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Developing a Bilateral Allocation Approach to Determine the Optimum Land-uses

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ABSTRACT

This paper addresses the problem of determining the most appropriate land-uses for the most appropriate land parcels using ANP, a multi-criteria decision-making technique. In this study a bilateral approach was designed and implemented not only to find the best places for applications but also to determine the most suitable applications for these places. The bilateral approach tries to prevent the experts to make a wrong decision. In order to assess the proposed methodology, a case study that assigns the best land-use for eight land parcels in district five of Tehran, the capital of Iran was selected. The results revealed that the decisions of the same experts are not consistent even in the same problem. This means that when the action is reaching from land-use to the land-parcel the result may be different from while the act is vice versa. Thus, the proposed approach, revealed the mistakes of the experts' judgments.

KEYWORDS: ANP, Decision Making, Allocation, GIS, consistency.

1. INTRODUCTION

A GIS can be used for a wide range of applications such as urban and regional planning, agriculture, emergency response systems, wildlife and natural resource management. A GIS is capable of capturing, storing, manipulating, and displaying spatially referenced information to allow for efficient data organization and access[1]. GIS can also be used to answer location-based questions, identify resource distribution patterns, and to model complex environmental and ecosystem processes, making it an extraordinary tool for planning and decision-making[3, 4]. A GIS can be used as a tool for suitability analyses of site selection, although many techniques and methods are integrated with GIS facilities to perform a proper method for site selection[5, 6, 7]. Site selection is a kind of decision making which is about selecting the best place/places for a known usage. Consequently, methods of decision making have been widely used in many applications of GIS such as site selection[5].

In spatial problem solving, decision making is usually used to determine the relative importance of maps which must be combined to produce some other maps. Determining the relative importance of information is called map layer weighting[8]. There are two main methods for weighting the information layers, namely: data-driven and knowledge-driven[3]. In data-driven methods the importance of data are decided based on the data itself while in knowledge-driven methods an expert or experts perform this task. Assigning these weights is a decision making process and in this paper it is done by Analytical Network Process (ANP). ANP is a multi-criteria decision making method which takes the interdependence among the items and the alternatives into account[9].

Knowledge-driven as well as data-driven methods are incapable to tackle all spatial issues in isolation. Often a combination of the methods is more realistic to do[10]. An important disadvantage of knowledge-driven methods is their uncertainty. It means that the accuracy of results directly depends on the decisions of expert/experts and usually there is no criterion for testing this accuracy. Nonetheless, data-driven methods are limited to be usable in some cases of problems which no relation between data and results can be established[8]. In these types of problems some samples of result have to be included in the input data, enabling the model to discover the relations among data. These types of data are often found in natural phenomena.

This paper discusses the methodology of using ANP in GIS to determine eight land-uses for eight land parcels. The parcels are located in district five of Tehran, the capital city of Iran. To overcome the disadvantages of knowledge-driven methods like ANP which is the impossibility of testing the accuracy of results, a bilateral (two directional) procedure has been proposed and used in this study.

This paper is structures in eight sections. A brief review of usages of ANP is exposed in Sec. 2. Section 3 shortly explores theoretical foundations of ANP and Sec. 4 precedes the maps and material which are used. Section 5 discusses the method that is applied in this study to perform allocation using ANP. While Sec. 6 is about the

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calculation aspects of implementation, Sec. 7 describes how the final allocations were performed. At last, Sec. 8 concludes the paper and offers some suggestions for further researches.

2. LITERATURE REVIEW

Studies show that human beings do not have enough ability to perform effective and intuitive synthesis for complex decisions[11]. Having this in mind, the Analytical Hierarchy Process (AHP) originated by Saaty says: instead of making people obligated to use a method on how to make decisions; provide them the opportunity to follow their own decision making mechanisms[11]. After that, Saaty offered ANP as a general case of AHP and so AHP was known as a special case of ANP.

ANP has been used in many applications such as: product design, project evaluation and selection, supply chain management, environmental issues, performance measurement, manufacturing systems and strategy selection[12]. ANP has also been efficiently used in decisions related to energy product design, policy planning, and equipment replacement[13]. ANP has many successful applications in location related applications, as well. For instance: ANP has been used for determining the best transfer mode (road or rail or sea) between Turkey and Germany[14]. ANP was used to rank between alternative locations for locating undesirable facilities in Istanbul[12]. A fuzzy ANP was the method which successfully used to determine the best location for placing shipyard in Turkey[11]. Another use of ANP in Turkey was about finding the most appropriate fuel (such as oil, natural gas, wind, coal etc.) for electricity generation[15]. ANP and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methods were used to find out the ideal city for medical service ventures in China[16]. ANP was utilized to evaluate the performance of four management strategies for forest management in Austria[17], and it was a method used to quantify the combined effects of factors on organizational performance measures for appropriate resource allocation in Taiwan[18].

