting matrix must be column stochastic, that is its columns must add to one, for a limit that is not zero to exist. To form the limit matrix which provides the relative importance weights for every factor in the model, the powers of the weighted matrix converged to a matrix whose columns were all the same (Saaty and Vargas 2006). Afterward, the weighs of sub-criteria were gauged. Ultimately, ANP assists in not only prioritizing the sub-criteria contributing to the site selection but also understanding their relationship and interactions. As a result, the Geographic Information System (GIS) utilizes the output of ANP (weighted sub-criteria) to create the suitability map of fire stations. It scores each pixel of the city based on the combined criteria. Indeed, the application of a geographic information system can enhance facility planning and management of public facility spaces (Huang, Chiou, and Li 2020). In conclusion, the ANP and GIS serve complementary roles in the site selection. ANP determines the relative importance of each evaluation criterion by considering interdependencies among factors, whereas GIS spatially integrates these weighted criteria to generate a continuous suitability surface for fire station site selection.

$$\text{Weight} = \begin{array}{c} \\ \text{Goal} \\ \text{Criteria} \\ \text{Sub-Criteria} \end{array} \begin{array}{c} \begin{array}{ccc} \text{Goal} & \text{Criteria} & \text{Sub-Criteria} \end{array} \\ \begin{bmatrix} 0 & W_{12} & 0 \\ 0 & W_{22} & W_{23} \\ 0 & W_{32} & W_{33} \end{bmatrix} \end{array}$$

Fig. 2. The structure of unweighted super matrix.

4. The study areas

The present research juxtaposes the city of Mashhad with Calgary City in terms of locating fire stations and their distribution. Mashhad is the capital of Razavi Khorasan Province which is in the northeast of Iran and is known as a religious pilgrimage site. As reported by Census Center, it had a population of 3,001,184 people with a population growth rate of 2.65% (Management and Planning Organization of Khorasan Razavi Province 2017), area of 307.9 km2 and a population density of 9747.3 people per square kilometer in 2016. In 2021, there were 50 fire stations with 13 municipal zones (Figure 3). The largest area (47.5 km2) belongs to zone number 7, located in the southern part of the city, where Mashhad International Airport is situated. As mentioned by the head of the Mashhad Fire Department, zone number 2 was considered as an area with high density of incidents in 2021 whereas the Samen zone fell into the category of lowest density of incident (Mashhad Municipality Journal 2022).

Calgary is located in the south of Alberta, Canada. As Canada's fourth largest city, the city's population was 1,306,784 people in 2021, a land area of 820.62 km2 and a population density of 1592.4 people per square kilometer (Statistics Canada 2021). Expected to experience a significant demographic shift with the labor force consisting of older persons and relatively fewer young people (The City of Calgary 2020). As reported by Statistics Canada (2021), the percentage of population change was 5% from 2016 to 2021

The city has been divided into 14 geographical areas called ward and each of which is run by a City Councilor (The Official Web Site of The City of Calgary 2022) (Figure 3). Wards number 12 (an area of 127.40 km2) and number 8 (an area of 23.7 km2) have the largest and smallest area respectively. According to Figure 3, there were 42 fire stations distributed across the city with a total area of about 43898 m2 in 2021. Also, three fire stations have been approved by the council for 2024. The high density of incidents centered on the city center adjacent to the Calgary train (C-Train).

The total number of Mashhad's Incidents rose from 29,383 in 2019 to 36,619 in 2021 (by 24 %). Likewise, in 2021, the number of total incidents responded to by the Calgary Fire Department (CFD) was 12 % higher in comparison to 2019. Compared to Calgary, Mashhad's total incidents are almost 34,000 lower. Although the CFD could reduce the expenditures of property loss originating from fire incidents by $20M, Calgary and Mashhad both experienced an upward trend in terms of fire incidents by roughly 66 % and 24 % respectively from 2019 to 2021 (Table 2). The Calgary Fire Department (CFD) has a target response time of arriving within seven minutes, 90 % of the time at fire and fire-related incidents, and within 6 minutes and 30 seconds at critical medical intervention incidents, which is one minute more than the Canadian national fire standards and 3 minutes more than the standard fire response of the National Fire Protection Association (NFPA). In Mashhad, the response time fluctuates between 1 minute and 7 minutes. Indeed, the average response time is 4 minutes. Similar to Calgary, Mashhad's response time is 3 minutes higher according to NFPA. In addition, conforming to the definition of a dense urban area by the National Fire Protection Association, both the city of Mashhad and Calgary fall into the category of dense urban areas.

Accordingly, the dire consequence of that is putting the lives and homes of citizens at risk. The fire control system is by far the costliest element of a fire department's operations and should be designed and operated in the most cost-effective fashion (International Association of Fire Fighters 1993). The budget constraints significantly affect the number of fire stations. As a result, the fire departments cannot achieve the goal of maximum coverage areas (Badri, Mortagy, and Ali Alsayed 1998). As reported by the Calgary Fire Department (2021), the city is getting bigger and bigger; in contrast, the CFD is running very light and lean considering the population increase. CFD's operating cost per $ 1000 property value is $ 0.86, one of the lowest

of Canadian major municipalities and considerably lower than the median of $ 1.12 (the Municipal Benchmarking Network Canada). Calgary does not have physical barriers to limit outward growth (Guo and Fast 2019), so it sprawls into open fields around the city. In the same way, Mashhad City confronts unscheduled growth to the northwest (Jahanbani and Lashkari 2022). In terms of population, not only Mashhad but also Calgary is populated. The last but not least, the current fire stations and staff are not adequate to respond to urban fire incidents. On the other hand, Calgary's area is 2.6 times larger than that of Mashhad and has a low number of fire stations compared to Mashhad. Calgary's current response time is 7 minutes. However, Mashhad with a smaller area has a standard response time of 3 to 5 minutes. Therefore, investigating the distribution of fire stations in both cities and efficient deployment of fire stations is necessary to cover the newly developed areas of the city, and mitigate the widespread property damage, loss of citizens' lives, and pure economic loss. To achieve that, it is necessary to define the factors influencing the locations of fire stations.

Table 2. Annual reports related to Fire Department

City	Trends	2019	2020	2021*
Mashhad	Fire Incidents	11,784	12,726	14,664
	Fire Incidents (per 1000 population)	3.92	4.24	4.88
	Total Incidents	29,383	29,341	36,619
Calgary	Fire Incidents	1266	1420	2098
	Fire incident (per 1000 population)	0.98	0.91	1.60
	Total Incidents	62,904	60,949	70,645
	Property Loss (Approximately)	$34M	$33.4M	$14M

Source: Calgary Fire Department 2021; Fire Department and Safety Services of Mashhad Municipality 2021.
*The most recent data available at the time of the research was from 2021.

