A GIS-ASSISTED OPTIMAL BAGHDAD METRO ROUTE SELECTION BASED ON MULTI CRITERIA DECISION MAKING

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Abstract: Baghdad City suffers from severe traffic congestion due to the rapid urban expansion and travel demand growth. Based on many studies, urban rail transit was proposed by experts and the related transit agencies as an optimal solution to solve this problem. Accordingly, Baghdad metro route selection based on multi-criteria was proposed to be studied, evaluated and searched in the present research. The methodology utilizes a GIS to prepare and analysis data. Data was analyzed using a two-stage multiple-criteria decision making (MCDM) model which includes Analytical Hierarchal Process (AHP) and TOPSIS methods. Moreover, Geographic Information System (GIS) was used to explore the various route alternatives. To select the best alternative, all alternatives were evaluated according to the selected criteria. The weighting system is not only based on expert’s opinions but also includes a set of measures based on real data. Based to the outcomes of the present study, alternative route number 1 can be recognized to be the optimal route in the year 2014, and alternative route 2 is recommended to be adopted to meet the high travel demand requirement in the year 2035.

Keywords: Optimal Route Selection, MCDM, AHP, TOPSIS, GIS.

1. Introduction

The selection process attempts to optimize a number of objectives in determining the suitability of a particular route for a defined transit facility. Such optimization often involves a multitude of factors, sometime contradicting. Some of the important factor that add to the

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difficulty of the proper choice include the existence of numerous possible options, multiple objectives and intangible objectives [1].

The goal in a route selection project in transportation planning is to find the best optimal location based on predefined selection criteria. Route selection typically involves two main phases: (i) site investigated (i.e., define a number of candidate sites and number of selection criteria) and (ii) site evaluation (i.e., investigate each of candidate sites to find the optimum selection) [2].

GIS application is a computer-integrated tool proposed to be used in the present study to evaluate transportation network. Moreover, GIS applications include transit service area analysis, and network representation. In addition, network Analysis is a tool in Arc GIS software used to estimate, find the relationship, locations of network facilities in transportation, communication systems and others.

GIS and spatial analysis is used to analyze the station access and closeness of people and employees to the proposed and existing transit stations. The optimum route alternative is selected based on the evaluation of the related indicators and adopted criteria as an application of Multi-Criteria Decision making approach. It deals with a number of criteria, rather than on a one criterion and leads the decision maker with a recommendation on the best decision alternatives. This study identifies the application of GIS and spatial analysis to delineate catchment area of transit station, and determine which stations would serve a much more people by using socioeconomic data of transportation analysis zones around area surrounding each station. AHP (Analytic Hierarchy Process) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methods, as a multiple attribute decision making (MADM) methodologies are used to select an optimal route of Baghdad metro. In this regard, weight of the criteria is derived using AHP, while TOPSIS method is adopted to evaluate the alternatives.

2. Identification Metro Route Alternatives

Developing Metro routes alternatives are proposed and presented based on dual metro lines as the base case. Identification of route corridors and the destinations that will serve is based on several criteria as follows:

• Proposed alternatives should avoided tunnel, bridges.
• Proposed alternatives should pass through main road.
• Proposed alternatives should serve high residential density and pass through commercial area.

Based on these criteria, the following routes alternatives are proposed as follows:

1- Route Alternative 1

Route Alternative 1 represents metro 2 Line as the base case as shown in Fig. 1.
Route Alternative 1 has a length of about 21.5 km with 21 stations crosses Baghdad City from South East to West and South West also through the CBD area. This line starts from Aqba Bin Nafi Square in Al Masbah and continues in Al Saadoon street to reach Al Fath Square. Then it reaches the Al Firdaws Square and continues on Al Saadoon street to Al Tahrir Square and reaches Al Kalani Square before continuing on Al Khulafa street passing in front of Amanat Baghdad Administration Building where the interchange station with Line 1 is located. Then in Wathba Square the alignment turns left to reach Al Rashed street and crosses the Tigris River between Al Ahrar Bridge and Shuhada Bridge. It continues on Qahira street and passes in front of the National Museum before reaching Damascus street and Al Faris Al Arabi Square. The two branches start from this place.

