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# ANALYTIC HIERARCHY PROCESS FOR EVALUATION OF TRANSPORTATION ALTERNATIVES ON THE KARKH SIDE OF BAGHDAD

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**Abstract:** The Analytical Hierarchy Process (AHP) is a mathematical method which is considered This method is considered one of the most accurate methods in terms of making decisions by providing multiple options so that the decision-maker can calibrate and evaluate the alternatives. The city of Baghdad suffers from stifling traffic congestion due to the increase in population, which leads to a significant increase in the number of trips inside and outside the city, and with this, the number of vehicles is more than the capacity of the city's road network; especially on the Karkh side. Three alternative roads were proposed in the network; namely: the first alternative is the fourth ring road that connects the Abu Ghraib highway and the roundabout bridge, the second road represents the link between the Washash roundabout and the Muthanna Airport intersection, the third alternative is constructing a tunnel from the Al-Paratha Mosque intersection in the direction of Haifa Street. The purpose of the study is to analyze and select the best alternative by using multi-criteria decision-making. Based on the results, it appears that the economic factor has the greatest effect on the selection of alternatives with its weight equal to 55%, followed by the accessibility factor with a weight of 29.8%. Although the second alternative was chosen as the best alternative in this manuscript, the first alternative is also important in terms of reducing traffic congestion and truck crossing within the city. To increase the efficiency of the network, it is proposed to implement the first and second proposals as well as widen the study region.

***Keywords:*** *Analytical Hierarchy Process (AHP); Karkh side of Baghdad; transportation alternatives; multi-criteria decision-making; GIS*

## 1. Introduction

The Analytical Hierarchy Process (AHP) is highly recommended for choosing the best alternatives that meet the needs of the project; it is used to evaluate alternatives according to specified criteria, choose the best alternative, and make a decision [1,2]. In addition, it is useful in choosing alternatives that achieve specified functions [3]. In 2001, Al-Harbi [4] used the AHP method through the Export Choice program to implement this method to be able to manage projects and evaluate alternatives. In 2022, Mirzahossein et al. [5]. In Qazvin, the AHP method was used by conducting questionnaires to choose the best way to increase the efficiency of the network and transportation system. In 2002, Lai et al. [6] Using surveys and questionnaires, the AHP was combined with Software Engineering to pick the optimal solution for the multi-media authorizing system. In 2001, Tam and Tummala [7] chose the best telecommunication network system using the AHP method, through a group of decision-makers and made important criteria for selection. The result showed a reduction in the time taken to choose the system. In 2019,

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Darko et al. [8] used the AHP in construction management to evaluate and compare different options for a project based on factors such as cost, schedule, and quality. The AHP process involves breaking down the decision problem into a hierarchy of criteria and sub-criteria and then using a pairwise comparison process to assign relative importance to each level of the hierarchy. This allows the decision-maker to consider the relative importance of different factors and make more informed decisions choosing the best criteria for it and the best management method by using a hierarchical analysis program [8]. In 2020, Sari et al. [9] used the AHP method to choose a suitable site for apiaries for beekeeping in Konya, Turkey, where the area is suitable in all respects. The AHP method was used in 2019 by Stojčetović, et al. [10] in the municipality of Strpce to improve the electricity in the region by using criteria, the most important of which are the factors that threaten the security of this power as well as its weaknesses. In 2020, Lyu et al. evaluated the metro sites that were exposed to floods, which amount to 11 flood sites, by applying the AHP program and with the help of GIS software [11]. In 2019, Baffoe [12] in eastern Ghana used the AHP method to evaluate projects and their sustainability in the region, as well as to benefit the largest number of residents through decision-makers in choosing the appropriate criteria. In Croatia in 2021, Otkovic et al. [13] conducted a study on sustainable traffic and its infrastructure to make decisions using the AHP method. Several criteria were evaluated such as safety, functional, economic, environmental, and spatial factors; in addition to other important sub-factors to improve the transport system in the region. In Irbid in 2020, Al-Omari et al. [14] conducted a study to identify areas where accidents abound and to propose solutions to reduce them using the GIS program with the assistance of AHP method. In 2022, Farooq and Moslem [15] did a research paper on the driver's behavior, because it varies widely depending on age, response speed, and other aspects; and this is highly important at this time. The AHP method was used in this study. The most crucial criterion was the difference between drivers exceeding the specified speed and bypassing prohibited sites. In 2021, Shaon et al. [16] used the AHP technique to identify smart system options linked with traffic systems via decision-makers who used other transportation systems in the city that satisfy the proposed standards. Djouani et al. [17] chose the best tram route in 2022, using the GIS software and the AHP approach to discover the variables that might influence the selection of the best option based on the closeness or distance of the areas from this suggested route. Finally, in 2008, Pogarčić et al. [18] researched how the planning of the transportation system and traffic has a direct impact on the economy of countries as well as businesses in them by using the AHP method. The increase in the rate of human activities affects negatively the region's traffic condition, as they cause increased congestion as well as cost and time losses [19]. Therefore, To ease this congestion, the Iraqi Ministry of Planning has been working on ideas for new highways to be added to the area's road network [20]. To select the optimal option, these suggested options must first be analyzed. The objectives of this research is to determine the areas in which the alternatives represent and to compare the proposed alternatives by setting specific criteria using a Multi-criteria approach through the AHP process.

