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Spatial Analysis of Urban Fire Station Locations by Integrating AHP Model and IO Logic Using GIS (A Case Study of Zone 6 of Tehran)

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Abstract: This study tried to integrate Analytical Hierarchy Process model and Index Overlay logic in GIS to present a model for fire station location planning. A comprehensive GIS-based fire station location study can be the central component for a master plan for the station locations. This plan can show both the efficiency and deficiency of current fire station coverage for a specified travel time and provide a model for future fire station location. The model is applied to the zone of 6 of Tehran. The existed stations are located in the southern part which a large area of the North and North West is out of emergency aid. Also these sites have other location problems as they have access only to one sided road. The results of this research introducing two sites which are most appropriated for the establishing the two new stations. The major advantages of the new proposed sites are: Accessibility to two sided road, setting in the most populated area of the zone and the high potential for interventions.

Key words: Land use, site selection, urban facilities, multi-criteria decision analysis, model

INTRODUCTION

Fire stations are one of the important and vital land uses in urban areas that have to guarantee the life and safety of urban residents. So the location and number of the stations is very significant for the efficient coverage of the area which intended to be protected. Industrial revolution integrated the economic growth and profit by over concentration of different functions in cities. Also, the increase of urbanization growth has multiplied the population growth of urban areas in the developing countries which the risk of hazardous fire and its impact on the city became more obvious. By the increasing level of urban growth especially in the capital Tehran some of the urban zones faced with the shortages of urban amenities like fire stations. The 6 zone of Tehran with a population of 220312 and a density of 108 people in hectare includes about 3% of the capital total area and 3.6% of Tehran population. From geographical point of view the zone has located in the central area of the capital and is adjacent to many old elements like bazaar, Arg squire and Topkhaneh. However, the central position of the city shifted towards the North and North West due to some interventions in the first Pahlavi era in the 1960s. But still the zone placed many of important land uses (Fig. 1).

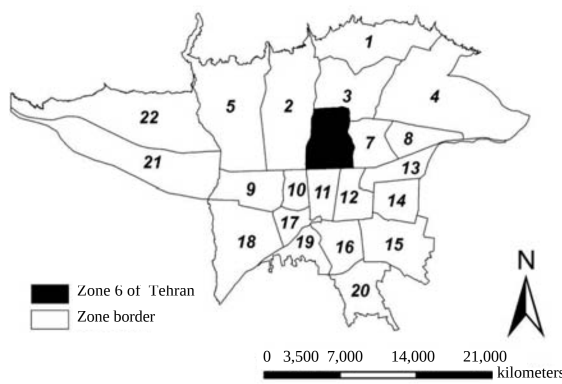

Fig. 1: The location of zone 6 in Tehran city

Some of these land uses are ministry buildings, higher education central office, medical centers and public hospitals, large economic companies and the religious land uses like churches, temples, central governmental offices and parks. So, the zone has a high strategic importance. The proportion of different land uses are classified in Table 1.

With respect to the high importance of the zone from national to local scale specific action must taken into account to guarantee the safety of the area. However, the strategic importance of the zone is quite clear for urban

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Table 1: The proportion of different land uses in the zone 6 of Tehran

Scale	Activities	Proportion/city (%)
National	Ministries and related institutions	33
	Higher education institutions	28
	Specialized hospitals	19
Provincial	Central administrative offices	40
	Public hospitals	20
The city	Cinemas	18
	Religious spaces of minorities	80
	Higher schools and professional/ technical institutions	6.5

management, but unfortunately there are many problem in the emergencies events where many highly and prestigious activities of the capital are located. One of the problems is the limit number of fire station which the zone has only three stations which one of them is for rescue without fire extinguishing cars. Clearly they can not have good coverage on the zone and reflex to the incidents. The two stations are located in the Southern parts with a short distance from each others. So, the broad parts of the North and North West is out of emergency aid or rescue.

The zone needs another two stations according to the population standard (a station per 50000 people). Fire station location planning should consider the several important characteristics of the zone in general. First of all the area has a high political and economic importance as Table 1 shows. Secondly the limitation of financial resources dictates the careful planning to avoid any kind of human and energy waste. Thirdly, urban planners have to address the issue of social justice and the distribution of urban services to all residents.

GIS have been defined as automated systems for the capture, storage, retrieval, analysis and display of spatial data (Clarke, 1995). To day, using the models and soft wares in urban planning became prevailed with respect to the complex dimension of the urban issues and the role of many different indicators in this field. Geographical Information Systems is one of the powerful tools to response the request of such study.

There is a growing body of literature that is advancing the use of GIS as a part of a multi-participant, multi-criteria framework that takes into account multiple views and consensus (Erkut and Moran, 1991; Heywood *et al*., 1995; Malczewski, 1999; Hokkanen *et al*., 2000; Jankowski and Nyerges, 2001; Joerin *et al*., 2001; Phua and Minova, 2005).

Kontos *et al*. (2005) used AHP in conjunction with GIS in order to find suitable sites for landfill for an island in Greece using 10 suitability criteria taking into account both environmental and social variables and individual site constraints. Again the relative importance of the criteria was assessed by experts-in this instance, the scientific advisors responsible for the sitting study. Although, the study showed the benefits of MCDA- GIS approaches, the final site was selected on the basis of local non-quantifiable factors such as public opposition highlighting the potential to incorporate public opinion from the outset.

Svoray *et al*. (2005) incorporated the use of a multi-criteria mechanism in a GIS for the evaluation of the suitability of ecologically sensitive areas for four possible land-uses: nature reserves; forest plantations; residential areas; and industrial areas. The evaluation procedure pronounces the effect of: existing land-uses; soil characteristics; topographic attributes; vegetation cover; and landscape heterogeneity. The evaluation method used here provides a suitability layer for each of the four land-uses and a final layer that could recommend the most suitable land-use for each cell. The outcome of the system developed can be used as a basis for planners and decision makers dealing with the development of cities and their surroundings in regions of high ecological and environmental sensitivity.

