Available online at www.CivileJournal.org

Civil Engineering Journal

Vol. 1, No. 1, November, 2015

Site Locating for Inspection Posts of Freight Cars in Railway Network Using Analytical Hierarchy Process (AHP) and Geographic Information System (GIS) (Case Study: Iranian Railway Network)

Saeed Monajjem[a], Mohammad Mahanpoor[b*], Mohammad Sadathoseini[c]

[a] *Associate professor of K.N.Toosi University of Technology, Faculty of Civil Engineering, Tehran, Iran.*

[b]*PhD. student of Road and Transportation, K.N.Toosi University of Technology, Faculty of Civil Engineering, Tehran, Iran.*

[c]*Assistant professor, Head of Iranian Railway Research Center, Tehran, Iran.*

Received 28 October 2015; Accepted 28 November 2015

Abstract

Freight car inspection and maintenance system have an undeniable role in total costs imposed on system for repair and rehabilitation process of different components of it. This issue shows its importance when railway transportation comes to competition with other modes of transportation. In this competition, lower total cost means more demands and more benefits for optimum systems. Using preventive maintenance methods for rolling stock are among appropriate solutions in order to lower the costs. These methods require to have an exact monitoring system to achieve a reliable scope of system. Inspection posts play an essential role as “wise eyes” on inspection system.

Using Analytical Hierarchy Process (AHP) in this article has developed decision tree including goals, criteria, sub criteria and alternatives. The main criteria are 1-traffic, 2-geographical position, 3-loction of station on railway network, and 4-repair and maneuver equipment of station. These criteria and sub criteria have been weighted and quantified using expert’s opinion. The use of Geographical information system, 403 stations had been evaluated with 26 criteria and sub criteria and prioritized. By considering coverage of network in next step, 43 stations are recommended as required station numbers in railway network to provide 70.53% Coverage of railway network traffic.

Keywords: Analytical Hierarchy Process (AHP), Geographical Information System (GIS), Freight-car, Inspection posts.

1. Introduction and research background

The aim of a site-selection is to find the optimum location that satisfies a number of predetermined selection factors. The process of problem solving typically involves two main stages: screening and evaluating. The first stage is to identify limited numbers of candidate sites, from a broad geographical area, taking into account the selection criteria. The second stage includes careful examination of alternatives to find the most appropriate site (Chang, Parvathinathan and Breeden 2008). The second stage is an important issue; for example, in the waste management the selection of an appropriate solid waste landfill requires to be considered by multiple alternatives and evaluation criteria (Guiqin, Li,Guoxue and Lijun 2009). In recent years, several decision-making methods have been proposed for different site selection applications. For example, Ballis (2003) used the analytical hierarchy process (AHP) for an airport-site selection on the Island of Samothraki, Greece. Also, Guiqin et al. (2009) applied geographical information systems (GIS) and AHP to solve the problem of selecting a landfill site for solid waste in Beijing, China. Similarly, Vahidnia,

* Corresponding author: Mahanpoor@gmail.com

Alesheikh (2009), and Alimohammadi (2009) suggested a fuzzy AHP method for determining the optimum site for a hospital.

This paper explores the problem of finding the optimum location of a railway station to provide service as inspection posts in Iranian railway network, using a hierarchy structure. We introduced the inspection posts site-selection problem as a hierarchy model consisting of four levels, each with its own main criteria. The main criteria are: (1) traffic related, (2) repair equipment (3) position on railway networks and (4) geographical position. Each of these main criteria is then divided into several sub criteria, giving a total number of 26 sub criteria. In addition, the hierarchy model has 403 railway stations, as candidates or alternatives. We use expert judgment to perform them in individual pair wise comparisons in the AHP. Furthermore, in next steps the number of inspection posts, are determined with traffic coverage of these stations.

Iranian railway network with about 7192 kilometers length, connects four corners of Iran to each other. Located in heart of Middle East, its east-west corridor acts as a link that connects Europe to Asian countries and in north-south corridor, connects Caspian Sea to Persian Gulf. Its strategic location and more than $20*10^6$ ton-kilometers of freight transportation, the maintenance issue plays a vital role in total costs of transportation. With good inspection program it would be possible to reduce the costs of damages, equipment failures and derailments. Inspection posts, as "wise eyes of maintenance system", have an important role in this matter. The main issue to watch the system is the location of these posts to ensure best performance of system.

2. Site selecting by Analytical Hierarchy process

The AHP, initiated by Saaty (1980), is a flexible multi-criteria decision-making methodology that transforms a complex problem into a hierarchy with respect to one criterion or more.

