International Journal of Constructive Research in Civil Engineering (IJCRCE)
Volume 4, Issue 3, 2018, PP 11-22
ISSN 2454-8693 (Online)
DOI: http://dx.doi.org/10.20431/2454-8693.0403002
www.arcjournals.org

Optimal Railway Routing using Spatial-Temporal Analysis in Gis (A Case Study of Bafgh – Yazd, Iran)

Ali Hasanabadi[1], Sayed Ali Almodaresi[2*], Ali Boloor[3]

[1] *Ph.D. Research Scholar, Department of Geography and Urban Planning, Yazd Branch, Islamic Azad University, Yazd, Iran.*

[2*] *Associate Professor, Department of Geography and Urban Planning, Yazd Branch, Islamic Azad University, Yazd, Iran.*

[3] *Assistant Professor, Department of Arts and Architecture, Yazd Branch, Islamic Azad University, Yazd, Iran.*

Corresponding Author:** ***Sayed Ali Almodaresi, *Associate Professor, Department of Geography and Urban Planning, Yazd Branch, Islamic Azad University, Yazd, Iran.*

Abstract: *Communication network is important in transportation of goods and passengers between residential areas. The main concern of planners and experts is to select suitable location for communication network construction. Since, the classical and traditional methods are costly and time consuming for routing and inaccurate proposed route are not included factors as environment, economic, technical and engineering. The use of Geographic Information System in spatial-temporal analysis causes macro saving in economic issues and time, providing a framework to obtain accurate and easy access to the aim of the planners. This study determines the best optimal route using multiple information sources such as topographic information, land-use, geology, faults and pathways. The result indicates high efficiency of GIS analysis in determining the optimal route. The study area is located in southeast of Yazd province as the second railway track of Yazd – Bafgh. The data and factors influencing railway routing is by using AHP and GIS software, methods are designed to determine railway route location. Consequently, a number of factors were studied influencing the railway route. Using ILWIS and ArcMap software, models were designed and the results proposed routes for the planners to select the most suitable and shortest path between two points.*

Keywords: *Multi-Criteria Evaluation; Optimization; Bafgh – Yazd railway; ILWIS*

1. Introduction

The expansion of transport network is the main key to the socio-economic development for every country, especially the developing countries. The railway due to the relative advantage of high safety and low energy consumption has a special place in transport system. With respect to the extension and position of country in the Middle East, sprawl of urban centers and long distances between the trip production and trip attraction centers in the country is the vital necessity for the development of railway network. In route construction one of the most important and basic stages for research and design is the initial-route design theme or study of zero phase. Using multiple criteria is one of the comprehensive methods designed for decision making. Choosing the optimal route from among the designed routes in fact is a multi-criteria decision in which the purpose of decision making is to select optimized route. Since the decision on the selection of optimal route is very important issue and errors may be in-compensable. Therefore there is the need to adopt logical and suitable method for selecting an optimal option for correct decision making. Hence, GIS and its utility is the best tool. Research has been conducted in Iran and the world which includes: [1] the research on the design of optimal route of road transport relief in GIS environment based on the hot spots along the Bandar Imam Khomeini – Ahvaz route using the GIS capabilities and using travel time weight the volume in Dijkstra's algorithm determines the fastest route from the relief base to the accident site. It concludes that the shortest path in terms of distance and the fastest route in terms of travel time differ tremendously. [2], states that in designing suitable route network various factors have to be considered that includes unstable hillside factor along the path especially in forest areas. [3], has determined the optimal route of intercity train between Yazd – Ardakan was conducted using Fuzzy Logic method. This method uses Gama and Sum operators, and from these two operators the route that was drawn using sum with regard to a population of 779589 people over the length of 58547 meters had greater priority than the second route. [4], the optimal routing of railway were investigated using GIS modeling (case study: fastest railway line of Qom – Isfahan). The research result produced several proposed route and optimized according to the designers criteria. As part of designed route with length of 31492 meter has crossed the unauthorized areas and in some areas the designer’s criteria has not been considered. While all the route designed with these models with length near to the shortest distance of 31976 meter and has crossed authorized area. [9] in a study has used intelligent optimization tool and applied spatial data analysis to find a better and appropriate way. In Maryland region, sensitive analysis has been conducted to the key parameters, different cultural and natural parameter and land-use. They concluded that the required low-travel time for route design and benefit of this approach to design low-cost route solution. [10] in a study, they faced a big problem to determine the rail transport lines with large number of effective options. The model presented in this method has been known as a suitable model for designing route based on the criteria considered. Their results suggest that for designing optimal route using genetic algorithm with respect to lot of data processing. [11], research aimed to determine the most suitable location for new transport infrastructure by Spatial Decision Support System (SDSS) and utilize a hybrid structure to achieve mobility and dynamic location. They have used spatial and statistical data to design optimal route in the targeted area. The results showed that using statistical data was beneficial.

2. Material And Method

2.1. Introduction of the study area

Yazd province is located in central Iran with an area of 15672 sq. m. between latitude 29^{o}48’ to 33^{o}31’ North and longitude 52^{o}45’ to 56^{o}31’ East of Greenwich Meridian and located on the plains of Kavir and Lut. In this study, an area of 1507000 hectares located in zone 40 UTM projection has been selected as a case study. Bafgh city is located 120 km southeast of Yazd with an altitude of 927 meters above sea level. The geographic coordinates of Bafgh are longitude 55^{o}3’ East and 32^{o}1’ North latitude. Figure 1, shows the Bafgh city in Yazd province as the study area.