Baja *et al*. (2007) developed spatial modeling procedures for a MCDM analysis using compromise programming (CoPr) integrated with a raster GIS. Five sets of information, as noted above, are used to undertake an optimal spatial decision analysis for land use planning purposes. As the analysis deals with conflicting objectives (minimizing and maximizing) in a spatial context, a Co-pr technique is used and integrated with a raster GIS in the assessment procedures.

Lee and Chan (2007) adopt the analytic hierarchy process (AHP) to work out the most sustainable design proposal for an area undergoing urban renewal. AHP is a robust multi-criteria decision making (MCDM) method for solving social, governmental and corporate decision problems. Since there is a lack of published papers demonstrating a systematic and effective way for urban renewal proposal assessment, this paper attempts to fill this gap with the help of AHP.

Ohta *et al*. (2007) developed several alternative site plans for a new neurosurgical emergency hospital in Sapporo, Japan. Hospitals, population data, routes and the numerical information for the Analytic Hierarchy Process computations were input into a Geographical Information System. They conclude that the integration of Geographical Information Systems and the Analytic Hierarchy Process constitutes a powerful tool for analyzing traffic conditions in mid-sized cities and for suggesting city planning to improve prognosis of stroke.

Present study tried to integrate Analytical Hierarchy Process model and Index Overlay logic in GIS to present a model for fire station location planning to select the most appropriated sites. The model is applied to the zone 6 of Tehran. The main works of the research was conducted in 2007 and early 2008.

RESEARCH METHOD

The Multi Criteria Decision Making (MCDM) is a set of techniques (e.g., sum of weights or conversion analysis) which is able to weight and score a range of criteria and then the scores are ranked by the expertise and other related interested groups (Higgs, 2006). The MCDA techniques are spatial in much degree. In fact, criteria are different among the number of decision in space (Malczewski, 1999). However, despite the potential of MCDA model for integration to deal with spatial units problems, it gained attention only in a certain period of times in some practical researches and managerial limits (Higgs, 2006). Urban planners used the strategy of MCDA integration for dealing with spatial issues from 1990s (Phua and Minova, 2005). A city system can not be studied only by considering the simple concepts like land use or traffic. Now planners need to develop and deepen their understanding about a city system by analyzing a various socio-economic and political indicators. The issues which need to be dealt at same times create a condition which many alternatives should be tested and integrated to improve

The AHP approach, developed by Satty (1980), is one of the more extensively used MCDM methods. The AHP has been applied to a wide variety of decisions and the human judgment process (Lee *et al*., 2001). This technique is one of the MCDA methods with many capabilities which are used in different scientific disciplines. The previous researches show that the technique of MCDA which is known AHP is very suitable for solving complicated issues (Yuksel and Dagdeviren, 2007). Obtaining solutions in the AHP is not a statistical procedure, because it can help either a single decision maker or a decision group to solve a MCDM problem (Chen, 2006).

The five-stage AHP set out by Satty (1980) is summarized as follows (Wong and Li, 2007):

- Define the problem and determine the objective
- Development of the hierarchy from the top (the objective from a general viewpoint) through the intermediate levels (attributes and sub-attributes on which subsequent levels depends) to the lowest level (the list of alternatives)
- Employ a simple pair-wise comparison matrices for each of the lower levels
- Undertake a consistency test
- Estimate relative weights of the components of each level.

In first stage, the decision makers need to break down complex multiple criteria decision problems into its component parts of which every possible attributes are arranged into multiple hierarchical levels.

The criteria and sub criteria are not each equally important to the decision at each level of the hierarchy and each alternative rates differently on each criteria.

One notes that two elements being compared at a given time greatly reduces the conceptual complexity of an analysis. This simplification involves assumptions that Satty (1980) and others (Muralidhar *et al*., 1990; Partovi, 1994) considered reasonable. Given a pairwise comparison, the analysis involves three tasks: (1) developing a comparison matrix at each level of the hierarchy starting from the second level and working down, (2) computing the relative weights for each element of the hierarchy and (3) estimating the consistency ratio to check the consistency of the judgment. (Chen, 2006) the comparisons can be carried out through personal or subjective judgments (Ho, 2008).

The 9-point scale used in typical analytic hierarchy studies is ranging from 1 (indifference or equal importance) to 9 (extreme preference or absolute importance) (Table 2). This pair wise comparison enabled the decision maker to evaluate the contribution of each factor to the objective independently, thereby simplifying the decision making process.

Table 2: 9-point intensity of relative importance scale

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above nonzero	If activity has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

Saaty and Kearns (1985)

Elements in each level are compared in pairs with respect to their importance to an element in the next higher level. Starting at the top of the hierarchy and working down, the pairwise comparisons at a given level can be reduced to a number of square matrices $A = [\alpha_{ij}]_{n\times n}$ as in the following:

$$\begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ . & . & & . \\ a_{1n} & a_{2n} & \cdots & a_{nn} \end{pmatrix}$$

The matrix has reciprocal properties, which are:

$$a_{ji} = \frac{1}{a_{ij}}$$

After all pair wise comparison matrices are formed, the vector of weights, $w = [w_1, w_2, ... w_n]$, is computed on the basis of Satty's (1980) eigenvector procedure. The computation of the weights involves two steps. First, the pair wise comparison matrix is normalized by Eq. 1 and then the weights are computed by Eq. 2:

$$a_{ij}^* = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (1)$$

for all j = 1, 2....n,

$$w_i = \frac{\sum_{j=1}^{n} a_{ij}^*}{n} \quad (2)$$

for all i = 1, 2....n,

Satty (1980) showed that there is a relationship between the vector weights, w and the pairwise comparison matrix, A, as shown in Eq. 3.

