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Performance evaluation of Indian Railway zones using DEMATEL and VIKOR methods

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Abstract

Purpose – The purpose of this paper is to propose the application of a decision-making tool for performance evaluation of Indian Railway zones. It basically seeks to analyze the effects of various evaluation criteria on the performance of Indian Railways using a combined multi-criteria decision-making approach which employs decision-making trial and evaluation laboratory (DEMATEL) and "VIse Kriterijumska Optimizacija kompromisno Resenje" (VIKOR) methods.
Design/methodology/approach – The performance of 16 Indian Railway zones is first evaluated using DEMATEL method which addresses the inter-relationships between different criteria with the aid of a relationship structure. The VIKOR method which is a compromise ranking approach is then adopted to rank those candidate railway zones. Pareto analysis is also carried out to identify the benchmark railway zones for the under/poor performers so as to improve their operational excellence.
Findings – A numerical example from Indian Railways is illustrated and solved for better understanding of the integrated decision-making tool in which the relevant information for the considered railway zones with respect to different evaluation criteria are collected from various websites and Indian Railways annual statistical report. Western and North-Eastern zones, respectively, take the first and the last positions in the derived ranking list. The relevance of selecting different performance indices/evaluation criteria is also discussed.
Practical implications – The application of this integrated methodology would serve as a systematic approach for measurement of the aggregate operational performance of Indian Railway zones so as to gain valuable academic and practical insights. It is also expected to provide an insightful guidance to the railway administrators in taking valuable strategic decisions in promoting the service of Indian Railways.
Originality/value – The integrated DEMATEL-VIKOR method is conceptually simple and easily comprehensible which can consider numerous attributes simultaneously. This paper enables the readers to gain some valuable inputs from a managerial perspective for Indian Railways to formulate strategies for its zones to foster better performance.

Keywords Indian Railways, VIKOR, DEMATEL, Pareto analysis, Rank
Paper type Research paper

1. Introduction

Service sector or tertiary sector is frequently defined as one of the three major parts of economy in the "three-sector hypothesis" which divides economy into three main areas. The other two major parts are the primary sector, which covers farming, mining and fishing, while the secondary sector covers manufacturing. The service sector encompasses a wide array of activities ranging from services provided by

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the most sophisticated sectors, like telecommunications to other services, like retail, banks, hotels, real estate, education, health, social work, computer services, recreation, media, electricity, gas and water supply; highly capital intensive services, like civil aviation and shipping to employment-oriented activities, like tourism and housing; and infrastructure-related activities, like road, rail and air transports and ports. The service sector plays an important role for the development of a nation's economy and human resources. Efficient transport is a critical component for a nation's national and global economic development. Transport accessibility influences global development patterns and can be a boost or an obstacle to the economic growth of a nation.

Indian economy has been sharing a common attribute in the composition of its gross domestic product (GDP) in the form of growing contribution of its service sectors. Rapid growth in service sectors during the past few years has further strengthened its position as one of the leading sectors of Indian economy. Service sectors now account for more than 60 percent of overall GDP in India (Rath *et al.*, 2007). Transport has affected economic development from the beginning of human civilization. Since the era of industrial revolution, there has been a massive demand for new transport facilities across the globe. Railway is an efficient transport mode, concentrating people and goods, and transporting them over a fixed route using one prime mover and multiple carriages and freight wagons. Indian Railways is one of the largest systems in the world under a single management. It is also one of the very few railway systems in the world generating operating surpluses. Indian Railways started its journey in 1853 with a modest network, but today, it has become an integral part of the entire nation. It has emerged today as the main vehicle for socio-economic development of the whole country. It is a self-propelled social welfare system, which has become the lifeline of the nation, and can be appreciated to bring a population of 1.2 billion a little more closer. At present, there are 17 zones in Indian Railways with each of them having its own division and headquarter. Kolkata Metro has been the last addition to this list. It thus becomes critical to evaluate the performance of all the railway zones in India, as Indian Railways plays a decisive and significant role in the overall growth of the Indian economy. Moreover, the fact that railway is still the most convenient and cheapest mode of transportation in India makes this analysis all more important. The importance of performance evaluation of railway zones can be explained from the fact that it may help the Indian Railways in providing safer and secured journey with improved service quality.