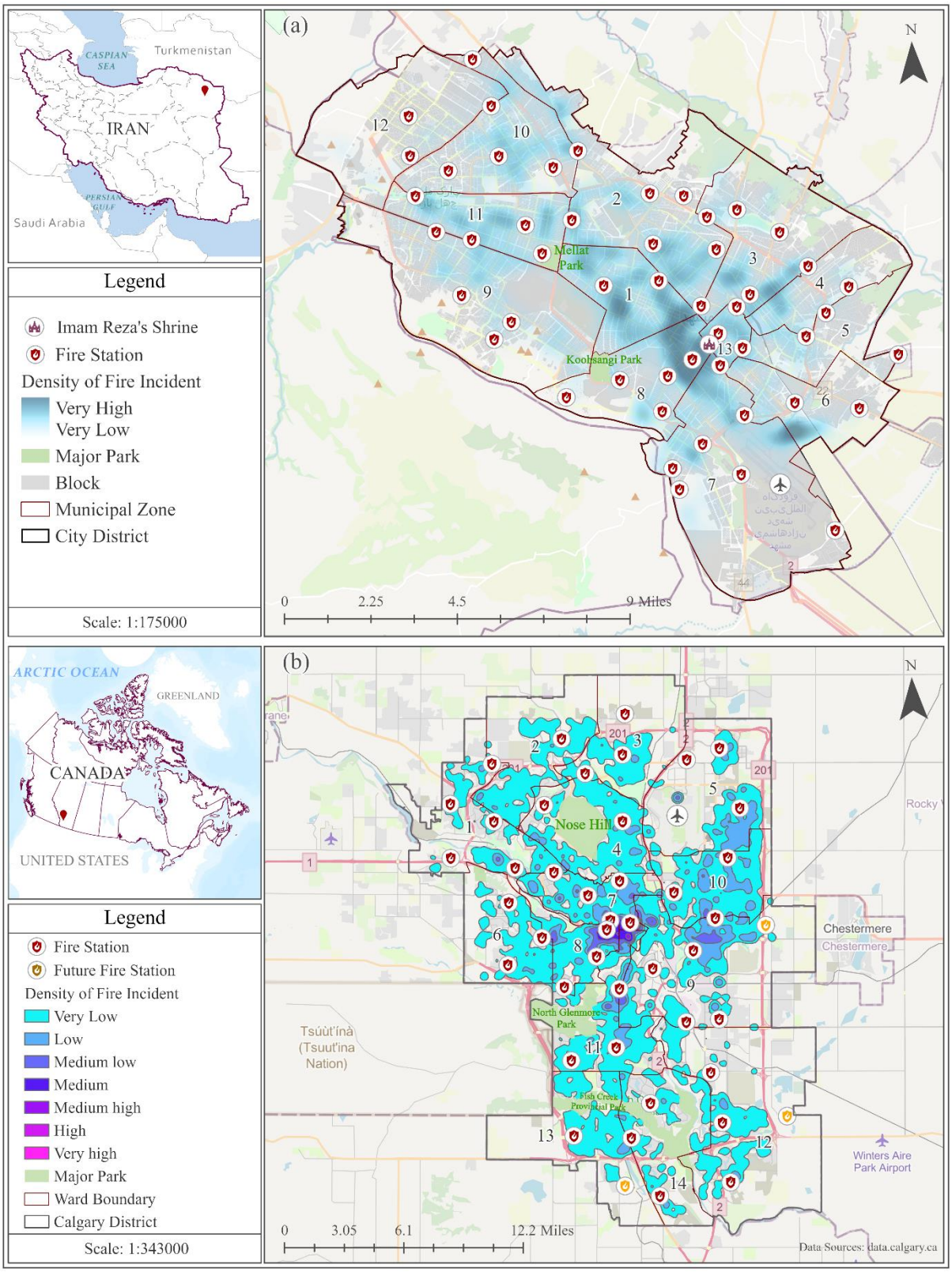


Fig. 3. Geographical location and fire stations. a) Mashhad City b) Calgary City.

5. Results and Discussion

The time limit reported by Iran's Institute of Industrial Standards and Research for each individual fire station is between 3 and 5 minutes. Although Mashhad City has 50 fire stations,

many segments of the city are out of the standard time limit of an individual fire station. The west and the northwest parts of the city have fairly high population density, also the north of zone 2 is the location of informal settlements and important industrial uses which are not covered by any fire station. However, the city center seems to have better service coverage. In Calgary City, travel time is set at 7 minutes which is defined as 4 minutes by the NFPA. As shown in Figure 4, the majority of the city is situated in areas with higher response times (7 minutes). The existing fire stations can only cover some communities with a travel time of 7 minutes which is 3 minutes higher than the standard time, so if Calgary set the response time at 4 minutes the coverage areas of these stations will reduce; consequently, it will reduce efficiency and the functionality of the stations. Calgary's area is roughly 2.6 times higher than that of Mashhad and Mashhad has a higher number of stations, it is expected that one of these cities has better performance than the other one. However, in view of the distribution of urban fire stations and areas with higher response times, it is self-evident that both Mashhad and Calgary are in similar circumstances. The number of existing fire stations does not meet the fire incidents and cannot provide acceptable coverage (Figure 4).

An exhaustive literature review was carried out to gather the determining criteria affecting the Fire station site selection. As a result, Table 3 displays the selected factors that have a significant role in planning for an optimum fire station.

Table 3. The criteria and sub-criteria for locating fire stations.

Criteria	Sub-Criteria
Service Area (SA)	Response time
Accessibility (A)	Proximity to main roads
	Distance from intersections (at least 60 meters)
	Wide streets (not less than 6 m widths)
Environment (E)	Being adjacent to fire hydrants
	Distance from fault and rivers
	Proper slope (less than 8%)
Spatial Characteristics (SC)	Locating in high population density
	Locating in an area with a high density of fire incidents
	Being close to informal settlements, worn-out contexts and buildings with poor conditions
	Distance from existing fire stations
	Distance from large and important land uses (Hazardous material facilities, hospitals, airports, railway stations, sports centers)