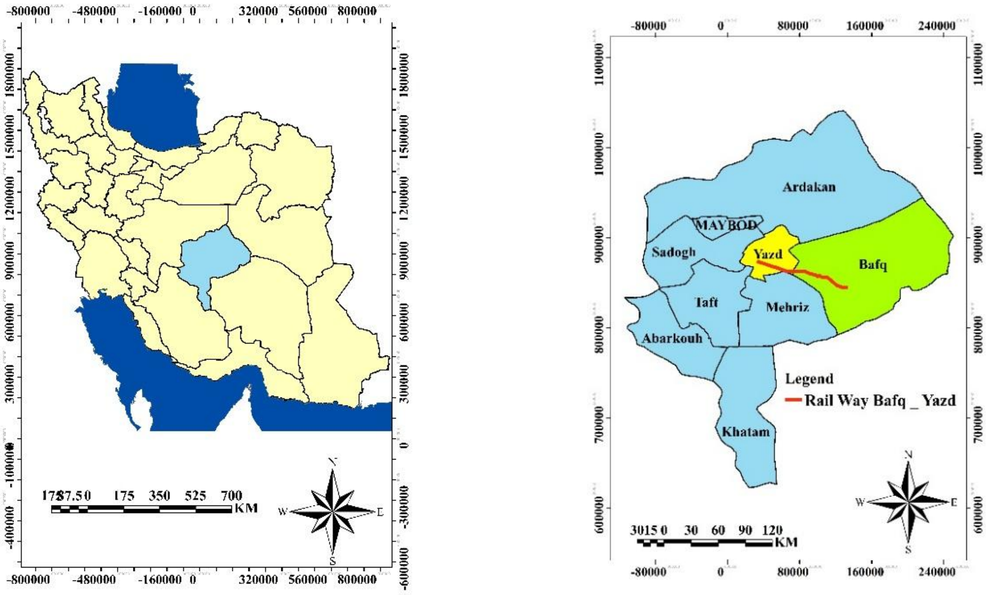

Figure1. *Study area in Yazd province*

2.2. Layers used for the research

To achieve the goal of the study was to identify the effective characteristic of the railway route. This has been conducted by studying the natural and artificial effect of the area and the existing information layers within an surveying and geological organization of the country, environmental impacts of the railway and according to the routing and conventional methods. After recognition of the initial stage the feature data are collected and a proper database is prepared in GIS environment. The layers used in the research were (1) Digital Elevation Model (DEM) of the area, (2) topographic map of the area, (3) slope map of the area, (4) slope direction map, (5) geological map, (6) land-use map, (7) main station points (railway stations), (8) residential area map, (9) stream map, (10) road map of the study area, (11) ecological zone map, (12) fault map of the region, (13) route designed by Tusar consultant of the study area along with all the data used to design the route.