The AHP method has been used for a wide variety of decision making problems in the fields such as government, business, industry, healthcare, and education (Boroushaki and Malczewski 2008; Forman and Gass 2001; Jyrki et al., 2008; Linkov, Satterstrom, Steevens, Ferguson and Pleus 2007; Raharjo, Xie, and Brombacher 2009; Saaty 2008), and also for site selection problems. For example, Ballis (2003) used the AHP method for an airport-site selection on the Island of Samothraki, Greece, Korpela, Lehmusvaara, and Nisonen (2007) selected a warehouse operator network using a combination of the AHP and DEA methods. Also, Onut and Soner (2008) used the method for trans-shipment site selection. Rosenberg and Esnard (2008) used a hybrid version for a transit site selection. Furthermore, Hsu, Tsai, and Wu (2009) used the method to analyze tourist choice of destination, Dagdeviren, Yavuz, and Kilinc (2009) to analyze the problem of weapon selection, Garcia-Cascales and Lamata (2009) to choose a cleaning system for engine maintenance. The AHP method requires the following pair wise comparison matrix, A, which contains the relative weights of the criteria:

$$A = \begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{w_i}{w_1} & \frac{w_i}{w_2} & \cdots & \frac{w_i}{w_n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{w_i}{w_1} & \frac{w_i}{w_2} & \cdots & \frac{w_i}{w_n} \end{pmatrix} \quad (1)$$

Where w_i is the importance weight of the i-th criteria with respect to goal, or the importance weight of the i-th sub-criteria (i = 1,. . ., n) with respect to criteria and so on. Furthermore, the importance weights can be obtained using the following equation (Saaty 1980, 2008):

$$A_w = \lambda_{max}.w \quad (2)$$

Where λ_{max} is the maximum Eigen value of the matrix and w= (w_1, w_2 . . . , w_n) is the corresponding eigenvector of A.

3. Application of ArcGIS on site locating

Numerous researches have been done based on Geographical information system on site locating for different sites and facilities. Delevar and Naghibi (2003) have been investigated pipeline routing using geospatial information. Ocalir and et al. presented an integrated model of GIS and Fuzzy Logic (FMOTS) for location decisions of taxicab stands.

Beheshtifar (2006) has investigated Site selection of thermal power plants using GIS system. Alesheikh and et al. (2008) did a Land assessment for flood spreading site selection using geospatial information system.

In this paper, for geographical analysis on railway network, a model of Iranian Railway Network on ARCGIS (version 9.3) has been developed. In GIS software the spatial analysis, data process and inquiry extraction has been used in space analysis and for slope analysis of railway network a DEM (Digital Elevation Map) with 40*40 meter pixels has been used.

Using GIS also helped to manage huge comprehensive data for 403 stations (about 52 data for each) that without using this software was quite impossible. It is also used for data generating of slopes and distance calculations in C-1-1, C-1-2, C-3-3, C-3-1, and C-4-1criteia, furthermore for data management in C-1-3, C-2-3 data.

4. Identifying the criteria and sub criteria

First step is obtaining an insight to frame work of inspection posts. Tasks that have been accomplished in these sites are divided into 3 main categories:

1- Reaction-base activities; such as orders to change failed components of rolling stock,

2- Detection-base activities; such as checking the components for defects and watching the repair schedules of wagons.

3- Prediction-base activities; such as brake control and pre-failure change of components.

To be congruous with their frame work of posts the decision making tree is proposed in Figure 1 and would be illustrated in next section.

