Application of Analytical Hierarchy Process (AHP) for Multi-Storey Car Parks Location in a Small Area

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The use of Multi-Criteria Decision Making (MCDM) precisely the Analytic Hierarchy Process (AHP) method in planning a suitable location for car parking, planners put into consideration a lot of factors. These different considerations make the planning process complex and as such there might be confusion of interest in the decision making. This paper was assessed the potential suitable areas for selecting of the car parking areas, among three areas (ABC), which are located in Al-Nahrain University, based on some criteria and their factors. The criteria were location, area, space hour, parking accumulation, parking volume, parking load, parking duration and parking turnover. First, a resource inventory and a list of selection of the multi-store car parking areas criteria were developed using the AHP method. At the next stage a computer program was developed by using MATLAB software to find the land suitability map based on criteria and factors with their respective weights. Based from the final suitability map, the areas of fair class can be used for selecting the car parking areas.

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1. INTRODUCTION

Parking facilities are a basic part of the modern community's transportation system. The vehicle moves towards a destination and having arrived there it must be parked [1].

Convenient parking space is considered a sign of welcome. Every vehicle trip requires parking at its destination, so parking facilities are integrated components of the roadway system. Parking is one of the first experiences that people have when traveling to a destination. Convenient and affordable parking space is considered a sign of welcome. Parking place that is difficult to find, inadequate or expensive will frustrate users and can contribute to spillover parking problems in order areas. As a result, inadequate parking supply can create problems to both users and nonusers [2].

The need for parking spaces is usually very great in areas where land uses include business, residential, or commercial activities. Providing adequate parking space to meet the demand for parking in the CBD may necessitate the provision of parking bays along curbs, which reduces the capacity of the streets and may affect the level of service [3]. This problem usually confronts a city traffic engineer. The solution is not simple, since the allocation of available space will depend on the goals of the community, which the traffic engineer must take into consideration when trying to solve the problem. Parking studies are therefore used to determine the demand and the supply of parking facilities in an area, the projection of the demand, and the views of various interest groups on how best to solve the problem [4].

Site selection of car parking, which had done by a traditional method causes inefficiency of these car parking and makes traffic problems. Thereafter, it is necessary to employ new systems, which have the ability to analyze a lot of parameters simultaneously, in parking site selection. One of these systems is known as combining between Analytical Hierarchy Process (AHP) and Geographical Information System (GIS) [5].

2. METHODOLOGY OF AHP

The AHP provides a means of decomposing the problem into a hierarchy of sub-problems, which can more easily be comprehended and subjectively evaluated. The subjective evaluations are converted into numerical values and processed to rank each alternative on a numerical scale. The methodology of the AHP can be explained in following steps [6].

Step 1: The problem is decomposed into a hierarchy of goal, criteria, sub-criteria and alternatives. This is the most creative and important part of decision-making. Structuring the decision problem as a hierarchy is fundamental to the process of the AHP. Hierarchy indicates a relationship between elements of one level with those of the level immediately below (Fig. 1). This relationship percolates down to the lowest levels of the hierarchy and in this manner every element is connected to every other one, at least in an indirect manner. A hierarchy is a more orderly form of a network. An inverted tree structure is similar to a hierarchy.

Step 2: Data are collected from experts or decision-makers corresponding to the hierarchic structure, in the pairwise comparison of alternatives on a qualitative scale as described below. Experts can rate the comparison as equal, marginally strong, strong, very strong, and extremely strong. The opinion can be collected in a specially designed format, as shown in Fig. 2, "X" in the column marked "Very strong" indicates that B is very strong compared with A in terms of the criterion on which the comparison is being made. The comparisons are made for each criterion and converted into quantitative numbers as per Table 1 as developed by [7].

Step 3: The pairwise comparisons of various criteria generated at step 2 are organized into a square matrix. The diagonal elements of the matrix are 1. The criterion in the ith row is better than criterion in the jth column if the value of element (i, j) is more than 1; Otherwise the criterion in the jth column is better than that in the ith row. The (j, i) element of the matrix is the reciprocal of the (i, j) element.