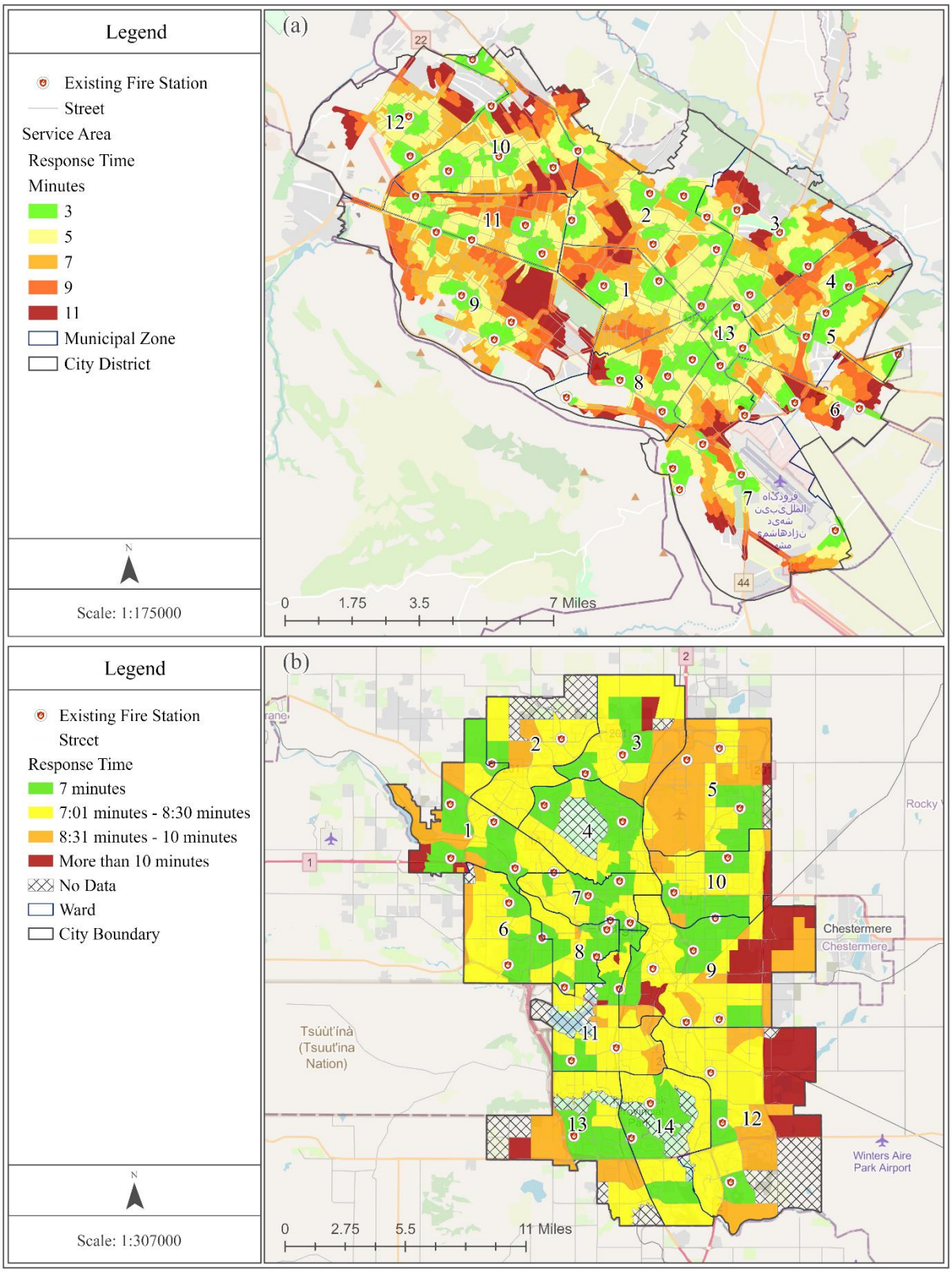


Fig. 4. Service area based on travel time. a) Mashhad City b) Calgary City.

The priority of each sub-criteria was determined using the ANP method. Having been defined, the criteria were inputted into Super Decision to create an ANP network. As illustrated in Figure 5, the network consists of 3 main clusters: A goal, a cluster including criteria (4 nodes), and a cluster with 12 nodes indicating sub-criteria. In this network, there are interdependencies within the clusters and outer dependencies among clusters. External dependencies and inner dependencies are shown by two-way arrows and looped arcs successively.

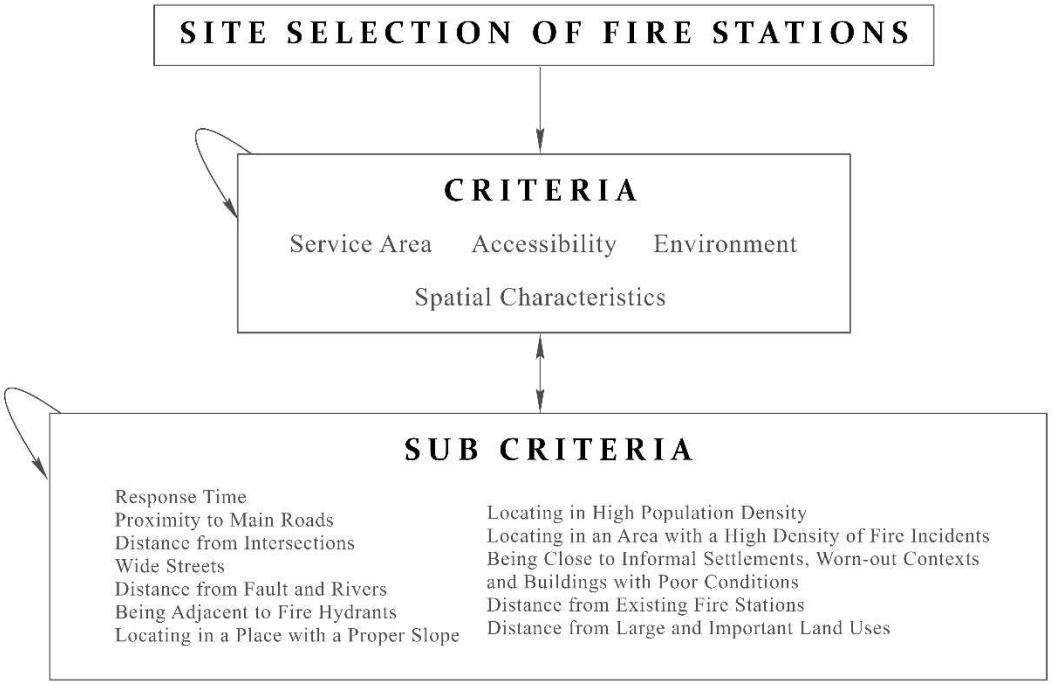


Fig. 5. The network structure for locating fire station.

First, the matrices of pairwise comparison of criteria with respect to the objective, criteria with respect to each individual criterion, criteria with respect to sub-criteria and vice versa, and sub-criteria with respect to each other were formed in Super Decisions software. Judgments are based on numbers from the fundamental scale introduced by Saaty (Table 4).

Table 4. The fundamental scale of absolute numbers representing the intensities of judgments

Intensity of Importance	Definition
1	Equal importance
2	Weak
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong/ demonstrated importance
8	Very, very strong
9	Extreme importance

Source: Saaty and Vargas, 2006

Afterward, the unweighted and weighted super matrices were computed. The degree of inconsistency should be checked for each matrix. The inconsistency ratio in all the pairwise comparison matrices was less than 0.1 which is a tolerable inconsistency according to Saaty (Mulalidharan, Anantharaman, and Deshmukh 2003) (Figure 6). Table 5 reveals the priorities and final weights of the sub-criteria. It is concluded that Response time has the highest

importance and effect (with a weight of 0.142) among the other sub-criteria, on the other hand, the lowest importance belongs to the sub-criterion of distance from fault and rivers with a weight of 0.043. In terms of criteria, the top and last priorities are spatial characteristics and service area respectively.