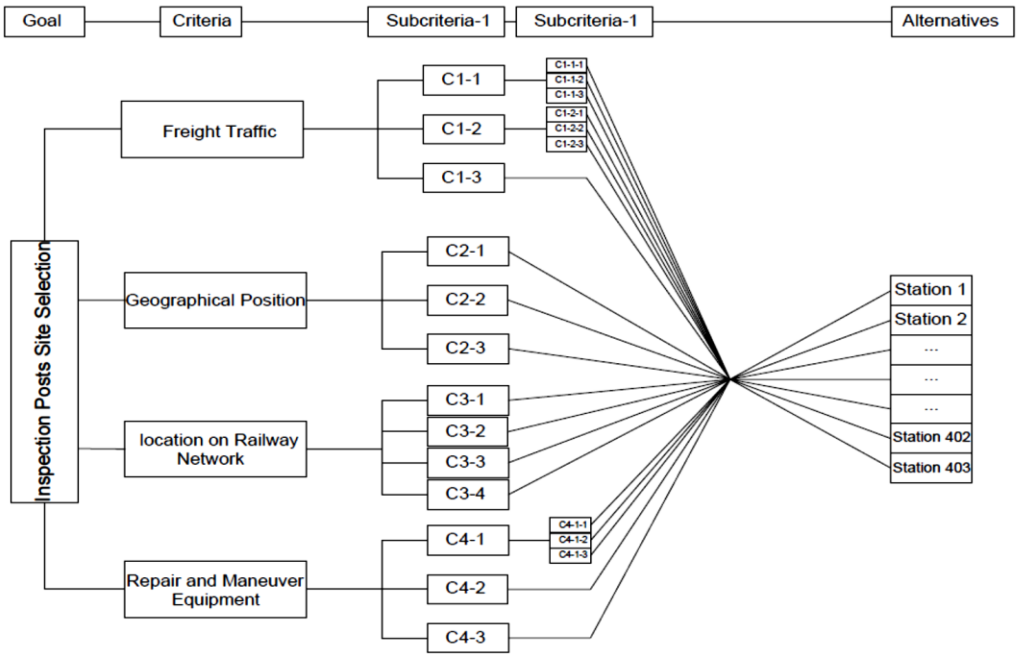

Figure 1. Proposed decision making tree

The criteria are considered to be relevant with Framework of inspection posts. These criteria are also considered to take into account these three factors**:** reactions, detection and prevention activities of inspection posts.

5. Description of multi objective decision making hierarchy

The components of decision making process have been divided into four main categories named C-1to C-4 from main branches into more sub-categories. each part would be more discussed in this section.

C-1: **Traffic related includes**:

C-1-1: **Freight car traffic (except dangerous materials)**: This item is one of the most important tasks in inspection post selection because it is one of the indices that inspection post performance on network can be measured. This item includes three main sub criteria that are:

C-1-1-1: **Loading in station**: according to Iranian railway code, it is essential to inspect the train after loading. If there is an inspection post in loading center this task will be done with inspection post technicians. Otherwise it should be done with train managers. It is obvious that inspection with train manager is more time consuming and not as exact as inspection post assess of rolling stock.Figure1 shows the loading tonnage of each station.

C-1-1-2: **Unloading in station**: for unloading, train should be detached and discharge its loads. Then it should be connected together and form the train again. This train should be inspected before re-entrance to railway network. And like loading stations, it is better to be there and do the inspection posts there as well.

C1-1-3: **Passing traffic of station**: This item plays a reaction and detection role on passing trains. When a train enters the inspection post, the inspector should go to entrance zone of station and check the cars while train enters the station.Figure5 shows the passing traffic in railway network.

C1-2: **Dangerous material freight car traffic**: This item will be investigated and weighted separately with C-1-3 because loading, transporting and unloading of dangerous materials need more care and investigation; The sub-criteria are same as C-1-3:

C-1-2-1: Loading in station: The same as C-1-1

C-1-2-2: Unloading in station: The same as C-1-2

C1-2-3: Passing traffic of station: The same as C-1-3

C-1-3: Characteristics of passing wagons; every type of trains needs special care and investigation. it is different in type and time of inspection. More vulnerable types need more attention and inspection post is more necessary for these types.

C-2: Geographical position

C-1-1: Dominant slope: This item is an index for vulnerability of covered length (distance between stations and its adjacent stations). Sharper slopes need more intact brake system, coupling, axle and wheel system to prevent disaster.

C-1-2: Slope change: This sub-criteria is assumed to consider the effect of slope variation where the extra tension force is needed (extra locomotive). It results in train to dissection and re-formation. According to rules, the brake test in every train re-formation is mandatory, so existence of inspection posts have logical justification.

C-1-3: Environmental vulnerability of covered route: More vulnerable routes cause more loss if an accident occurs. So the necessity of inspection post in this region will be increased by preventive performance of inspection posts.

C-3: Station position on railway network: Includes:

C-3-1: Coverage length: As stated before, this length is defined as the distance between station and its adjacent stations. More coverage length means more need of inspection in long distance between stations.

C-3-2: History of failures of rolling stock in covered route: Needless to say, failure repetition means there is a need for more inspection of system in vulnerable routes. Figure 8 shows accident and failure repetition in railway network.

C-3-3: Intersecting lanes position: If a station locates in a junction, it would provide service for two or three routes instead of single route.

C-3-4: Curves on covered length: Existence of curves with less than 1000 meter diameter means that there are some vulnerable points in block. The frequency of these curves on a block increases the risk of accidents or derailment if these curves are followed with defects on rolling stock. Figure 6 shows the frequency of curves on blocks with under 1000 meter radius in railway network.