Step 4: The principal eigenvalue and the corresponding normalized right eigenvector of the comparison matrix give the relative importance of the various criteria being compared. The elements of the normalized eigenvector are termed weights with respect to the criteria or sub-criteria and ratings with respect to the alternatives.

Step 5: The consistency of the matrix of order n is evaluated. Comparisons made by this method are subjective and the AHP tolerates inconsistency through the amount of redundancy in the approach. If this consistency index fails to reach a required level then answers to comparisons may be re-examined. The consistency index, CI, is calculated as

$$CI = (Λ_{max} - n)/(n-1) \qquad (1)$$

Where $Λ_{max}$ is the maximum eigenvalue of the judgment matrix. This CI can be compared with that of a random matrix, RI. The ratio derived, CI/RI, is termed the consistency ratio, Table 2 shows the average random consistency. CR. The value of CR should be less than 0.1 [8].
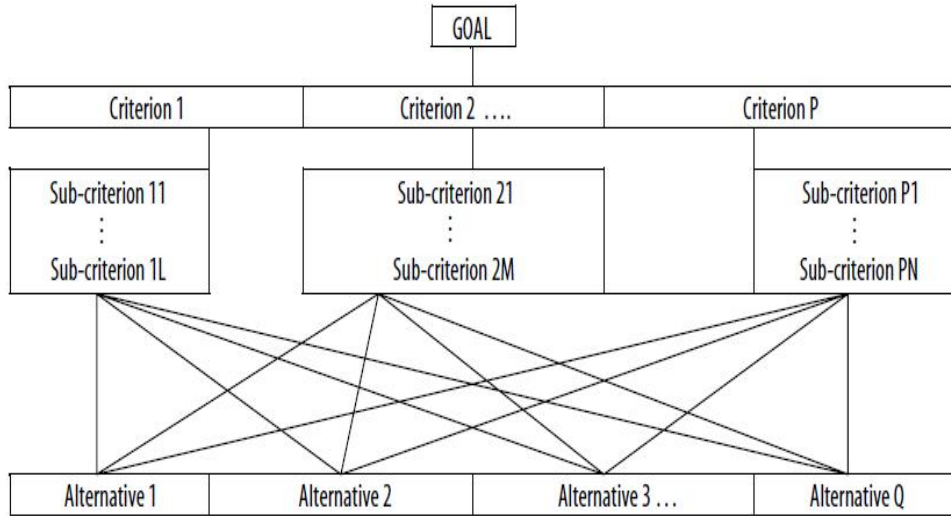
Fig. 1. Generic hierarchic structure [6].
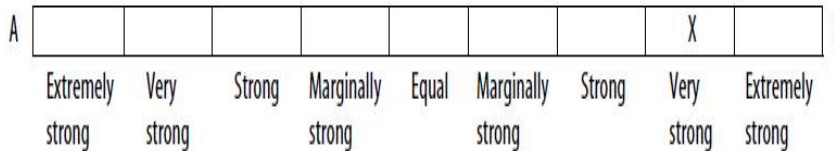
Fig. 2. Format for pairwise comparisons [7]

Table 1. Gradation scale for quantitative comparison of alternatives [9,10,11]

Option	*Numerical value(s)*
Equal	1
Marginally strong	3
Strong	5
Very strong	7
Extremely strong	9
Intermediate values to reflect fuzzy inputs	2, 4, 6, 8
Reflection dominate of second alternative compared with the first	Reciprocals

Table 2. Averag random consistency (RI) [6]

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Step 6: The rating of each alternative is multiplied by the weights of the sub-criteria and aggregated to get local ratings with respect to each criterion. The local ratings are then multiplied by the weights of the criteria and aggregated to get global ratings. The AHP produces weight values for each alternative based on the judged importance of one alternative over another with respect to a common criterion.

3. CASE STUDY

Al-Nahrain University site was selected as a case study for this research. Al-Nahrain University established in 1988 and located in Al-Jadriya in Baghdad, Iraq. Fig. 3 illustrate the location of Al-Nahrain University in Baghdad. Because of the rapid growth in both buildings and people, the site need to a multistory car park.