$$Aw = \lambda_{max} w \quad (3)$$

The λ_{max} value is an important validating parameter in AHP and is used as a reference index to screen information by calculating the Consistency Ratio (CR) of the estimated vector. To calculate the CR, the Consistency Index (CI) for each matrix of order n can be obtained from Eq. 4:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (4)$$

Then, CR can be calculated using Eq. 5:

Table 3: Random inconsistency indices (RI) for n = 10

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

Satty (1980)

$$CR = \frac{CI}{RI} \quad (5)$$

where, RI is the random consistency index obtained from a randomly generated pairwise comparison matrix. Table 3 shows the value of the RI from matrices of order 1 to 10 as suggested by Satty (1980). If $CR<0.1$, then the comparisons are acceptable. If, however, $CR\geq 0.1$, then the values of the ratio are indicative of inconsistent judgments. In such cases, one should reconsider and revise the original values in the pair wise comparison matrix A.

The AHP was adopted in education, engineering, government, industry, management, manufacturing, personal, political, social and sports (Vaidya and Kumar, 2006). The wide applicability is due to its simplicity, ease of use and great flexibility. It can be integrated with other techniques, for instance, mathematical programming in order to consider not only both qualitative and quantitative factors, but also some real-world resource limitations. This method integrated with the Index Overlay method.

In IO model the different factors and classes has different values and then a set of flexible maps will be provide which has a range of numbers. For example, gradient has different degrees for different purposes which may change from 3 to 10% or more. Here, an appropriate gradient for urban development is between 3 to 8%. The process of weighting will be done for fault line, gradient direction, soil and etc. Then by two variable analyses the layers composite and each location with higher values would be selected. The conceptual flow of the research is shown in Fig. 2.

THE MAIN FINDING OF RESEARCH

The zone has about 2200000 populations and covers 20 km of the Tehran total area. There are two fire stations (No. of 18 and 40) and one rescue station (No. of 49). The stations are located in the Southern parts near to each others. The total vehicles of the stations are 5 fire extinguishing car and 66 personnel.

Station No. 40: This station is located in the end part of the Southern area of the zone. The coverage area of the station is 2318 m^2 and was renovated in 2002. The station has 24, 2 extinguishing cars and 4 emergency cars. The most important problems of the station are the shortage of personnel and inappropriate access to transport network as the station is linked to a congested road.