Figure 2 – Figure 12

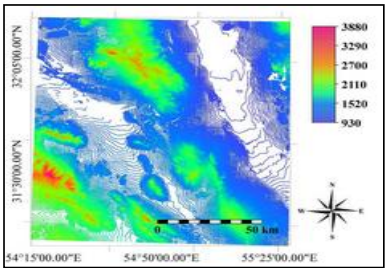

Figure2. *Topographic map of the study area*

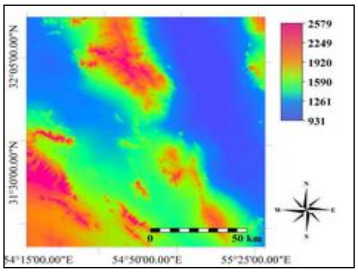

Figure3. *DEM map of the study area*

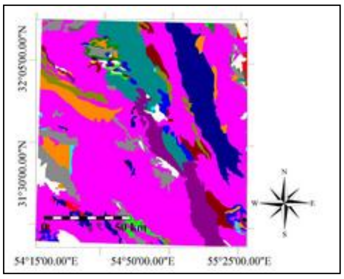

Figure4. *Geological map of the study area*

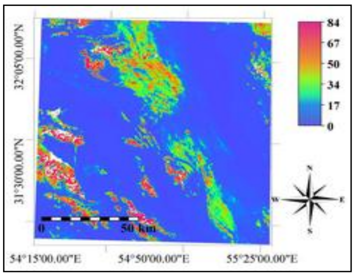

Figure5. *Slope map of the study area*

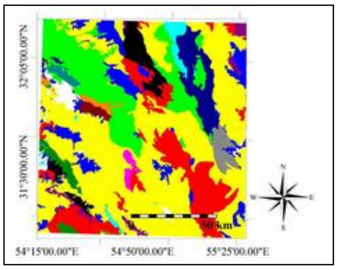

Figure6. *Land-use map of the study area*

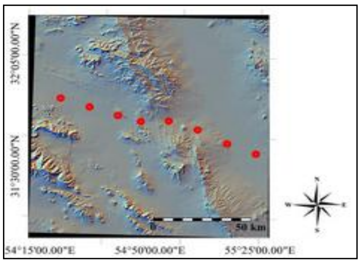

Figure7. *Railway station points of the study area*

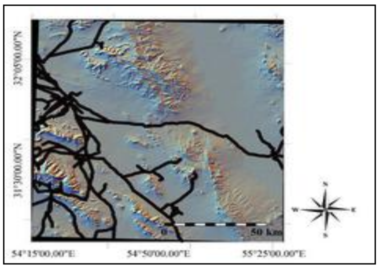

Figure8. *Existing road map of the study area*

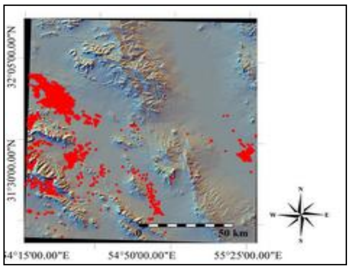

Figure9. *Residential area map of the study area*

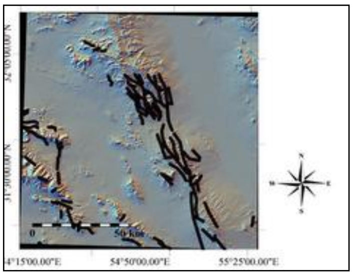

Figure10. *Faults of the region*

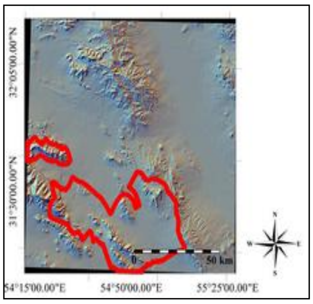

Figure11. *Ecological zone map of the study area*

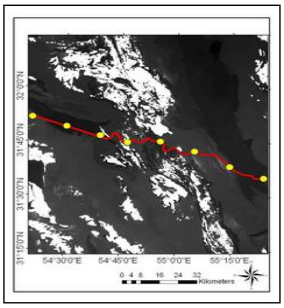

Figure12. *Route designed by the consultant*

2.3. Methodology

The study performs two general methods of multi-criteria evaluation.

- Multi-criteria evaluation using criteria tree in ILWIS
- Modeling spatial multi-criteria in ArcMap environment

Overall production process of the layers and finally selecting the optimal route using spatial multi-criteria modeling to a model tree method is as follows:

1. Preparing the data and initial maps in different format was collected from the respective departments, agencies and consulting firms.
2. Extracting the information layers from the collected data.
3. Entering the layers in ArcMap software for initial processing, editing and preparing the images.
4. Transfer of the prepared layers to the ILWIS software.
5. Confirming and re-establishing the appropriate images.
6. Converting the factor and constraint layer to raster.
7. The construction of criteria tree.
8. Standardization of factor and constraint.
9. Weighing the factor and groups.
10. Overlapping the layers and prepare appropriate areas for passing of the rail route in the layers.
11. Transfer of map to ArcMap for selecting the optimal route.

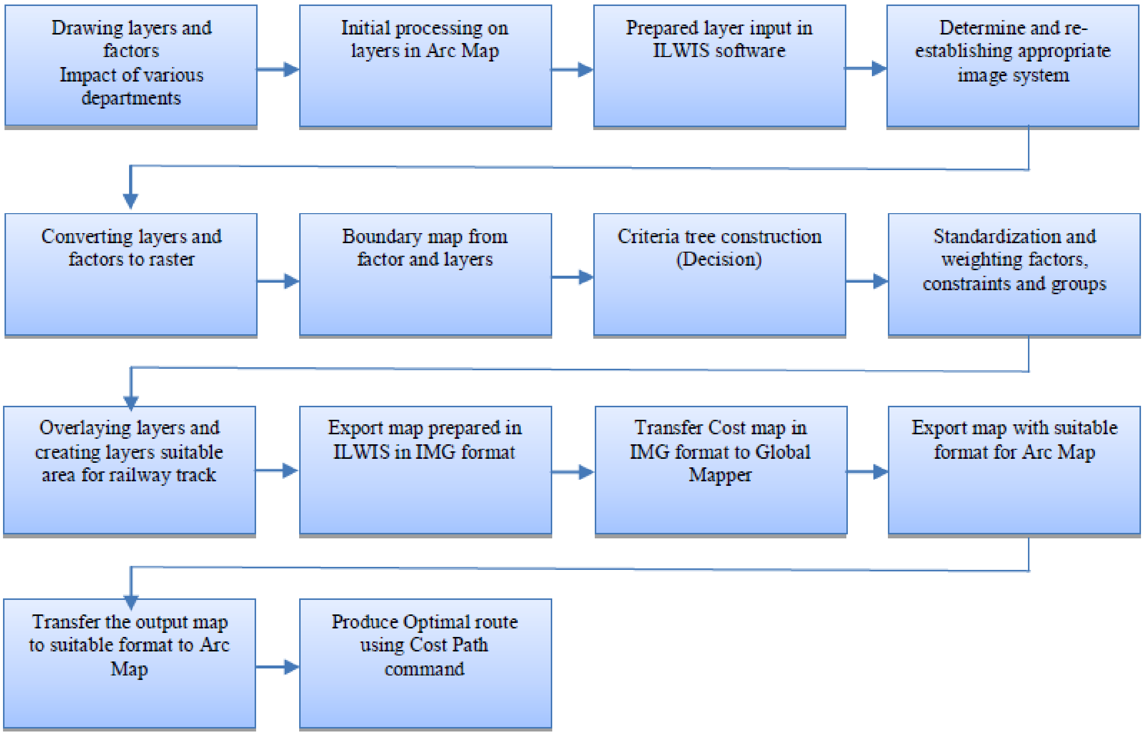

Figure13. *Conceptual model*

After collecting the data in different format, it has been converted to raster or vector digital map format which are used in the GIS environment. The layers without coordinate system and georeferenced, they are georeferenced and coordinates are assigned. Later all the layer are entered in ILWIS software. These layers are point, line and polygon with the same coordinate system when entered into the ILWIS software. In ILWIS all the three features including the image system, elliptical reference and the relative datum of the information layer should be the same.

In the next stage of the raster maps the spatial distance, preparing the percentage slope map and the land-use and geological map will be necessary to prepare the spatial multi-criteria model. After naming the groups, factors and constraints the raster layer the prepared maps are incorporated into the model for standardization of factors and constraints which is shown in Figure 14.