C-4: Maneuver or repair equipment of station: Which includes:

C-4-1: Distance with repair shops: According to detection duty of station post, if a wreck has been detected or deadline for repair has been arrived, it should be sent to a repair shop that are categorized into:

C-4-1-1: Four-year repair shops: In Iranian repair schedule the fundamental repairs should be done in every 4 year period. Nine repair shops and zone that every station provide service shown in Figure 3.

C-4-1-2: Annual repair shops: Some minor check and repair actions have been done annually in freight-cars to prevent accumulation of wagons in repair shops. The undercover region of each repair shop (for 1 and 4 year repair service) proposed considering capacity of repair, loading tonnage of undercover stations and neighborhood of every repair shop.

C-4-1-2: Unscheduled repair shops: These repair shops are more prevalent in network than scheduled repair shops (26 stations in total) but are less equipped. every station provides support for nearest stations because of its unpredictable nature of failure and necessity of repairing (in contrast with scheduled repair shops).

C-4-2: Locomotive existence: If a freight car has been recognized as a “failed car” it should be separated from wagons and sent to repair shops. Existence of locomotive accelerates this action.

C-4-3: Total length of repair and maneuver lanes: Maneuver line length of every station provide space for changing line, stopping and repair of trains. Furthermore it is implies the size and equipment existence of a station.

6. Determining AHP weights

The proposed hierarchy model for the railway station site-selection problem is shown in figure1, where the overall objective is in the first level. Also, the figure shows the main criteria in the second level, 26 sub criteria in the third, and five potential stations in the last level. According to the AHP method, the elements of each level are pair wise compared with the element in the next higher level. This results in a number of pair wise comparison matrices (Saaty 1980, 2008). We assess the importance of the i-th criteria against the j-th criteria using the following five-point assessment values:

(i) If criteria i and j are equally important then the corresponding element of the comparison matrix will be $aij = \frac{w_i}{w_j} = 1$ & $aji = \frac{w_j}{w_i} = 1$.

If criteria *i* be moderately more important than criteria j then $aij = \frac{w_i}{w_j} = 3$ & $aji = \frac{w_j}{w_i} = \frac{1}{3}$.
If criteria *i* be extremely more important than criteria j then $aij = \frac{w_i}{w_j} = 5$ & $aji = \frac{w_j}{w_i} = \frac{1}{5}$.

Also, values 2 and 4 are used to show an intermediate importance between the criteria. Using the hierarchy model and the criteria we developed standard questionnaires that were filled by railway transportation experts, inspection posts directors and college professors in railway fields. Also 2 economists and 2 environmental experts had been interviewed about consequences, advantages and disadvantages of site selection for inspection posts. With accomplishing a pair wise comparison and with help of Expert Choice (EC) software, valid data (with inconsistency rate less than 0.1) has been taken into account and final weights has been calculated. Final local and overall weights have been presented in Table 1 to 9.

Table 1. Main criteria comparison results

criteria	weight
C-1	0.685
C-2	0.104
C-3	0.085
C-4	0.126
Total inconsistency rate = 0.026	

Table 2-5. Sub criteria (level 1) priority comparison results

Table 2.

sub criteria	Weight
C-1-1	0.55
C-1-2	0.24
C-1-3	0.79
Total inconsistency rate = 0.083	

Table 3.

sub criteria	weight
C-2-1	0.41
C-2-2	0.38
C-2-3	0.21
Total inconsistency rate = 0.017	

Table 4.

sub criteria	weight
C-4-1	0.77
C-4-2	0.11
C-4-3	0.12
Total inconsistency rate = 0.074	

Table 5.

criteria	weight
C-3-1	0.19
C-3-2	0.33
C-3-3	0.43
C-3-4	0.05
Total inconsistency rate = 0.081	

Table 6-8: Sub criteria (level 2) priority comparison results

Table 6.

criteria	weight
C-1-1-1	0.71
C-1-1-2	0.11
C-1-1-3	0.18
Total inconsistency rate = 0.016	

Table 7.

criteria	weight
C-1-2-1	0.75
C-1-2-2	0.15
C-1-2-3	0.10
Total inconsistency rate = 0.015	

Table 8.

criteria	weight
C-4-1-1	0.13
C-4-1-2	0.15
C-4-1-3	0.71
Total inconsistency rate = 0.069	