## 2. Procedure and Methodology for Selecting Road Alternatives

The process of selecting alternatives (the alternative roads) was carried out according to the following steps:

1. Choosing the study area.

2. Collecting the traffic volumes at the intersections in the study area to find out which roads are the most crowded.

3. Building the road network (for the study area) through the ArcGIS program and entering the necessary data for it.

4. Using the TransCAD program to find the expected traffic movements according to the traffic volume.

5. Identifying the crowded areas and draw three alternative routes for them.

6. Determining the criteria for choosing the best alternative among the three alternatives.

7. Designing a questionnaire and distributing it to experts in transportation engineering for pairwise criteria comparison.

8. Finally, apply the AHP method to choose the best alternative.

## 3. The Study Area

The Republic of Iraq's capital is the city of Baghdad. and it is divided into two parts by the Tigris River to the Karkh and Rusafa. The study area of this research is located in the northern part of the Karkh side, where there are many residential and commercial areas and other vital activities, as it is an important area in Baghdad [21,22]; the study area is shown in Fig. 1.

## 4. Road Planning Analyses

The GIS program introduces a lot of benefits to researchers in building the road network and choosing the areas in which alternatives are added and drawn [23,24]. The simulation program is represented by the TransCAD program, where the traffic movements and the traffic congestion areas in the network are identified. When the new alternatives can be added to the network of the study area, the best alternative among them can be chosen through the AHP process [25], in which the criteria that separate the alternatives are selected to choose the best among them.
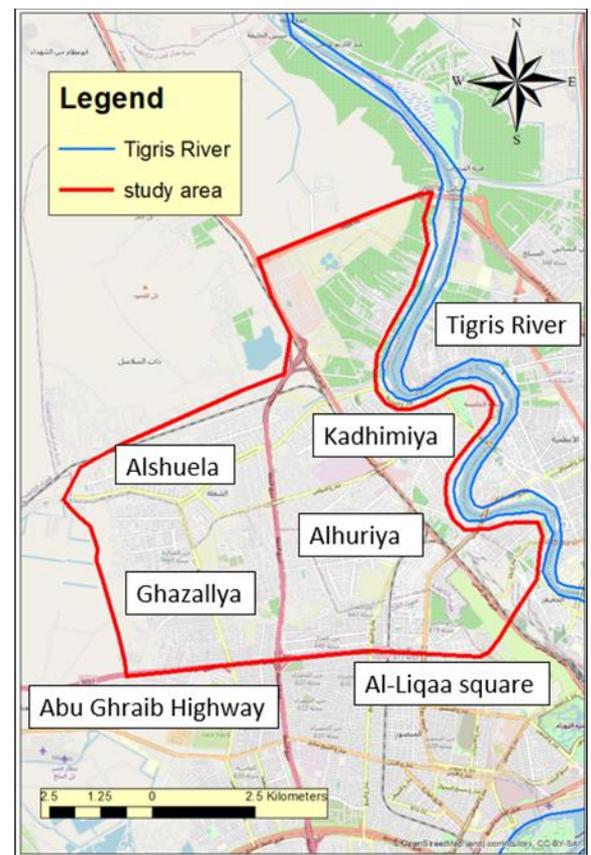