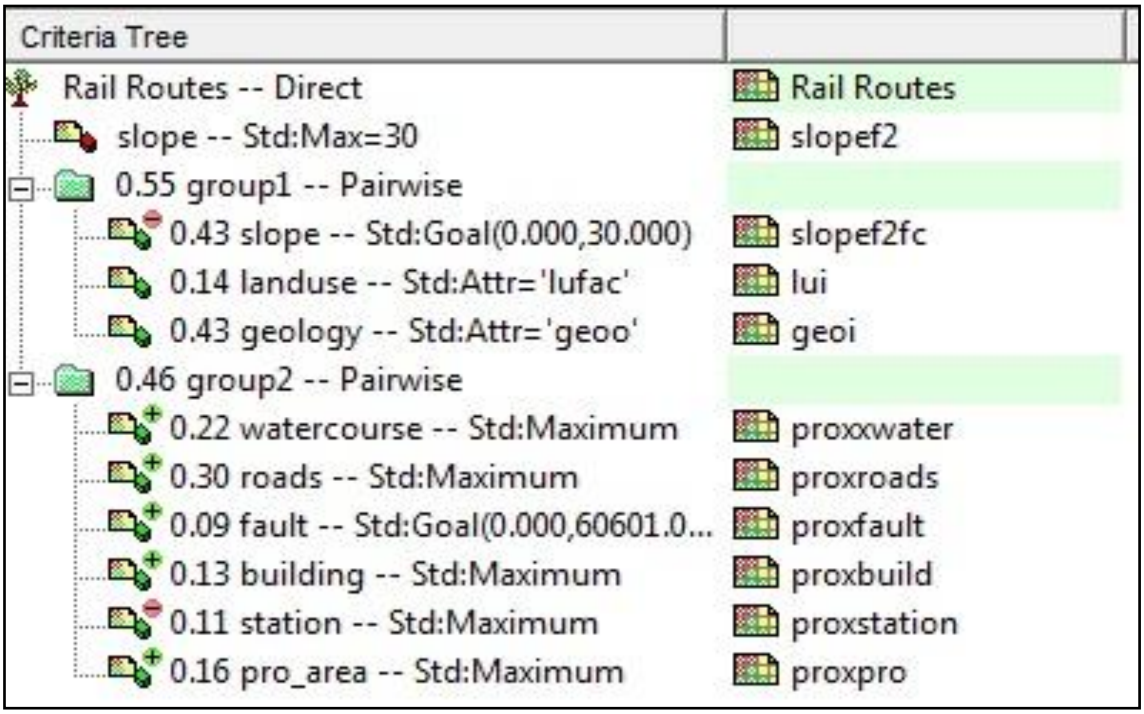

Figure14. *Multi-Criteria Evaluation tree model in ILWIS software*

Since each data layer after various processing has different values or in other words the pixel value of the layer differs after processing therefore, it must be to a scale which is comparable. This is standardization process. This process is different for each category of factors and constraints (Aghahadi, 2013). Standardization of constraint in SMCE model is based on Boolean that is 0 and 1, because it does not has the intermediate value. Pixel assigned with 0 values indicates non-suitable location and pixel with 1 value indicates suitable locations. Standardization of factors is based on fuzzy method that uses membership function; the degree of membership for each element is distinguished. In this research this element is characterized as pixel value. The standardization process of factors in SMCE is done in three ways;

1. Direct linear function (Benefit): This function is used for the criteria having linear relationship with the model. With the increasing value their standard value also increases and vice versa the inverse linear function (Cost) reduces.
2. Trapezoidal composite function: the pixel value increase and later is constant and then decreases.
3. Combined non-linear function their pixel values are standardized in a non-linear way.

Later more weights are allotted to the layers. Giving incorrect weights creates general error in the application of multi-criteria decision making system in the spatial decision problems. In SMCE, there are three methods for weighting the criteria, of which one is AHP pair-wise comparison. The AHP pair-wise comparison the normal group factor mutually conflict and by selecting one of the preferred pair weights are given. At this stage it is necessary to select reasonable weights. The uncertainty should be less than 1. After assigning weights to the prepared tree model and with respect to the different preparation for the factors and constraints and their standardization we can observe the zoning map of suitable location crossing the railway line. In fact, this map shows abundant suitable location for crossing railway line after different analysis. After the overlapping of the factor and constraint layers with 0 and 1value, the 0 value are for un-suitable location for railway line and 1 value for suitable location and other location are specified between 0 and 1 value. Finally, the preparation of the final route in ArcMap software was conducted by the generated layers of Cost Distance, Cost Back Link and shape file of the endpoints.