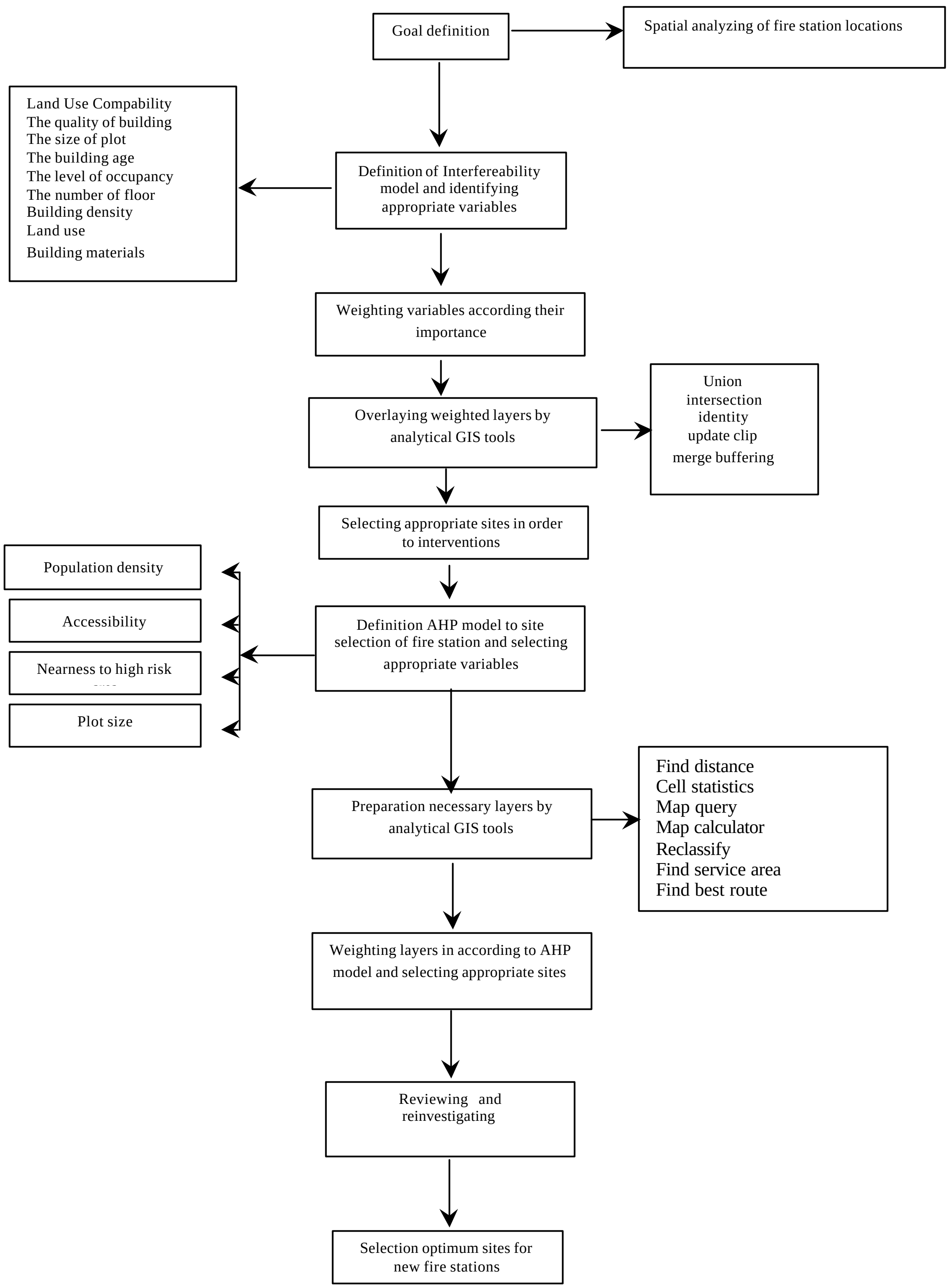

Fig. 2: The conceptual flow of the research

Table 4: Analytical matrix of the physical-spatial characteristics of existed fire stations in zone 6

Area (m^2) at different stations	Response radius (m)	coverage population	The under of coverage	The area Topo-graphy	earth quick	Stability against width (m)	Street connectivity to the street	Type of	One or two sided access	Distance to the nearest station	Compati-bility with adjacent land uses	The most important problems reported by the rescue team in last incidents
Station No. 40												
	2000 m^2 (appropriated with respect to the standard level of 1000-3000 for medium sized stations)	1750 m^2 (This radios is not appropriated as the standard for the station is 2000 m and 40 km per hour)	Inappropriate (The zone has 220231 population and the stations are 3 which one of them functions as post-incident remedy care. So, with respect to the 50000 people for each station, this number rises to 73444 people for each station)	Inappro-priate (The area is coverage 20 km^2 and each station has to service 6.5 km^2, so the standard limit is 5 km^2)	Appro-priated (Flat)	Unstable against earth quick	30 m (located beside a an arterial road and is suitable)	From the West direction of the station (There are many private cars which use the entrance of the station and it leads to the weak response)	Inappro-priate (One sided)	2400 m (appro-priated as fit to the standard limit of 2500 and overlaps with the radios response of station 18)	Relative compatible (there are 4 educational plot like secondary and high school in the 200 m of station limit)	Shortage of crew and traffic congestion
Station No. 18												
	1740 m^2 (It is suitable with respect the standard 1000-3000 m^2 for medium sized station)				Inappro-priate (high gradient in both of entrance and the adjacent road)	Unstable against earth quick	14 m (it located beside a distri-butor and gathering road and the station should have direct access to arterial road with more than 22 m width)	From the West direction	One sided towards the South (The station located in a one sided path and narrow width with a high gradient which decreases the speed of response)	2400 m (appro-priated as fit to the standard limit of 2500 and overlaps with the radios response of station 18)	Relative compati-bility (the presence of one educational plot like secondary school in the 200 m of station limit)	Shortage of crew and traffic
Station No. 49												
	147 m^2 (It has deep gap with the standard level)	800 m (Unappre-ciated)			Appro-priated (Flat)	Unstable against earth quick	18 m (almost appro-priated)	From the North of the station (the problem of private car parking in the entrance of the station)	Two sided	3700 m (inappro-priate wit respect to 2500 m between two stations, as some parts of two stations places beyond two stations, stations No. 49 and 18)	Compatible	Shortage of crew and facilities

Station No. 18: This station located in the Southern parts and covers an area with 555 m^2 and was constructed in 1976 which now it has 30 personnel, 2 extinguishing cars with 5 emergency cars (ambulance). The problem here again is the shortage of personnel and is connected to high congested traffic network.

Station No 49: This station located in the Northern part and has a coverage area of 150 m^2. It was established 1991 and is equipped by one extinguishing car, 12 personnel and one emergency car.

The spatial characteristics of existed stations are described is shown in Table 4.

THE MAIN CRITERIA FOR FIRE STATION LOCATION

Fire stations have been established in a historical evolution in many of the cities of the world. The important criteria were distance of stations to each other, the number under coverage population and the level of fir risk in the different parts of a city. Therefore, distribution of the stations has been according to the adjoining high risk area. Almost all of the regulations aimed to more people in the shortest time as the incidents are reported.

The following factors could be summarized for fire station site planning with respect to the Iranian cities and world experiences.

Accessibility: Some of the important regulations are as follow:

- Fire stations must have direct and quick access to the arterial or sub arterial road to avoid any traffic congestion
- To have a better response the stations should not sited in one sided or parallel routs, as the lack of connectivity in local and one sided streets decreases the access of the stations
- The station should not locate in the corner or adjacent to the crossroads which there are traffic congestions

The coverage area: Some the regulation considering to the coverage are:

- It is necessary to study the coverage limits of the existed stations and their potential to response in the area. Then by acknowledging the services, the new station should be planned
- The response time of each station is depended to its area of action, so the stations should cover 2000 m radius to guarantee the quick response with respect to the 40 km speed per hour
- The distance among the satiation is different however, with respect to population density and the land uses and so the response area would be different, but the maximum accessibility and a time interval of 3-5 min are determinant factors

Population: The following regulations should be considered for selecting a fire station location.

- There need at least one station for 50000 population
- It is necessary to allocate for each person 0.3 m^2 for station and 0.8 m^2 for the open space of station when the urban facilities and utilities are planned the least per people which in sum is about 1 m^2.