Table 9. Total weights of end-branches of decision making tree

Sub-criteria	Criteria weight	Sub criteria weight(1)	Sub criteria weight(2)	Total weight
C-1-1-1	0.685	0.55	0.71	0.267493
C-1-1-2	0.685	0.55	0.11	0.041443
C-1-1-3	0.685	0.55	0.18	0.067815
C-1-2-1	0.685	0.24	0.75	0.1233
C-1-2-2	0.685	0.24	0.15	0.02466
C-1-2-3	0.685	0.24	0.10	0.01644
C-1-3	0.685	0.79	-	0.54115
C-2-1	0.104	0.41	-	0.04264
C-2-2	0.104	0.38	-	0.03952
C-2-3	0.104	0.21	-	0.02184
C-3-1	0.085	0.19	-	0.01615
C-3-2	0.085	0.33	-	0.02805
C-3-3	0.085	0.43	-	0.03655
C-3-4	0.085	0.05	-	0.00425
C-4-1-1	0.126	0.77	0.13	0.012613
C-4-1-1	0.126	0.77	0.15	0.014553
C-4-1-1	0.126	0.77	0.71	0.068884
C-4-2	0.126	0.11	-	0.01386
C-4-3	0.126	0.12	-	0.01512

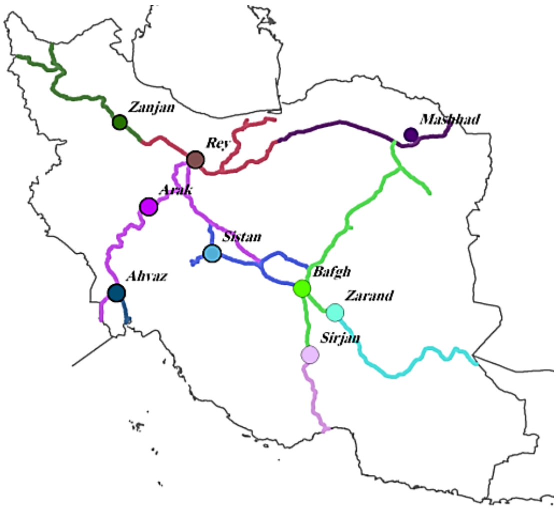

Figure 2. Annual and four-year repair shops and covered route of each shop

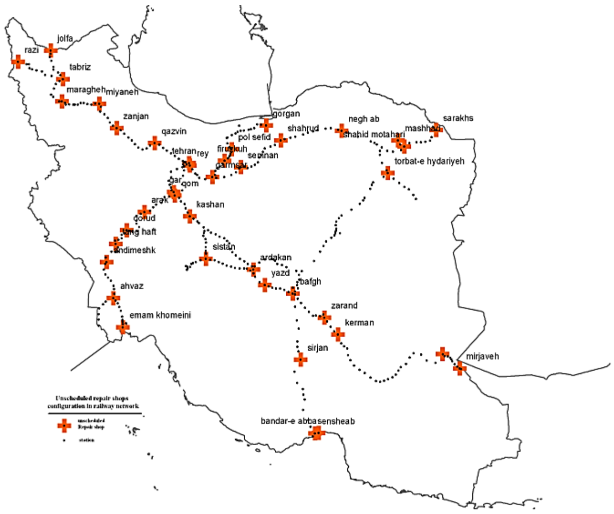

Figure 3. Existing repair shops

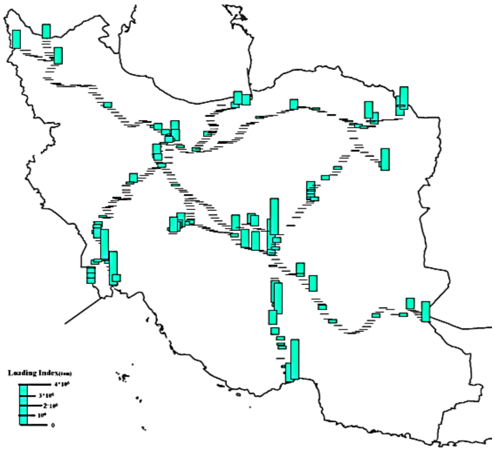

Figure 4. Loading (tonnage) in stations

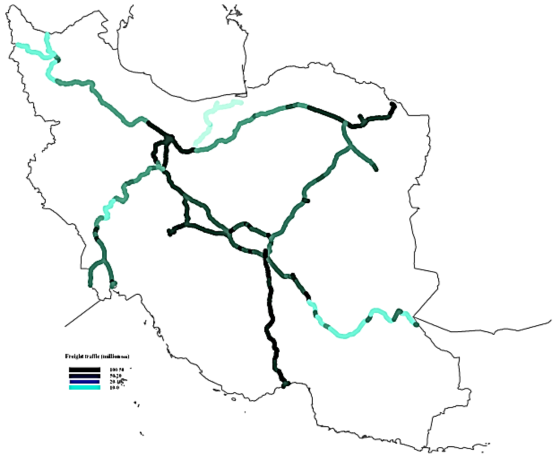

