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Investigation and Prioritization of Railway Reconstruction Projects by Using Analytic Hierarchy Process Approach Case Study: Kerman and Southeastern Areas in Iranian Railways

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Abstract
Transportation development is one of the important goals of countries which is associated with economic and social development. Therefore, expanding the transportation infrastructure and construction has always been a key issue for managers in developed and developing countries. Due to the high costs of infrastructure projects in the transportation industry, especially railways as the safest and the most cost-effective mode of transportation, the financial resources must be managed with great sensitivity and precision. In current economic conditions, various methods have been proposed for decision-making in transportation infrastructure projects and prioritization of railway reconstruction projects. In this research, different decision models to prioritize transportation infrastructure projects are reviewed and according to the selected AHP (Analytic Hierarchy Process) model, railway reconstruction projects in Iranian railway networks are prioritized. In this regard, first, reconstruction projects have been reviewed from a technical and economic point of view, and then prioritization has been done according to the weight of effective criteria in the projects. In this study, important criteria for prioritization in terms of importance are considered as: Cost of Reconstruction, Train Speed Restriction, Allowable Speed, Railway Capacity, Traffic, Time, and Railway Track Quality. The effect of cost of reconstruction criterion is about 12 times greater than the time criterion and the output of the model showed that Jalalabad-Golezard block is the first priority for reconstruction in the area of Kerman and Southeastern in Iranian Railways.

Keywords
prioritization, railway, reconstruction, Analytic Hierarchy Process

1 Introduction

Managing and decision about how the budget is allocated to the reconstruction, modernization or rehabilitation of transport infrastructure is a vital issue in the transport industry [1]. In developing countries, low level of investment on railway tracks in the previous years and the low quality of maintenance resulted in reduction of the quality of infrastructure [2]. In this regard, the need to maximize railway operation efficiency complicates prioritizing railway reconstruction projects. Due to the limited financial resources, economic crisis and the fact that most railway lines need to be reconstructed, making decision about reconstruction projects is considered as a fundamental challenge in the railway industry [3].

In this research, prioritization of reconstruction projects has been investigated based on the criteria affecting reconstruction process. By considering Iranian railway transit position in the world and the domestic railway network, the importance of railway infrastructure investment at the national and international levels is quite significant. Therefore, it is completely urgent to investigate the different available assessment methodologies for prioritization of infrastructure projects.

The different assessment methodologies in various transportation modes which are utilized in EU are discussed by Prokić et al. [4]. According to their information, the Cost-Benefit Analysis (CBA) method is the most used

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method in the rail transport part in Europe [4]. Table 1 demonstrates different methods for prioritization of transportation projects. The meaning of the abbreviations in Table 1 is explained in the paragraphs after the table [5–17].

The decision-making process with the CBA method is usually done based on a single criterion which is a cost-benefit ratio. This method has some limitations, because some effective factors are immeasurable including: socio-economic effects, environmental effects [18], political effects, evaluation time [5] (the lifespan of different transport infrastructure projects varies from 20 years which is the normal reconstruction period for a railway superstructure [19], to more than 100 years like some of the bridges [20]). As mentioned before, the CBA method cannot consider the effect of political issues and this is a very important flaw in this method. Therefore, due to the influence of several factors that are effective in the prioritization of projects, the use of multi-criteria methods to evaluate the railway reconstruction projects are suggested [6].

Based on the limitations of the CBA method mentioned above, it is recommended to apply Multi-Criteria Decision Analysis Methods (MDAM) to prioritize reconstruction projects. The CBA is a great method to evaluate a small number of projects in a specified location, but it cannot consider the different criteria that are not financially measurable while the MDAM method deals with large amounts of complex information including qualitative and quantitative data. One of the multi-criteria methods is AHP method in which different weights are allocated to the effective criteria [15]. This method was presented to prioritize the selection of road projects by Al-Harbi [14].

Management of infrastructure projects in the field of transportation is complex and in this regard, different approaches of MDAM with multiple perspectives have been addressed. These decision tools have been created with the aim of comparing different projects by considering various criteria. According to these criteria, the mentioned methods offer a plan for decision making [7].

Table 1 Various methods for prioritization of transportation projects

Method		Researchers, year
CBA		Thomopoulos & Grant-Muller, 2013 [5] Shafiepour et al., 2018 [6]
MDAM	MAUT	Macura et al, 2011 [7] Tsamboulas et al., 2007 [8] Tsamboulas, 2007 [9] Chang et al., 2009 [10]
	GP	Zhang et al., 2014 [11] Blagojević et al., 2020 [12]
	AHP	Daniyan et al., 2020 [13] Al-Harbi, 2001 [14] Nyström & Söderholm, 2010 [15]
	ANP	Tudela et al., 2006 [16] Longo et al., 2009 [17] Prokic et al., 2018 [4]

The MDAM method can be used with multiple perspectives which are shown in Table 1. These methods are MAUT (Multi Attribute Utility Theory); GP (Goal Programming); AHP (Analytic Hierarchy Process); ANP (Analytic Network Process) [13].

The GP method is employed to prioritize railway investment projects as a multi-criteria method [21]. The purpose of this model is achieving maximum goals with a specific budget. This method has been utilized in all railway projects by Zhang et al. [11] and Blagojević et al. [12].