The size of plot: The regulations considering to the plot are as follow:

- The selected site for station must be sufficient for the present and future needs
- The standard area for small sized stations is 1500 m^2 and for the medium sized stations is 3000 m^2
- To sitting the station in the concentrated area of the city, the plot size for small sized station should be at least 1000 m^2
- The standard plot for large sized stations with more than 7500000 people is 6000 m^2.
- It is necessary to allocate a specific plot of land for the rescue near the stations in the case of any incident and in usual time can be used as green space

The directions of city expansion: Some of the important regulations are:

- It is necessary that the pattern of physical expansion of the city should be studied exactly and the new fire stations establish by the increase of population in the 10-20 years and building density
- The final development pattern of the city should be considered for the new fire station location planning
- The new selected sites should not locate in adjacent with preventive factors like gardens, agricultural lands, hills and so on, as it decreases the level of station reflex. Also the station should not be place by the future expansion in n unsuitable location
- It is necessary to allocate plots for future fire stations in the high density areas due to population increase

It is worth to mention that these factors can be changed and altered with respect to the specific characteristics of each region.

APPLICATION OF THE MODEL

The data of the study were obtained from the following organizations (Table 5). The research is divided in three stages as follow:

Table 5: Sources of used data

Date	Source	Type of data
2006	Statistical centers of Iran	Geographic census information
2007	Municipality of zone 6	Street network
2007	Municipality of Tehran with joint work of crises management organization of Tehran	Hazardous points
2005	Municipality of zone 6	Boundary lines (lots, etc.)
2006	Statistical centers of Iran	Socioeconomic information

First stage: Planning for the high density areas of a city has always its specific character and the scarcity of vacant lands has imposed limitations on urban planners. The study area is one of the high dense zones of the capital which includes many high rise buildings. So, intervention for physical changes is not quite easy. Clearly, it is logic to analysis the potential of intervention in different sites to avoid heavy financial or social disintegration or even political constrains. Then the most appropriated sites selected for future fire station location.

The sites with higher potential of interventions were selected in this stage by applying index overlay in GIS. The existed classes and elements were weighted and the results were a set of flexible maps with range of numbers.

- **Incompatible land uses:** The most incompatible land uses were more suitable for change and intervention.
- **The quality of building:** The eroded building with low quality had more potential for intervention.
- **The building age:** The older building had more potential for intervention.
- **The level of occupancy:** The building with high level of occupancy has the less condition for change of land use.
- **The number of floor:** It meant that building with more floors have less potential for interference.
- **Building density:** The assumption was that the higher density decreases the level of intervention and vice versa.
- **Land use:** vacant lands, green space, medical have the best conditions for locating fire station in this model and major and micro commercial and the establishing commercial land uses have the minimum potential for intervention.
- **Building materials:** The assumption is that the buildings with metal and concrete skeleton have minimum degree of intervention and the buildings with cement materials have the maximum intervention potential.

These criteria were classified and weighted on the base of their importance by IO logic (Table 6).

The weighted layers were overlapped in GIS and then the level of interventions was determined for each site as the following map. The areas with high dark color have more intervention. It means that by establishing new stations in this area the socio-economic costs would be very low and the urban decision makers are able to operate their plan without disturbing the physical fabric of the region. As the Fig. 3 shows there are many options in the zone 6 to create new fire stations.

Second stage: In this stage, initially the most important criteria for fire station location will be studied to apply the AHP model on the more potential sites for intervention (selected from first stage):

- **Population density:** Clearly the area with higher population density has priority to be protected as in the case of an incident the risk will be very high. In this study the areas with more population were more prioritized than other areas.
- **Accessibility:** Perhaps one of the main criteria for fire station location is accessibility. Fire stations have to be located beside the arterial or sub arterial road for best reflex time. Therefore thoroughfares with more than 22 m width are preferred in this study.
- **Proximity to high hazardous points:** Some of the land uses are more hazardous and impose a huge loose of life and financial resources and have a quick flashover. For example gas stations, hospitals, urban amenities and so on.
- **The plot size:** There are many physical regulations for fire station establishment which the size of plot is one of them. In average, the plots with 1000-3000 m^2 area have more preference.

To applying AHP the pairwise comparison matrix of above criteria were showed as follow (Table 7).

These pairwise comparisons were based by several meeting with local urban authorities and the municipal experts. They have been reviewed many times to coordinate with local conditions and finally the following results were confirmed by the city authorities.

The Consistency Ratio (CR) of this comparison obtained the figure of 0.0054 which was acceptable as this should be lesser or equal 0.1. In this study expert-choice software was used to calculate the relative importance of factors and indicators (Table 8).

Then the informational layers each criterion will be determined by the help of analytical functions of GIS and each of them classified for the most appropriate class for fire station locations (Fig. 4-7).

Table 6: selected criteria and weighting in index overlay model

Quantity	Classes	Scores
Compatibility scores of plot		
1	1	0.56
2	2	1.13
3	3	1.69
4	4	2.25
5	5	2.81
6	6	3.38
7	7	3.94
8	8	4.50
9	9	5.06
10	10	5.63
11	11	6.19
12	12	6.75
13	13	7.31
14	14	7.88
15	15	8.44
16	16	9.00
Scores of floor No.		
More than 10 floors	1	0.8
10-Aug	2	1.6
7-May	3	2.4
4-Mar	4	3.2
0-2	5	4.0
Score of plot size		
Very high density	1	0.6
High density	2	1.2
Moderate density	3	1.8
Low density	4	2.4
Very low density	5	3.0
Scores of building density		
Very large	1	1.4
Large	2	2.8
Medium	3	4.2
Small	4	5.6
Very small	5	7.0
Score of occupancy level		
Very high level of occupancy	1	1.0
High level of occupancy	2	2.0
Medium level of occupancy	3	3.0
Low level of occupancy	4	4.0
Very low level of occupancy	5	5.0
Scores of building age		
Less than 5 years	1	1.2
5-15 years	2	2.4
16-25 years	3	3.6
Uncertain	4	4.8
More than 25 yrs	5	6.0
Scores of building quality		
Maintainable	1	2.00
Repairing	2	4.00
Others	3	6.00
Demolishing	4	8.00
Scores of building materials		
Metal skeleton and concrete	1	0.25
Others	2	0.50
Brick	3	0.75
Cement block	4	1.00