However, this study offers a bilateral method to increase the low reliability of knowledge-driven methods.

3. Analytical Network Process

The Analytical Network Process is a comprehensive framework for the analysis of social, governmental and corporate decisions that is available today to the decision-maker[19]. It is a process that allows one to include all the factors and criteria, tangible and intangible that has bearing on making a best decision. ANP allows both interaction and feedback within clusters of elements (inner dependence) and between clusters (outer dependence). Such feedback best captures the complex effects of interplay in human society, especially when risk and uncertainty are involved[20].

Many decision problems cannot be structured hierarchically, (like AHP), because they involve the interaction and dependence of higher-level elements on a lower-level element[9]. Structuring a problem involving functional dependence allows for feedback among clusters, which so called a network system[18]. Figure 1 shows a general form of a network. The ANP addresses how to determine the relative importance of a set of activities in a multi-criteria decision problem. The process utilizes pair-wise comparisons of the project alternatives as well as pair-wise comparisons of the multiple criteria[18].

Instead of comparison matrices of AHP, a “supermatrix” is constructed in ANP to involve pair-wise comparisons and calculate the weights. A standard form of a supermatrix to deal with the interdependence characteristics among elements and components is illustrated in Figure 2[9]. The supermatrix was suggested by Saaty for solving network structure. The supermatrix is column stochastic as all its columns sum to unity. This matrix means that any column of the limiting power $lim_{k\to\infty} \mathbf{A}^{2k+1}$ gives the outcome of the cyclic interaction of the alternatives and the criteria[18].

The first step of ANP is constructing the network which involves determining interdependencies. After that, the process of comparisons is like AHP and a range of digits between 1 and 9 are assigned to determine the relative importance in pair-wise comparisons. Hence in this study, as will be mentioned later, two networks were constructed and pair-wise comparisons were done by experts.

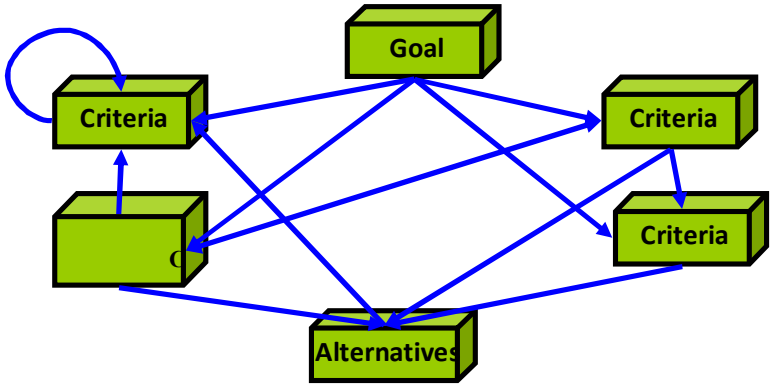

Figure 1: A sample of a network problem

$$
W = \begin{array}{c|c|cccc}
 & & C_1 & C_2 & \cdots & C_n \\
 & & e_{11}\ e_{12}\ \cdots\ e_{1m_1} & e_{21}\ e_{22}\ \cdots\ e_{2m_2} & \cdots & e_{n1}\ e_{n2}\ \cdots\ e_{nm_n} \\
\hline
C_1 & \begin{matrix} e_{11} \\ e_{12} \\ \vdots \\ e_{1m_1} \end{matrix} & W_{11} & W_{12} & \cdots & W_{1n} \\
\hline
C_2 & \begin{matrix} e_{21} \\ e_{22} \\ \vdots \\ e_{2m_2} \end{matrix} & W_{21} & W_{22} & \cdots & W_{2n} \\
\hline
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\hline
C_n & \begin{matrix} e_{n1} \\ e_{n2} \\ \vdots \\ e_{nm_n} \end{matrix} & W_{n1} & W_{n2} & \cdots & W_{nn}
\end{array}
$$

Figure 2: Supermatrix (Saaty, 1996)

4. Case Study

Urban planning and land-use policy is a challenging study area. The huge number of known and unknown factors, dynamic nature of land developments and dependency on human complex decision making, makes it a challenging and difficult to forecast area through spatial techniques and sciences. However, many methods have been implemented to systematically determine the best land-uses for the best places[21]. These methods were less or more successful to their goal but due to the complex nature of the problem, the successes were relative and no unique method has been suggested till now. In this study ANP is used to overcome some difficulties of land allocation methods like handling the thoughts of experts.