This sector attracts many researchers because the extracted results have the potential to focus on the real picture/condition of Indian Railways. In this paper, decision-making trial and evaluation laboratory (DEMATEL) method is first applied to address the inter-relationships between the decision criteria with the aid of a relationship structure. The weights of the considered criteria are determined using Shannon's entropy method (Rao, 2007). Finally, a compromise ranking of 16 Indian Railway zones with respect to nine evaluation criteria is derived employing VIse Kriterijumska Optimizacija kompromisno Resenje (VIKOR) method. The obtained results may serve as a reference point to the decision/policy makers to choose the best zone of Indian Railways with respect to the considered evaluation criteria. Western zone is identified as the best performing zone having several positive dimensions. On the other hand, North-Eastern zone has the worst performance along with some major weaknesses, where special emphasis needs to be provided.

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2. Review of the past researches

Gathon and Pestieau (1995) introduced the idea that technical inefficiency measures generally used to assess the performance of firms might not reflect the slack in management and then applied the concept in European railways. Coelli and Perelman (1999) adopted multi-output distance functions to investigate technical inefficiency in European railways, and compared the results of three different methods, i.e. parametric linear programming, corrected ordinary least square and data envelopment analysis (DEA), which provided reassuring of similar information on the relative productive performance of 17 railway organizations. Singh (2002) appraised the performance of Kolkata Metro Railway, and suggested various measures to be taken for making it viable and more profitable. It was also suggested to set up a unified Metropolitan Transport Authority to look after all modes of transport apart from other useful measures. Kaakai *et al.* (2007) developed a macroscopic simulation model of railway transit stations based on hybrid petrinets. A performance evaluation methodology based on analysis of making of the model was also explained through a real time case study. Azadeh *et al.* (2008) presented an approach for performance improvement and optimization of railway systems with multifaceted limitations, which would require both qualitative and quantitative assessments. An integrated model with a combination of DEA, analytic hierarchy process and computer simulation was proposed for complex railway systems with severe limitations, different priorities and multiple objectives. Employing DEA method, George and Rangaraj (2008) carried out a performance benchmarking study of Indian Railway zones to develop an alternate approach for measurement of aggregate operational performance of those railway zones and envisage their operations in a supply chain perspective so as to gain academic and practical insights. Yu and Lin (2008) proposed a multi-activity network DEA (NDEA) model to decompose the performance of railways into passenger technical efficiency, freight technical efficiency, service effectiveness and technical effectiveness that would help in identification of sources of poor performance. Yu (2008) investigated the efficiency and effectiveness for a group of 40 global railways in the year 2002, using traditional DEA and NDEA. The results showed that the performance measures were quite different in terms of magnitude, and even different DEA models used to evaluate railway system performance could not distort the derived ranking of the alternatives. Raghuram and Gangwar (2008) studied the issues and strategies related to financial and physical aspects of revenue generating freight and passenger traffic from 1987 to 2007 for Indian Railways. Jitsuzumi and Nakamura (2010) analyzed the causes of inefficiency among 53 Japanese railway firms. The DEA model and total factor productivity were incorporated to calculate the optimal subsidy levels for individual organizations. Awasthi *et al.* (2011) proposed a hybrid approach based on SERVQUAL and fuzzy TOPSIS methods for evaluating the quality of metro transportation services of Montreal. Schittenhelm and Landex (2012) presented a series of existing and newly developed key performance indicators for railway timetables. Tahir (2013) analyzed the performance of Pakistan Railway in a multistage framework, and applied DEA method to estimate product, earning and financial efficiency to understand the decline in Pakistan Railway in comparison with Chinese and Indian Railways. Havenga *et al.* (2013) indicated how benchmark analysis could be adopted to inform a rail reform agenda for South Africa's freight rail system. Bhanot and Singh (2014) applied DEA approach to carry out a benchmarking study on the performance indicators in Indian Railways container business and selected private players. Kyriakidis *et al.* (2015) presented a framework to identify the most significant human performance factors, known as performance shaping factors, which would influence the performance of railway operators. Laurino *et al.* (2015) reviewed the railways models for 20 countries and analyzed those models to provide an *ex-ante* overview of the current practices, both in quantitative and qualitative terms. It was identified that each country had developed its own framework according to its transport system, political context, economic situation, business and regulatory environment.