2- Route Alternative 2

This route alternative include Route Alternative 1 and extension to new Baghdad area has a length of about 28.5 km which starts at al-Hurah square continues straight to Aqba Bin Nafi Square until reach garage al Amina square then it turning and passing reaching to new Baghdad through Cinema al badhaa square and continues straight to al mushtal area. The extension ends close to al mushtal Bridge. Route Alternative 2 represents as shown in Fig. 2.
3-Route Alternative 3

This route alternative includes Route Alternative 1 and extension to Shulah area has a length of about 29 km. It start at the end of Al Mansour Branch of Route Alternative 1 and turning to reach al Gazila main street, continues in straight line and ends in Al-Hamazia mosque intersection. It proposed to serve Shulah area, which is represents a high demand area. Fig. 3 shows route alternative 3.
3. Potential Metro Rail Ridership by Walking

Walking accessibility is one of the factors that will affect people’s willingness to travel by transit system. It is one of the most important factors that influence the transit system use. Therefore, pedestrian’s accessibility is playing an important factor in the design transit route alignment and the location of transit stops [3].

Highway network representation in ArcGIS version 10.0 cannot represent the actual walking distance because it neglects the highway’s width. Creation walkway network represents the topology of the network used by pedestrians. This network is different from the street centerline network in having a separate line segment for each side of the street and line segments representing crosswalks [4].

As shown in the Fig. 4, the existing highway network mapping in ArcGIS is represented as centerline in the left side of the above mentioned Figure. This technique is proposed and used as the base to build and represents the pedestrian network. In this regards, Freeways are removed from pedestrian walkway network because it is an inaccessible to pedestrians. The right side of Fig. 4 represents pedestrian network as coded in in ArcGIS.

![Figure (4) Representation of Pedestrian Network](image)

ArcGIS network analysis tools is used to estimate access coverage of a transit station, measuring service areas or catchment areas help to find which station has the largest demand for walking. As per the local traffic study [5], the average walk speed is estimated to be 2.585 km/hr (43.092 m/min) which is used in this study which is found to be slower than national average speed equal to 4 km/hr. Fig. 5 illustrates the service area within a 5, 10 and 15 minute from proposed and existing transit station.

Population and employment data is gathered from central organization for statistics and technology information and entered in ArcGIS using Transportation Analysis Zones (TAZ). Higher population and employment near transit station increase public transit by minimizing the time and cost of accessing transit. Service areas within five minutes walking time will be well served and areas within ten minutes walking time will be served. Increasing the access to the transit station more than 15 minute walking time will tend people to take several modes like bus, car, and bicycle. Network service area method results are more realistic than a circular buffer method for estimating the catchment area of a transit station.
People are generally willing to walk farther to a rail stop than a bus stop [6]. The population and employment within the 5, 10 and 15 minute can be estimated from a query between socio-economic data and catchment area. The following equation used interpolation method to estimate catchment area properties.

\[
P = \sum_{i=1}^{n} P_i \times aPi
\]  

(1)

Where \( P \) is the population in the surrounding catchment area of the metro station, \( i = 1 \ldots n \) represents the transport zones totally or partially covered by the catchment area, \( P_i \) is the Population in transport zone \( i \), and \( aPi \) is the area proportion of the transport zone \( i \) that is contained within the catchment area. Population and employment around the metro station for the year; 1997, and 2014 is provided on Table (1). Prediction population of 2014 is based on medium growth scenario of Baghdad Comprehensive City Development Plan project (CCDP) study and prediction employment data for 2014 dependent on the following equation:

\[
\text{Employment 2014} = \frac{\text{Population 2014}}{\text{Population 1997}} \times \text{Employment 1997}
\]  

(2)
### 4. Optimization Techniques based on Multi Criteria System

Optimization techniques solution the optimum location based on multi criteria using different optimization methods. To solve a decision problem, there are several methods used to select the best decision alternatives. The selection of an appropriate method depends on the decision problem and the preference of decision makers. Some of these techniques of optimization used in this study are as following:

#### 4.1 Analytic Hierarchy Processes Method (AHP)

AHP was presented by Saaty [7] to solve decision-making problems depended on multiple attributes. Over the time, it has been widely used. It is an optimization method based on the Multi criteria decision principle. AHP is a multi-criteria decision making technique that can help express the general decision operation by decomposing a complicated problem into a multilevel hierarchical structure of objective, criteria and alternatives [8]. AHP is used to determine relative priorities on absolute scales from pair comparisons in multilevel hierarchic structures [9]. A comparison scale developed by Saaty (1980) is used to represent the relative importance of the criteria.

At the first the Problem is structured and decomposed into a series of level. Each level shows a definite attributes. The second phase includes collecting the data. The third phase includes a decision maker was asked to assigns weight for each pairs of attributes; the most common nine-point Saaty scale is used. The problem structuring graphics of optimum metro route selection is presented in Fig.6.

<table>
<thead>
<tr>
<th>Name</th>
<th>Catchment area 1997</th>
<th>Catchment area 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Population</td>
<td>Employment</td>
</tr>
<tr>
<td>Al–Hurah</td>
<td>5855</td>
<td>6855</td>
</tr>
<tr>
<td>Al–Karada</td>
<td>3317</td>
<td>5505</td>
</tr>
<tr>
<td>Al Musbah</td>
<td>4238</td>
<td>4412</td>
</tr>
<tr>
<td>Aqba</td>
<td>1965</td>
<td>5004</td>
</tr>
<tr>
<td>Garage Al-Amina</td>
<td>6350</td>
<td>6480</td>
</tr>
<tr>
<td>Cinema Al-Badhaa</td>
<td>14970</td>
<td>8496</td>
</tr>
<tr>
<td>Almushtal</td>
<td>11841</td>
<td>795</td>
</tr>
<tr>
<td>Al-shulah</td>
<td>14308</td>
<td>795</td>
</tr>
<tr>
<td>Al Gazila</td>
<td>4861</td>
<td>334</td>
</tr>
<tr>
<td>Inter Gazila</td>
<td>3150</td>
<td>902</td>
</tr>
</tbody>
</table>
In Fig.6, the first level represents the goal of the decision problem which is the selection of the optimum route alternative. In the second level, the problem is consisted of main criteria and the lower level is divided into other sub-criteria. Based on the available literatures, the selected criteria can be shown in the above mentioned figure.

4.1.1 Design of the Questionnaire

Weighting the criteria by multiple experts avoids the bias decision making and provides impartiality [10]. Questionnaire form was designed and filled out via experts (specialists in the field of transportation engineering) to gather their opinions. Special academic staff and specialists in the related agencies are selected. The experts were asked to assess the importance of each criterion on a nine point Saaty’s scale to give the relative rating of two criteria. Moreover, personal interviews with the experts are conducted to assist this process. The sample size of 20 is selected for the experts to fill out the designed questionnaire. The scale of scoring assumes that the row criteria are equal or more importance than the column criteria. The reverse values such as (1/3, 1/5, 1/7, or 1/9) where used when the column criteria is more important than the row criterion [11]. After receiving the results of the respondents, the criteria were arranged and averaged using AHP Excel Template. Geometric means of experts’ choice values are calculated to form the final pairwise comparison matrix. The judgment should be consistent; all judgment matrices are checked for consistency test using the consistency ratio C.R. The consistency ratio (C.R.) is the last step of the AHP method. Priority weighting acceptance is inspected by consistency ratio, where the CR value equal or lower than 0.1, the weight values are valid. Fig. (7) and (8) show the analysis of AHP results.
4.2 TOPSIS Method

TOPSIS, a method was used by Yoon in (1980) [12]. A MCDM (multiple criteria decision making) problem was solved by “TOPSIS” method, taking into account the concept that stat the selection alternative should has:

- The smallest distance from the positive ideal solution (PIS)
- The farthest distance from the negative ideal solution (NIS).