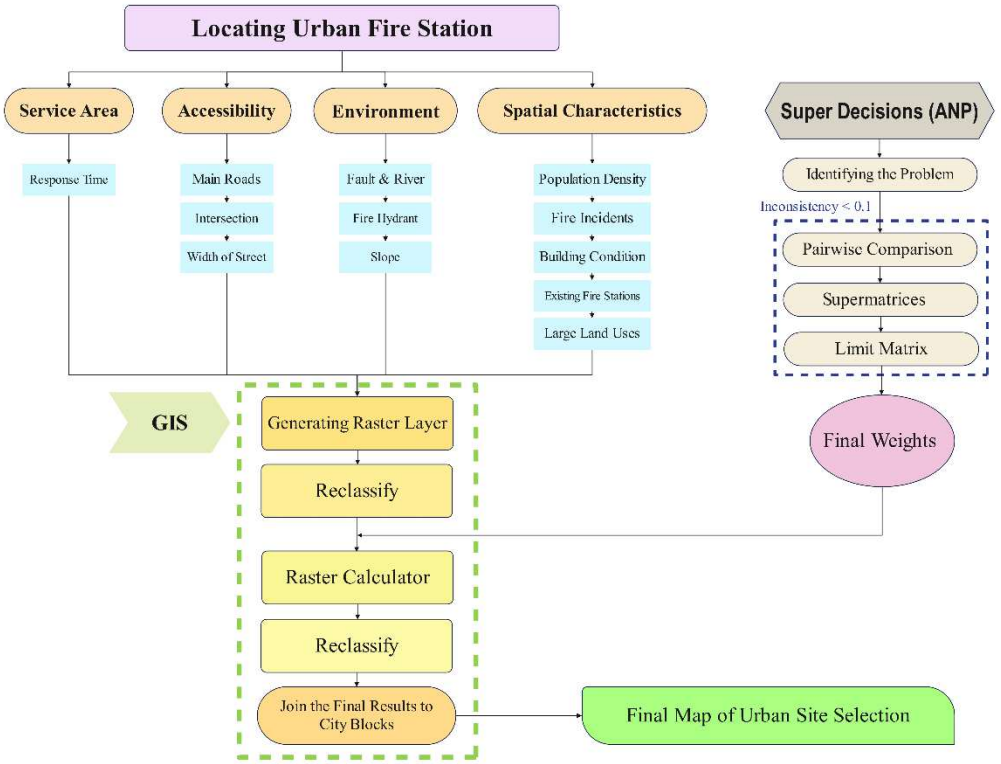


Fig. 6. Flow chart of locating urban fire stations.

Table 5. The calculated weights of criteria and sub-criteria on Super Decision software.

Criteria	weights	Sub-Criteria	weights
(SA)	0.142	Response time	0.142
(A)	0.252	Proximity to main roads	0.127
		Distance from intersections	0.079
		Wide streets	0.046
(E)	0.183	Being adjacent to fire hydrants	0.096
		Distance from fault and rivers	0.043
		Proper slope	0.044
(SC)	0.424	Locating in high population density	0.105
		Locating in an area with a high density of fire incidents	0.108
		Being close to informal settlements, worn-out contexts and buildings with poor conditions	0.094
		Distance from existing fire stations	0.060
		Distance from large and important land uses	0.057
Sum	1	-	1

From the four aspects (Service Area, Accessibility, Environment, Spatial Characteristics), the locations of fire stations were evaluated in Mashhad and Calgary using ArcGIS Pro. Numerous datasets and analyses were utilized and performed for the aim of this study. In Mashhad City, several data were collected from the Mashhad Fire Department. However, in some cases, like

Response Time, the data was produced in the GIS platform through Network Analyst. A network analysis was implemented to pinpoint the area with a higher response time. In addition, Calgary's data were obtained directly from the source of the City of Calgary website.

In ArcGIS Pro, twelve input map layers were evaluated and prepared to be used in the analyses for both cities. Each layer was converted into an individual raster map depending on the sub-criteria by using 3 tools: Euclidian distance, Kernel density and conversion tools. Afterward, the pixels of the map should be ranked for the suitability of the site selection which can be done by using Reclassify tool. The priorities fell into 9 categories in which 1 shows an extremely improper location and 9 visualizes a highly proper place. Take the sub-criterion of proximity to main roads as an example, being adjacent to main roads has a high priority for locating urban fire stations; accordingly, the shorter the distance to arterial roads, the higher rank it gets. Through the Raster Calculator tool, the sub-criteria were multiplied by their weights and the map layers of criteria were produced (Figure 7). Based on Figure 7, Dark-brown areas depict the highly valued locations in each criterion. In terms of Service Area, the pixels which have the highest suitability values for locating fire stations are observed throughout the city of Mashhad; however, Calgary's suitable pixels are the peripheral segments of the city. In the category of Environment, the sites which are away from faults and rivers, have a suitable slope and are close to fire hydrants gained high rank, when these layers combine, considering their weights, the areas which have higher scores are the southeast to northwest in Mashhad and northeast and northwest in Calgary. Considering Spatial Characteristics, In Calgary, the scattered dark-brown zones are located across the city representing a high score and priority for the site selection. In Mashhad, the southeast and northwest areas are considered proper locations with spatial characteristics. Ultimately, the final candidate locations of fire stations would be generated by adding the layers of criteria together considering their specific weights. To pinpoint the proper sites for fire stations, the raster of priorities was converted into a polygon layer and the data was transferred to blocks of the city by the Spatial Join tool (Figure 6).

Figure 8 shows the layout plans of the proper locations of the future fire stations. According to the spatial overlay analysis of the 12 sub-criteria, the area of the site selection was classified into 9 classes highly suitable level to unsuitable level. The most suitable sites (the highest value) were represented by dark red, while the least suitable ones (the lowest value) were presented by transparent cream. In order of priority, it shows that Mashhad's zone 2 (with a suitable area of 9.55 km^2), zone 3 (5.84 km^2), and zone 1 (5.65 km^2) are the top three districts. Considering the fact that the mentioned zones have a higher response time and population density and there is a poor quality of housing owing to informal settlements in the northern 100-meter expressway as well as in the vicinity of Tus's boulevard, it is requisite to contemplate more stations as a safety precaution for future spread of fire incidents.