Figure 5. Passing traffic

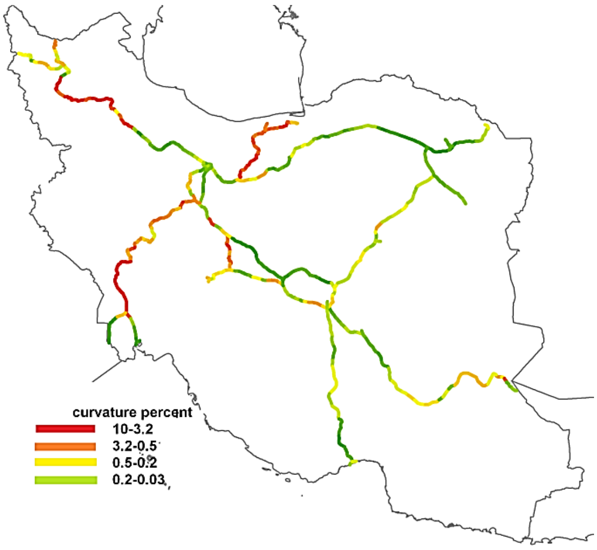

Figure 6. Curvatures rate in railway corridors

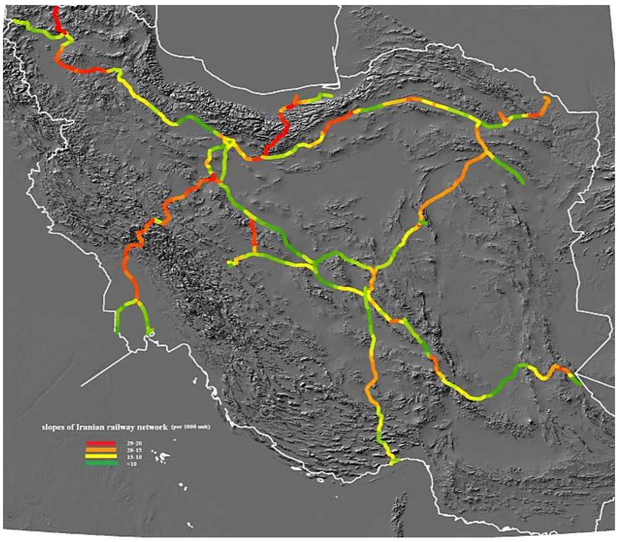

Figure 7. Slopes rate in railway corridors

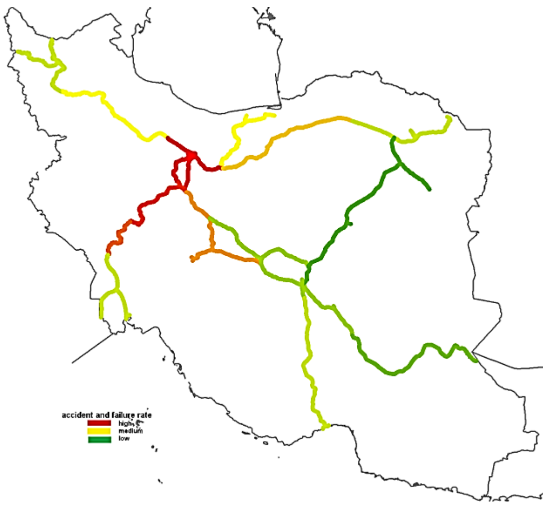

Figure 8. Failure and accident occurrence in different corridors of Iran railway network

7. Determining number of stations in railway network

Main idea for determining quantity of inspection posts is highest coverage of system. Traffic coverage is the most important factor that its relative importance has been proved by experts pair-wise comparison results (Table 9).

Therefore for each station the network coverage of freight cars total transport has been calculated (different types of traffics that described in C-1-1 and C-1-2). This coverage has been sorted by priority of each station that has been determined in previous chapters, and the accumulative traffic coverage versus station numbers has been calculated. This diagram presents Figure 9.

