Predefined Evaluating Criteria to Select the Best Tramway Route

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***Abstract*—The primary goal of any route selection is to find the best one with adopted conditions that meet the predetermined selection criteria. Manipulating spatial data of multiple criteria using Geographic information system (GIS), GPS, and Civil 3D programs is presented in the paper. A case study in Al-Ramadi City, in which the best tram route was chosen, was applied. Six alternative routes were proposed. A multi criteria decision-making (MCDM) methodology was adopted to decide the best alternative. The study proved that a GIS based system combined with (MCDM) techniques may be a suitable tool for transforming geographical data into a decision and can be applied in tramway route planning and design.**

***Index Terms*—tram route, best route selection, criteria weighting, multi criteria decision-making.**

I. Introduction

Any public transportation infrastructure development project should begin with the recognition of an existing or projected need to meet the present and growing demand in the future. This problem will result in a series of actions, starting with searching out and screening geographic areas and specific locations. Routes that satisfy the screening criteria are subject to detailed evaluation [1].

Each railway line is a complex system that must fulfill certain objectives, some of which include: sufficient capacity, appropriate speed of travel, comfortable transport, high level of traffic safety, economic viability, blending in with the existing and planned developments, and environmental protection.[2].

The goal in a route selection process is to find the best location with the desired conditions that satisfy predetermined selection criteria. Locating rail stations and planning railways, involves specialized resource allocation and laying routes, which are really complex problems that depend on multiple factors

The solutions of these complex problems, in order to make decisions, require sequences of processes for factors and criteria that need to be processed so that relevant information can be obtained [3].

Geographic Information Systems (GIS), Multi-Criteria Decision Making methods (MCDM), and Expert Systems (ES) have been extensively used in solving site selection problems for the last few decades. However, these techniques have their own limitations in addressing spatial data, which is indispensable when addressing spatial decision problems such as route or site selection problems. For example, traditional MCDM techniques have been non-spatial. However, in real-life situations, the entire study area can hardly be assumed to be spatially homogenous because the evaluation criteria previously varied across space.

A GIS system is utilized to perform the spatial analysis required when screening candidate sites. A MCDM procedure is used for evaluations. (MCDM) can be explained generally as a tool that assists decision maker to select the best alternative from all possible alternatives under the presence of multiple choice criteria and diverse criterion priorities [4].

This paper has accomplished sequences of processes for factors and select criteria required by and important to the tram route alternative selection process. An application case study was also conducted to choose the optimal alternative for Al-Ramadi City.

II. Research Goals

The main goal of this study is to highlight the main limitations and features that can be used as discriminating factors when choosing the best tram route in urban areas using a multi-criteria approach. Thus, the objectives of the study are:

- To analyze and explain factors along with their limitations, which should be considered when collecting geometric data during the process of choosing candidate routes and their stop stations.
- To express the most important criteria (parent and sub-criteria) that will govern the decision of selecting the best tram route in urban areas.
- To reflect how GIS and MCDM tools can help improve the quality of decision making through increasing the capacity of data analysis, display, and management.

III. Review of Related Literature

A. History of Tramway

The first electric street tramway was opened in1885 in Britain. It used a conduit collection along Black pool Promenade. The first true electric tramway “with overhead wires” opened in Rio de Janeiro in 1892 [5].

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The trend of using light rails in the United Kingdom was firmly established with the success of the Manchester Metro link system and the Sheffield Super tram in 1992, followed by Midland Metro in Birmingham in 1999, and the Tram link in London in 2000 [6].

B. Advantages and Disadvantages of Tramway

Tramways have several advantages that encouraged its use in developed countries. Semaly found that the tramway system reduces traffic congestion and environmental problems as well as improves public transport [7]. In addition, Zwolski explains that the design of tramway lines, which are dependent from streets, will enable its fluent operation and avoid traffic jams. He also concluded that maintenance costs will be at reasonable levels because it uses long-lived and durable vehicles [8].

The primary disadvantages of light rail transit is the capital cost, Rail cars cannot operate beyond the limits of their tracks, and The visual impact of overhead wiring may be considered a disadvantage [9].

In conclusion, tram transportation is environmentally friendly and provides comfortable travel, flexibility of movement, and safety. It is capable of transporting a large number of passengers at high speed, is inexpensive to run, and is adaptable to future needs.

C. Route Selection Process

Route selection is a complex process that represents the first step in design and construction, whereas the process of selecting the best route is very important for maximizing safety and efficiency as well as for minimizing cost [10].