There are several irregular small parks in Al-Nahrain University. Table 3 shows the peak hour volume of cars in specific times in two respective years. Fig. 4 shows the locations of parks in Nahrain University. Table 4 shows the numbers of cars that parked in these parks.

Table 3. Peak-hour volume

Times	Average Hadi's study (2014)	Times	Our case study (2016)
7.30-8.30	506	7.00-9.00	795
1.30-2.30	495	1.30-2.30	600

Table 4. Number of cars in each park

No.	Parks	No. of cars
1	P1	20
2	P2	106
3	P3	25
4	P4	26
5	P5	81
6	P6	75
7	Irregular cars parking	50
Total		383

Three new locations of parking in Al-Nahrain University are selected according to some criteria:

1. the first location (A)is located near AL-Salaam hall,
2. the second location (B) is located near AL-Mustafa mosque and
3. third location(C) is located near the gate of Nahrain University.

Fig. 5 shows the location of the three suggested locations of the multi story parks in Al-Nahrain University.

3.1 Modeling the AHP of the Case Study

Step 1: The problem is decomposed into a hierarchy of goal, criteria, sub-criteria and alternatives. The selected criteria for the suggested locations are location, area, space hour, parking accumulation, parking volume, parking load, parking duration and parking turnover.

Fig. 3. The location of Al-Nahrain University in Baghdad (Google earth image, last seen on May 2016)

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Fig. 4. Locations of parks in Al-Nahrain University

Fig. 5. The location of the three suggested locations of the multi story parks in Al-Nahrain University

Structuring the decision problem as a hierarchy is fundamental to the process of the AHP. Hierarchy indicates a relationship between elements of one level with those of the level immediately below (Fig. 6).

Step 2: Data are collected from experts or decision-makers corresponding to the hierarchic structure, in the pairwise comparison of alternatives on a qualitative scale. The comparisons are made for each criterion and

converted into quantitative numbers as shown in Table 5.

Step 3: Then the pairwise comparisons of various criteria generated at step 2 are organized into a square matrix (Table 6). The diagonal elements of the matrix are 1. The criterion in the ith row is better than criterion in the jth column if

the value of element (i, j) is more than 1; otherwise the criterion in the jth column is better than that in the ith row.

This process must be iterated until the eigenvector solution does not change from the previous iteration (remember to four decimal places in our case), as it is clear in Table 7.
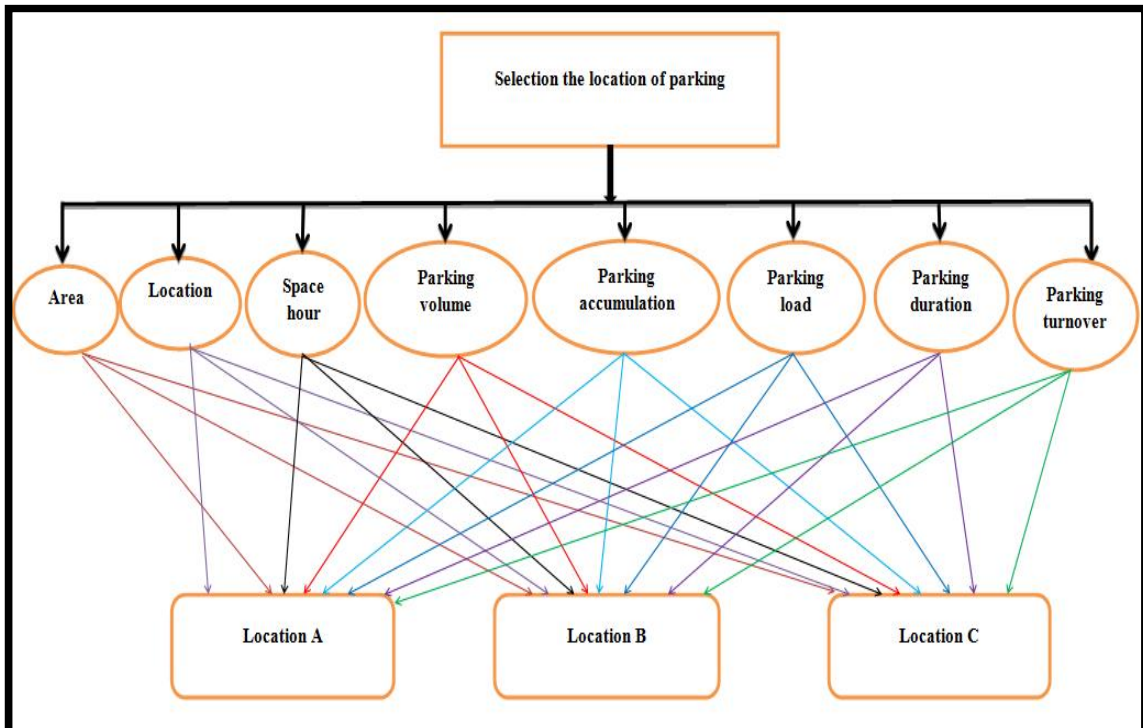
Fig. 6. Generic hierarchic structure of the case study