It is observed from the review of the past researches that very little work has been carried out for appraising the performance of railway zones in Indian context. Till date, only a few multi-criteria decision-making (MCDM) methods, specially DEA approach have been mainly employed for dealing with the problem of performance evaluation of railways. DEA is mainly used for benchmarking in operations management, where a set of measures is selected to benchmark the performance of manufacturing and service operations. It has several advantages, like there is no need to explicitly specify a mathematical form for the considered function, it is proven to be useful in uncovering relationships that remain hidden for other methodologies, it is capable of handling multiple inputs and outputs, it is also capable of being used with any input-output measurement, and the sources of inefficiency can be analyzed and quantified for every evaluated unit. But, it has also some major disadvantages that hinder its wide spread applications, such as the derived results are sensitive to the selection of inputs and outputs, the best specification cannot be validated, the number of efficient solutions on the frontier tends to increase with the number of inputs and outputs, there is no account for measurement error/random noise, it is sensitive to outlier data and it does not provide tests of the significance of input or output variables included in the model (Ali and Lerme, 1997). Based on a huge set of mathematical formulations (to be solved using a linear programming solver, like LINDO), DEA method can only identify the efficient candidate solutions from the available set of alternatives and it miserably fails to provide an entire preorder of the considered alternatives for any performance evaluation problem. These drawbacks and inefficiencies of DEA method have motivated to implement an integrated DEMATEL-VIKOR method for performance evaluation of Indian Railway zones. DEMATEL is applied to predict the inter-relationships between the considered evaluation criteria while using a relationship structure. Unlike other MCDM methods, it has the unique capability to segregate all the considered criteria into cause and effect groups to have a better understanding of a performance evaluation problem. On the other hand, a compromise ranking tool in the form of VIKOR method is employed to derive an entire ranking list of the participating railway zones. VIKOR method is quite easy to comprehend, has simple computational steps and has been proven to provide almost accurate ranking results.

3. Indian Railways at a glance

The railway age dawned in India on April 16, 1853, when the first train ran from Bombay to Thane. The railway system of India was nationalized as one unit in 1951. Today, it is one of the largest networks in the world, and operates both long distance and suburban rail systems on multi-gauge network which consists of broad, meter and narrow gauges. The Indian Railways' contribution to national integration is unparallel. It has knit India together by connecting all the regions, and almost all the states, in a single transport network. It has always played a unique role in meeting the transportation needs of the common man, while simultaneously serving as a critical infrastructure facilitator for the carriage of goods. It caters to the needs of the people across geographies and income

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strata as well as ethnic, religious and social diversities. Indian Railways has its own locomotive and coach production facilities at various places in India. It also provides limited international services to Nepal, Bangladesh and Pakistan.

Indian Railways is a state-owned enterprise, operated by the Government of India through the Ministry of Railways. It has 112,000 km of track over a route of 65,000 km and 7,500 stations. In 2011, 8,900 million passengers and 2.8 million tons of daily freight were transported through Indian Railways. It is the world's ninth largest commercial or utility employer with almost 1.4 million employees. As for rolling stock, it has 239,289 freight wagons, 59,713 passenger coaches and 9,549 locomotives. As of March 31, 2013, 23,541 km out of 65,000 km route length was electrified. Indian Railways is divided into several zones, as shown in Table I. Initially, it was divided into six zones, but later, it has been increased to eight in 1951, nine in 1952, 16 in 2003 and 17 in 2010. Each zone has certain number of divisions, while each division has divisional headquarters. Indian Railways has collaborated with Indian Institute of Technology, Madras to develop a technology to tap solar energy for lighting and air conditioning in the coaches, which can significantly reduce fossil fuel dependency. Recently, an automated fire alarm system has been developed and tested in Rajdhani Express trains. In near future, this system would be applied to AC coaches of all regular trains. The suburban railway of Mumbai is spread over 30 km, and carries more than 6.1 million people daily. It is one of the most utilized public transports in the world. The first underground rapid transit system in India is Kolkata Metro, which began in 1984. In December 2002, Delhi Metro was started. It is the second largest underground rapid transit system in India. Delhi Metro has a combination of elevated, at-grade and underground lines.