Before route selection, the area should be navigated and surveyed. However, several requirements should be considered for optimal selection, such as the shortest route, the topography of the area, the land use of the area, and population density [11].

Moreover, according to HIPAP, various factors may affect route selection, such as environmental and land use, operational factors including economics and operator's requirements, relevant codes, standards, and mandatory considerations that must be observed transport economics of the various route alternatives, and emergency response capability [12].

D. Stop Station Location Selection and Design

Stations are the places where trams stop to collect and deposit passengers. Given that stations are the first point of contact most passengers have with the tramway. The main considerations when selecting the location of stop stations are as follows: property access, land use, environment, traffic operations, intersections, and transit location [13].

Platform width is also an important feature of station design. The width must be sufficient to accommodate the largest number of expected passengers but must not waste space, which is always a premium for station areas in expensive land districts of a city. Platforms come in two types: Island and Side Platform Stations [14].

IV. Limitations and Factors That Affect Data Collection

To select an appropriate and secure track, proper and accurate data should be collected. Therefore, setting up assumptions and limitations is considered important. These assumptions and limitations are governed by the following:

1) The geometric design of the track, which depends on the length and shape of the selected tram vehicle. The elements of the tramway track were assigned depending on global references.

2) Location of track. This factor is governed by land use; population density; traffic density and congestion; and the existence of important positions, generations, and attractions.

The following are recommended regarding land use:

- Possessing the land owned by the transport authority is preferable to decrease the cost.
- Higher population density land should be made available.
- Sufficient space is required for the construction of the main parking area at origin and destination stations.
- The track passes through attractive and generating areas.
- The track route should avoid tunnels and suspension bridges as much as possible.
- The track should be secure and as far away from residents as possible.

V. Alignment Important Considerations and Limitations

The navigation and surveying involved in choosing the tram route include two important fieldworks: Origin-Destination selection and Candidate Routes selection. Based on the specifications and limitations, these two points must be selected accurately to meet the requirements of the city.

Origin-Destination Selection

Origin-destination selection is considered the basic elementary step in the route choice process. A complete tram trip starts at the origin station and ends at the destination station. Each route should start from the origin node and end at the destination node. Origin and destination nodes are detected using GPS. GPS is sufficiently accurate for such investigation.

Candidate Routes Selection

After origin and destination locations were selected, routes are selected to connect them according to specifications and decided limitations. The selected candidate routes are characterized by:

a) High population density near the track;
b) Traffic congestion; and
c) Disparity between generation and attraction areas.

VI. Stop Platform Locations Selection

To select the platform locations for the candidate routes, a land use layer is necessary. Arc GIS maps are used to explain the types and categories of the adjacent lands through which the routes pass.

The stop stations (platforms) are selected depending on the land use layer categories and according to generation and attraction zones.

The land use layer always has the following categories:

a) Residential area “generation zone”;
b) Commercial area “attraction zone”;
c) Services area, “which includes schools, hospitals, and others of governmental departments.”
d) Amusement areas“ include the agricultural and recreational areas”; and
e) Industrial areas.

VII. Checking the Candidate Routes Validity

The validity of candidate routes should be checked by ensuring that they conform to the specifications and limitations that were decided for the tram route. The main factors that govern route validity are track location and geometry.

A. Location of Track

Candidate routes should pass through areas of various land use and have available population density, in addition to the existing exchange trips between generated and attracted zones.

B. Track Geometric Design

Three geometric elements were considered for checking the validity of candidates.

1) Cross-sections, which depend on the adopted specifications for vehicle cross-sections, its track width, and recommended clearances. Its validity is checked against available street cross sections.

2) Curvature of the route. The critical highway curvature should be compared with the allowable tram route curvature. AutoCAD is a suitable tool for computing the curvature of the highway.

3) Vertical clearance. The existence of bridges that pass over the tram route is the sole obstacle in the vertical clearance category. The overpasses vertical clearance should be measured and their locations should also be assigned using GPS and then represented using Arc GIS Map.

VIII. Selection and Adoption of Criteria

The properties and the characteristics of each route should be identified following proposed criteria, which may slightly differ depending on ambience conditions. A list of criteria that are relevant for evaluating alternative route solutions should be selected and adopted. The selected list assists in forming quantitative, qualitative, and socio-economic criteria.