Table 5. Pairwise comparison matrix of case study criteria

	location	area	Space hour	Parking accumulation	Parking volume	Parking load	Parking duration	Parking turnover
location	1	1/3	3	3	1/3	3	5	3
area	3	1	5	3	3	3	7	5
Space hour	1/3	1/5	1	1/3	1/3	1/3	1	1/5
Parking accumulation	1/3	1/3	3	1	1/3	1/3	3	1/3
Parking volume	3	1/3	3	3	1	3	7	3
Parking load	1/3	1/3	3	3	1/3	1	3	1/3
Parking duration	1/5	1/7	1	1/3	1/7	1/3	1	1/3
Parking turnover	1/3	1/5	5	3	1/3	3	3	1

λ_{max}= 8.8425   CI=0.1204   RI= 1.41   CR= 0.0854 <0.1

Table 6. Square the matrix to determine the eigenvector

	location	area	Space hour	Parking accumulation	Parking volume	Parking load	Parking duration	Parking turnover
location	8.0000	4.6921	46.6667	28.6667	6.3810	20.6667	44.6667	12.9333
area	21.7333	8.0000	78.0000	52.0000	13.3333	44.0000	88.0000	33.3333
Space hour	2.7556	1.0273	8.0000	5.2000	1.8095	4.3111	10.0000	3.9556
Parking accumulation	4.4889	2.0952	15.3333	8.0000	3.4286	6.6667	17.3333	6.0444
Parking volume	12.4000	5.8667	56.6667	37.3333	8.0000	29.3333	61.3333	21.6000
Parking load	5.3778	2.9841	23.3333	12.0000	4.3175	8.0000	25.3333	6.9333
Parking duration	1.9238	0.8889	7.4095	4.4571	1.4476	3.5683	8.0000	2.8317
Parking turnover	6.5333	4.0508	34.0000	20.2667	5.4730	12.2667	34.4000	8.0000

Table 7. Second-square the matrix to determine the eigenvector for more accuracy (1.0E+003)

	location	area	Space hour	Parking accumulation	Parking volume	Parking load	Parking duration	Parking turnover	Eigen value	Cumulative Eigen value
location	0.7839 +	0.3743 +	3.1667 +	1.8927 +	0.5721 +	1.4346 +	3.4510 +	1.1288 =	12.8041	0.1525
area	1.5851+	0.7778+	6.6271+	3.9542+	1.1712+	2.9501+	7.1392+	2.2795 =	26.4842	0.3153
Space hour	0.1805+	0.0887+	0.7642+	0.4596+	0.1328+	0.3431+	0.8199+	0.2619 =	3.0507	0.0363
Parking accumulation	0.3108+	0.1502+	1.3020+	0.7891+	0.2261+	0.5943+	1.4027+	0.4546 =	5.2298	0.0623
Parking volume	1.0665+	0.5180+	4.3887+	2.6157+	0.7855+	1.9607+	4.7514+	1.5284 =	17.6149	0.2097
Parking load	0.4166+	0.1980+	1.7092+	1.0373+	0.3012+	0.7891+	1.8528+	0.6098 =	6.9140	0.0823
Parking duration	0.1462+	0.0708+	0.6076+	0.3655+	0.1069+	0.2748+	0.6561+	0.2121 =	2.4400	0.0291
Parking turnover	0.5772+	0.2722+	2.3269+	1.4038+	0.4170+	1.0745+	2.5364+	0.8412 =	9.4492	0.1125
									83.9869	**1.00**