Land users

Land use	Weight
Vacant land	2.00
Green space	1.89
Medical and health	1.80
Storage	1.71
Sport	1.62
Cultural and art	1.53
Educational	1.44

Table 6: Continued

Land use	Weight
Land users	
Residential	1.35
Mixed residential-service	1.26
Higher education	1.17
Religious	1.08
Urban facilities	0.99
Urban utilities	0.90
Administrative	0.81
Tourism	0.72
Transport	0.63
Industry and cottages	0.54
Military and police	0.45
Mixed services	0.36
Under construction	0.27
Micro-commercial	0.18
Commercial macro-	0.09

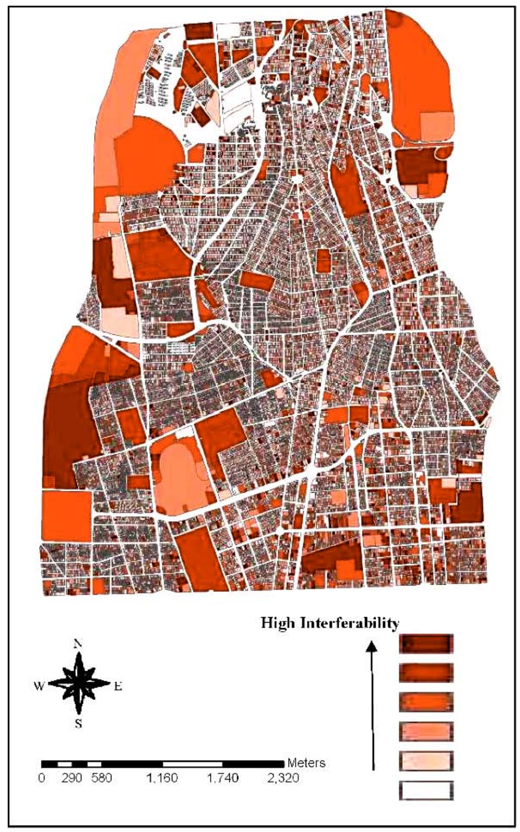

Fig. 3: The level of intervention

These layers were weighted by applying an extension to ArcGIS9.2 according to the AHP and the score of each fire station site assigned on the raster maps (Fig. 8).

Third stage: In this sage the radius responses of fire stations in four- minutes is determined by using network analysis in GIS environment in the zone (Fig. 9).

Using the network analysis gives the possibility that the distances from facilities are calculated most exactly in

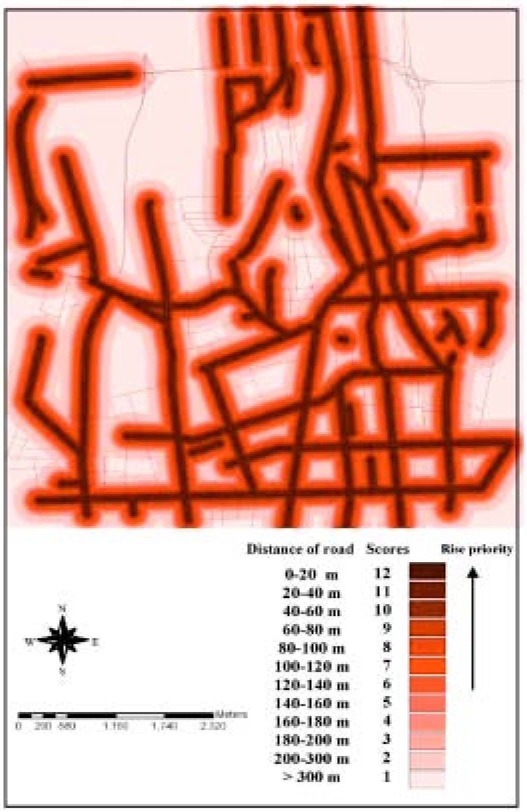

Fig. 4: Scores of accessibility factor

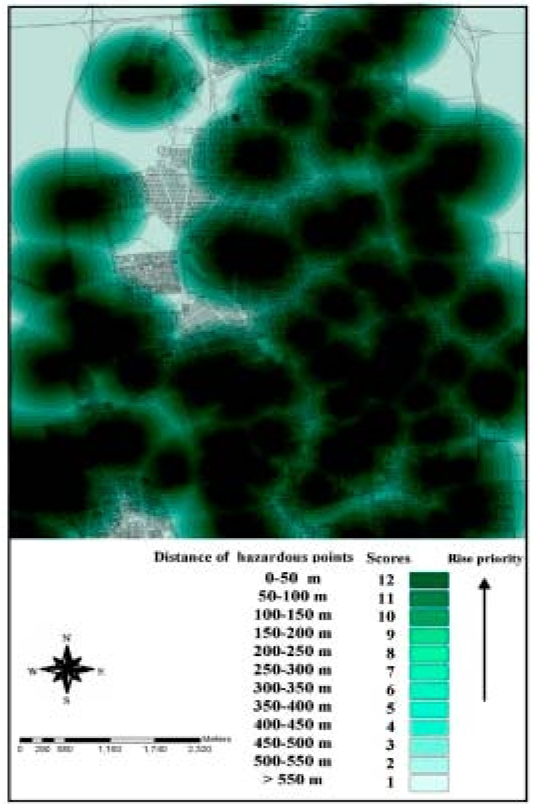

Fig. 5: Scores of nearness to high risk points

Table 7: The pairwise comparison matrix in AHP model

	Population density	Accessibility	Nearness to high risk points	The size of divided plot
Population density	1.0	2.0	3.0	5
Accessibility	0.5	1.0	2.0	3
Nearness to high risk area	0.3333	0.5	1.0	2
The size of divided plot	0.2	0.3333	0.5	1

Table 8: The criteria weighting in AHP model

Criteria	Relative weight
Population density	0.4829
Accessibility	0.2720
Distance to high risk area	0.1570
Size of divided plots	0.0881

the street networks compared the physical distance of Euclid. The calculation of these distances was done by using GIS. Transport network and average speed of fire car (30 km h^{-1}) were essential for determining of tedious responses. Then by investigating all aspects, two alternative sites with higher scores were selected as first and second priority. Also a third site was assigned to be replaced by the second priority (Fig. 10).