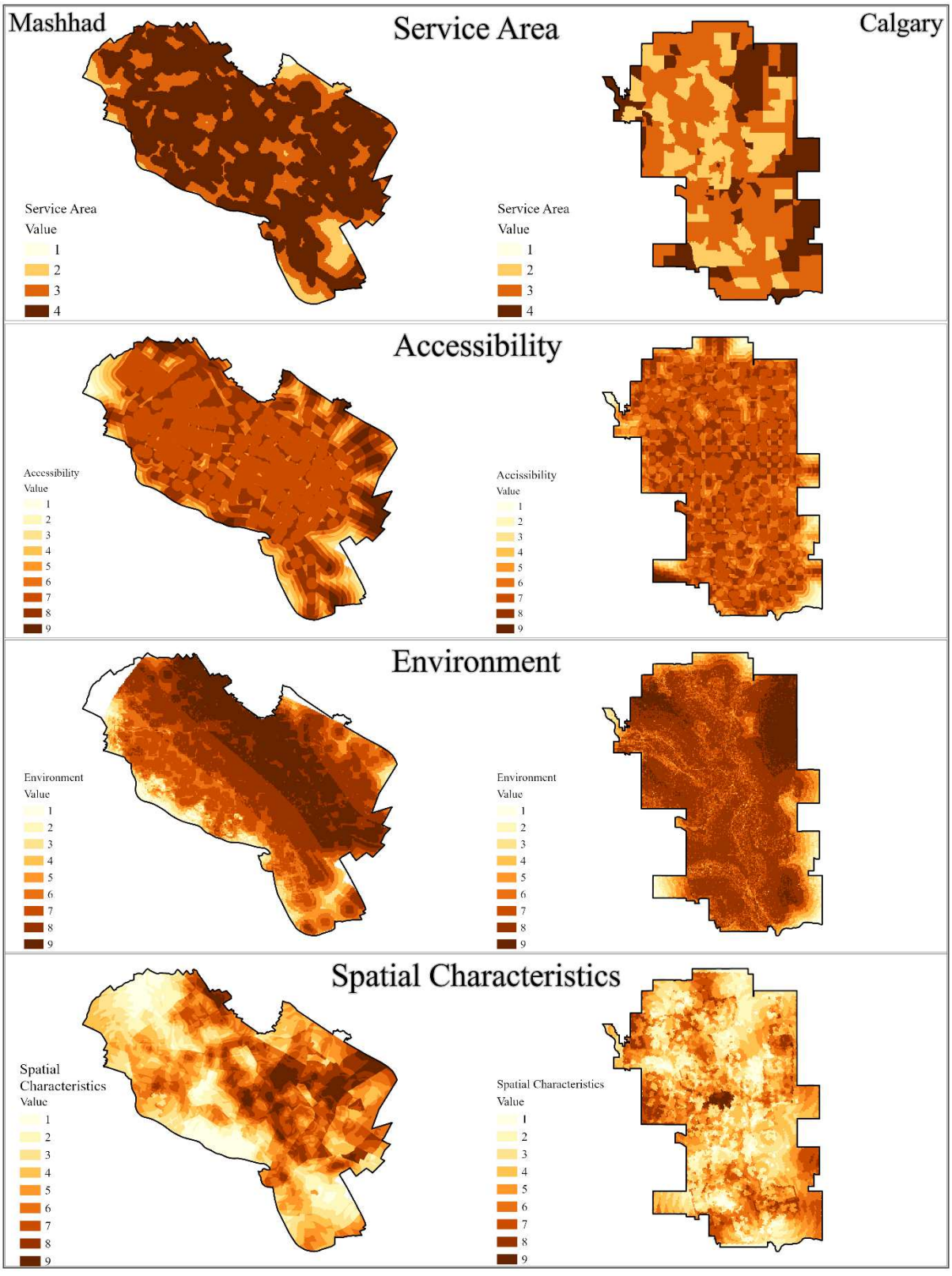


Fig. 7. Reclassification of criteria

In Calgary, the three high priorities are ward 6 (3.64 km^2), ward 12 (2.94 km^2) and 8 (2.93 km^2), where the spatial characteristics and accessibility are high indicating potential areas for future locations of urban fire stations. Similar to Mashhad, in which zone 7 with an unsuitable area of 18.93 km^2 is recognized as a place with low value, Calgary's ward 3 is identified as an area that contains most of the unsuitable locations (values of 1 and 2) for fire stations with an area of 14.99 km^2. Calgary's top priorities are centered in the southern part of downtown, the east of Calgary's airport which has a high population density, the western segment and ward 12. In contrast to Mashhad where the main places for site selection are located in the north and the northwest areas, Calgary's peripheral areas, and the city center are ranked as optimal sites. It is worth mentioning that the response time is different between Mashhad (3-5 minutes) and Calgary (7 minutes); therefore, if new stations are located in areas with higher values, the response time will be reduced; as a result, it will descend fire damage.

Mashhad's area is 2.6 times lower in comparison to Calgary's area. Apart from that, Mashhad's number of fire stations is more than that in Calgary (8 stations more). Despite Calgary, Mashhad should have a better coverage area apparently. Therefore, unlike Mashhad, it is assumed that Calgary's areas which are recommended for locating fire stations will be more. However, Mashhad's highly valued locations are significantly more in contrast to Calgary because the large area of Mashhad possesses worn-out context and poor conditions of housing which has high population density. Additionally, it is located close to main roads and it is out of the fire stations' time coverage too. These are the main reasons proposed Mashhad's larger area as a high priority for the site selection.

In Calgary, Industrial regions are placed in the large parts of ward 9, northern parts of ward 12, and the south and north of the airport, so the population density of these areas is fairly low. Furthermore, the density of fire incidents is low too. They were ranked low for locating future fire stations, as a result. Alternatively, the industrial sectors of Mashhad sited surrounding Tus's boulevard were given a high value (priority) for the site selection of future stations. The high values can be attributed to high population density, prominent industrial land uses, and poor station coverage.

Overall, an approximate area of 38.49 and 26.54 km^2 is highly suitable (a value of 9) for a fire station site selection in Mashhad and Calgary respectively. Conversely, the total area of unsuitable blocks is 0.087 km^2 in Mashhad and equals 14.7 km^2 in Calgary. The number of highly prioritized blocks equals 1971 in the city of Calgary which reaches 6671 in Mashhad. In Mashhad, the number of appropriate blocks which have been given a value of 9 is almost 3 times higher than that in Calgary which reveals that there are more alternatives for locating fire stations in the future (Table 6).

Table 6. Outcomes regarding suitable locations for future fire stations in both cities.

Cities	Mashhad	Calgary
The number of blocks (Gaining value of 9)	6671	1971
Highly suitable area (km^2)	38.49	26.54
Highly unsuitable area (km^2)	0.087	14.70

Comparing the locations of existing fire stations with the results of the final site selection shows that in Mashhad, a bulk of current stations are located in suitable sites. In Calgary, in spite of the stations which have suitable locations, there are some stations situated in locations that gained lower values. As mentioned earlier, Calgary's council has passed the layout for locating three fire stations. Comparing their locations with the scored blocks shows the future fire stations will be situated in the blocks which have gained values more than 6 (Figure 8).