MAUT is a tool for prioritizing transportation projects in an international transportation network. In recent years, this issue has become very important due to the globalization and application of this method throughout the European transport network. The MAUT multi-criteria approach applies to projects that involved in high amount of investment. This model has been developed to prioritize the projects according to the financial, economic, social, environmental, traffic impacts and benefits of the projects [8, 9]. MAUT method has some advantages compared to CBA method. The main features of this method are: the weight of the criteria, independent criteria, the differentiation of project performance over time and a new approach to convert qualitative data to quantitative scales. This method has been exerted in transportation infrastructure investments [8, 9].

The results of the analysis of CBA and AHP methods were compared by Tudela et al. [16]. They compared the output of these methods to select and prioritize the transportation projects and to demonstrate that the results of prioritization are different in the two methods. They showed that the final decision for prioritization was based on the results of AHP method. As long as there are various factors other than financial factor, it is clear that the CBA method is useless. Consideration of parameters such as noise, accidents and air pollution that are effective in prioritizing projects is not significant in the CBA approach [16, 22].

In a strategic project related to the historic Alishan Forest Railway in Taiwan following criteria were considered by Chang et al. [10].

In a case study related to railway infrastructure (a selection of solutions related to the new railway route), AHP and ANP models were conducted and their outcomes were compared with each other by Longo et al. [17]. In the prioritization process, four main criteria of cost (project costs), transportation efficiency (safety, performance efficiency, capacity and reliability), environmental impacts (natural, physical and urban resources) and executive aspects (modification of the main project and interaction in the existing network) were considered and the results obtained by AHP and ANP were same [17].

As a conclusion for selecting the proper method for prioritization which discussed above, review of the technical literature confirms that a multi-criteria approach should be applied in the selection of railway transportation infrastructure projects. Also, based on the literature and the current status in Iran's railways, an AHP model is utilized to prioritize Iranian railway infrastructure projects. The AHP model has several advantages like multi-criteria analysis and considering the weight of effective criteria in the system [23]. The final result in prioritizing infrastructure projects should be realistic and have a flexible approach in selecting the final alternative. The Administration of Railways of Kerman and Southeastern as part of Iran's railway network studied in this research according to Fig. 1. It is predicted that there will be striking increase in the passenger and freight in these lines in the coming years and also Kerman and Southeastern Administrations are close to Yazd state railways which is one of the busiest railway lines in Iran (Fig. 1). Hence, Kerman and Southeastern railways are significantly important for the railway managers.

In this paper, the main goal is to prioritize the railway reconstruction projects in two regions of Iran's railway network. Seven alternative projects in Kerman and Southeastern Administrations of Iran's railway network are considered as a case study. An AHP model is used for prioritization since there are various effective criteria and the nature of the main goal in this research demands a multi-criteria analysis. The effective criteria in decision-making for prioritization have been identified as cost of reconstruction, train speed restriction, allowable speed, railway capacity, traffic, time, and railway track quality. In the next step, the decision-making criteria in the process of prioritization of reconstruction projects have been sorted in order of importance. Then, the effective criteria have been calculated quantitatively, since in general, most of the criteria in decision-making have qualitative nature. Finally, the decision-making between the alternative projects has been done through an AHP multi-criteria analysis.