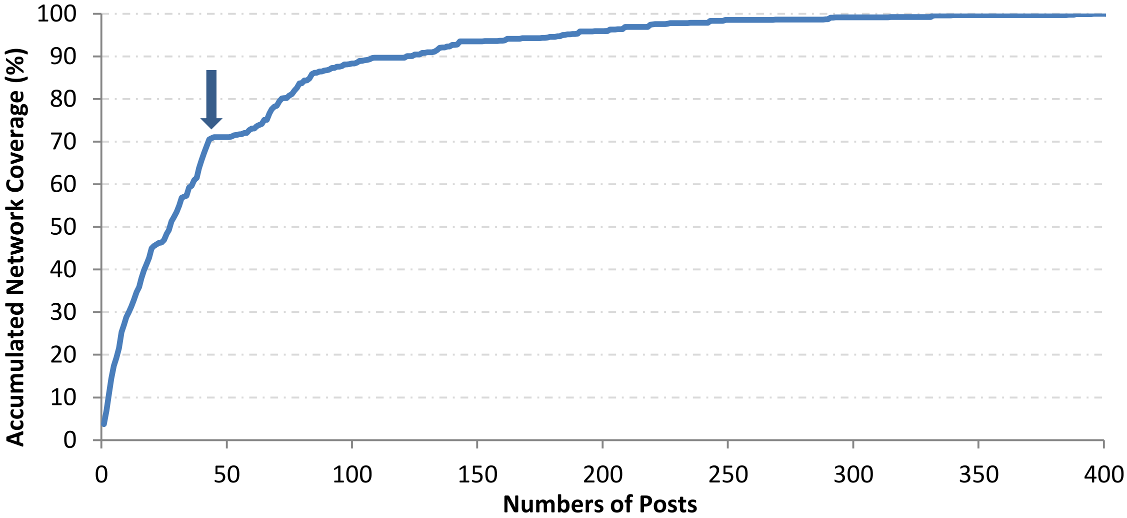

Figure 9. Increase trend of network coverage with increasing inspection posts.

As shown in Figure 9, we can cover 70.53% of loading for 43 recommended stations in railway network. After this station, because other factors have more proportion in prioritization of stations comparing with traffic tasks in 13 stations we have very mild increase in coverage; so with respect to economical evaluation, this increase in station numbers is out of financial justification. Therefore with respect to the total number of 43 stations and prioritization order of stations, the final arrangement of stations is suggested in Figure 10.

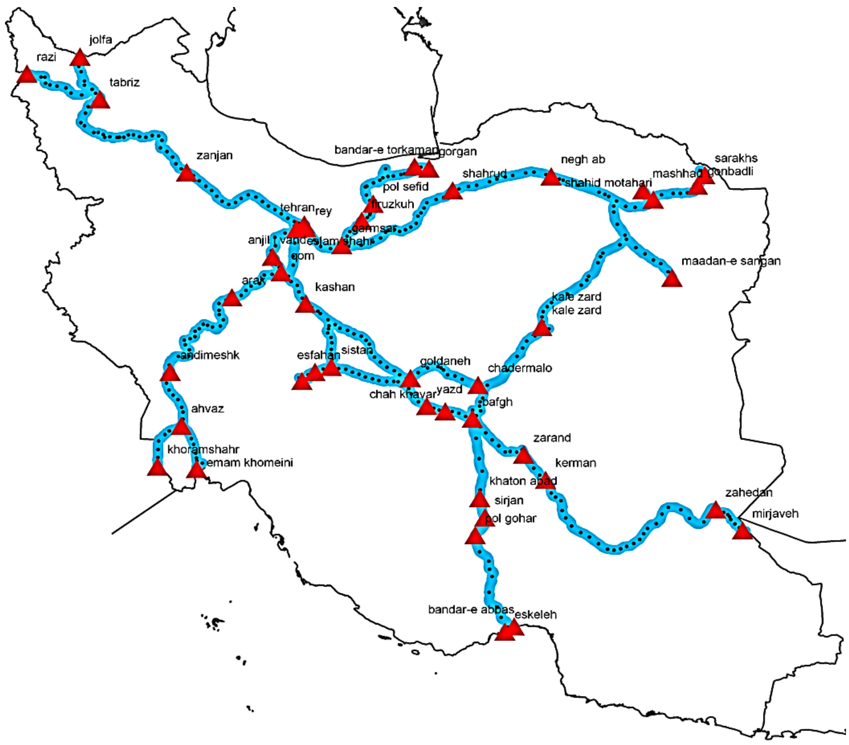

Figure 10. Position of recommended inspection posts within Iranian railway network

8. Summary and conclusion

In this research, main factions of inspection posts were taken into accounts, a decision making tree was suggested and with Analytical hierarchy process and pair-wise comparison the weight of each factor was gained. Then 403 stations were prioritized using GIS software. By considering coverage length of network, as most important factor and one of the leading important tasks that can figure out with site locating of inspection posts, the total number of 43 station posts with provided priority were recommended.

9. References

[1] Saaty, Thomas L. "The analytic hierarchy process: planning, priority setting, resources allocation." New York: McGraw (1980).