I.E 12.8041/83.9869 = 0.1525

The (j, i) element of the matrix is the reciprocal of the (i, j) element. Tables 8 to 15 show the square matrices of the case study.

Table 8. Pairwise comparison matrix of alternatives with respect to location

	A	B	C
A	1	5	3
B	1/5	1	1/3
C	1/3	3	1

λ_{max}= 3.0385 CI=0.0425 RI= 0.58 CR= 0.073<0.1

1. bb=b^2=

	A	B	C
A	3.000	19.0000	7.6667
B	0.5111	3.0000	1.2667
C	1.2667	7.6667	3.0000

2. B=bb^2=

	A	B	C	Eigen value	Cumulative Eigen value
A	28.4222+	172.7778+	70.0667=	271.2667	0.6370
B	4.6711+	28.4222+	11.5185=	44.6118	0.1048
C	11.5185+	70.0667+	28.4222=	110.0074	0.2583
				425.8859	1.00

Table 9. Pairwise comparison matrix of alternatives with respect to area

	A	B	C
A	1	3	5
B	1/3	1	3
C	1/5	1/3	1

λ_{max}= 3.0385 CI=0.0193 RI= 0.58 CR= 0.0332<0.1

1. cc= c^2=

	A	B	C
A	3.0000	7.6667	19.0000
B	1.2667	3.0000	7.6667
C	0.5111	1.2667	3.0000

2. C=cc^2=

	A	B	C	Eigen Value	Cumulative Eigen value
A	28.4222+	70.0667+	172.7778=	271.2667	0.6369
B	11.5185+	28.4222+	70.0667=	110.0074	0.2583
C	4.6711+	11.5185+	28.4222=	44.6118	0.1048
				425.8859	1.00

Table 10. Pairwise comparison matrix of alternatives with respect to space hour

	A	B	C
A	1	1	1
B	1	1	1
C	1	1	1

λ_{max}= 3   CI=0   RI= 0.58   CR= 0.<0.1

1. $dd=d^2=$

	A	B	C
A	3	3	3
B	3	3	3
C	3	3	3

2. $D=dd^2=$

	A	B	C	Eigen Value	Cumulative Eigen value
A	27+	27+	27=	81	0.3333
B	27+	27+	27=	81	0.3333
C	27+	27+	27=	81	0.3333
				243	1.00

Table 11. Pairwise comparison matrix of alternatives with respect to parking accumulation

	A	B	C
A	1	1	1
B	1	1	1
C	1	1	1
$\lambda_{max}= 3$	CI=0	RI= 0.58	CR= 0.<0.1

1. $ee=e^2=$

	A	B	C
A	3	3	3
B	3	3	3
C	3	3	3

2. $E=ee^2=$

	A	B	C	Eigen Value	Cumulative Eigen value
A	27+	27+	27=	81	0.3333
B	27+	27+	27=	81	0.3333
C	27+	27+	27=	81	0.3333
				243	1.00

Table 12. Pairwise comparison matrix of alternatives with respect to parking volume

	A	B	C
A	1	3	5
B	1/3	1	3
C	1/5	1/3	1
$\lambda_{max}= 3.0385$	CI=0.0193	RI= 0.58	CR= 0.0332<0.1