The spatial characteristics of proposed new stations are described is shown in Table 9.

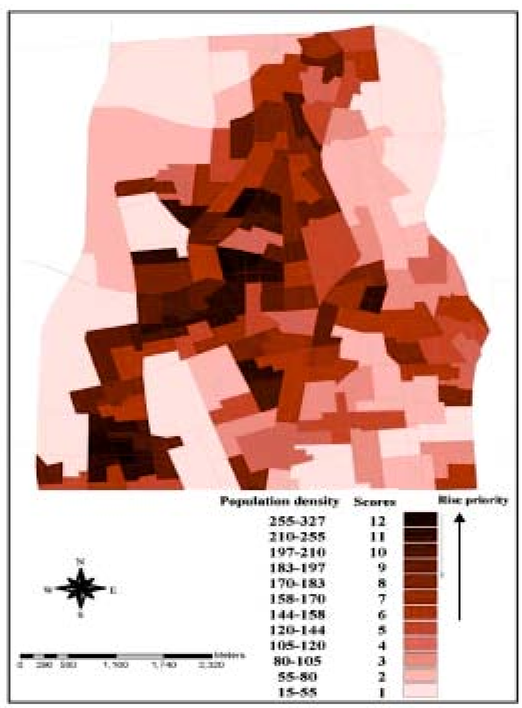

Fig. 6: Scores of population density factor

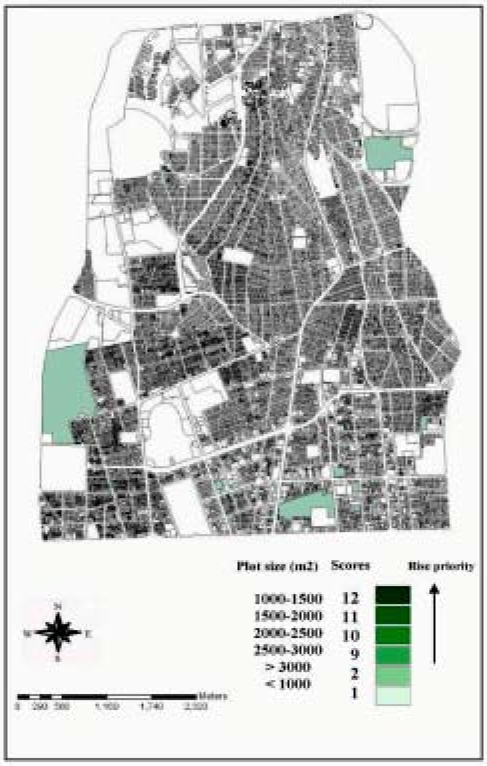

Fig. 7: Scores of size of divided plot factor

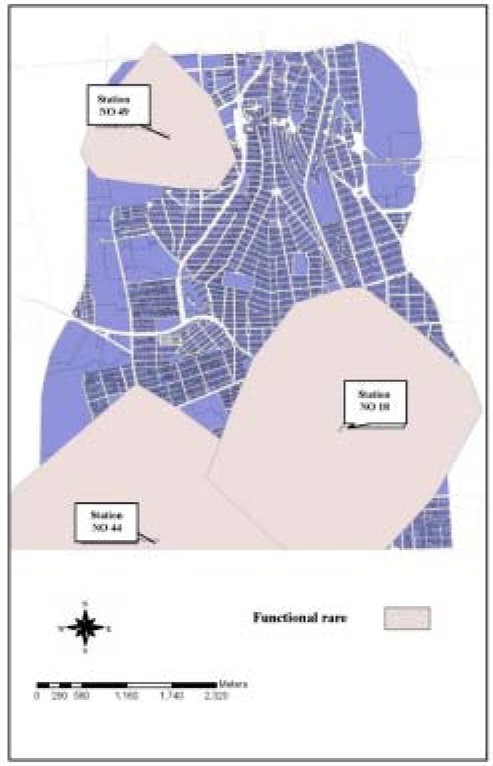

Fig. 9: Radius responses of existed fire stations in 4 min stations

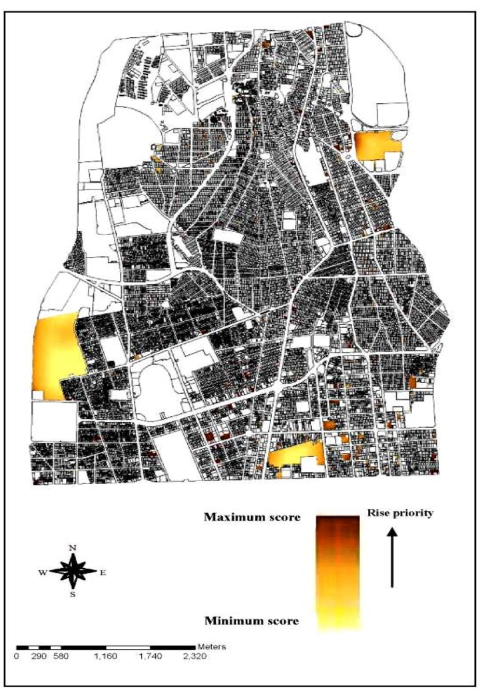

Fig. 8: Sites scores for the establish fire stations

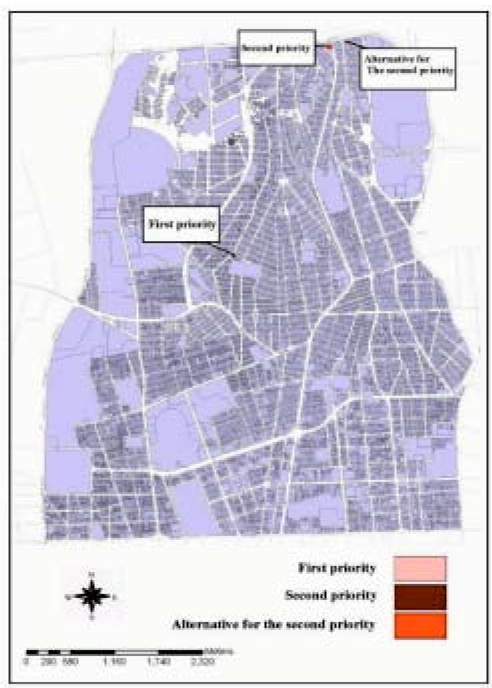

Fig. 10: Proposed new fire stations

Table 9: Analytical matrix of physical-spatial of proposed stations in the zone

The proposed sites	Area (m^2)	Street width	One or two lined street	Connection to the street	Topography of the site	Distance to the nearest station	Compatibility with adjacent land uses	The present land use of the site
1st priority	850 m^2 (It is appropriated as the least standard is 1000 m^2 with respect to the low intervention potential and its high density)	23.5 m (the optimum is 22 m)	Two sided (the site is adjacent to a two sided street)	From the West direction of the site	Almost flat	Distance is 2800 m to the station 18, so it is almost close to the standard distance of 2500 m	Compatible with adjacent land uses	Unequipped green space-renovating residential
2nd priority	1500 m^2 (The standard is 1000-3000 m^2)	30 m (This site is located adjacent to the arterial road of Valiasr)	Two sided (The site is adjacent to a two sided street)	From the West direction (some arrangements need to prevent of private car parking in the front of the main door)	Almost flat	2800 m (to 1st priority) (The standard is 2500 m)	Compatible with adjacent land uses	Unequipped green space
3rd priority	700 m^2 It is appropriated compared to the standard of 1000 m^2 and the high density and low intervention potential)	20 m (This site is located adjacent to sub arterial road)	Two sided (the site is adjacent to a two sided street)	From the West and North directions (The site has two direction access which could be used in the peak hours)	Almost flat	3000 m (to 1st priority) (almost appropriated with respect to the standard of 2500 m)	Relative compatibility (a primary school is located in 200 m limit of the site)	Unequipped green spaces

CONCLUSION

As described, fire stations are one of the vital utilities of the urban areas which provide safety and comfort for the citizens. This high importance of such land uses dictate the necessity of fire station location planning and so applying new and efficient techniques for site sleeting is quite unavoidable. This study intended to illustrate the efficiency of the integrated Index Overlay logic and AHP in GIS. The results of this study supports the findings of the recent researches considering the MCDM in the other parts of the worlds (Baja *et al*., 2007; Ohta *et al*., 2008; Svoray *et al*., 2005). The ability of such methods would be multiplied when they are integrating with GIS, as the model is applied for the safety issues of the zone 6 of Tehran.

The results of this research are as follow:

- One of the most important value in the use and application of the GIS tools lies in that they constitute a distinctive information integration and management system that allows to gather, concentrate, analyze, represent and facilitate the management and interpretation (qualitative and quantitative) of spatial and attribute information in a far more effective, rapid and integrated way. Additionally, it makes good use of the enormous capacity of spatial technology in a single work environment for the fusion and review of various information layers, extraction of relevant data and ongoing information updating to enrich the system, compared to other types of manual methodologies and traditional map interpretation techniques used before. Such advantages allow us to handle several scenarios and generate cartography during the planning stage, before any decision is made on actions to take
- Regarding the application of the AHP techniques, the advantage of this methodology integrated in GIS as relatively common tools for a number of investigations like the reported here is worth mentioning, where there are several factors and variables influencing in the occurrence of a given fact, phenomenon or objective and there are several points of view in the decision-making process. Furthermore, these allow us to handle the assessment in a quantitative way, providing us greater real-world approximation validity and less subjectivity in the analysis and selection of criteria
- Another important reason for using AHP is that they make possible to assess all criteria simultaneously, with no need to carry out several map-overlaying operations, modifying value attributes using a constant value and making a final map reclassification resulting from the combination of all criteria layers

- New fire station location planning should consider the socio-economic cost in the old and high density areas of a city. In the present research by using the weighting logic and overlaying in GIS the different criteria were analyzed in relation to the intervention potential. Finally this case was determined in different sites and the most appropriate sites for AHP analysis selected to locate the new fire stations
- The proposed model has the potential to be applied in the other cities of the country. Also the model has enough flexibility to be generalized by considering other criteria for different regions, while the generality of the model is maintained
- The numbers of fire station are inadequate as more than two thousand people live in this zone. Now, the area needs another more two stations to have sufficient coverage and quick response to the incidents
- The main part of the central and northern areas of the zone is out of fire stations access because the two existed stations are located in the southern part
- The existence of strategic and important land uses in the zone 6 highlights the safety issue. This case impacted the commuting function of the transport network and slowed the movement circulation. So, it seems that traffic consideration must be taken into account to increase the speed of fire cars
- It seems that enacting a specific taxation for the zone of six is quite necessary as the major land uses here are commercial and administrative which impose an extra cost for maintaining their safety and rescue.

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