Metro stations site selection in Karbala city using (GIS)

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Abstract. Karbala city suffers from a range of traffic congestion problems due to increased travel demand, population growth, and limited transportation infrastructure. A metro system has been proposed as a solution for this problem, and this paper thus aims to determine the best locations for stations based on multiple criteria, to serve largest volume of passengers and to connect vital places, and highly populated areas. This analysis is done using geographic information systems (GIS) as a powerful tool for spatial analysis. The Analytic Hierarchal Process (AHP) was used in weighting the criteria and a degree of importance selected for each one. The results showed that 31 station sites could be selected as the best sites for metro stations.

Keywords: Analytic Hierarchy Process (AHP), Geographic Information Systems (GIS), Multi Criteria Decision Analysis (MCDA), Metro station.

1. Introduction
Public transport systems are generally recognized in developed countries as solutions for urban traffic congestion problems [1]. Metro transportation is one of the public transport network options, and the metro system is described as a fast, safe, reliable, and low-cost, comfortable option for transportation purposes [2]. The metro system includes two main components, stations and routes, which are necessary for the comfort and safe delivery of users. Metro stations are defined as places where metro vehicles stop to pick up and drop off passengers, thus acting as places where people start and end their journeys [3]. Metro stations and service can thus be considered an important component of public transportation systems and their benefits include increased mass transit capacity, speed safety, comfort, reliability, and regularity [4]. There are three types of metro stations, which are based on the level of the metro route in question: underground, elevated, and ground-level stations. The construction costs of the elevated stations are lower than for underground stations because underground stations require more construction work [5]. Optimal station design also requires an optimal location. Locating stations in close proximity to more active centres and main roads will make them more accessible [3]. Metro stations should be located in a way that ensures adequate coverage and fast accessibility user destinations [6]. Determining the optimal location of metro stations is an important issue and must be part of any strategy to promote public transport and improve the urban mobility.

GIS programs provides powerful tools for developing analysis techniques due to their ability to, store, process, manage, and aid evaluation of data [7]. The aim of this study is thus to determine the optimum location of several metro stations in Karbala using Geographic Information Systems (GIS) and Multi Criteria Decision Analysis (MCDA).

2. Site description
Karbala is one of the religious and tourist centres of Iraq, and it is located 110 km to the south west of the country's capital, Baghdad, at 32:60 N, 44:00 E. It is around 36 meters above average sea level, and its total difference in contour lines is 15 meters compared to the city centre. It is roughly 10 by 3 km in
size, and has direct road to the west to Syria, Jordan, and Saudi Arabia. To the north, Karbala is connected to Baghdad and the Nnorthern governorate Figure. 1 shows an overview of Karbala.

![Karbala city centre](image)

**Figure 1. Karbala city centre**

3. **Literature view**

Gendreau and Laporte [8] addressed the problem of locating a metro or rapid transit line, and used a tabu-heuristic for this purpose. The objective function included maximising the total population covered by the metro alignment. Bruno et. al [9] similarly presented a heuristic mathematical model for the location of rapid transit stations for Milan city using population criterion in their objective function. Laporte et. al [10] presented mathematical models using the traveling salesman heuristics to design metro networks. Three main criteria were used in these mathematical models: (1) the total construction cost; (2) the total population covered by the network; and (3) the total O/D traffic captured by the network.

Samanta and Jha [11] proposed an optimisation model based on the Genetic Algorithm to plan a rail transit line in the Washington, D.C. area. In their model, three objective functions were used: minimisation of total system cost per person, maximisation of ridership, and minimisation of user cost per person. The feasible locations for stations were further identified by developing a Geographic Information System (GIS)-based algorithm.