A part of district 5 of Tehran, Iran is the study area of this research. The selected area is about 7 squared kilometers. This area is intentionally selected to be small to enable the expert to consider all effective elements in his mind. Then, the unused parcels with the area greater than 5000 square meter that has no legal prevention were detected. The scale of the data is 1:2000. Finally, eight parcels were chosen (Figure 3). Then the appropriate land-uses for this area were determined. For this task, the primary candidates were: Urban Terminal, Hotel, Parking, Park, Fire Station, The Game Park, Clinic, Cinema, Gas Station, Cultural Center, Shopping Center, Sport Place, Hospital, Mosque, School, Green Land, and Green Grosser Square. However, the aim was matching eight land-parcels to eight land-uses. So, among the above applications eight most appropriate ones were selected. They were: Green Grosser Square, Mosque, Teaching Center, Cinema Complex, Sport Place, Hospital, Park and Shopping Center.

The reasons for choosing these usages are validated by a group of municipal experts through long discussions based on the necessity of the application for the study area and the existence of similar places around the study area. However, with respect to the extents of selected land parcels, applications like cinema and school are too small, thus they modified to Cinema Center and Teaching Center respectively to match the extents of land parcels.

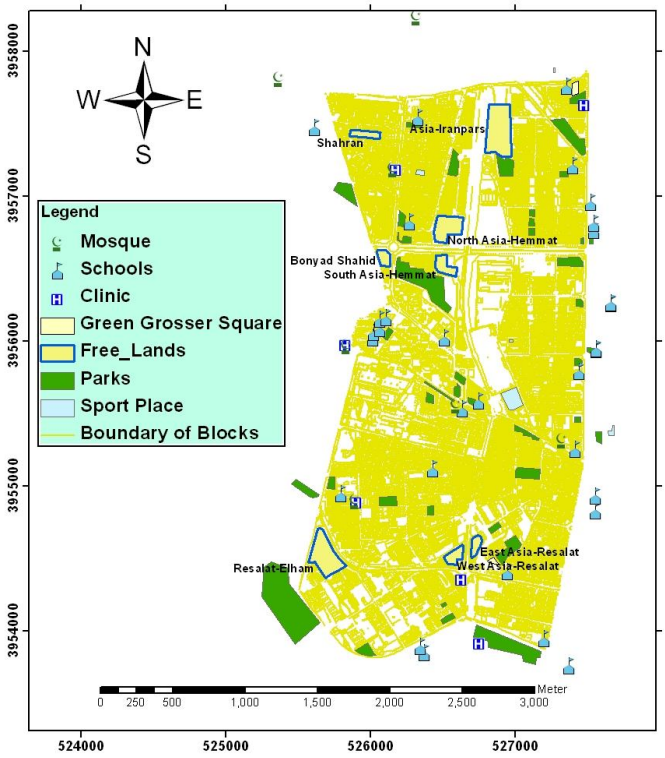

Figure 3: Study area and existing land-uses

To perform precise decisions, it was necessary to know about existing similar land-uses. So, the land-used in the study area and their influence zone were detected precisely that can be seen in Figure 3. It is noticeable that there is no cinema or hospital in the study area.

5. METHODOLOGY

After knowing the land-parcels and selected land-uses, the next step is constructing the network. As mentioned before, a bilateral approach was used in this study. Therefore, two networks should be designed. In one of them alternatives would be the land-parcels and in the other, land-uses would be the alternatives. These two networks have some similarities (Figures 5 and 6).

Constructing a proper networks require high level of experience and knowledge. Thus, after constructing the network and doing the judgments, two groups of responses would be available from two networks. An essential step is to compare and discuss the results to prevent probable mistakes. This method quantifies the judgments because,

each assignment of land-use to the land-parcel is obtained from two networks. In this method, assigning each of eight land-uses to each of eight land-parcels receives two weights from two designed networks. Each weight shows the suitability of the selected land-use for the selected land-parcel. Thus, if assigning a specific land-use to a specific land-parcel achieves the highest weight both networks, this assign is approved as the proper allocation. However, if the rank of two weights for a specific allocation is not proportional it needs more considerations by the experts and regarding the other allocations into account. (Figure 4). The detailed information about the procedure of decision making for allocations is given in section 7.