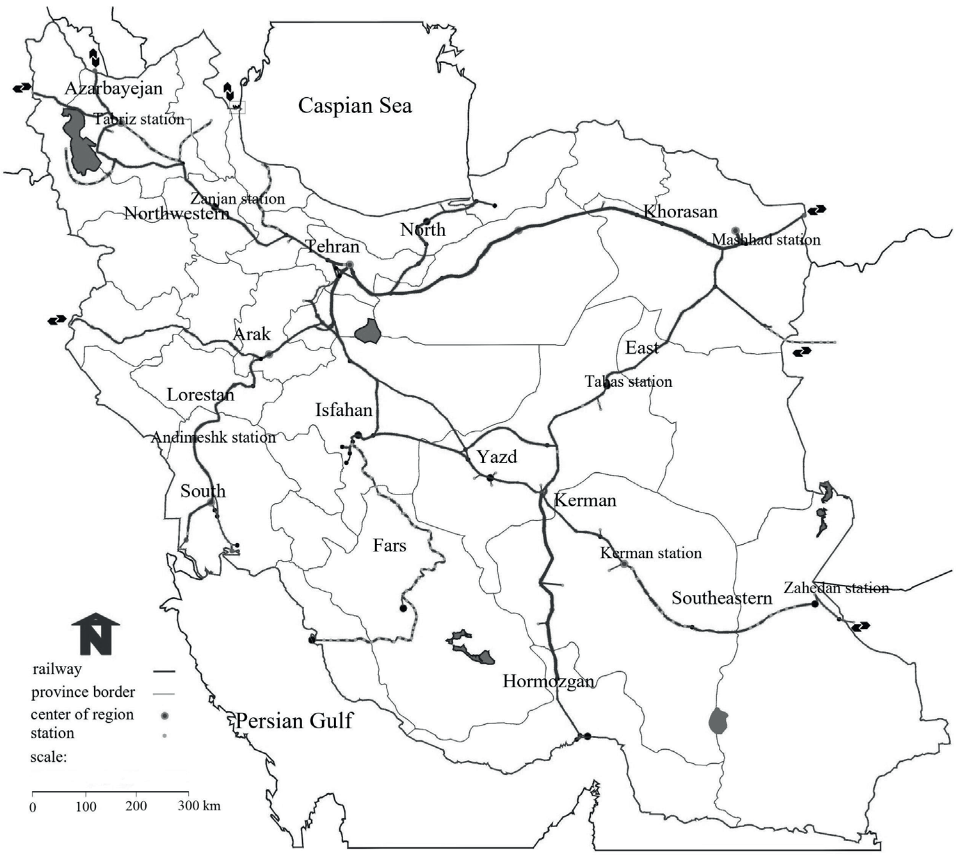

Fig. 1 Iran's railway network

2 Methodology

2.1 The case study area in Iran's railway network

The Iran's railway network is more than 14,000 kilometers which is divided into 21 regions (or general administration) and most of them are single lane and all of them belong to "Railway of the Islamic Republic of Iran" company (RAI). Kerman and Southeastern general administrations are selected to be investigated in this case study, which are shown in Fig. 1. The general administration of Kerman railway is 550 km, which starts from the Rig Valley station at 876 km + 100 m and ends at Shourgaz station at 1424 km + 000 m and general administration of the Southeastern railway is 329 km, which starts from Shourgaz station at 1424 km + 000 m and ends at Mil station at 1753 km + 327 m.

Kerman railway is located next to Yazd railway as the busiest area in Iran's railway network. Also the connection to railway profitable cargo sources such as Jalalabad mine and steel producing factory makes Kerman administration an important area in Iran's railway network for the managers. General administration of Southeastern is considered important because of future improvements and reconstruction operations, having a border station with Pakistan and also containing lines which pass through sandy desert areas with high rate of deterioration [24].

2.2 Reconstruction alternative projects

According to the previous section, there are various blocks which are considered to be reconstructed in Kerman and Southeastern regions in the coming years. Regarding the blocks proposed for reconstruction in Kerman and Southeastern and the maintenance status of the blocks, final alternatives for reconstruction projects and prioritization are presented in Table 2.

2.3 AHP model

For decision-making in complex issues such as prioritizing infrastructure projects, a multi-criteria decision-making method is essential. AHP method is an approach for decision-making by considering several criteria among all the parameters of a system. In this method, problem structure is formatted by considering the hierarchy importance of the criteria and it is possible to compare them from low level of importance to higher level of importance. Besides, consideration of the qualitative and quantitative criteria is available simultaneously.

Effective criteria in prioritization have been selected based on the existing literature, scientific principles and recommendations of experts which are shown in Table 3. The last column of Table 3 indicates the positive or negative effects on the prioritization in reconstruction projects based on different criteria. For example, increasing the allowable speed of travel has positive effect on prioritization.

In continuation, all of the prioritization criteria in reconstruction projects as presented in Table 3 are described.

Table 2 Alternative projects for railway reconstruction

	Starting Station	Area	Block Length(km)	Ending Station
1	Siriz	Kerman	38	Golezard
2	Golezard		17	Jalalabad
3	Jalalabad		18	Zarand
4	Zarand		38	Pourmand
5	Pourmand		40	Kerman
6	Roodshour	Southeastern	28	Shourgaz
7	Namakzar		24	Roodshour

Table 3 Effective criteria on the prioritization in reconstruction projects

Effect		Criterion	Unit	Effect
1	X1	Cost of Reconstruction	USD	negative
2	X2	Train Speed Restriction	Train-hour	positive
3	X3	Allowable Speed	Train-hour	positive
4	X4	Railway Capacity	ratio with no unit	positive
5	X5	Traffic	tonnage	positive
6	X6	Time	hour	negative
7	X7	Railway Track Quality	CoSD	positive

2.3.1 X1: Cost of Reconstruction

The importance of economic issues in infrastructure projects is undeniable. Obviously, the reconstruction of railways as one of the most expensive projects in the field of technology and infrastructure is a serious issue. This issue has been widely investigated by researchers from various countries like Serbia, Hungary, South Korea, Sweden, Denmark, Greece, Turkey and Iran [1, 5, 6, 25–27]. In calculating the cost of reconstruction projects, the region of reconstruction operations, the number and length of technical structures such as bridges and tunnels are important [7]. In this research, according to the estimation of existing reconstruction contracts, an accurate calculation has been made to prioritize the reconstruction projects.

2.3.2 X2: Train Speed Restriction

Elimination of speed restriction due to the deterioration of railway track has always been a concern of railway managers. By reducing the train speed, transmission rate of freight and passenger reduces and consequently revenues decrease [4, 7, 28, 29]. As mentioned in Table 3, elimination of train speed restriction has a positive effect on prioritization in reconstruction projects. Speed restriction is generally applied along a certain length of railway blocks to maintain the safety of passing trains. It must be noticed that only sections with speed restriction must be calculated where the speed restrictions are removed after reconstruction [4, 7, 28, 29].

According to this criterion, the railway blocks (alternatives) with more delays due to speed restrictions are in priority for reconstruction, where the costs of the projects are equal. This criterion for all trains passing along a block with speed restriction is calculated using Eq. (1):

$$\Delta \boldsymbol{TSR} = \sum_{i=1}^{n} \left(\frac{\boldsymbol{li}}{\boldsymbol{ai}} - \frac{\boldsymbol{li}}{\boldsymbol{di}} \right) . \boldsymbol{Pi} \ . \tag{1}$$

- $\Delta \boldsymbol{TSR}$ the total travel time lost in a part of the railway track with speed restriction (Train-hour)
- $\boldsymbol{li}$ length of the track with speed restriction (km)
- i number of speed restrictions
- $\boldsymbol{di}$ designed speed in the speed restriction zone (km/h)
- $\boldsymbol{ai}$ allowed speed in the speed restriction zone (km/h)
- $\boldsymbol{Pi}$ the number of passing trains through speed restriction zone per year (train)