1. $ff=f^2=$

	A	B	C
A	3.0000	7.6667	19.0000
B	1.2667	3.0000	7.6667
C	0.5111	1.2667	3.0000

2. $F=ff^2=$

	A	B	C	Eigen value	Cumulative Eigen value
A	28.4222+	70.0667+	172.7778=	271.2667	0.6369
B	11.5185+	28.4222+	70.0667=	110.0074	0.2583
C	4.6711+	11.5185+	28.4222=	44.6118	0.1048
				425.8859	1.00

Table 13. Pairwise comparison matrix of alternatives with respect to parking load

	A	B	C
A	1	1	1
B	1	1	1
C	1	1	1

λ_{max}= 3 CI=0 RI= 0.58 CR= 0.<0.1

1. $gg=g^2=$

	A	B	C
A	3	3	3
B	3	3	3
C	3	3	3

2. $G=gg^2=$

	A	B	C	Eigen Value	Cumulative Eigen value
A	27+	27+	27=	81	0.3333
B	27+	27+	27=	81	0.3333
C	27+	27+	27=	81	0.3333
				243	1.00

Table 14. Pairwise comparison matrix of alternatives with respect to parking duration

	A	B	C
A	1	1	1
B	1	1	1
C	1	1	1

λ_{max}= 3 CI=0 RI= 0.58 CR= 0.<0.1

1. $hh=h^2=$

	A	B	C
A	3	3	3
B	3	3	3
C	3	3	3

2. $H=hh^2=$

	A	B	C	Eigen Value	Cumulative Eigen value
A	27+	27+	27=	81	0.3333
B	27+	27+	27=	81	0.3333
C	27+	27+	27=	81	0.3333
				243	1.00

Table 15. Pairwise comparison matrix of alternatives with respect to parking turnover

	A	B	C
A	1	3	5
B	1/3	1	3
C	1/5	1/3	1

λ_{max}= 3.0385 CI=0.0193 RI= 0.58 CR= 0.0332<0.1

1. $ii= i^2=$

	A	B	C
A	3.0000	7.6667	19.0000
B	1.2667	3.0000	7.6667
C	0.5111	1.2667	3.0000

2. $I= ii^2=$

	A	B	C	Eigen Value	Cumulative Eigen value
A	28.4222+	70.0667+	172.7778=	271.2667	0.6369
B	11.5185+	28.4222+	70.0667=	110.0074	0.2583
C	4.6711+	11.5185+	28.4222=	44.6118	0.1048
				425.8859	1.00

4. RESULTS AND DISCUSSION

The AHP produces weight values from applying steps 4, 5, and 6 above for each alternative based on the judged importance of one alternative over another with respect to a common criterion. Then all the comparison matrices had been solved in eigenvector by using the developed Matlab program. The overall priorities for locations A, B and C are 0.5732, 0.2506 and 0.1762 respectively. Thus, location A is the most valuable, because it achieves the highest weight.

5. CONCLUSIONS

The conclusions drawn from this paper can be summarized as follows:

1. The analytic hierarchy process (AHP) is an excellent method, which has been applied in this study for estimating the relative weighs of different factors that considered in spatial analysis process to the case of selecting a proper location of car park. It provides a convenient approach for solving complex MCDM problems in engineering. The main advantage of the AHP is its ability to rank choices in the order of their effectiveness in meeting conflicting objectives.
2. The steps of modeling the AHP for the case study include the inputs of elements (criteria, sub-criteria and alternatives) as weighs of important of intensity.
3. In this study, comparisons matrices were developed as weighs of AHP process according to judgments of experts who have an experience in road maintenance projects.
4. Al-Nahrain University site was selected as a case study for this research because of the rapid growth in both buildings and people, the site need to a multistory car park. This paper was assessed the potential suitable areas for selecting of the car parking areas, among three locations (A, B C), based on some criteria and their

factors. The criteria were location, area, space hour, parking accumulation, parking volume, parking load, parking duration and parking turnover.
5. The overall priorities for locations A, B and C are 0.6264, 0.2234 and 0.15 respectively. Thus, location A is the most valuable, because it achieves the highest weight.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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