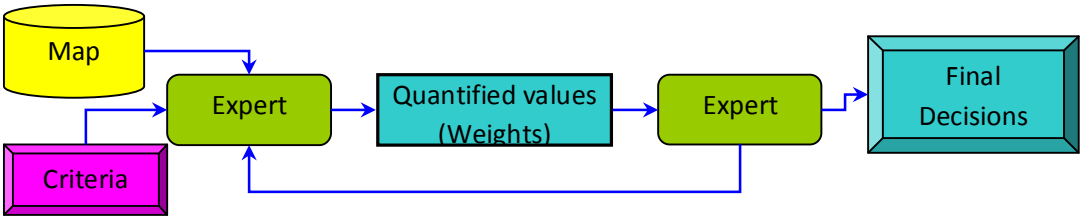

Figure 4: The general methodology of study

6. Implementation

The model constructed in "Superdecision" software and an expert in municipality did the judgments. Each comparison must be consistent with others and anytime inconsistency was detected the comparison was performed again. Afterward, the weights of alternatives were obtained and the problem became ready for final decision making. The determinant step of this study was discussion about the results of two networks. The weights extracted for alternatives from two networks are shown in Tables 1 and 2.

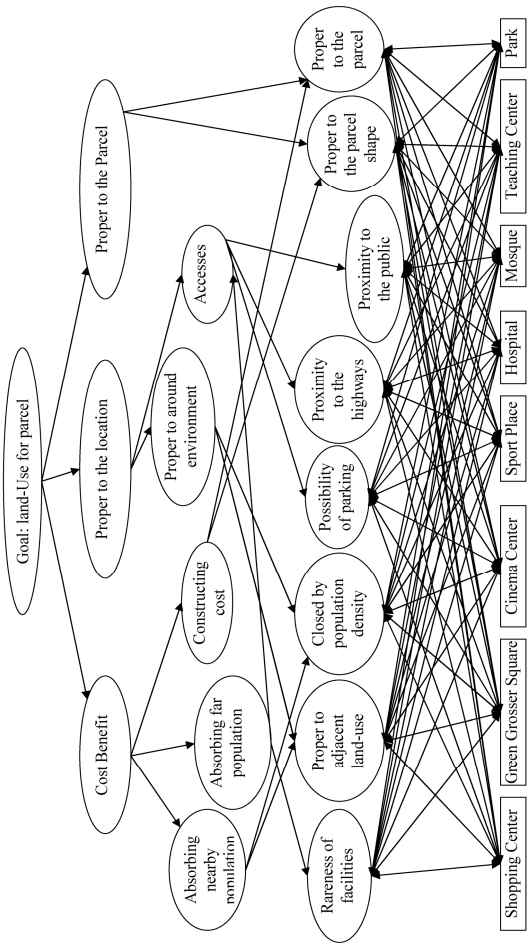

Figure 5: The network of selecting the best land –uses for parcels

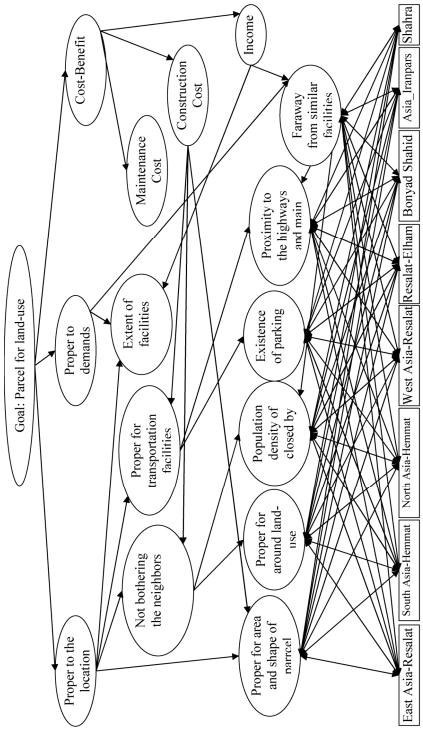

Figure 6: The network of selecting the best parcels for land –uses

Table 1: Determining the best parcels for land-uses, the lowest red row of table is the principal result