**Figure 1.** The Study area

This was achieved by the following steps:

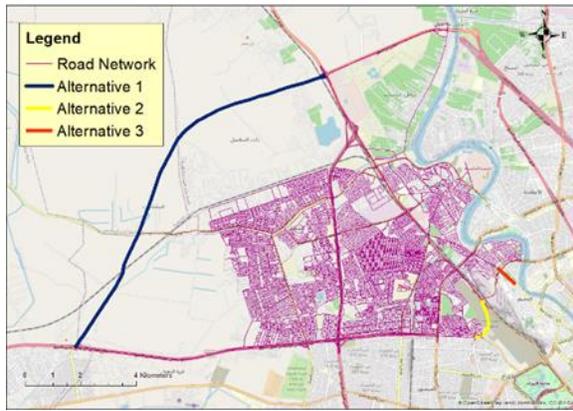a) Determine the areas in which the alternatives represent as shown in Fig.2. These alternatives are:

**Figure 2.** Network with alternatives

1. A road linking the Abu Ghraib Expressway and the rotating bridge in Taji.

2. A road linking Al-Washash and the intersection of Al-Muthanna Airport.

3. The tunnel at the intersection of the Paratha Mosque, which heads toward Haifa Street.

   b) Choose the best alternative among them; which can reduce traffic congestion, construction cost, time, and human efforts; using the AHP method.

## 5. Data Collection

In this study, the collected data is identified based on the selected criteria which will be used in evaluating the suggested alternatives and identifying the weight of each alternative. These criteria were chosen according to their importance to the alternatives. To calculate the weight of alternatives, a questionnaire was designed and distributed to decision-makers and experts in the transportation planning field; a group of six professors in the Highway and Transportation Engineering Department at Mustansiriyah University was chosen. For this, the questionnaire shows the used scale which reflects the intensity of importance of each criterion with their definition and explanations as shown in Table 1. The form of the questionnaire is shown in Appendix A, Fig. A-1, and Fig. A-2.

**Table 1.** Scales of Criteria Comparisons. Source: Adapted from Saaty (1980)

| Intensity of importance on an absolute scale | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 3 | Moderate importance of one over another | Experience and judgment strongly favor one activity over another |
| 5 | Essential or strong importance | Experience and judgment strongly favor one activity over another |
| 7 | Very strong importance | Activity is strongly favored and its dominance demonstrated in practice |
| 9 | Extreme importance | The evidence favoring one activity over another is of tile highest possible order of affirmation |
| 2,4,6,8 | Intermediate values between the two adjacent judgments | When compromise is needed |

## 6. Methodology for Route Selection

The three alternatives were entered in the ArcGIS program into the road network, and the location of each of them was determined and tested if they could be applied or not by

doing a traffic assignment through the TransCAD program. After that, the proposed alternatives were checked to make sure that they worked correctly according to the default setting. Then, the criteria were determined as shown in Fig. 3. The AHP tree includes the selected criteria as follows:

1. Target, which is choosing the optimum alternative.

2. Criteria are economic factor (EF), accessibility factor (AF), mobility and quality of travel of facility (MQF), and maximizing the road network (MRN).