2.3.3 X3: Allowable Speed

In some cases, the reconstruction is accompanied by an improvement in the track line class, especially in cases where a new track route is constructed. Consequently, the train speed could be enhanced which increases the capacity of the railway network. According to this criterion, as long as the cost of reconstruction for two alternatives is approximately equal, the alternatives with enhanced allowable speed after reconstruction are in priority. The calculation of this criterion is similar to the train speed restriction [4, 7]. This criterion is achieved by Eq. (2):

$$\Delta \boldsymbol{AS} = \sum_{i=1}^{n} \left(\frac{\boldsymbol{Ai}}{\boldsymbol{sai}} - \frac{\boldsymbol{Ai}}{\boldsymbol{sbi}} \right) . \boldsymbol{Bi} \ . \tag{2}$$

- $\Delta \boldsymbol{AS}$ the total time saved in a railway block due to an increase in the allowable speed after reconstruction (train-hour)
- $\boldsymbol{Ai}$ length of the track with increased allowable speed (km)
- i number of increased allowable speed
- $\boldsymbol{sai}$ the designed speed after reconstruction (km/h)
- $\boldsymbol{sbi}$ the designed speed before reconstruction (km/h)
- $\boldsymbol{Bi}$ the number of trains that pass through the increased speed zone (train)

2.3.4 X4: Railway Capacity

The railway capacity indicates the number of trains that pass through a railway section for a specified period of time. This criterion depends on track routes, technical items of railway track (design, super-structure properties), available equipment in railway tracks and stations, distance of railway to cargo centers, railway signaling system and other parameters. The railway capacity criterion demonstrates the difference between the current capacity and the achievable additional capacity after reconstruction. According to this criterion, alternative projects that attain more passing trains (passenger and freight) and consequently their capacity will be enhanced after reconstruction, are in priority [4, 19].

There are at least three main reasons for choosing this criterion: Firstly, the limited capacity of a block can result in creating bottleneck for the entire relevant railway network. Secondly, lower achievable capacity during daily traffic may result in chain delays. In these kinds of cases the quality of service is reduced. Thirdly, sometimes reconstruction projects may cause further costs for the traffic control without any change in the volume of traffic [7].

Railway capacity criterion is the ratio of the number of passing trains in the block after reconstruction to the current railway capacity in that block, which is shown in Eq. (3):

$$\boldsymbol{rc} = \frac{\boldsymbol{ta}}{\boldsymbol{c}} \ . \tag{3}$$

- $\boldsymbol{rc}$ railway capacity criterion
- $\boldsymbol{ta}$ number of passing trains through block after reconstruction (train per day)
- $\boldsymbol{c}$ current railway capacity (train per day)

The railway capacity for alternative projects at Kerman and Southeastern areas of Iran's railway network has been calculated. To do so, firstly the average number of passing trains in 24 hours was calculated. Then the ratio of this number to the maximum possible passing trains obtained. The number of trains calculated according to the freight and passenger capacity information, gathered from the commercial sector of Iran's Railway Company [30].

2.3.5 X5: Traffic

Traffic on a railway track expresses the number of trains passing through the railway block. This criterion indicates that the maximum amount of investment should be allocated to the blocks with the highest volume of traffic while all other criteria are the same. In other words, between two alternatives for reconstruction with almost the same infrastructure and maintenance conditions, priority should be given to the alternative with the higher traffic [4, 7].

The volume of passenger traffic is usually expressed by the number of passenger trains (person-kilometers) and the volume of freight traffic expressed by the number of freight trains (ton-kilometers). In this research, the alternative projects are defined based on the railway blocks; therefore this criterion is calculated as Eq. (4):

$$t = f + p \ . \tag{4}$$

- t number of passing trains through blocks per day (train per day)
- f number of freight passing trains through blocks per day (train per day)
- p number of passenger passing trains through blocks per day (train per day)

2.3.6 X6: Time

The effect of this criterion on the prioritization of railway reconstruction projects can be discussed from two perspectives. For the maintenance administrative team, increasing the reconstruction allowable deadline is considered as a positive point, because the team can properly focus on quality of railway reconstruction regardless of the time. However, managers and companies emphasize on both quality and time limits and even more on the time factor, which means that the most important thing is the number of trains passing through the railway blocks. So the commercial sectors of railway companies always try to reduce the reconstruction time as much as possible and maximize the capacity of the railway network. Therefore, mostly this criterion has a decreasing effect on the prioritization of reconstruction projects; because, as the time needed for reconstruction of a block increased the capacity of the block is reduced and consequently the company's income falls [4, 7, 31, 32].

Another point that should be noted is the importance of the block in the railway network. In other words, if two alternative projects with equal conditions, require equal time for reconstruction, the block with less traffic is in priority [4]. For calculating this criterion, according to Eq. (5), several parameters must be considered, such as the reconstruction technology, the contractor's capacity, the weather conditions and the geography of the area [7]. Due to applying the effect of the block position in the rail network in this criterion, a coefficient should be considered which is calculated from the Eq. (6):

$$rt = \theta . ct \ , \tag{5}$$

$$\theta = 1 + \frac{lr}{lt} \ . \tag{6}$$

- rt modified time for reconstruction (hours)
- θ coefficient of reconstruction time
- ct the time allocated for reconstruction by the contractor (hours)
- lr volume of load passing through the block (ton-kilometers)
- lt volume of load passing through the railway network in the last year (ton-kilometers)

2.3.7 X7: Railway Track Quality

One of the main goals of railway reconstruction is enhancement of the quality of track and there are a variety of ways to measure track quality. Analyzing the outputs of the track recording machine (EM120) is one of the methods for measuring track quality which is common in Iran's railway network [33]. It shows the geometric parameters of the track from different aspects such as: twist, alignment, track gauge, and other parameters [28, 33, 34]. The outputs of the track recording machine, after statistical processing is modified into indexes that are employed in track maintenance. One of the indexes which are used to evaluate the railway track geometry in Iran's railway network is Combined Standard Deviation (CoSD) [33]. The CoSD is one of the outputs of the track recording machine, which increasing in this item indicates the unsuitable maintenance condition of the railway track. This parameter has a positive effect on railway reconstruction prioritization. For example, between two alternatives with similar conditions, the reconstruction of a block with a higher CoSD is in priority [33].