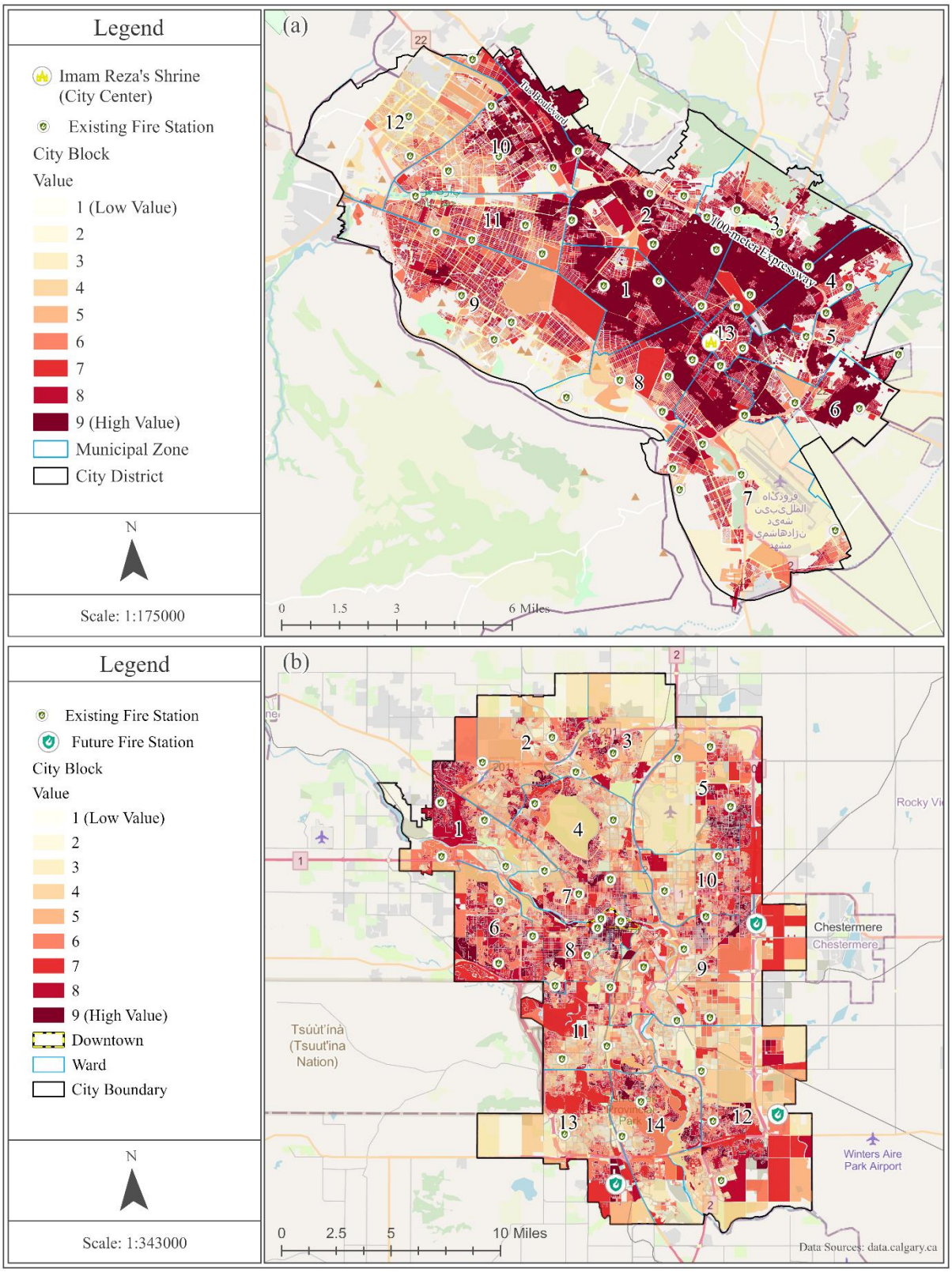


Fig. 8. Suitability of locating fire stations based on city blocks. a) Mashhad City b) Calgary City.

Consistent with prior conducted research on sprawl cities by Dey, Heger, and England (2022), Ming, Richard, and Zhu (2021) and Han et al. (2021), we also observed response time as a highly influential variable gaining highest weight among the other sub-criteria. While there are contextual differences that may impact the results, including the last two research focused

highly on the factors related to traffic analysis, this research tried to include multi-facet factors such as spatial and environmental characteristics. Unlike Kharaghani, Etemadfard, and Salem Rafush's findings (2022), the distance from existing fire stations had the highest weight, in this research evidence showed that this criterion had the low influence on the process of locating fire stations. All in all, observed differences could be due to variations in the number of variables, methodological procedures, data collection techniques. Subsequent studies may investigate the factors such as community engagement or how demographic shifts, land cover change can affect the process of site selection.

6. Conclusion

Rather than comparing the performance of the two cities, Mashhad and Calgary were intentionally selected to evaluate whether the proposed GIS–ANP framework can be applied across different urban contexts. While both cities experience rapid urban expansion and urban sprawl, they differ substantially in planning systems, governance structures, socioeconomic conditions, and data availability. This contrast provides an opportunity to assess the transferability and robustness of the proposed methodology. This study considerable indicators were examined and evaluated their relative importance and influence in the site selection fire stations process; as a result, the requisite multiple indicators influencing the locations of fire stations were pooled. The results showed that the response time had the highest weight, and the distance from faults and rivers had the lowest weight. Indeed, the sub-criteria which had a weight lower than 0.100 and played a small role were “Distance from intersections, existing fire stations, fault, rivers and large and important land uses, as well as “Wide streets”, “Being adjacent to fire hydrants”, “Proper slope “, and “Building conditions”. The criterion of spatial characteristics and its sub-criteria all had high weights demonstrating that this criterion had a more significant effect on the location of fire stations.

The main contributions of this study are threefold. First, it develops an integrated GIS–ANP framework for fire station site selection in rapidly growing cities. Second, the framework is evaluated across two contrasting urban contexts (Mashhad and Calgary), demonstrating its transferability beyond a single case study. Third, the study addresses data limitations in developing-country contexts by deriving response-time information through GIS network analysis, providing a practical approach for data-constrained urban environments.

Conducting the site selection and general planning of the locations of fire stations in Mashhad and Calgary as a multi-criterion decision-making process on ArcGIS Pro and the suitability of locations was exhaustively evaluated and scored to attain a broad outline of the most suitable sites for locating future fire stations. In Mashhad, zone 2 has the most suitable areas for the site of fire stations with an area of 9.55 km^2; in the same way, Calgary’s ward 6 has the top priority with a suitable area of 3.64 km^2, which gained high values in each criterion indicating potential areas for future locations of urban fire stations. However, zone 7 and ward 3 are made up of the most unsuitable sites (values of 1 and 2) with an area of 18.93 and 14.9 km^2 in Mashhad and Calgary consecutively. Generally speaking, it appears that, in Mashhad, the appropriate and highly prioritized areas are more than that in Calgary. There is a wide array of options to locate future fire stations in Mashhad, in comparison to Calgary. In fact, the percentages of blocks achieving the highest values in Mashhad and Calgary are around 33% and 8% respectively. The percentages of stations located completely within the highly prioritized blocks (values of 8 and 9) are 34% and 15% in Mashhad and Calgary in a row.