Positive ideal solution tries to maximize the “benefit” and minimizes the cost, whereas in contrary the negative ideal solution maximizes the “cost” and minimizes the “benefit”.

*Figure (7) AHP of Main Criteria*

*Figure (8) AHP of Engineering Criteria.*
The method proposes, each criterion must be maximized or minimized. TOPSIS method is a useful and simple method for ranking alternatives priority, depending on the closeness of selected alternative from the ideal solution. Advantages of TOPSIS method is the pair-wise comparisons are avoided [13]. The steps of TOPSIS method are as follows:

• Formulation of the Decision Matrix

A matrix is formed with the existing real data in which the rows are the alternatives and the columns show the selected criteria. In this matrix, $X_{ij}$ represent the value of alternative $i$ based on the criterion $j$.

• Normalize the Decision Matrix

Normalization removes units from all data sets and values are between 0 and 1. Making the data from different scales converted to a one scale.

• Estimating the (PIS) and (NIS)

\[
A^+ = \{V_{1}^+, \ldots, V_{n}^+\} = \{(\max_j V_{ij} | i \in I) , (\min_j V_{ij} | i \in J) \}
\]

\[
A^- = \{V_{1}^-, \ldots, V_{n}^-\} = \{(\min_j V_{ij} | i \in I) , (\max_j V_{ij} | i \in J) \}
\]

Where $i$ is the benefit criteria, $j$ is the cost criteria.

• Separation Measure Calculation

To find the Euclidian distance of each alternative from the PIS, the equation below is used to find this distance:

\[
D_{i}^+ = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_{j}^+)^2}, \quad i = 1, \ldots, m
\]

The equation below is used to find the Euclidian distance of each alternative from the NIS:

\[
d_{i}^- = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_{j}^-)^2}, \quad i = 1, \ldots, m,
\]

• Find the Ranking of the alternatives Based on Closeness to the (PIS) and (NIS).

The final weight of the alternatives is calculated based on the following equation:

\[
C_i = \frac{d_i^-}{(d_i^+ + d_i^-)}
\]

Where $i=1,\ldots,m$

The final score of the routes is calculated and the optimum route is selected. TOPSIS method requires the weight for each criterion to calculate the normalized weighted matrix. The obtained weights from the AHP stage were applied.

5. Perdition of Optimal Baghdad’s Metro Route

In order to predict the optimal Baghdad metro route, AHP and TOPSIS methods are used in this selection process. For alternatives route evaluation, first the weight of criteria is derived from the AHP. Second, TOPSIS method is adopted to evaluate the alternatives.
5.1 Factors Affecting Route Selection

Route selection is the process to find locations that meet the desired conditions set by the selection criteria. In such a process, manipulation of spatial data and satisfaction of multiple criteria are essential to the success of decision-making [14]. Measuring criteria affecting the optimum route is conducted with aid of GIS spatial analysis can be presented as follows:

- **Population Density and Major Employment Center**

Population and employment density around metro station is a major factor for trip generation and attraction of current and future demand. The higher population and employment density around metro station increase the potential volume of ridership. To determine these values, network service method by the aid of ArcGIS software is used. A travel time equal 15 minute can be considered as the proper time for access to the metro station on foot. Catchment area properties were calculated previously in Table (1).

- **Connectivity to Existing Network and CBD**

Connectivity maximizing the highway network, increasing highway capacity and improves the traffic operation by reducing congestion. Metro route stations connected with a series of major network intersection will result in reducing the amount of congestion on existing intersections thus making the overall transportation service faster and more reliable. Connectivity to existing major network is measured by street density within the station catchment area which is the ratio between street length and service catchment area [15]. This is done by considering the sum of highway network length inside catchment area of each station of the network divided by the coverage served area. The results are shown in the Fig. 9.

![Figure (9) Street Density of the Proposed Routes](image)

Distance from CBD is measured using Near Distance tool in ArcGIS to determine the distance from each station feature to nearby CBD feature, the results are recorded in the output Table (2).