3. Alternatives, which are alternative 1 (Alt.1), alternative 2 (Alt.2), and alternative 3 (Alt.3).

The variables that are used to measure each criterion are as below:

1. EF: construction cost is used as a measure to evaluate this factor.

2. Accessibility Factor: travel time is used as a measure to evaluate this factor.

3. Mobility and Quality of Travel of Facility: volume/capacity ratio is used as a measure to evaluate this factor.

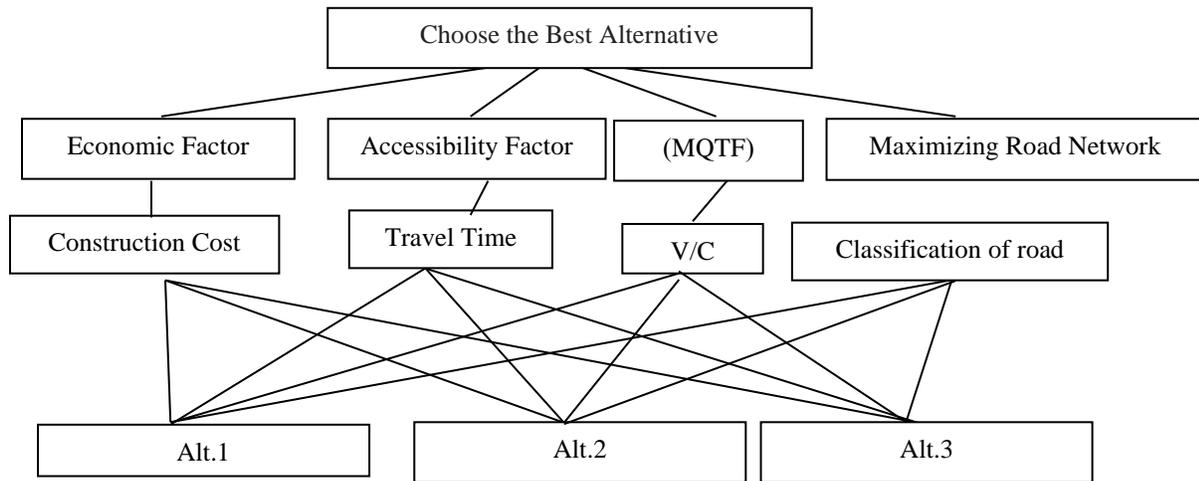4. MRN: classification of road is used as a measure to evaluate this factor.



**Figure 3.** The Analytic Hierarchy Tree

## 7. Results

The results of scaling the selected criteria are presented in the matrix form shown in Table 2. These results will be used to determine the weight of each criterion.

**Table 2.** Comparison Matrix

| Criteria | EF | AF | MQF | MRN |
|---|---|---|---|---|
| EF | 1 | 3 | 4 | 9 |
| AF | 0.33 | 1 | 5 | 4 |
| MQF | 0.25 | 0.2 | 1 | 3 |
| MRN | 0.11 | 0.25 | 0.33 | 1 |

The weights are computed using Equation 1.

$$Wx = \frac{Ix}{I1+I2+I3+\ldots In} \tag{1}$$

Where:

W = weight of criteria, I = Geometric Mean, x = The arithmetic mean number for which the weight is calculated, n = number of criteria.

The consistency ratio (CR) is calculated for each criterion, and it must be less than 10%, otherwise, the relative importance of each criterion will be reconsidered as it is calculated in equation 2:

$$CR = \frac{CI}{R1} \tag{2}$$

Whereas RI is the Random Consistency Index, CI: is the index of consistency.

The index of consistency (CI) is computed using equation 3 (Saaty, 1977).

$$CI = \frac{\cup \max - x}{x-1} \tag{3}$$

whereas:

Umax = Higher subjective values, x= The number of criteria selected.to find Umax:

$$\max \cup = AVG.\,[matrix\ between\ criteria]\ [weight]/ [weight] \tag{4}$$

To find CR, choose RI from Table A-1; so the CR is equal to 8.7% which is less than 10%. This means that the ratio of consistency ratio reflects that the selected criteria are relative to the importance of alternatives. The results of the weights of the selected criteria are shown in Table 3.