Gutiérrez-jarpa et. al [12] proposed a tractable model for the design of a rapid transit system for Milan city where travel cost was minimised and traffic capture was maximised. A frequently used objective in rapid transit network design is also to maximise the covered population, that is, to focus on population located close to the stations, rather than maximising trips. Ahmed and Asmael [13], presented a methodology for optimal metro route selection in Baghdad based on Multi Criteria Decision Making (MCDM) and GIS methods; there, route corridor identification was based on several criteria such as population, main roads, tunnels, and bridges. The weight of these criteria was derived by using the AHP method.
Skaik [14] presented a methodology for determining the placement of metro stations on the Gaza strip based on GIS-MCDM; the criteria for choosing the best sites included population density, vital places, important intersections, suitable land, soil type, ground water, and slopes. For criteria weighting purposes, a simple linear combination method was used. El-Hallaq and Khalid [15] included the evaluation of a case study in Gaza city to select metro station sites using spatial multi criteria decision analysis and GIS. The criteria used to choose the best stations included population density, vital places, available parking, intersections, traffic importance of intersections, and land use; a simple linear combination method was utilised to define the weighting of these criteria.

4. Methodology
The purpose of this study is to determine the best locations for a metro network in Karbala. This selection is based on many criteria, and the locations that satisfy these criteria will be selected as optimal locations. The station site selection methodology is divided into two parts as follows:

- Identifying the main criteria and related data required for suitable site location;
- Using GIS Model Builder to incorporate all necessary series of data for processing and analysis to obtain the best locations for metro stations.

4.1 Main criteria and data identification.
El-Yazory [16] defined criteria as a set of guidelines or requirements that are used as a basis for decision making or a choice between alternatives; thus, identifying the optimal locations of stations should satisfy the following criteria:

1. The stations should be close to highly populated area; the required data for this criterion is thus the population for each neighbourhood in Karbala.
2. The stations should be located in high travel demand areas; the relevant data here come from trip origin and destination surveys.
3. The stations should be located near educational, commercial, industrial, recreation, religious, and residential areas, alongside main roads and main intersections, and avoid agricultural and vacant areas; thus, the required data is land use information about Karbala.
4. Stations should be placed near to vital and active centres, within walking distance of such places; this is specified as from 500 to 1,000 metres [17].
5. The distance between stations must be in the range of 500 to 2,000 metres [9].

4.2 Data collection.
The main data were obtained from several different sources, including CAD, and Excel files and Geodatabases. CAD and Excel formats were converted to Environmental Systems Research Institute (ESRI) Geodatabase Feature Classes using the same coordinates system, which is the Universal Transverse Mercator (UTM) projection system with coordinates (x, y meters) with Zone Number 38N. Data were represented as follows:

1. Karbala city population
   Population data were obtained for each neighbourhood from the General Directorate of physical planning. The total population of Karbala by the year 2037 is estimated to be 2,097,404. Figure 2 shows the Karbala population.

2. Trip origin and destination surveys
   These data were obtained by means of a questionnaire that was distributed to households in each neighbourhood of the city to ask people about their trips, including the purposes of their trips, trip frequency, and where their trips begin and end, to capture the most popular trip destinations. It was thus necessary to check the sample size using the following equation [18].

\[ N = \left( \frac{Z^2 \sigma^2}{d^2} \right) \ldots (1) \]

\( N = \) minimum sample size of household for each neighbourhood.
To predict trip distribution in the year 2037, growth factor modelling as represented in the following equations was used [19]:

\[ Ti = fi \times ti \quad \quad (2) \]

where \( Ti \) is the future trips number in an area, \( ti \) is current trips number, and \( fi \) is a growth factor. The growth factor, \( fi \), takes into consideration several variables such as the population (\( P \)) of an area, mean household income (\( I \)), and mean vehicle ownership (\( V \)). The \( fi \) form is represented as follows [19]:

\[ fi = \frac{Pi^d \times i^d \times Vi^d}{Pi^c \times i^c \times Vi^c} \quad \quad (3) \]

where \( d \) refers to the design year, (2037) and \( c \) refers to the current year (2017). From the Central Organization for Statistics, the yearly growth rate for the population is 4.1%; for vehicle ownership it is 6%; and for household income it is 2.2%.

\[
\begin{align*}
P_{12017} &= 923763 \\
P_{12037} &= 2097404 \\
I_{12017} &= 1166 \\
I_{12037} &= 1689 \\
V_{12017} &= 55819 \\
V_{12037} &= 179019
\end{align*}
\]

By applying equation (3), the growth factor (\( fi \)) = 10. Equation (2) was then used to estimate the trip distribution in design year 2037; Figure. (3) shows the trip distribution in 2037.