[2] Beheshtifar M. Site selection the thermal power plants. Master thesis of GIS, K.N. Toosi University of Technology;2006; p.36-50.

[3] Poormohamadi M. Schematization of urban land use. Tehran, Iran: SAMT publication; 2003, p.70-71

[4] Ocalir, Ebru Vesile, Ozge Yalciner Ercoskun, and Rifat Tur. "An integrated model of GIS and fuzzy logic (FMOTS) for location decisions of taxicab stands." Expert Systems with Applications 37, no. 7 (2010): 4892-4901.

[5] Alesheikh, Ali Asghar, Mohammad Jafar Soltani, Nahal Nouri, and M. Khalilzadeh. "Land assessment for flood spreading site selection using geospatial information system." International Journal of Environmental Science & Technology 5, no. 4 (2008): 455-462.

[6] Raharjo, Hendry, Min Xie, and Aarnout C. Brombacher. "On modeling dynamic priorities in the analytic hierarchy process using compositional data analysis." European Journal of Operational Research 194, no. 3 (2009): 834-846.

[7] Saaty, Thomas L. "Relative measurement and its generalization in decision making why pairwise comparisons are central in mathematics for the measurement of intangible factors the analytic hierarchy/network process." RACSAM-Revista de la Real Academia de Ciencias Exactas, Fisicas y Naturales. Serie A. Matematicas 102, no. 2 (2008): 251-318.

[8] Vahidnia, Mohammad H., Ali A. Alesheikh, and Abbas Alimohammadi. "Hospital site selection using fuzzy AHP and its derivatives." Journal of environmental management 90, no. 10 (2009): 3048-3056.

[9] Forman, Ernest H., and Saul I. Gass. "The analytic hierarchy process-an exposition." Operations research 49, no. 4 (2001): 469-486.

[10] García-Cascales, María Socorro, and María Teresa Lamata. "Selection of a cleaning system for engine maintenance based on the analytic hierarchy process." Computers & Industrial Engineering 56, no. 4 (2009): 1442-1451.

[11] Wang, Guiqin, Li Qin, Guoxue Li, and Lijun Chen. "Landfill site selection using spatial information technologies and AHP: a case study in Beijing, China." Journal of environmental management 90, no. 8 (2009): 2414-2421.

[12] Korpela, Jukka, Antti Lehmusvaara, and Jukka Nisonen. "Warehouse operator selection by combining AHP and DEA methodologies." International Journal of Production Economics 108, no. 1 (2007): 135-142.

[13] Linkov, Igor, F. Kyle Satterstrom, Jeffery Steevens, Elizabeth Ferguson, and Richard C. Pleus. "Multi-criteria decision analysis and environmental risk assessment for nanomaterials." Journal of Nanoparticle Research 9, no. 4 (2007): 543-554.

[14] Nijkamp, P. (2004). Transport systems and policy. USA: Edward Elgar Publishing, Inc.Onut, S., &Soner, S. (2008). Transshipment site selection using the AHP andTOPSIS approaches under fuzzy environment. Waste Management, 28(9),1552–1559.

[15] American Planning Association. Planning and urban design standards. John Wiley & Sons, 2006.

[16] Boroushaki, Soheil, and Jacek Malczewski. "Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS." Computers & Geosciences 34, no. 4 (2008): 399-410.

[17] Chang, Ni-Bin, G. Parvathinathan, and Jeff B. Breeden. "Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region." Journal of environmental management 87, no. 1 (2008): 139-153.

[18] Charnes, Abraham, William W. Cooper, and Edwardo Rhodes. "Measuring the efficiency of decision making units." European journal of operational research 2, no. 6 (1978): 429-444.

[19] Cooper, William W., Lawrence M. Seiford, and Kaoru Tone. Data envelopment analysis: a comprehensive text with models, applications, references and DEA-solver software. Springer Science & Business Media, 2007.

[20] Emrouznejad, Ali, Barnett R. Parker, and Gabriel Tavares. "Evaluation of research in efficiency and productivity: A survey and analysis of the first 30 years of scholarly literature in DEA." Socio-economic planning sciences 42, no. 3 (2008): 151-157.

[21] Ballis, Athanasios. "Airport site selection based on multicriteria analysis: the case study of the island of Samothraki." Operational Research 3, no. 3 (2003): 261-279.

[22] Dağdeviren, Metin, Serkan Yavuz, and Nevzat Kılınç. "Weapon selection using the AHP and TOPSIS methods under fuzzy environment." Expert Systems with Applications 36, no. 4 (2009): 8143-8151.