Nevertheless, this study found that some established fire station locations are incompatible with the derived results of the suitability map in both cities. Consequently, the urban planning department and government policymakers should re-evaluate these locations in terms of suitability and efficiency.

Furthermore, in response to the research questions: Based on Figure 4, it can be concluded that the current locations of fire stations have a balanced distribution across both cities but they cannot cover the whole segments and many City's parts are excluded from the standard response time. Moreover, since these two cities are growing, Mashhad's zone 2 has the most suitable areas for the site of fire stations with an area of 9.55 km^2; in the same way, Calgary's ward 6 has the top priority with a suitable area of 3.64 km^2, which gained high values in each criterion indicating potential areas for future locations of urban fire stations. Despite Calgary, Mashhad is a small city and the urban area of Mashhad is 307.9 km^2 with 50 stations. On the other hand, the proper area for locating fire stations is higher than that in Calgary. This can be attributed to the fact that in Mashhad, there are some urban characteristics such as worn-out context, high population density, poor conditions of housing, and low permeability of urban texture, which accelerate the speed of the fire so the response time must be shorter and the number of stations must be high otherwise it may result in severe and irreversible consequences. In other words, these characteristics necessitate both maximum urban coverage and a short response time. Therefore, undoubtedly, the response time as a significant factor that gained the highest score in the sub-criteria of the site selection is subject to various parameters namely, type of urban texture, population density, and permeability. As a result, the response time differentiates in various sprawl cities and the number of fire stations and their distribution is dependent on not only the city's area but also all of the factors mentioned above. Thus, it can be concluded that there is not necessarily a direct relationship between the city's area and the number of fire stations. The number of stations relying on different parameters may vary in other cities.

This study has several limitations. First, the weighting process relies on expert judgment, which may introduce subjectivity. Second, temporal traffic variations and future urban growth scenarios were not explicitly incorporated. Future studies may integrate dynamic traffic data and machine learning techniques to improve site selection accuracy.

Data availability statement

Data of Calgary City generated or used during the study are available in a repository or online in accordance with funder data retention policies (The official web site of The City of Calgary, 2022. Available at: https://www.calgary.ca/council/councillors-and-wards.html.). Mashhad's data that supports the findings of this study are available from the corresponding author upon reasonable request.

References

Alberta office of the fire commissioner. n.d. "Establishing and Operating a Fire Department."

Aldabbas, Mohammad, Francesca Venteicher, Lenna Gerber, and Marino Widmer. 2018. "Finding the Adequate Location Scenario after the Merger of Fire Brigades Thanks to Multiple Criteria Decision Analysis Methods." *Foundations of Computing and Decision Sciences* 43 (2): 69–88. https://doi.org/10.1515/fcds-2018-0006.

Arifin, Shamsul. 2011. "Location Allocation Problem Using Genetic Algorithm and Simulated Annealing : A Case Study Based on School in Enschede." Twente.

Badri, Masood A., Amr K. Mortagy, and Colonel Ali Alsayed. 1998. "A Multi-Objective Model for Locating Fire Stations." *European Journal of Operational Research* 110 (2): 243–60.

https://doi.org/10.1016/S0377-2217(97)00247-6.
Bolouri, Samira, Alireza Vafaeinejad, Ali Asghar Alesheikh, and Hossein Aghamohammadi. 2018. “The Ordered Capacitated Multi-Objective Location-Allocation Problem for Fire Stations Using Spatial Optimization.” *ISPRS International Journal of Geo-Information* 7 (2). https://doi.org/10.3390/ijgi7020044.
Calgary Fire Department. 2021. “Annual Report.” Calgary. https://www.calgary.ca/categories/subcategory-calgaryfiredepartment-grid.html.
Chen, Mengmeng, Kai Wang, Xiangluan Dong, and Haili Li. 2020. “Emergency Rescue Capability Evaluation on Urban Fire Stations in China.” *Process Safety and Environmental Protection* 135: 59–69. https://doi.org/10.1016/j.psep.2019.12.028.
Chevalier, Philippe, Isabelle Thomas, David Geraets, Els Goetghebeur, Olivier Janssens, Dominique Peeters, and Frank Plastria. 2012. “Locating Fire Stations: An Integrated Approach for Belgium.” *Socio-Economic Planning Sciences* 46 (2): 173–82. https://doi.org/10.1016/j.seps.2012.02.003.
Corcoran, Jonathan, Gary Higgs, Chris Brunsdon, and Andrew Ware. 2007. “The Use of Comaps to Explore the Spatial and Temporal Dynamics of Fire Incidents: A Case Study in South Wales, United Kingdom.” *Professional Geographer* 59 (4): 521–36. https://doi.org/10.1111/j.1467-9272.2007.00639.x.
Dey, Arnab, Andrew Heger, and Darin England. 2022. “Urban Fire Station Location Planning Using Predicted Demand and Service Quality Index.” *International Journal of Data Science and Analytics*, 19.
Dong, Xin Ming, Ye Li, Yue Lei Pan, Ya Jun Huang, and Xu Dong Cheng. 2018. “Study on Urban Fire Station Planning Based on Fire Risk Assessment and GIS Technology.” *Procedia Engineering* 211: 124–30. https://doi.org/10.1016/j.proeng.2017.12.129.
Fire Department and Safety Services of Mashhad Municipality. 2021. “Annual Report of Fire Incidents.”
Ghasemi, Peiman, and Abdollah Babaeinesami. 2020. “Simulation of Fire Stations Resources Considering the Downtime of Machines: A Case Study.” *JIEMS Journal of Industrial Engineering and Management Studies* 7 (1): 161–76. https://doi.org/10.22116/JIEMS.2020.110013.
Guo, Jiaao, and Victoria Fast. 2019. “Spatial Insights on Urban Density: A Case Study of Calgary.” *CEUR Workshop Proceedings* 2323 (3).
Habibi, K., S. Lotfi, and M. Koohsar. 2008. “Spatial Analysis of Urban Fire Station Locations by Integrating AHP Model and IO Logic Using GIS (A Case Study of Zone 6 of Tehran).” *Journal of Applied Sciences* 8 (19): 3302–15.
Hacioglu, Cigdem. 2010. “Spaial Requirements of Fire Stations in Urban Areas: A Case Studey of Ankara.” Middle East Technical University.
Han, Bing, Mingxing Hu, Jiemin Zheng, and Tan Tang. 2021. “Site Selection of Fire Stations in Large Cities Based on Actual Spatiotemporal Demands: A Case Study of Nanjing City.” *ISPRS International Journal of Geo-Information* 10 (8). https://doi.org/10.3390/ijgi10080542.
Hoggt, Jane M. 1968. “The Siting of Power Stations.” *Journal of the Operational Research Society* 19 (3): 275–287. https://doi.org/10.1038/179401b0.
Hou, Guanjie, and Quanwang Li. 2021. “Firefighting Capacity Evaluation of Water Distribution System Subjected to Multi-Ignitions of Post-Earthquake Fires.” *Structural Safety* 88 (October 2020): 102035. https://doi.org/10.1016/j.strusafe.2020.102035.
Hou, Guanjie, Quanwang Li, Zhigang Song, and Hao Zhang. 2021. “Optimal Fire Station Locations for Historic Wood Building Areas Considering Individual Fire Spread Patterns and Different Fire Risks.” *Case Studies in Thermal Engineering* 28 (July): 101548. https://doi.org/10.1016/j.csite.2021.101548.
International Association of Fire Fighters. 1993. *IAFF Safe Fire Fighter Staffing – Critical Considerations*. Second. Department of Research and Labor Issues, IAFF.
Iran’s Institute of Industrial Standards and Research. 2001. “Standards of Locating Urban Fire Stations.” Tehran.
Jahanbani, Marjan, and Elham Lashkari. 2022. “Investigation of Spatial-Physical Development Model Based on Spatial Analysis, GIS and Holdern Entropy Model.” *International Journal of Human Capital in Urban Management* 7 (4): 545–60. https://doi.org/10.22034/IJHCUM.2022.04.08.
Jaldell, Henrik. 2017. “How Important Is the Time Factor? Saving Lives Using Fire and Rescue Services.” *Fire Technology* 53 (2): 695–708. https://doi.org/10.1007/s10694-016-0592-4.
Kharaghani, Hamed, Hossein Etemadfard, and Ahmad Salem Rafush. 2022. “Allocation of Fire Stations by Hybrid Method (Case Study: Mashhad) (In Persian).” *Urban Management Studies* 13 (48): 55–67.
Liu, Dingli, Zhisheng Xu, Zhengyang Wang, Yang Zhou, and Chuangang Fan. 2021. “Estimation of Effective Coverage Rate of Fire Station Services Based on Real-Time Travel Times.” *Fire Safety Journal* 120 (January): 103021. https://doi.org/10.1016/j.firesaf.2020.103021.
Management and Planning Organization of Khorasan Razavi Province. 2017. *Statistical Year Book of Khorasan Razavi Province (In Persian)*. Edited by First. Management and Planning Organization of the country, Center for Scientific Documents and Publications.