So far, the effective criteria on the prioritization of railway reconstruction projects have been discussed. These seven criteria (X1 to X7) are considered to match the local condition in Iran's railway network. These items have been classified based on their importance and then the AHP model has been created.

3 Method of analyses

Before analyzing the alternative projects by the AHP model, the criteria (X1 to X7) should be hierarchically identified. This is possible by using the Saaty fundamental scale which is shown in Table 4 [35]. In other words, this hierarchical arrangement is a prerequisite for the formation of matrices and describes the priority among the effective criteria in prioritization from a higher to lower levels. This scale has been validated for effectiveness, not

Table 4 The importance scales and definitions

Definition	The importance
Equal	1
Weak	2
Moderate importance	3
Moderate plus	4
Strong importance	5
Strong plus	6
Very strong importance	7
Very, very strong	8
Extreme importance	9

only in many applications by a number of people, but also through theoretical justification of what scale one must utilize in the comparison of homogeneous elements [35]. In addition, experts in the railway industry must define priorities between criteria [35].

According to Eq. (7), matrix $\boldsymbol{A}$ shows a comparison between the parameters. This indicates the prioritization of experts' opinions on the effective criteria in prioritization [7, 35].

$$\begin{array}{c} \\ \boldsymbol{A}_1 \\ \boldsymbol{A}_2 \\ \vdots \\ \boldsymbol{A}_j \\ \vdots \\ \boldsymbol{A}_n \end{array} \begin{array}{c} \begin{array}{cccccc} \boldsymbol{A}_1 & \boldsymbol{A}_2 & \cdots & \boldsymbol{A}_i & \cdots & \boldsymbol{A}_n \end{array} \\ \boldsymbol{A} = \begin{bmatrix} 1 & \boldsymbol{a}_{12} & \cdots & \boldsymbol{a}_{1i} & & \boldsymbol{a}_{1n} \\ \boldsymbol{a}_{21} & 1 & & \vdots & & \boldsymbol{a}_{2n} \\ \vdots & \cdots & & & & \vdots \\ \boldsymbol{a}_{j1} & \boldsymbol{a}_{j2} & & 1 & & \boldsymbol{a}_{jn} \\ \vdots & & & & & \vdots \\ \boldsymbol{a}_{n1} & \boldsymbol{a}_{n2} & \cdots & \boldsymbol{a}_{ni} & \cdots & 1 \end{bmatrix}, \boldsymbol{a}_{ji} = \frac{1}{\boldsymbol{a}_{ij}} \end{array} \tag{7}$$

The matrix $\boldsymbol{M}$ in Eq. (8) represents the normalized $\boldsymbol{A}$ matrix, in which elements are indicated by $\boldsymbol{a}_{ij}'$.

$$\boldsymbol{M} = \begin{bmatrix} \boldsymbol{a}_{11}' & \boldsymbol{a}_{12}' & \boldsymbol{L} & \boldsymbol{a}_{1n}' \\ \boldsymbol{a}_{21}' & & & \\ & & & \\ \boldsymbol{L} & & \boldsymbol{a}_{ij}' & \boldsymbol{L} \\ \boldsymbol{a}_{n1}' & \boldsymbol{L} & & \boldsymbol{a}_{nn}' \end{bmatrix}, \boldsymbol{a}_{ij}' = 1 / \sum\nolimits_{i=1}^{n} \boldsymbol{a}_{ij} \tag{8}$$

The $\boldsymbol{W}$ matrix in Eq. (9) is a special unit vector of the $\boldsymbol{A}$ matrix and is called the priority vector. In the factor $\boldsymbol{\lambda}_{\max}$ (Eq. (10)), n is the number of criteria used to calculate the accuracy of a comparative matrix index, $\boldsymbol{CI}$. To improve the compatibility of effective parameters in prioritizing and validating the opinion of experts, the $\boldsymbol{CR}$ is applied which is calculated by Eq. (12).

$$\boldsymbol{W} = \begin{bmatrix} \boldsymbol{W}_1 \\ \vdots \\ \boldsymbol{W}_i \\ \vdots \\ \boldsymbol{W}_n \end{bmatrix}, \boldsymbol{W}_i = \frac{1}{n} \sum\nolimits_{j=1}^{n} \boldsymbol{a}_{ij}' \tag{9}$$

$$\lambda_{max} = \sum\nolimits_{j=1}^{n} \left(\boldsymbol{W}_i \cdot \left[\sum_{j=1}^{n} \boldsymbol{a}_{ij} \right] \right) \tag{10}$$

$$\boldsymbol{CI} = \left(\lambda_{max} - n \right) / \left(n - 1 \right) \tag{11}$$

$$\boldsymbol{CR} = \boldsymbol{CI} / \boldsymbol{RI} \tag{12}$$

After calculating the dependency index of criteria and $\boldsymbol{CR}$ ratio, it is possible to utilize the following relation to validate experts' opinions about relationship between prioritization criteria. Table 5 shows the different $\boldsymbol{RI}$ values for various amount of n.