	Cinema & Art Center	Hospital	Mosque	Park	School	Shopping Center	Sport Place	Square	Best Land-use
Asia-Iranpars	0.094304	0.11455	0.097293	0.164899	0.12801	0.188374	0.173617	0.115902	Shopping Center
Boniad Shahid	0.184491	0.134629	0.141782	0.072098	0.116231	0.119504	0.101908	0.113845	Cinema
East Asia-Resalat	0.191962	0.128295	0.209564	0.123615	0.182875	0.10087	0.100398	0.091626	Mosque
North Asia-Hemmat	0.097665	0.122452	0.118088	0.121167	0.126891	0.110833	0.128646	0.163031	Square
Resalat-Elham	0.126448	0.127851	0.062697	0.11356	0.105549	0.160045	0.124324	0.128488	Shopping Center
Shahran	0.091014	0.098133	0.168196	0.174463	0.155582	0.105206	0.1379	0.143203	Park
South Asia-Hemmat	0.12511	0.145797	0.075444	0.093865	0.073685	0.114557	0.110691	0.126733	Hospital
West Asia-Resalat	0.089006	0.128295	0.126937	0.136333	0.111178	0.10091	0.122516	0.117171	Park
Best Parcel	East Asia-Resalat	South Asia-Hemmat	East Asia-Resalat	Shahran	East Asia-Resalat	Asia Iranpars	Asia-Iranpars	North Asia-Hemmat	

Table2: Determining the land-use for parcels, the right red column is the principal result

	Cinema & Art Center	Hospital	Mosque	Park	School	Shopping Center	Sport Place	Square	Best Land-use
Boniad Shahid	0.133259	0.20098	0.084767	0.100038	0.082837	0.145013	0.13686	0.116246	Hospital
East Asia-Resalat	0.1023	0.105561	0.141707	0.121012	0.134405	0.151417	0.144948	0.09865	Shopping Center
North Asia-Hemmat	0.09759	0.192471	0.071143	0.121362	0.072822	0.152343	0.123594	0.168674	Hospital
Resalat-Elham	0.08658	0.228682	0.063703	0.118992	0.068196	0.13834	0.140283	0.155225	Hospital
Shahran	0.100004	0.171316	0.113685	0.142738	0.115465	0.141889	0.120463	0.09444	Hospital
South Asia-Hemmat	0.110354	0.191755	0.067982	0.150781	0.075528	0.145239	0.113455	0.144906	Hospital
West Asia-Resalat	0.094795	0.121649	0.111133	0.131241	0.138267	0.152244	0.153452	0.097218	Sport Place
Best Parcel	East Asia-Resalat	South Asia-Hemmat	East Asia-Resalat	Shahran	West Asia-Resalat	Asia Iranpars	Asia-Iranpars	North Asia-Hemmat	

The tables have arranged similarly to simplify the peer to peer comparison. So, other criteria for discussion can be obtained by summation of the two tables. These weights are illustrated in Table 3.

Table 3: Summation of weights of Table 1 and Table 2

	Cinema & Art Center	Hospital	Mosque	Park	School	Shopping Center	Sport Place	Square	Best Land-use
Asia-Iranpars	0.182885	0.362768	0.177175	0.265486	0.210945	0.29509	0.321897	0.260701	Hospital
Boniad Shahid	0.31775	0.335609	0.226549	0.172136	0.199068	0.264517	0.238768	0.230091	Hospital
East Asia-Resalat	0.294262	0.233856	0.351271	0.244627	0.31728	0.252287	0.245346	0.190276	Mosque
North Asia-Hemmat	0.195255	0.314923	0.189231	0.242529	0.199713	0.263176	0.25224	0.331705	Square
Resalat-Elham	0.213028	0.356533	0.1264	0.232552	0.173745	0.298385	0.264607	0.283713	Hospital
Shahran	0.191018	0.269449	0.281881	0.317201	0.271047	0.247095	0.258363	0.237643	Park
South Asia-Hemmat	0.235464	0.337552	0.143426	0.244646	0.149213	0.259796	0.224146	0.271639	Hospital
West Asia-Resalat	0.183801	0.249944	0.23807	0.267574	0.249445	0.252854	0.275968	0.214389	Sport Place
Best Parcel	East Asia-Resalat	South Asia-Hemmat	East Asia-Resalat	Shahran	East Asia-Resalat	Asia Iranpars	Asia-Iranpars	North Asia-Hemmat	

For best understanding and comparing the results of two networks, the values of three tables are shown graphically in Figures 7, 8 and 9.