**Table 3.** Weight of criteria

| Criteria | Weight |
|---|---|
| EF | 0.549 |
| AF | 0.290 |
| MQF | 0.109 |
| MRN | 0.052 |

The following information was used to generate matrices for each criterion that had alternatives:

1. For the EF criteria, that it is related to (economic component), it estimated based on the judgment of specialists in the field of road. Estimation of construction costs is as below:
   a. The construction cost of the first alternative is 5 billion and 230 million.
   b. The construction cost of the second alternative is 352.7 million.
   c. The construction cost of the third alternative is 3 billion and 366 million.
2. For the accessibility factor, the travel time was calculated by selecting the segment in network with the largest flow. The road between Rotary Bridge and Aden Square was picked, and the travel time between them was computed using the GIS software findings as follows:
   a. Travel time before considering alternatives = 10 minutes

b. Trip time with alternative 1 added = 6 minutes.

c. Trip time with alternative 2 added = 8 minutes.

d. Trip time with alternative 3 added = 8.5 minutes.

3. For the third criterion (MQF), a ratio (v/c) was calculated by selecting the road segment in the network with the greatest flow. the following ratio was derived based on the average for the whole segment using the TransCAD software results:

4. Concerning the MRN factor, the alternatives are classified based on Scott Wilson's categories as follows:

   a. The Alt.1 route's functional classification: freeway

   b. The Alt.2 route's functional classification: expressway

c. The Alt.3 route's functional classification: Tunnel

Then comparisons were made between each criterion with the three alternatives. Also, the weights for each of them appeared according to the following matrices: as shown in Tables 4, 5, 6, and 7.

1. The matrix between economic factors and alternatives is shown in Table 4.

2. The matrix between the accessibility factor and alternatives is shown in Table 5.

3. The matrix between mobility and quality of travel of a facility and alternatives is shown in Table 6.

4. The matrix between the criterion of maximizing the road network and alternatives is shown in Table 7

**Table 4.** The comparison between alternatives with respect to economic factor

| Economic factor | Alt. 1 | Alt. 2 | Alt. 3 | Weight |
|---|---|---|---|---|
| Alt. 1 | 1 | 0.11 | 0.33 | 0.0653 |
| Alt. 2 | 9 | 1 | 7 | 0.7862 |
| Alt. 3 | 3 | 0.14 | 1 | 0.1485 |

**Table 5.** The comparison between alternatives with respect to Accessibility Factor

| Accessibility factor | Alt. 1 | Alt. 2 | Alt. 3 | Weight |
|---|---|---|---|---|
| Alt.1 | 1 | 5 | 7 | 0.73 |
| Alt.2 | 0.2 | 1 | 3 | 0.19 |
| Alt. 3 | 0.14 | 0.33 | 1 | 0.08 |

**Table 6.** The comparison between alternatives with respect to Mobility and Quality of Travel of a Facility

| MQF | Alt. 1 | Alt. 2 | Alt. 3 | Weight |
|---|---|---|---|---|
| Alt. 1 | 1 | 9 | 5 | 0.75 |
| Alt. 2 | 0.11 | 1 | 0.33 | 0.07 |
| Alt. 3 | 0.2 | 3 | 1 | 0.17 |

**Table 7.** The comparison between alternatives with respect to Maximizing the Road Network

| Maximizing the Road Network | Alt. 1 | Alt. 2 | Alt. 3 | Weight |
|---|---|---|---|---|
| Alt.1 | 1 | 3 | 5 | 0.64 |
| Alt. 2 | 0.33 | 1 | 3 | 0.26 |
| Alt. 3 | 0.2 | 0.33 | 1 | 0.10 |

After selecting the criteria, the three alternatives mentioned previously will be evaluated to choose the best one. This process is carried out according to equation 5.

$$=[0.549]\begin{bmatrix}0.0653\\0.7862\\0.1485\end{bmatrix}+[0.290]\begin{bmatrix}0.73\\0.19\\0.08\end{bmatrix}+[0.109]\begin{bmatrix}0.75\\0.08\\0.17\end{bmatrix}+$$

$$[0.052]\begin{bmatrix}0.64\\0.26\\0.10\end{bmatrix}=\begin{bmatrix}0.363\\0.508\\0.129\end{bmatrix} \qquad (5)$$

According to the results of this equation, the best among them will be selected.