<table>
<thead>
<tr>
<th>Name</th>
<th>Near Distance m</th>
<th>Name</th>
<th>Near Distance m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aquba</td>
<td>1794</td>
<td>L2 Station 13</td>
<td>2081</td>
</tr>
<tr>
<td>Al Masraah Al Watany</td>
<td>802</td>
<td>L2 Station 14</td>
<td>2797</td>
</tr>
<tr>
<td>Mordjane Square</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 10 represents the sum of distance from CBD of all station for each alternative.

![Near Distance to CBD for each Alternative.](image)

- **Cost and Land Acquisition**

Cost should be minimizing for construction, operation and maintenance. Cost of the underground with an estimated one hundred twenty (120) million dollars per Km (Baghdad Comprehensive City Development Plan project (CCDP), 2014) [16]. Land price is conducted based on the existing average price gathered from the real estate offices surrounding the proposed metro routes areas. The cost and land acquisition of each alternative can be seen in Table (3).

<table>
<thead>
<tr>
<th>Name</th>
<th>Cost Million $</th>
<th>Land Acquisition Million $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>2580</td>
<td>60</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>3420</td>
<td>100</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>3480</td>
<td>200</td>
</tr>
</tbody>
</table>

- **Environmental Effects**

Field measurements of the intersections along the proposed routes were done for one hour to obtain various values of noise level, CO and CO$_2$. Try to minimize intersection-related air pollution and noise to protect the natural resources. Fig. 11 shows the pollution for each alternative.
5.2 Selection of Optimal Alternative

Field measurement, data collection and analysis results are used as an input data for the implementation of TOPSIS method to select the best alternative. The results can be shown in Table (3) and Table (4). The analysis results appeared that alternative 1 can be considered to be the optimum Metro route for the case study in 2014. This alternative operated on high demand corridors which will maximize revenues to the operator.
Table (3) TOPSIS Analysis Results.

<table>
<thead>
<tr>
<th>MIN.</th>
<th>MAX.</th>
<th>MAX.</th>
<th>MAX.</th>
<th>MAX.</th>
<th>MAX.</th>
<th>MIN.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>Population</td>
<td>Demand</td>
<td>Employment</td>
<td>CBD</td>
<td>Connectivity</td>
<td>Environment</td>
</tr>
<tr>
<td>2640</td>
<td>204975</td>
<td>310000</td>
<td>289863</td>
<td>49028</td>
<td>0.10992</td>
<td>7326</td>
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<tr>
<td>3520</td>
<td>283335</td>
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<td>360705</td>
<td>63932</td>
<td>0.14256</td>
<td>9472</td>
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<td>3680</td>
<td>240715</td>
<td>340000</td>
<td>293132</td>
<td>81792</td>
<td>0.13312</td>
<td>8161</td>
</tr>
<tr>
<td>0.293</td>
<td>0.08</td>
<td>0.152</td>
<td>0.098</td>
<td>0.102</td>
<td>0.146</td>
<td>0.128 weight</td>
</tr>
</tbody>
</table>

Table (4) Optimum Alternatives

<table>
<thead>
<tr>
<th>Alternative</th>
<th>S+</th>
<th>S-</th>
<th>Closeness</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td>0.036882</td>
<td>0.060576379</td>
<td>0.62156302</td>
<td>1</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>0.046861</td>
<td>0.040973775</td>
<td>0.46648761</td>
<td>2</td>
</tr>
<tr>
<td>Alternative 3</td>
<td>0.059634</td>
<td>0.019746045</td>
<td>0.248753465</td>
<td>3</td>
</tr>
</tbody>
</table>

6. Conclusions

Analytical Hierarchal Process (AHP) and TOPSIS methods are very effective tools can be used to select and evaluate optimal alternative. The evaluation system is not only based on expert opinions, but also take into account a set of measures based on real data. Based to the results of this study, alternative route number 1 can be recognized to be the optimal in the

- Weight in this Table from AHP
year 2014, and alternative route 2 is recommended to be adopted to meet the expected high travel demand requirement in 2035.

7. References


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