3. RESULTS

3.1. Rasterization data layer results

Figure 15 till Figure 21

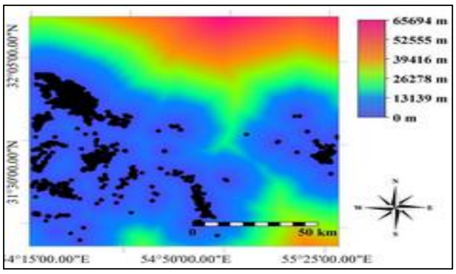

Figure15. *Slope raster map of the study area*

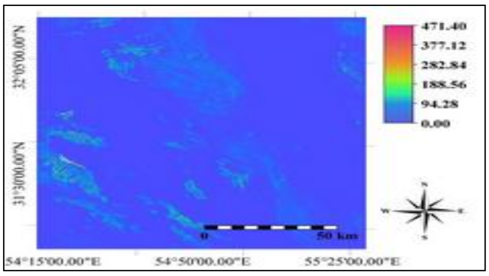

Figure16. *Residential boundary of the study area*

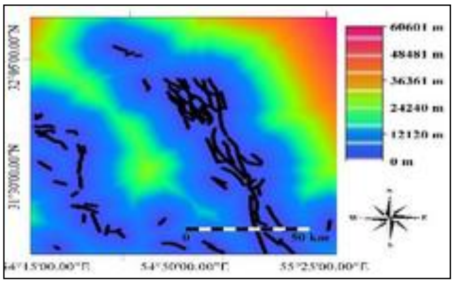

Figure17. *Fault limitation map*

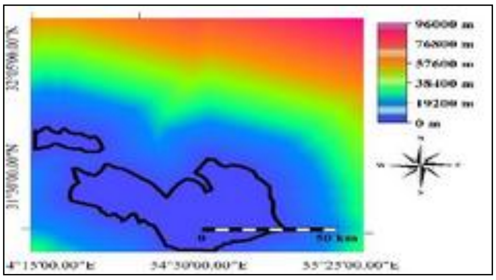

Figure18. *Ecological limitation map*

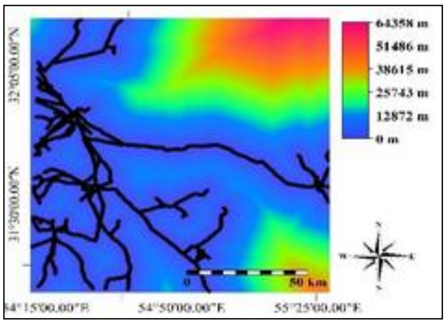

Figure19. *Route suitability map*

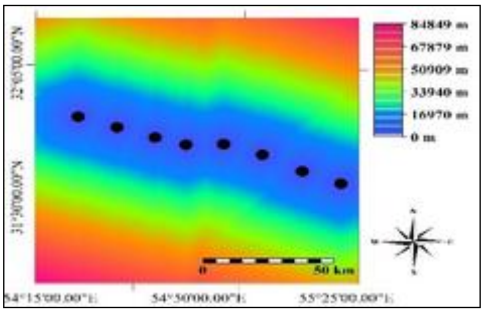

Figure20. *Main station points map*

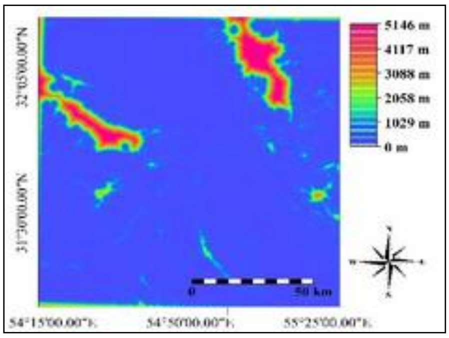

Figure21. *Waterways (or stream) limitation map*

3.2. Standardization results of factor and constraints of the research

The standardization of slope as a contributing factor, the highest value for 30 percent slope with value 1 and lowest value for 0 percent slope and the remaining slope has value between 0 and 1 shown in Figure 22. Standardization of slope as constraint, the slope more than 30 percent are eliminated by given 0 value and slope less than 30 percent are given value 1. Figure 23 shows the slope values by Boolean method.

Figure 22 and Figure 23

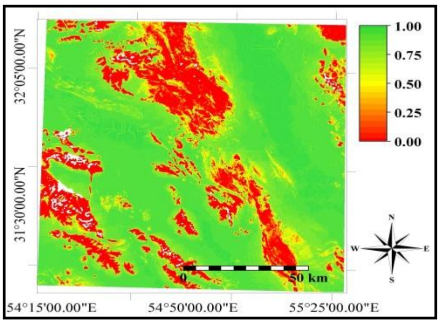

Figure22. *Standardization of slope as factor*

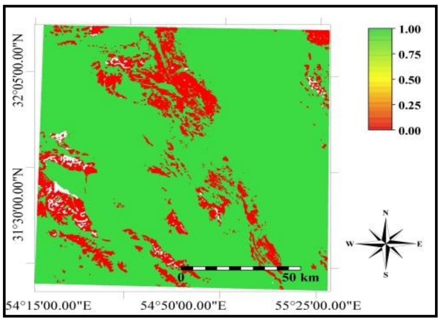

Figure23. *Standardization of slope as constraint*

To standardize the fault layer, greater the distance of the fault the more valuable it is with the most appropriate one. The closer to the active faults can be of greater risk to the project and its security in the future. The standardization of the roads, the close or far proximity of the rail route from the road should be evaluated. Therefore, in this study, according to the road buffer an optimal distance of 1000 meter is considered to close proximity of paved roads and 0 value is given to lesser distance, and the distance more than 1000 meters will be more closer standardized (Figure 25).

Figure 24 and Figure 25

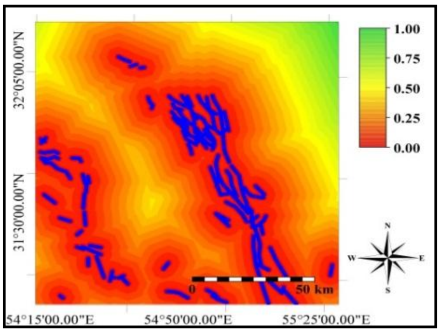

Figure24. *Standardization of the faults*

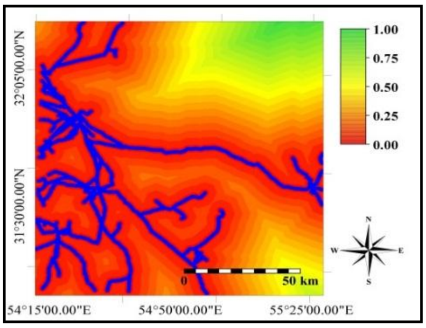

Figure25. *Standardization of the paved roads*

The residential layer less value is given to the close proximity and more value is given to far proximity (Figure 26). Another important criteria affecting the modelling and optimization of railway route is the main points on the route of the railway line which is usually determined by the employer. Some of these areas are industrial and commercial areas were the need to transfer the workers as well as the development of industry, different route of communication from city center and the residential area to these areas is constructed. In this study, six points of railway track from Bafgh to Yazd has been considered. This criteria is categorized factors as fuzzy and direct function (Benefit) was considered. Therefore close proximity to these points has higher value and far proximity from these points has lesser value and zero value. The other intermediate value is between 0 and 1 with respect to the distance.