Depending on the AHP method, the best alternative route was chosen from among the three proposed alternatives, which were built in the network by the ArcGIS program and analyzed in the TransCAD program, and tested for its validity. Through this method, the second alternative appeared, which is the road linking the Al-Washash roundabout and the intersection of Al-Muthanna Airport.

This road is considered the shortest among the proposed methods, and the least expensive to construct.

## 8. Conclusion

In this study, the focus was on choosing the best alternative among the proposed alternatives. The alternatives are a road linking the Abu Ghraib highway and the roundabout bridge in Taji, a road that connects the Washash roundabout and the intersection of Muthanna Airport, and the tunnel that is located at the intersection of the Paratha Mosque in the direction of Haifa Street.

These alternatives were entered into the network and evaluated to see if they work or not (by default). Then the criteria were selected, on which the comparison was made between the alternatives; they are economic factor, accessibility factor, mqtf, and maximizing the road network of the road.

The results of this manuscript showed that the best alternative is the second proposal, as it connects the Washash roundabout and the Muthanna Airport intersection, which is the best in terms of construction cost and other factors. Although the second alternative was chosen as the best alternative in this manuscript, the first alternative is also important in terms of reducing traffic congestion and truck crossing within the city. To increase the efficiency of the network, it is proposed to implement the first and second proposals as well as widen the study region.

## Abbreviations

AHP          Analytic hierarchy process

## Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

## Author Contribution Statement

Author 1 collected data, built road network in ArcGIS, estimated the proposed criteria, and made a questionnaire.

Author 2: proposed the research problem, developed the methodology, and supervised the results of this study.

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## Appendix – A

**Table A-1.** The Random Consistency Index

| CI | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|----|------|------|------|------|------|------|------|------|------|------|------|------|------|
| RI | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 | 1.48 | 1.56 | 1.57 | 1.59 |

Source: Adapted from Saaty (1980), pp. 21

Comparison of the selected criteria

There are three alternative methods proposed to choose the best, which will depend on several main criteria, namely (the economic factor, the accessibility factor, the mobility and quality of travel of a facility, and road network maximization) to rely on your preference among these key criteria.

Where this questionnaire is compared between these criteria and which one would you prefer to choose the best alternative through the following questions. And the selection of scales for each criterion concerning the other according to its importance is based on the following table.

Attention :

Choose the number only once, do not repeat its choice in two questions, neither 1 / n.

For example, if you choose the scale n=2 between the economic factor and the accessibility factor

Do not choose it in any other question and do not choose 1/2.

Table 1: Scales of Pairwise Comparisons

| Intensity of Importance | Definition | Explanation |
|---|---|---|
| 1 | Equal Importance | Two criteria contribute equally to the objective |
| 3 | Moderate Importance of one over another | Experience and judgment slightly favor one criterion over another |
| 5 | Essential or Strong Importance | Experience and judgment strongly favor one criterion over another |
| 7 | Very Strong or demonstrated Importance | A criterion is favored very strongly over another; its dominance demonstrated in practice |
| 9 | Extreme Importance | The evidence favoring one criterion over another is of the highest possible order of affirmation |
| 2, 4, 6, 8 | Intermediate values between the adjacent scale values (when compromise is needed) | |
| Reciprocals | If criteria i has one of the above numbers assigned to it when compared with criteria j, then j has the reciprocal value when compared with i | |

Source: Adapted from Saaty (1980)

**Figure A-1**. Questionnaire Part1

Choose the best alternative

**The following are questions to choose the best among the criteria you prefer in choosing the best alternative**

\* the scale between economic factor and accessibility factor

اختيار ▾

⊙ هذا السؤال مطلوب

\* the scale between economic factor and *mobility and quality of travel of a facility*

اختيار ▾

\* the scale between economic factor and maximizing the road network

اختيار ▾

\* the scale between accessibility factor and *mobility and quality of travel of a facility*

اختيار ▾

\* the scale between accessibility factor and maximizing the road network

اختيار ▾

\* the scale between *mobility and quality of travel of a facility* and maximizing the road network

اختيار ▾

**Figure A-2.** Questionnaire Part2