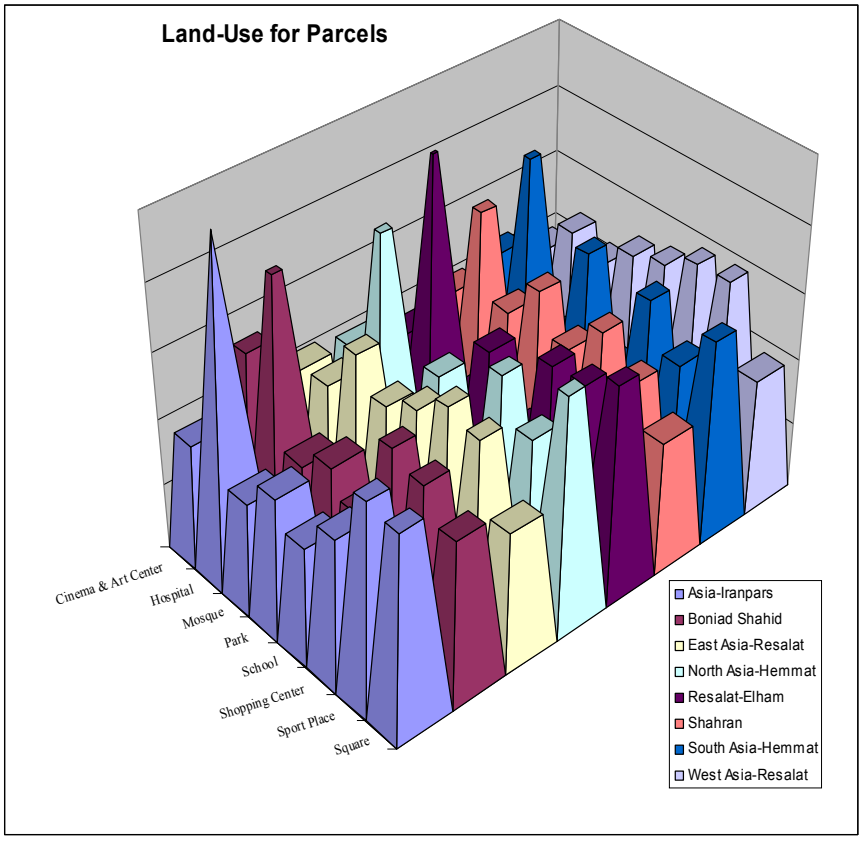

Figure 7: The weights obtained from the network of determining land-uses for parcels

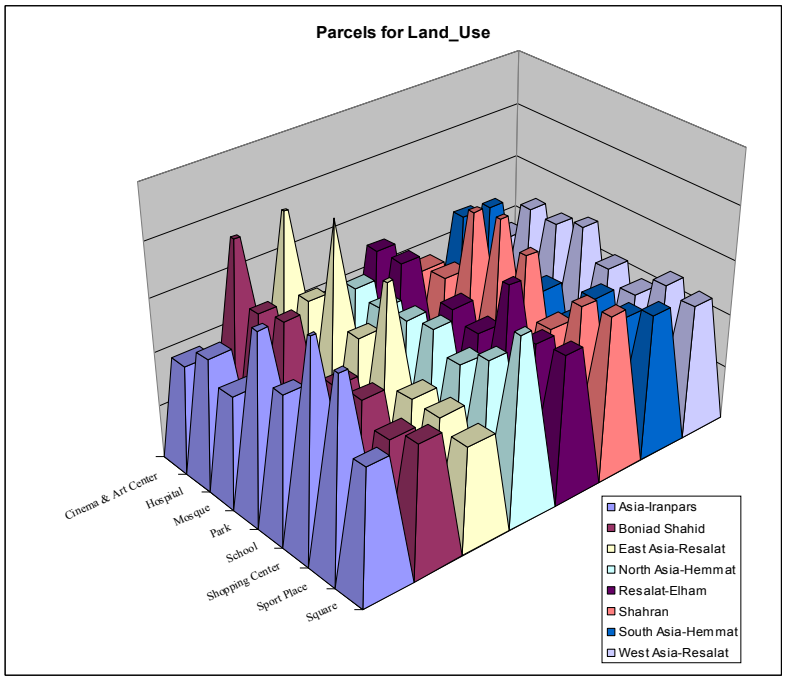

Figure 8: The weights obtained from the network of determining parcels for land-uses