Figure 26 and Figure 27

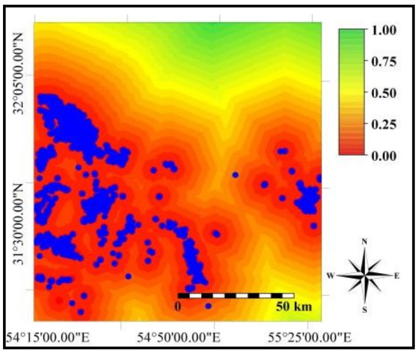

Figure26. *Standardization of residential area*

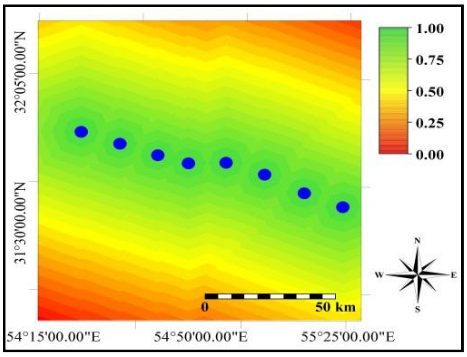

Figure27. *Standardization of main points*

Another effective criterion to optimize railway route is the distance from the stream and the route of flooding. Therefore, knowing the accurate location of the waterway and the area prone to flooding is essential. It is necessary to observer proper distance from the structure to avoid damage. Therefore, in this study the benefit function is used for standardization. The geometric design of railway the environmental factors should be considered.This option is not only in construction stage but also included in the performance (geometric design railway regulation, 2004). In this research for standardized, these areas are considered as a factor and was standardized as fuzzy cost function.

Figure 28 and Figure 29

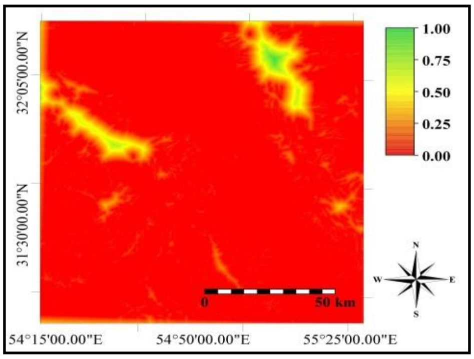

Figure28. *Standardization of stream (waterways)*

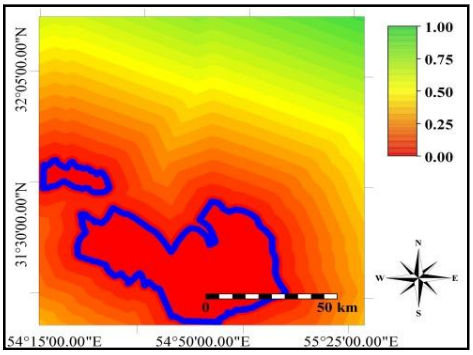

Figure29. *Standardization of ecological zones*

The experts have determined the standardization criteria of land use. The land-use is an effective criterion and is non-linear standardized. Another important and effective criterion in the optimization model is the type of land of the area. Detection and identification the type of soil and rock is very important and sensitive which requires knowledge, experience and expertise done by the professional engineers of geological organization of the country. This layer under the study is weighted by the experts and inappropriate pixel with zero value and suitable pixel with 1 and other areas have been given the median values.

Figure 30 and Figure 31

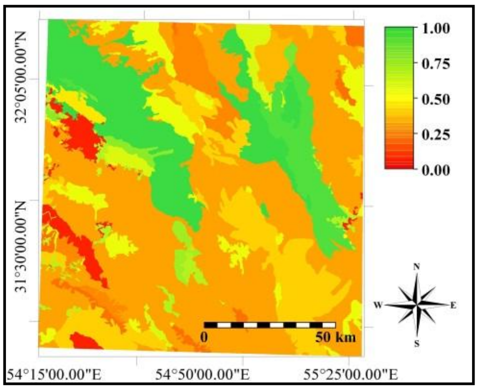

Figure30. *Standardized land-use map*

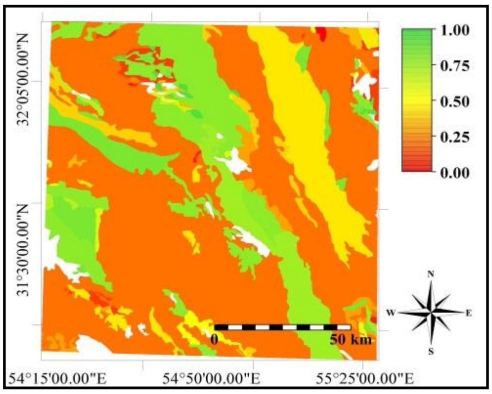

Figure31. *Standardized Geological map*

3.3. Result of the zoning layers

Finally, after applying weights the final zoning map of the area was obtained. This map shows the abundant suitable area for railway crossing after different analysis and overlaying the factors and constraints from 0 to 1 value. Zero value is for the non-suitable area for railway line crossing and 1 value for the most suitable area. Other places were marked with median value between 0 and 1. The zoning layer generated in ILWIS shows the suitable area for railway line crossing as a raster layer and entered in the ARCMAP software which was used for the production of cost and Cost Distance layers.