IX. Case Study

The objective of this part is to show how the proposed criteria and limitations decided above can affect the choice of the best tram route. The study area is Al-Ramadi City, located in the province of Al-Abnar in western Iraq, which has a rapidly growing population of approximately 550,000. It is located approximately110 km west of the capital, Baghdad, and occupies one third of the total area of Iraq. It has an important strategic location because it lies on the main expressway that leads to the Syrian and Jordanian borders.

A. Data Collection and Processing

The first stage was a wide-ranging navigation and exploration of the study area so that the origin and destination of the track can be assigned and the best candidate routes of the tramway can be allocated. Suitable locations for tram stop stations are then assigned while taking into consideration the above limitations and criteria.

Different tools and devices were used to facilitate and manipulate the accuracy of the collected data. These tools are:

1) Measuring tape to measure the cross-section of roads.

2) Garmin **e**trex GPS was used to collect position coordinates and calculate distances.

3) Total Station device. Leica (TC 1202) was used to calculate the radii of curves in roads.

4) Arc GIS10 program was used to represent the collected data on the satellite image of Al-Ramadi for the 2010, which was obtained from the Al-Ramadi Department of Urban Planning. Data was also produced from the Master Plans (2012 and 2033) of city of Al-Ramadi, the land use map,and the contour map.

B. Origin-Destination Selection

The eastern and western accesses of the city were chosen as the origin and destination, respectively. A position located 700 meters before the new entry gate was chosen to be the origin station for the followings;

1) It is the largest vacant area, which is needed to construct the main station and the main parking area.

2) A residential area with high population density surrounds this position.

3) Rural users can easily reach this area.

The destination station was decided to be in the western side of Al-Ramadi. The 18-kilometer region was chosen based on the future city extension following the new 2033 master plan. The coordinates of the origin and destination were saved using a GPS device and then represented on an Al-Ramadi Satellite Image using the GIS program, as shown in Fig. 1.

Figure 1. Origin-destination locations

C. Candidate Routes Selection

Six candidate routes were selected. Arc GIS10 was used to represent the routes on satellite images of Al-Ramadi. Fig. 2 shows the six candidate routes.

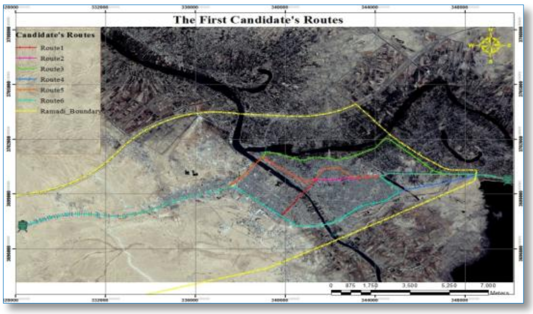


Figure 2. The location of the six candidate routes

D. Stop Platform Location Selection

Stop stations have been selected for each route. Arc GIS10 was used based on the Al-Ramadi master plan. Following the land use sub criteria, the platforms were chosen. Fig. 3 illustrates the land use categories and the platform locations.

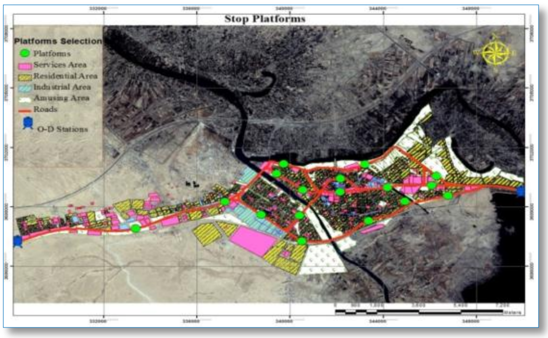


Figure 3. Land use categories and the platform locations

E. Candidate Routes Validity

Explanation and navigation clarified that the six candidate routes passed through areas of various land use, available population density, and existing important positions, in addition to the existing exchanging trips between generated and attracted zones. Based on the above, the six candidate routes conform to the tramway track requirements related to the location.

Three geometric elements were considered to ensure the validity of the candidates: cross-sections, curvature of the route, and vertical clearance. The data of each candidate were collected from origin to destination to check if they met the required specifications.

Cross-section: A GPS instrument was used to assign the positions of change in cross-sections, whereas the collected data has been presented for each route using Arc GIS10 Map. The cross section for the tram route should be 20.8 meters or more [15]. The cross-section along the route for all candidates is not the same. Thus, the critical cross section, which has the minimum width, will be adopted to check the suitability of the candidate. Table I shows the cross sections in the routes. Routes 5 and 6 are unworkable and will be discarded from the discrimination process.