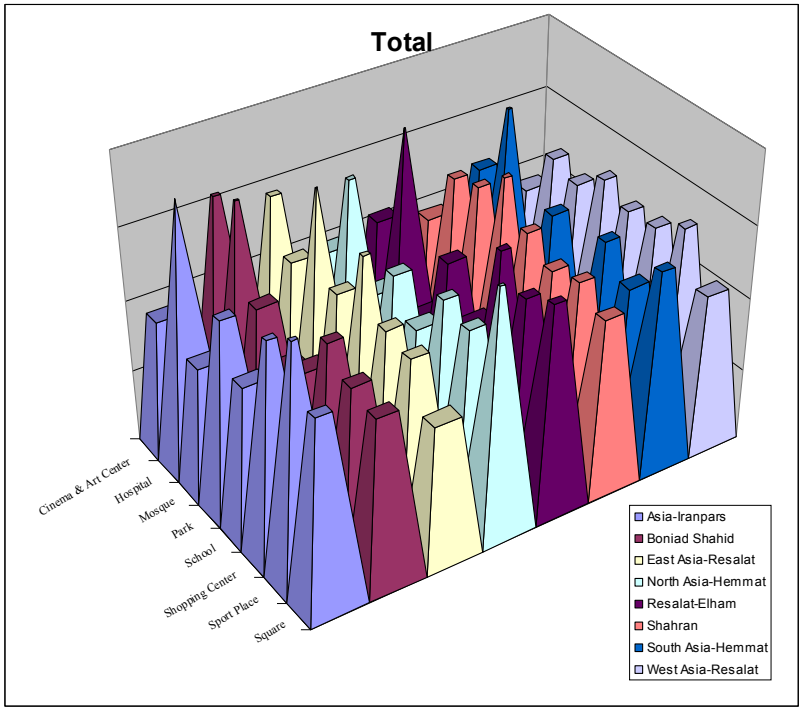

Figure 9: The summation of weights in Figures 7 and 8

7. Discussion for matching the land-uses to the land parcels

At first look to Tables 1 and 2, it is obvious that the weights of the same allocations are different in two tables, though the same expert has done the comparisons. Also the comparisons are consistent in their networks. Therefore, this proves that the structure of the network affects the results directly.

In consequence, to decide about the allocations the weights should be assessed carefully. If the ranks of two weights for a specific allocation are perfectly in contrast then, the whole comparisons in two networks have to be done again. Otherwise the proper allocation can be concluded. In such cases, fully agreed weights need no discussion and for the others the allocation can be confirmed by deduction.

Before discussing about matching the alternatives, it is necessary to notify that the whole study area is suffer from lack of hospital. Therefore, hospital has gained a high weight of allocation to almost all of the land-parcels by both networks. Thus, allocating the hospital to a land-parcel needs more considerations. Also it is important to note that, when using the weights obtained from network of "parcels for usage", the parcels are essential filed and otherwise the land-use is more reliable. In ambiguities, the summation of weights can be a good leader.

We define three principles as the guide lines to validate the final allocations. An allocation can be finalized which agree with the following principles:

- Must not gain the lowest weights in both of the networks
- The ranks of the weights is not low with respect to the other cases
- Optionally obtain the highest weight in two networks

Based on the mentioned principles, the process of decision-making about the allocations is discussed in the following.

(1) North Asia-Hemmat: Green Grosser Square

The reasons for this allocation are clear when looking at the weights. That is the best matching case in all of the tables.

(2) Shahran: Park

This allocation is reasonable too. North Asia-Hemmat could also be selected for park but the best matching land-use for this parcel has been assigned before (That is Green Grosser Square).

(3) East Asia Resalat: Mosque

Perhaps shopping center seems to be the best option for this parcel but Figure 8 and Table 1 show that such allocation is in contrast with the first principle. At the other hand, a mosque is appropriate for this parcel and this usage is not appropriate for any other parcel. Consequently, mosque is the best matching case.

(4) Asia-Iranpars: Sport place

It may seem that the best option for this parcel is shopping center. However Figure 7 and Table 2 show that this matching is in conflict with the first principle. Thus, based on Table 1, Sport place is confirmed as the best land-use for this parcel.