For $\boldsymbol{CR} < 0.1$, the degree of consistency is satisfactory. Otherwise, the judgment of experts should be revised [7, 35]. The AHP includes a consistency index for an entire hierarchy. An inconsistency of 10 percent or less implies that the adjustment is small compared to the actual values of the eigenvector entries [35].

4 Results and discussion

Based on the previous sections, all the defined criteria (X1–X7) for the projects are calculated. Then, a pairwise comparison matrix is created which is performed by a survey of experts in Iran's Railway Company. The values of criteria in the prioritization of railway reconstruction projects are given in Table 6.

If the value of a criterion is zero in the matrix, that criterion does not affect the prioritization. As shown in Table 6, some of the criteria such as the train speed restriction

Table 5 The values of ***RI***

n	***RI***
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Table 6 The values of criteria in prioritization for selected alternatives

Alternative	X1 (USD)	X2 (Train-hour)	X3 (Train-hour)	X4	X5 (tonnage)	X6 (hour)	X7 (CoSD)
Golezard-Siriz	19113600	0.00	0	0.85	17.00	309.52	2.37
Jalalabad- Golezard	8486400	0.00	0	0.85	17.00	138.50	3.19
Zarand- Jalalabad	8985600	0.00	0	0.85	17.00	146.52	3.00
Pourmand- Zarand	18969600	0.00	0	0.85	17.00	309.52	2.77
Kerman- Pourmand	19200000	0.00	0	0.85	17.00	325.88	2.83
Shourgaz-Roodshour	17203200	327.04	0	0.70	7.00	224.68	1.90
Roodshour-Namakzar	14745600	0.00	0	0.70	7.00	192.58	2.02

and the allowable speed are zero, which demonstrate that after reconstruction in the selected alternatives there is no removed speed restrictions and also the allowable speed after reconstruction has not changed.

Table 7 shows the importance of the criteria compared to each other. In the last column of Table 7, the ranking of the criteria based on their importance are shown. This information is achieved through collecting the opinion of railway experts of Iran's railway company by standard questionnaires. Finally, to calculate the final prioritization, the values of criteria (Table 6) are multiplied by the values of importance shown in Table 7.

As shown in Table 7, the most important criterion is X1 or Cost of Reconstruction. X1 is the highest effective criterion with a W_i of 0.384, and the least effective criterion is the time criterion with a W_i value of 0.031. This means that according to the experience of railway experts, the most important factor in reconstruction projects is the costs, while the least important factor is the time needed for reconstruction.

Regarding the prioritization of reconstruction projects shown in Table 8, Jalalabad-Golezard block is the first priority and Roodshour-Namakzar block is at the seventh priority for reconstruction. Considering that all the criteria in prioritization for Jalalabad-Golezard block are at a better or equal condition in comparison with the criteria in

Table 7 The importance of the criteria compared to each other

Criteria	X1	X2	X3	X4	X5	X6	X7	W_i	Rank of criteria
X1	1	5	5	6	3	8	4	0.384	1
X2		1	1	2	1/4	3	1/3	0.072	5
X3			1	2	1/5	4	1/4	0.074	4
X4				1	1/7	1	1/6	0.064	6
X5					1	8	3	0.267	2
X6						1	1/6	0.031	7
X7							1	0.134	3

Table 8 Prioritization of alternative projects

	Alternatives	Weight	Rank
A1	Golezard-Siriz	0.1155	6
A2	Jalalabad- Golezard	0.1741	1
A3	Zarand- Jalalabad	0.1674	2
A4	Pourmand- Zarand	0.1185	4
A5	Kerman- Pourmand	0.1183	5
A6	Shourgaz-Roodshour	0.1606	3
A7	Roodshour-Namakzar	0.0974	7

prioritization for Roodshour-Namakzar block, it is completely logical that Jalalabad-Golezard block is in priority for reconstruction compared to Roodshour-Namakzar block. According to the results of the research, Iran's Railway Company has launched the reconstruction projects based on the prioritization outputs of the current research.

5 Conclusions

Managing the budgets in transportation infrastructure projects is an important issue in railway transportation. Some railway tracks don't have high quality due to the low level of investment in the past and the lack of attention to maintenance operations. The limited resources and the economic crisis necessitate the maximum efficiency in existing railway track operation and in this regard prioritization of railway reconstruction projects have particular importance.

In this research, according to the seven criteria including cost of reconstruction, train speed restriction, allowable speed, railway capacity, traffic, time, and railway track quality, the prioritization of reconstruction projects have been conducted based on the AHP multi-criteria model.

The importance of the seven criteria compared to each other has been determined by experts in the field of railway reconstruction in Iran's Railway Company. Seven blocks (alternatives) of Iran's railway network in Kerman and Southeastern areas including Golezard-Siriz, Jalalabad-Golezard, Zarand-Jalalabad, Pourmand-Zarand, Kerman-Pourmand, Shourgaz-Roodshour and Roodshour-Namakzar have been investigated in the AHP model for prioritization. According to the conditions of railway track reconstruction projects in Iran, it is considered to use the AHP multi-criteria prioritization model for prioritizing the railway reconstruction projects, since in this method it is possible to apply experts' opinions and investigate impact of all the criteria affecting prioritization. Another reason for applying the MDAM approach (like AHP method) instead of the CBA or other single criteria methods was the similar projects in other countries like Serbia, Hungary, Sweden, Denmark and so on. The results of AHP method in prioritizing the infrastructure projects (like railway reconstruction) in various countries like Serbia, South Korea, Hungary, Sweden, Denmark, Greece and so on, compared to other methods of prioritization demonstrated reasonable performance; therefore the AHP method was applied in this research.