Figure 32 and Figure 33

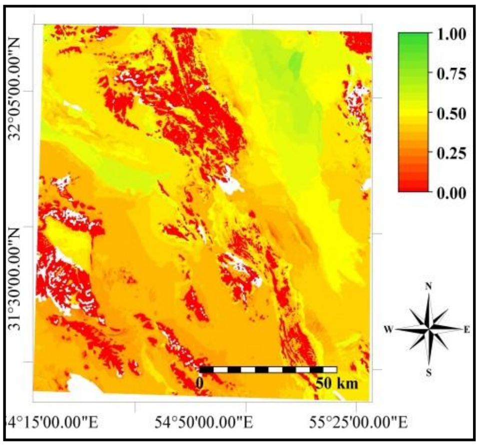

Figure32. *Cost Barrier generating layer*

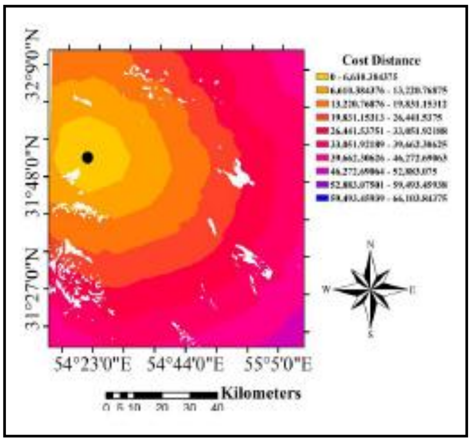

Figure33. *Cost Distance generating layer*

Another layer needed to be imported in short path function in order to determine the shortest and efficient route is the Cost Direction raster layer. This raster layer shows the barrier direction in eight geographical directions. Therefore, the Cost Direction raster layer is generated for the first point (Figure 34).

The final stage after generating the Cost Direction and Cost Distance layers is the start point and end point, determining the shortest path between start and end point from the compulsory crossing points. Therefore, by introducing the end point and two layers of Cost Distance and Cost Direction generated for the first point and using the method of searching for each cell that calculate on individual pixel can generate the shortest and the best route (Figure 35).

Figure 34 and Figure 35

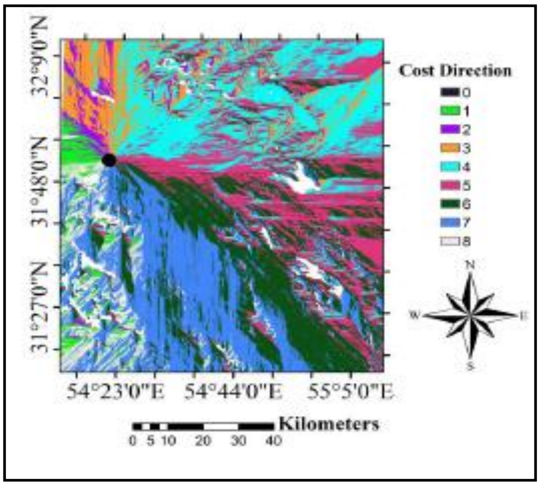

Figure34. *Cost Direction layer generation*

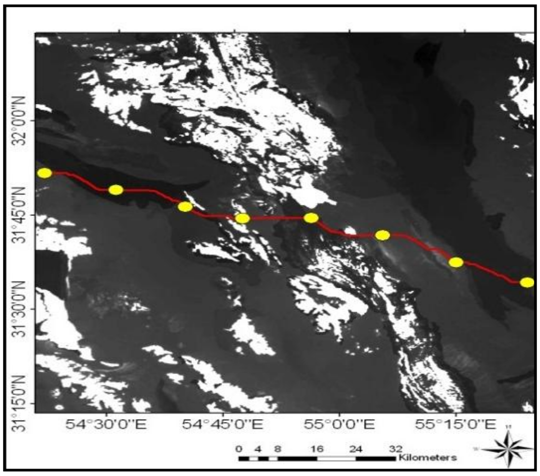

Figure35. *Route generation by SMCE modeling*

4. Discussion And Conclusion

In this paper, the main aim is routing the second railway line for Bafgh to Yazd using methods and new geographic Information System. So the shortest and the best route are generated using SMCE with respect to the influencing factor on locating the optimal railway route according to the standards introduced by the experts. The route generation initially a route is designed using Cost Path method between Yazd and Bafgh station and a route is designed using Cost Path method according to the stations between Yazd and Bafgh in form of stations. These two routes are composed and the design of station to station is more efficient.

Figure 36 and Figure 37

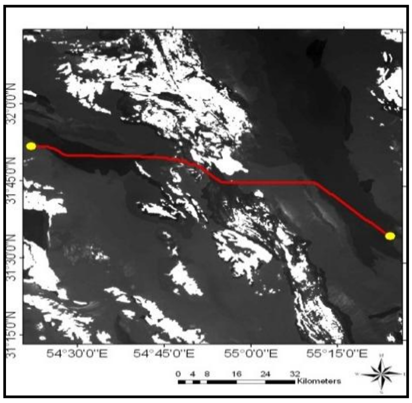

Figure36. *Route generated between Yazd and Bafgh station using Cost Path method*