(5) Other four remained parcels

In aforementioned four cases, the best matching cases were almost clear. However, for the other more considerations are required. Hospital is a land-use that is a suggestion for the most land-places in Figure 7. Therefore, the best matching parcel for this land-use is determined here to make other land-uses free for the remained parcels. In Table 2 which is essentially for determining the best land-uses for parcels, hospital has been offered as the best land-use for 6 parcels. Among those 6 parcels, three ones have been allocated before and the remained three options are: Boniad Shahid, Resalat-Elham and South Asia-Hemmat. Figure 9 and Table 3 also certify these three options. If hospital is assigned to one of them, it is obvious that two remained options should have other land-uses. Therefore, first we search that what are the other appropriate land-uses for these three parcels.

South-Asia Hemmat can only match with Hospital, it cannot match the other remained land-uses which are: School, Shopping Center and Cinema. Boniad Shahid can match Cinema and Hospital is more proper land-use for South Asia-Hemmat. Thus Boniad Shahid is ignored for Hospital. Resalat-Elaham is the most appropriate option for Shopping Center and also for gaining Hospital land-use; it stands in the second rank after South-Asia Hemmat. Therefore, Hospital is assigned to South Asia-Hemmat. By considering the remained land-uses, it is understood from three Figures 7, 8 and 9 that Cinema is the best matching land-use for Boniad Shahid.

Now, there are two parcels which are: Resalat-Elham and West Asia-Resalat as well as two land-uses which are: Shopping Center and School. Shopping Center is not a proper land-use for West Asia Resalat and this matter is obtained from Table 1. Shopping Center is the best matching case for Resalat-Elham in Table 1 and Table 3 and certainly is chosen for Resalat-Elham. School can be constructed in smaller parcels than here. So, it has not got a high weight in most of the parcels. However, it is worth that in Table 2 West Asia-Resalat has been chosen as the appropriate parcel for School. A brief review reveals that this matching does not break any of the principles. Consequently, School is allocated to West Asia-Resalat. Table 4 shows the final matched cases.

Table 4: The Final matching cases

Land-Parcel	Land-Use
North Asia-Hemmat	Green Grosser Square
South Asia-Hemmat	Hospital
Shahran	Park
Bonyad Shahid	Cinema and Art Center
East Asia-Resalat	Mosque
West Asia-Resalat	School
Resalat-Elham	Shopping Center
Asia Iranpars	Sport Place

This study showed that allocation is a complex process and the experts may not be able to make consistent decisions in this process. Using multicriteria decision making methods help the experts to avoid biased decisions. ANP as a multicriteria decision making method is an appropriate approach to get the ideas of experts. This method structures the problems involving functional dependence allows for feedback among clusters. This study revealed that despite using such a proper method, inconsistency may still exist in the decisions. A bilateral method implemented in this study reveals the inconsistencies which are not detected in ANP and thus prevent biased decisions. Using such a method causes more confidence in decision making. Therefore it is attributed here that this method can be more reliable than using only ANP (For instance, the study of Tuzkaya et al., 2008[12])

Conclusions and Recommendations

In this paper, we presented a multiple criteria decision making model to determine the best land-uses for eight land parcels in a part of Tehran, Iran, according to bilateral technique based on Analytical Network Process. The ANP methodology is capable of taking into consideration both tangible and intangible criteria without sacrificing their relationships and it can deal with all kinds of dependencies systematically. Unlike traditional Multicriteria Decision Making (MCDM) methods which are generally based on the independence assumption, the ANP is a MCDM methodology, incorporating feedback and interdependent relationships between decision attributes and alternatives.

The procedure of this study was quantifying the alternatives using a bilateral ANP employing an expert who decides based on map objects and then selecting the best matching alternatives based on quantified weights.

This paper showed how different can be the decisions of an expert when the structure of a decision networks varies. Also, the decisions of an expert are uncertain and the risk of mistake always exists. To overcome this incompetence, one may use group decision making. However, consistency among experts' opinion especially in spatial problems hardy achieved and preparing a group of experts is usually difficult. Furthermore, there is no warranty that the decisions of a group of experts are certainly right. Maybe there are another group of experts who are totally in contrast with the first group.

In this study, eight land-used were successfully assigned to eight land parcels. Nevertheless, if the agreement between two networks of ANP did not achieve, the comparisons should be performed again.

In this case, the number of parcels was equal to the number of land-uses. The case with different numbers of matching options would be a good choice for more researches.

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