It has been concluded that according to the experience of the railway experts in Iran; the seven criteria affecting the railway reconstruction in order of importance are: 1-Cost of Reconstruction, 2-Traffic, 3-Railway Track Quality, 4-Allowable Speed, 5-Train Speed Restriction, 6-Railway Capacity and 7-Time. The results showed that the effect of cost of reconstruction criterion is about 12 times greater than the time criterion. The output of the AHP model showed that the Jalalabad-Golezard block is the first priority for reconstruction amongst the investigated alternatives.

References

[1] Pamucar, D., Macura, D., Tavana, M., Božanić, D., Knežević, N. (in press) "An Integrated Rough Group Multicriteria Decision-Making Model for the Ex-Ante Prioritization of Infrastructure Projects: The Serbian Railways Case", Socio-Economic Planning Sciences, Article number 101098, (Accepted for publication June 2021). https://doi.org/10.1016/j.seps.2021.101098

[2] Zakeri, J. A., Galdiani, M. A., Mosayebi, S. A. "Field Investigations on the Effects of Track Lateral Supports on the Ballasted Railway Lateral Resistance", Periodica Polytechnica Civil Engineering, 64(3), pp. 640–646, 2020. https://doi.org/10.3311/PPci.15446

[3] te Boveldt, G., Van Raemdonck, K., Macharis, C. "A new railway tunnel under Brussels? Assessing political feasibility and desirability with competence-based multi criteria analysis", Transport Policy, 66, pp. 30–39, 2018. https://doi.org/10.1016/j.tranpol.2018.03.002

[4] Prokić, M., Macura, D., Bošković, B. "Prioritization of railway infrastructure projects using the ANP approach – Case Study Serbian Railway Network", In: 5th International Conference on Road and Rail Infrastructure, Zadar, Croatia, 2018, pp. 713–718. https://doi.org/10.5592/CO/CETRA.2018.755

[5] Thomopoulos, N., Grant-Muller, S. "Incorporating equity as part of the wider impacts in transport infrastructure assessment: an application of the SUMINI approach", Transportation, 40, pp. 315–345, 2013. https://doi.org/10.1007/s11116-012-9418-5

[6] Shafiepour, M., Tamannaei, M., Abtahi, M. "A Methodology to Prioritize the Construction Projects of New Railway Infrastructures for Privatization in Railway Networks (Case Study: Iran)", International Journal of Transportation Engineering, 6(2), pp. 123–143, 2018. https://doi.org/10.22119/IJTE.2017.52979

[7] Macura, D., Bošković, B., Bojović, N., Milenković, M. "A Model for Prioritization of Rail Infrastructure Projects Using ANP", International Journal of Transport Economics, 38(3), pp. 285–309, 2011. [online] Available at: http://www.jstor.org/stable/42747923

[8] Tsamboulas, D. A., Yiotis, G., Mikroudis, G. "A Method for Multi-Criteria Analysis in Transportation Infrastructure Investments", International Journal of Transport Economics, 34(1), pp. 113–131, 2007. [online] Available at: http://www.jstor.org/stable/42747790

[9] Tsamboulas, D. A. "A tool for prioritizing multinational transport infrastructure investments", Transport Policy, 14(1), pp. 11–26, 2007. https://doi.org/10.1016/j.tranpol.2006.06.001

[10] Chang, Y.-H., Wey, W.-M., Tseng, H.-Y. "Using ANP priorities with goal programming for revitalization strategies in historic transport: A case study of the Alishan Forest Railway", Expert Systems with Applications, 36(4), pp. 8682–8690, 2009. https://doi.org/10.1016/j.eswa.2008.10.024

[11] Zhang, F., Wang, X. D. Sheng, F. S. "Research on High-Speed Railway Line Selection Based on Analytic Hierarchy Process", Applied Mechanics and Materials, 577, pp. 1061–1064, 2014. https://doi.org/10.4028/www.scientific.net/AMM.577.1061

[12] Blagojević, A., Vesković, S., Kasalica, S., Gojić, A., Allamani, A. "The application of the fuzzy AHP and DEA for measuring the efficiency of freight transport railway undertakings", Operational Research in Engineering Sciences: Theory and Applications, 3(2), pp. 1–23, 2020. https://doi.org/10.31181/oresta2003001b

[13] Daniyan, I., Mpofu, K., Ramatsetse, B. "The use of Analytical Hierarchy Process (AHP) decision model for materials and assembly method selection during railcar development", Cogent Engineering, 7(1), Article number: 1833433, 2020. https://doi.org/10.1080/23311916.2020.1833433

[14] Al-Harbi, K. M. A.-S. "Application of the AHP in project management", International Journal of Project Management, 19(1), pp. 19–27, 2001. https://doi.org/10.1016/S0263-7863(99)00038-1

[15] Nyström, B., Söderholm, P. "Selection of maintenance actions using the analytic hierarchy process (AHP): decision-making in railway infrastructure", Structure and Infrastructure Engineering, 6(4), pp. 467–479, 2010. https://doi.org/10.1080/15732470801990209