The remaining four candidates will be checked against curvature and vertical clearances.

Curvature: The radius of the tramway track should not be less than 25 meters [8]. Thus, the radii of the six candidate routes were surveyed using a total station device to ensure that they correspond to previous specifications. Table 1 shows the critical radius for each route.

Vertical clearance: The existence of pedestrian overpasses is the sole obstacle according to the vertical clearance category. The vertical clearance for each pedestrian overpass was measured manually, whereas its location was assigned using GPS, and then represented by Arc GIS Map. Table I clarifies the vertical clearances for the candidate routes. Ref. [15] states that the minimum vertical clearance of the tramway should be equal to or greater than 4.1 meters.

TABLE I. ROUTES CRITICAL GEOMETRIC VALUES

Route	Critical cross-sec	Min. curve R	Over-pass H.
1	22	40	5.25
2	27	80	5.25
3	22.5	242.5	-
4	32	232.5	5.5
5	19.3	52	5.5
6	20	15.4	5.25

X. APPROACH TO THE BEST ROUTE EVALUATION

Conducting the following two steps prior to the best route evaluation process is essential. These steps will facilitate the process of choosing the best alternative.

Triage: This step involves discarding unworkable routes. Removing plainly unacceptable candidates in a triage step early in planning is valuable because it avoids wasting effort. However, documenting why a candidate was rejected and that the process was fair is still necessary. Table 1obviously indicates that Routes 5 and 6 will be discarded due to their low estimated values for cross sections and curve radius. Therefore, the following steps will be applied only to the remaining four routes.

Center nodes: One useful technique is to examine the network of route segments for what can be called "Center Nodes." The node splits the routes into partial routes. Using this technique, the task of finding the optimum route is reduced while maintaining evaluation quality. The selected case study routes were surveyed and examined, and the four alternatives were found to be joined at the last center node. Therefore, the evaluation of the alternatives ends at this node.

XI. EVALUATION OF ALTERNATIVE SOLUTIONS

The Multi-Criteria Decision Making (MCDM) method has been used to evaluate and select the best route among the four candidate routes. A multi-criteria decision rule is a procedure that allows for ordering alternatives to enable the selection of which is preferred to another. It integrates the data and information on alternatives and the preferences of the decision maker into an overall assessment of the alternatives. The (MCDM) methodology involves several steps [3].

1) Set of allowable route alternatives.
2) Selecting relevant list of evaluation criteria.
3) Initialize decision-making matrix.
4) Normalize decision-making matrix.
5) Calculation of weight coefficient
6) Calculation of the final decision making matrix
7) Ranking set of alternative solutions
8) The most favorable route alternative.

Four routes have been identified as proposed alternative routes. The subsequent step is selecting and adopting evaluation criteria that are relevant for the evaluation of alternative route solutions. The list of criteria represents qualitative, quantitative, and socio-economic criteria. Fig. 4 shows a hierarchy diagram for main adopted criteria and their sub criteria.

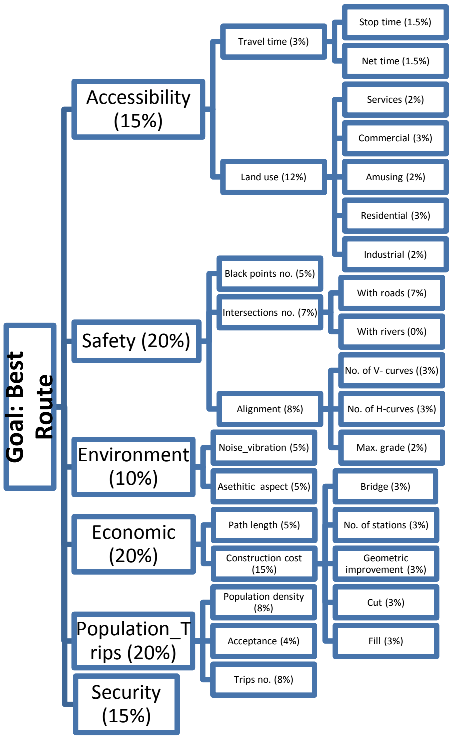


Figure 4. Selected criteria hierarchy diagram

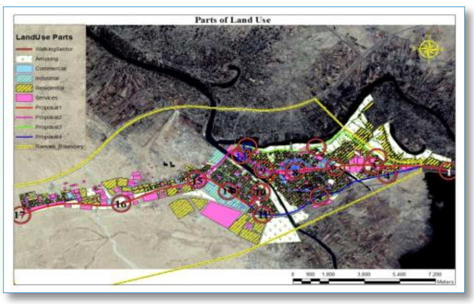
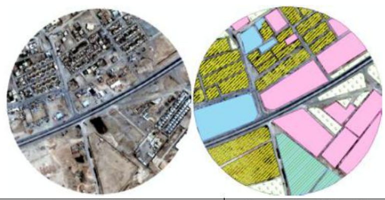