3. **Karbala land use**

This data layer was obtained from the General Directorate of physical planning; it is divided into ten sections: 0.64% educational, 0.38% health, 0.30% commercial, 4.3% industrial, 0.8% cemetery, 0.27%
recreation, 2.7% public, 0.046% religious, 32% residential, 21.6% vacant, and 12.07% transportation. Figures 4 and 5 show the land use layer and transportation layer.

**Figure 3.** Trip destinations in year 2037.

**Figure 4.** Land use type in Karbala.
4. **Vital places**

Vital places include all active centres such as universities, schools, public places, commercial areas, and industrials areas). This layer was obtained from the General Directorate of physical planning. Figure. 6 shows several such vital places.
4.3. Selection of suitable location for stations

The steps for selection included a series of analyses and processes designed to obtain the best locations for stations. These processes are represented as cartographic models, and a GIS Model Builder was thus required for these purposes. These steps were as follows:

1. **Feature to raster conversion**
   After collecting the main data and representing it as map layers, the population, land use, and trip destination layers were converted to a raster layer with 20 cell sizes using the feature to raster tool. After that, the population and trip destination raster layer values were reclassified to new values from 1 to 10, depending on their importance, using the Reclassify tool such that cells with high suitable values were rated as 10 and cells with lowest suitable values were rated as 1.

2. **Euclidean distance**
   The Euclidean distance tool was applied to calculate the distances from the vital places, then reclassification of these distances into three intervals, one from 0 to 500 metres, the second from 500 to 1,000 metres, and the third for distances more than 1,000 metres, was done using the Reclassify tool.

3. **Weighting process**
   The criteria weights were assigned according to their importance at two levels: the first level was driven by the influence of the main criteria using an Analytic Hierarchy Process (AHP) method, while the second level involved scaling the criteria components from 1 to 10 according to their importance as in step 1. The AHP method proposed by Saaty [20] is a powerful and flexible method of weighting using pair wise comparisons (PCM). The Saaty PCM involves a nine-points scale where 1 is of equal importance, 2 is weak or slight, 3 is moderate, 4 is moderate plus, 5 is strong importance, 6 is strong plus, 7 is very strong, 8 is very strong, and 9 is of extreme importance [21]. For this weighting process, expert opinions are required to assign the weights to each criterion; in other words, experts must assess the importance of each criterion in relation to the others.

![Figure 6. Karbala vital places.](image)
importance of each criterion based on the 9-point scales before the weights are averaged and an AHP method used in an Excel program to complete the weighting. After criteria weighting, the criteria and their weights were entered into the GIS system using a weighted overlay tool set to define the most suitable, moderately suitable, and unsuitable locations; the output layer was thus reclassified to suitable and unsuitable areas.

Figures 7a and 7b show the criteria weights in the weighted overlay tool.

4. Station location assignment
The main intersections were overlaid on suitable locations and the intersections of unsuitable locations were removed to measure the distance between vital places and intersections; based on the results, the nearest intersections were chosen as station sites.

Based on the full process, 31 sites were chosen as suitable station locations. Fig. 8 shows the results of the process, and Fig. 9 shows the Model Builder of suitable station locations.

![Suitable metro station locations](image1)

**Figure 8.** Suitable metro station locations.

![Metro station locations model](image2)

**Figure 9.** Metro station locations model.
5. **Conclusions**

1. The result of analysing and processing of data, represented as a GIS-Model-Builder, was a map which contained 31 optimal sites for metro stations to serve the most populous areas in the city while being integrated with main roads, main intersections, vital places, and active areas as based on an analysis of trip destinations.

2. The influence of each main criterion derived by the AHP method was based within the nine-point Saaty scale, which gave 45.95% land use, 27.22% population, 18.07% trip attraction, and 8.7% for vital place distance.

3. The resulting weighted model in GIS tended to identify the best locations at areas close to sites with high weightings such as main roads, main intersections, educational areas, avoiding sites with low weight such as vacant places, low populated areas, and high slope areas.

4. The distances between stations and vital places were within the accepted limits of walking distance, set as not more than 1,000 metres, and the distance between successive stations was within expected limits of 500 to 2,000 metres.

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