[16] Tudela, A., Akiki, N., Cisternas, R. "Comparing the output of cost benefit and multi-criteria analysis: An application to urban transport investments", Transportation Research Part A: Policy and Practice, 40(5), pp. 414–423, 2006.
https://doi.org/10.1016/j.tra.2005.08.002

[17] Longo, G., Padoano, E., Rosato, P., Strami, S. "Considerations on the Application of AHP/ANP Methodologies to Decisions Concerning a Railway Infrastructure", [pdf] In: Proceedings of the International Symposium on the Analytic Hierarchy Process, Pittsburgh, PA, USA, 2009. Available at: http://www.isahp.org/2009Proceedings/Final_Papers/65_Padoano_Longo_Strami_AHP-ANPGroupRailwayInfrastructureDecision_REV_FIN.pdf

[18] Csortos, G., Augusztinovicz, F., Bocz, P. "Optimal operation of a rail lubrication device with respect to noise reduction and wheel/rail friction coefficient", Acta Technica Jaurinensis, 14(2), pp. 138–154, 2021.
https://doi.org/10.14513/actatechjaur.00592

[19] Kerr, A. D. "Fundamentals of Railway Track Engineering", Simmons-Boardman Books, Omaha, NE, USA, 2003.

[20] Ricketts, N. "Railway Bridge Maintenance", ICE Publishing, London, UK, 2017.

[21] Hamurcu, M., Alağaş, H. M., Eren, T. "Selection of rail system projects with analytic hierarchy process and goal programming", [pdf] Sigma Journal of Engineering and Natural Sciences, 8(4), pp. 291–302, 2017. Available at: https://eds.yildiz.edu.tr/ArticleContent/Journal/sigma/Volumes/2017/Issues/6/YTUJENS-2017-8-4.3350.pdf

[22] Basili, M., Casini, P., Morelli, L., Vestroni, F. "Vibration Mitigation of Rail Noise Barriers by Hysteretic Absorbers", Journal of Applied and Computational Mechanics, 7(SI), pp. 1205–1217, 2021.
https://doi.org/10.22055/JACM.2020.32360.2044

[23] Fooladi Dehaghi, B., Khoshfetrat, A. "AHP-GP Approach by Considering the Leopold Matrix for Sustainable Water Reuse Allocation: Najafabad Case Study, Iran", Periodica Polytechnica Civil Engineering, 64(2), pp. 485–499, 2020.
https://doi.org/10.3311/PPci.14689

[24] Alizadeh Galdiani, M., Sabet, N., Mohit, M. A. "Increasing the lifespan of rail fastening systems in sandy environments with nano-coating", Global Railway Review, (2), 2020. [online] Available at: https://www.globalrailwayreview.com/article/99187/nano-coating-improving-rail-fastening-systems-sandy/

[25] Shin, M. H., Lee, H. K., Kim, H. Y. "Benefit–Cost Analysis of Building Information Modeling (BIM) in a Railway Site", Sustainability, 10(11), Article number: 4303, 2018.
https://doi.org/10.3390/su10114303

[26] Mátrai, T. "Cost benefit analysis and ex-post evaluation for railway upgrade projects", Periodica Polytechnica Transportation Engineering, 41(1), pp. 33–38, 2013.
https://doi.org/10.3311/PPtr.7102

[27] Sanili Aydin, U., Uste, A. N. "A review of Turkey's high-speed rail experience", Acta Technica Jaurinensis, 14(3), pp. 281–299, 2021.
https://doi.org/10.14513/actatechjaur.00608

[28] Nagy, R. "Description of rail track geometry deterioration process in Hungarian rail lines No. 1 and No. 140", Pollack Periodica, 12(3), pp. 141–156, 2017.
https://doi.org/10.1556/606.2017.12.3.13

[29] Andrade, A. R., Teixeira, P. F. "Assessing Temporary Speed Restrictions and Associated Unavailability Costs in Railway Infrastructure", International Journal of Civil Engineering, 16(2), pp. 219–228, 2018.
https://doi.org/10.1007/s40999-016-0121-3

[30] UIC "Capacity", 2nd ed., International Union of Railways (UIC), Paris, France, Leaflet 406, 2013.

[31] Arani, A. A. M., Jolai, F., Nasiri, M. M. "A multi-commodity network flow model for railway capacity optimization in case of line blockage", International Journal of Rail Transportation, 7(4), pp. 297–320, 2019.
https://doi.org/10.1080/23248378.2019.1571450

[32] Navarro, L. M., Fernandez-Cardador, A., Cucala, A. P. "Fuzzy maximum capacity and occupancy time rate measurements in urban railway lines", European Transport Research Review, 10, Article number: 61, 2018.
https://doi.org/10.1186/s12544-018-0335-3

[33] Sadeghi, J. "Development of Railway Track Geometry Indexes Based on Statistical Distribution of Geometry Data", Journal of Transportation Engineering, 136(8), pp. 693–700, 2010.
https://doi.org/10.1061/(ASCE)0733-947X(2010)136:8(693)

[34] Ágh, C. "Measurement Distortion Analysis of Repetitive and Isolated Track Geometry Irregularities", Periodica Polytechnica Civil Engineering, 65(3), pp. 852–865, 2021.
https://doi.org/10.3311/PPci.17638

[35] Saaty, T. L., Vargas, L. G. "Models, Methods, Concepts & Applications of the Analytic Hierarchy Process", Springer, Boston, MA, USA, 2012.
https://doi.org/10.1007/978-1-4614-3597-6