Figure5. Land use and sectors along the study area

A group of experts composed of three decision makers (civil engineers) in the city and the author determined the weights of the major objectives in the hierarchical decision model as shown in Fig. 5. The nature of the study area and its circumstances were taken into consideration during weighting. The final evaluation values were then averaged to represent the criteria weightings.

To initialize the decision-making matrix, assigning and computing the values of the main criteria and their sub criteria are important. Several tools and programs were used and much time was spent to achieve this task. The calculated value of the land use (sub criteria) is detailed and illustrated in the following section as an example to explain the calculated values of the criteria.

Land use: To facilitate the evaluation process, the study area was divided into 17 equal areas, called circular sectors. The radius of each sector was taken to be 350 meters. This value represents the maximum distance that pedestrian can walk according to the Iraqi specifications [15]. Each sector was surveyed to calculate the existing land use categories, which are the residential (R), commercial (C), industrial (I), service (S), and amusing (A) areas. Fig. 5 illustrates the entire sectors in the studied area, whereas, Fig.6 demonstrates the land use evaluation process for Sector 15.



Sector Satellite Image	Sector Land Use Shapefile
R = 22 S = 11 C = 8%AT ,I =7%AT = 7%AT	

Figure 6. Land use evaluation for Sector 15

TABLE II. LAND USE CATEGORIES VALUES AS % OF TOTAL AREA FOR ALTERNATIVES

Alt.	Sectors	(R)	(S)	(C)	(I)	(A)
1	$S_1+S_3+S_6+S_8+S_{10}+S_{14}+S_{15}+S_{16}+S_{17}$	162	58	55	47	17.0
2	$S_1+S_3+S_6+S_8+S_9+S_{13}+S_{15}+S_{16}+S_{17}$	144	69	62	9%	15.6
3	$S_1+S_2+S_7+S_{12}+S_{15}+S_{16}+S_{17}$	96	28	22	7%	17.2
4	$S_1+S_4+S_5+S_{11}+S_{14}+S_{15}+S_{16}+S_{17}$	161	23	24	45	18.2

TABLE III. TOTAL CALCULATED VALUES OF THE ADOPTED CRITERIA.

Criteria	Alternative	Route 1	Route 2	Route 3	Route 4
Access.	Travel time, s	24.65	24.36	24.16	31.22
	Land use.km2	492	440	325	435
Safety	Black points	4	5	6	5
	Intersect., no.	25	24	20	16
	Align, no.	74	81	89	59
Environ.	Noise, L %	39.2	33.1	47.2	35.9
	Aesthetic, L	11	9	30	5
Econom.	Path L, km	23.5	23.17	24.12	31.75
	Constr. cost	22507	42089	53290	101214
Density.	persons/km	36774	42985	24463	24263
	Accept.% of pop.	96	95	94.6	96
	Trips, no./month	2760	1775	1128	1000
Security points, no.		4	5	6	5

Then, the land use criteria for each route were calculated by aggregating the identical values for the sectors that the route passes through. Table II indicates these values for the proposed alternative routes.

The multi criteria decision-making process continues by assigning the relative values and weights to all criteria. Table III shows the sum of the calculated values of the adopted criteria for the alternative routes.

In the next step, the matrix values indicated in Table III were normalized using a scaling factor (ß), taking into consideration the desirable values among alternatives. Table IV represents the normalized values.