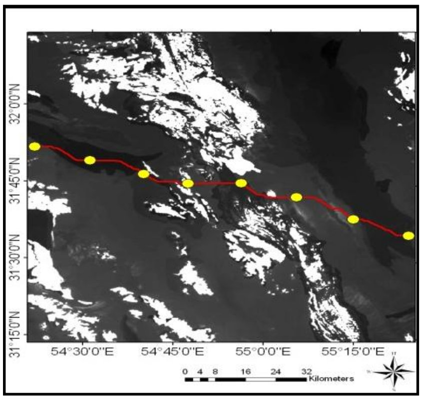

Figure37. *Route generated station to station using Cost Path method*

Determining the suggested route or earlier route and finding the best option among them is the determining factor in the cost construction and utilization of the project. Many factors are considered in designing the route which starts from the zero phases with respect to the need and later with a precise definition from the planners from the new route generated and prioritizing of these demands the route plan enters the next step. In the first method, the SMCE model determines the proposed general pattern of areas production corridor for the passage of the route. Perhaps one of the most important stages of route design starts from this stage. In case of any mistake at this stage, may impose cost to the project after which accurate routing these cost is not compensable. At this stage it is important to determine the threshold for each factor. If not observed in the design it will impose high cost to the country network.

Therefore, in this stage access to different parts of the route should be done with a comprehensive look and long term plan. Then the entire inter-urban connecting route must be constructed in the same general direction so as to create the most effective route network. According to the mentioned literature and using the two models, the routes designed are compared with classical route deigned by Metra Consulting Company. The route designed by Tusari Consulting Company from Yazd to Bafgh station designed from station to station with length of 118.099232 km. The route designed in 1962 by the engineers from Yazd to Bafgh station in the form of station to station the length of 120.682668 km. This designed route in the region has not considered the main criteria and has crossed the restricted areas. The restricted areas are areas which have lots of up and down and high slope and areas of geological layer is not suitable for the railway line. It has to be stated that in 1962 the route design of Yazd-Bafgh was not like this.

Figure 38 and Figure 39

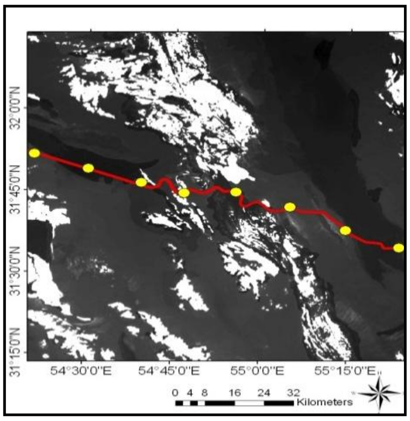

Figure38. *Route generated station to station by Tusari Consulting Company*

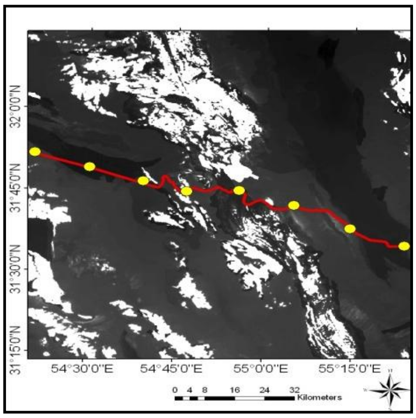

Figure39. *Route generated station to station by engineers in 1962*

In this study, according to the existing conditions and factors in the region the weighting and standardization is conducted in the form of Yazd to Bafgh station. A route has been designed that one method is from station to station and the next method is direct. In the station to station design method it was obligatory to pass along the stations and the route length was equal to 122.232938 km and the direct length was 111.681132 km.

The path that has been considered is the patzh we had pass the obligatory stations and the length of this route is longer than the Tusari Company. But this route has been considered because of need, science of the professional for standardization as well as the integration of all factors and criteria in respect to their importance and priority by assigning weights to each criterion. Therefore, this route does not pass the restricted area. This route may not be optimal in terms of length but in terms of location passes through the trained locations, this location is defined by the experts. So we can say that this route is the most optimal location in the region generated by the experts and can be considered as a new proposed route. According to the study results, other studies have also been conducted that had same results. In a study [5], the aim to provide a method for determining the optimal route automatically in GIS by considering environmental aspects and effective points in determining optimal route for creating a ring road in East of Tehran (Parchin road). Initially environmental factors affecting the routing in the region were identified. By defining two different scenarios and several proposed points for the start of the route, various corridors were designed automatically using GIS. These routes with influencing factor maps were compared with each other and the optimum route was determined using Analytic Hierarchy process. This route has a good fit with the priorities and limitations. The results of the study showed that by identifying the influential factors and using GIS one can determine suitable route for generating the path by considering the principles of ecology. The research conducted [6] by GIS software and according to a number of effecting factors in the model such as slope, environmental areas, the routes from Rasht-Anzali was designed. They concluded that from the environmental point of view the automatic route designed are better than the manual route designed. In a research [7], GIS software has been used to generate the shortest distance because the software is able to analyze the network. This group suggested that to determine the shortest route various factors has been considered, but the research that they have conducted only travel time factor has been considered. They say that short distance depends on time which is dependent on the traffic and traffic has accidents and continuous changes.

For this purpose, he model adopts only factor of short route and time and it is completed by assigning risk factor that most likely shows the direction of the route. In a study [8], a part of optimal route of the railway line of Yazd Eghlid according to the spatial multi-criteria modelling in GIS environment and it has been emphasized on competitiveness and alternative method based on GIS in comparison with the manual route design.

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Citation: *Ali Hasanabadi. et.al, "Optimal Railway Routing using Spatial-Temporal Analysis in Gis (A Case Study of Bafgh – Yazd, Iran)", International Journal of Constructive Research in Civil Engineering, 4(3), pp. 11-22. DOI: http://dx. doi.org/10.20431/2454-8693.0403002*