Mashhad Municipality Journal. 2022. “Shahrara News.” 2022.
Ming, Jinke, Jean Philippe P. Richard, and Jiping Zhu. 2021. “A Facility Location and Allocation Model for Cooperative Fire Services.” *IEEE Access* 9: 90908–18. https://doi.org/10.1109/ACCESS.2021.3091481.
Mu, Enrique, and Milagros Pereyra-Rojas. 2018. *Practical Decision Making Using Super Decisions v3: An Introduction to the Analytic Hierarchy Process*. Springer International Publishing.
Mulalidharan, Anantharaman, and Deshmukh. 2003. “Confidenceintervalapproach.” *West Indian Journal of Engineering*.
National Fire Protection Association. 2020. *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*.
Nedjati, Arman, and Gokhan Izbirak. 2013. “Evaluating the Intellectual Capital by ANP Method in a Dairy Company.” *Procedia - Social and Behavioral Sciences* 107: 136–44. https://doi.org/10.1016/j.sbspro.2013.12.840.
Plane, Donald R., and Thomas E. Hendrick. 1977. “Mathematical Programming and the Location of Fire Companies for the Denver Fire Department.” *Operations Research* 25 (4): 563–78. https://doi.org/10.1287/opre.25.4.563.
Rodriguez, Sebastian A., Rodrigo A. De la Fuente, and Maichel M. Aguayo. 2020. “Facility Location and Equipment Emplacement Technique Model with Expected Coverage for the Location of Fire Stations in the Concepción Province, Chile.” *Computers & Industrial Engineering* 147: 106522.
Saaty, Thomas L, and Luis G Vargas. 2006. *DECISION MAKING WITH THE Economic , Political , Social and Technological Applications with Benefits , Opportunities , Costs and Risks*. *Manufacturing Systems*. Vol. 95. United States of America: Springer Science+Business Media, LLC. http://www.amazon.com/dp/0387338594.
Savsar, Mehmet. 2014. “Fire Station Locations in a Metropolitan Area.Pdf.” *International Journal of Industrial and Systems Engineering* 16 (3): 365–81.
Shahparvari, Shahrooz, Masih Fadaki, and Prem Chhetri. 2020. “Spatial Accessibility of Fire Stations for Enhancing Operational Response in Melbourne.” *Fire Safety Journal* 117: 103149. https://doi.org/10.1016/j.firesaf.2020.103149.
Statistics Canada. 2021. “Census Profile.” 2021. https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/details/page.cfm?Lang=E&GENDERlist=1,2,3&STATISTIClist=1&HEADERlist=0&DGUIDlist=2021A00054806016&SearchText=calgary.
Sufianto, Heru, and Anthony R. Green. 2012. “Urban Fire Situation in Indonesia.” *Fire Technology* 48 (2): 367–87. https://doi.org/10.1007/s10694-011-0226-9.
Taridala, S., A. Yudono, M. I. Ramli, and A. Akil. 2017. “Expert System Development for Urban Fire Hazard Assessment. Study Case: Kendari City, Indonesia.” *IOP Conference Series: Earth and Environmental Science* 79 (1). https://doi.org/10.1088/1755-1315/79/1/012035.
The City of Calgary. 2020. “Municipal Development Plan (MDP).” Calgary.
“The Official Web Site of The City of Calgary.” 2022. 2022. https://www.calgary.ca/council/councillors-and-wards.html.
Uddin, Md Shahab, and Pennung Warnitchai. 2020. “Decision Support for Infrastructure Planning: A Comprehensive Location–Allocation Model for Fire Station in Complex Urban System.” *Natural Hazards* 102 (3): 1475–96. https://doi.org/10.1007/s11069-020-03981-2.
Wang, Wenxuan. 2019. “Site Selection of Fire Stations in Cities Based on Geographic Information System and Fuzzy Analytic Hierarchy Process.” *Ingenierie Des Systemes d’Information* 24 (6): 619–26. https://doi.org/10.18280/isi.240609.
Xiang, Yong, Wuwen Cao, Huidan Zheng, and Yangyang Su. 2020. “Optimization Research on the Site Selection of Fire Safety for Mega Projects Sites Based on Multi-Objective Particle Swarm.” *Evolutionary Intelligence* 15 (4): 2455–71. https://doi.org/10.1007/s12065-020-00520-7.
Yang, Lili, Bryan F. Jones, and Shuang-Hua Yang. 2007. “A Fuzzy Multi-Objective Programming for Optimization of Fire Station Locations through Genetic Algorithms.” *European Journal of Operational Research* 181 (2): 903–15. https://doi.org/https://doi.org/10.1016/j.ejor.2006.07.003.
Yao, Jing, Xiaoxiang Zhang, and Alan T. Murray. 2019. “Location Optimization of Urban Fire Stations: Access and Service Coverage.” *Computers, Environment and Urban Systems* 73 (November 2018): 184–90. https://doi.org/10.1016/j.compenvurbsys.2018.10.006.