- If a high criterion value is desirable (e.g. Population density, Trips ….etc.):

$$ß = \frac{Calculated\ Value}{Max.Value} * 100.$$

- If a low criterion value is desirable (e.g. Travel time, Cost … etc.):

$$ß = \frac{Min.\ Value}{Calculated\ Value} * 100.$$

Table IV. NORMALIZED DECISION MATRIX VALUES

Criteria	Alternative	Route 1	Route 2	Route 3	Route 4
Access.	Travel time, s	98.05	99.22	100	77.42
	Land use, km2	93.24	78.75	59.59	73.43
Safety	Black points, no.	100	80	66.67	80
	Intersection, no.	62.5	65.22	78.95	100
	Alignment, no.	87.2	63.7	57.88	80.41
Environ.	Noise, Length %	84.44	100	70.13	92.2
	Aesth.,% length	36.67	30	100	16.67
Econom	Path length, km	98.54	100	96.05	72.96
	Construct cost	63.45	54.16	79.49	46.44
Density	persons/km	85.55	100	56.91	56.45
	Accept.%of pop.	100	98.96	98.54	100
	Trips, no./month	100	64.31	40.87	36.23
Security, points, no.		100	80	66.67	80

The following step is rating the scores of each alternative route. The criterion rate for each alternative has been calculated by multiplying the scaling factor (ß) of each criterion by its own weighting factor.

Rating of Score = scaling factor (**ß**) * weighting factor.

The final step in the MCDM method is obtaining the total scores for each alternative and ranking them based on their ratings according to relevant criteria. The alternative with the highest score is the preferable route. The final decision making matrix is indicated in Table V and illustrated graphically in Fig. 7.

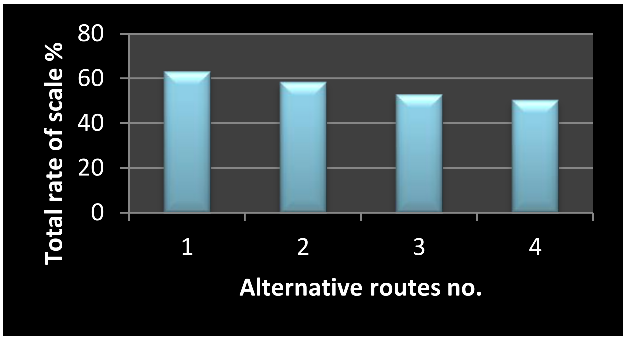


Figure 7. The final scoring rate and ranking of alternative routes

TABLE V. THE FINAL DECISION-MAKING AND RANKING MATRIX

Criteria	Alternative	Route 1	Route 2	Route 3	Route 4
Access	Travel time, s	4.90	4.96	5.00	3.87
	Land use, km2	2.85	2.42	1.56	2.22
Safety	Black points	4.0	3.20	2.67	3.20
	Intersection, no.	3.13	3.26	3.95	5.0
	Alignment, no.	1.74	1.27	1.15	1.60
Envirn	Noise, L %	4.22	5.0	3.51	4.61
	Aesth.,%length	1.83	1.50	5.0	0.83
Econm	Path length, km	4.93	5.0	4.8	3.65
	Construct cost	1.90	1.62	2.38	1.39
Denstiy	persons/km	7.70	9.0	5.12	5.08
	Accept.%of pop	8.0	7.92	7.88	8.0
	Trips, /month	8.0	5.14	3.27	2.90
Security, points, no.		10.0	10.0	8.0	6.67
	Sum	**63.2**	**58.29**	**52.96**	**50.35**

XII. RESULTS ANALYSIS

1) The first part for this research showed and predefined the real-life constraints and criteria that are necessary for choosing favorable alternative tram routes. These limitations and assumptions are considered important for the planners and engineers who are interested in the tram route selection.

2) The results of the multi-criteria ranking based on MCDM method (Table V) clearly indicate that Alternative Route 1 represents the best route. However, its score value is approximately 5% more than the second alternative, whereas the other two alternatives have low weighting value but they have similar ranking scores.

XIII. CONCLUSIONS

1) Analyze, locate, and explain factors along with their limitations, which should be considered when collecting

geometric data is playing cordial role during the process of choosing routes and their stop stations. Doing so in an accurate manner will result in the correct process of selecting the candidate routes and their stop stations.

2) The process of selecting alternatives mainly depends on the predefined criteria and their selected sub-criteria as explained in Fig. 4.

3) The weighting decision of the experts played the main role and had a significant effect on the ranking of the alternatives.

4) This paper shows how GIS with MCDM can support decision makers in designing, evaluating, and implementing the spatial decision-making processes. The analytical capabilities and computational functionality of GIS promotes the production of policy-relevant information to decision makers. Moreover, using this approach (integrating GIS and MCDM) provides considerable assistance in reaching a satisfactory compromise when ranking the alternatives according to criteria. The methodology can successfully be applied to resolve problems that involve the selection of railway routes.

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