The Railways Minister also proposed to use more IT services in the railways, which would help in increasing passenger and freight earnings by reducing operating cost, ensuring optimal utilization of human and resources. Enterprise resource planning packages are also implemented in most of the workshops and production units of the selected zonal railways. Indian Railways is one of the world's largest rail networks, and therefore, it requires a massive budget to provide safer and secured service to its passengers. It requires more funds for modernization, however, the current budget is

Table I.
Details of 17 railway zones in India

Sl. no.	Name	Year of establishment	Headquarter
1.	Central	1951	Mumbai
2.	Eastern	1952	Kolkata
3.	East Central	2002	Hazipur
4.	East Coast	2003	Bhubaneswar
5.	Northern	1952	Delhi
6.	North Central	2003	Allahabad
7.	North Eastern	1952	Gorakhpur
8.	North Frontier	1958	Guwahati
9.	North Western	2002	Jaipur
10.	Southern	1951	Chennai
11.	South Central	1966	Secundrabad
12.	South Eastern	1955	Kolkata
13.	South East Central	2003	Bilaspur
14.	South Western	2003	Hubli
15.	Western	1951	Mumbai
16.	West Central	2003	Jabalpur
17.	Kolkata Metro	2010	Kolkata

not sufficient to support the modernization. For example, the provision of automated signaling system in the entire network to prevent accidents is still missing. The other problem that Indian Railways is facing, is the accident rate, which consists of derailment, collision and human beings run over by the trains. It is a high time for the Ministry of Railways to enhance the budget allocation to Indian Railways.

4. Mathematical models of DEMATEL and compromise ranking methods

In this section, the basic concepts of DEMATEL method are presented to establish the relationship structure for the railway performance evaluation problem. A compromise ranking method is then applied to prioritize and rank the Indian Railway zones.

4.1 DEMATEL method

DEMATEL method is used to perceive intricate relationships and build a network relation map between the decision criteria. It was mainly developed by the Battelle memorial association of the Geneva research center (Gabus and Fontela, 1973; Fontela and Gabus, 1976) to study complicated world problems concerning about race, hunger, environmental protection, energy, etc. It is based on a concept of pair-wise comparison of decision-making attributes (alternatives and criteria). The attributes are compared with respect to relative influence of each over the other. The main objective of DEMATEL method is to directly compare the interaction relationship between different variables of a complicated system to determine direct and indirect causal relationships and influence levels between the variables. A visual structural matrix and a causal diagram are developed to express the causal relationships and influence levels between the considered variables, and assist in making appropriate decisions. The evaluation criteria are usually comprised of many complicated aspects, including financial and non-financial, as well as qualitative aspects, and are either directly or indirectly mutually related. DEMATEL method is based on the notion of digraphs, which can separate the considered decision criteria into cause and effect groups to visually observe the inside of a complex problem. It assumes a system containing a set of components $C = \{C_1, C_2, \ldots, C_n\}$, with pair-wise relations that can be evaluated. The application of DEMATEL method consists of the following six steps (Tamura and Akazawa, 2005; Chen *et al.*, 2009; Hamidi *et al.*, 2012).

Step 1: generation of the direct-relation matrix (A).

At first, the decision maker evaluates the relationship between the sets of paired criteria to indicate the direct effect that each ith criterion exerts on each jth criterion, as indicated by an integer scale (score) ranging from 0 to 4, representing no influence (0), low influence (1), medium influence (2), high influence (3) and very high influence (4). Then, as the result of these evaluations, the initial data is obtained as a direct-relation matrix (A) which is in the form of an $n \times n$ matrix, in which the individual element (a_{ij}) denotes the degree to which ith criterion affects jth criterion and n denotes the total number of criteria:

$$A = \begin{bmatrix} 0 & a_{12} & \ldots & a_{1j} & \ldots & a_{1n} \\ a_{21} & 0 & \ldots & a_{2j} & \ldots & a_{2n} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ a_{n1} & a_{n2} & \ldots & a_{nj} & \ldots & 0 \end{bmatrix}$$

Step 2: development of the normalized direct-relation matrix (X).

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Once the direct-relation matrix is developed, the normalized matrix (X) is obtained using Equations (1) and (2). Each element in matrix X ranges from 0 to 1:

$$X = k.A \tag{1}$$

where:

$$k = \frac{1}{\max\limits_{1 \leqslant i \leqslant n}\left(\sum_{j=1}^{n} a_{ij}\right)},\ i, j = 1, 2, ..., n \tag{2}$$

Step 3: computation of the total-relation matrix (T).

The total-relation matrix (T) is determined using Equation (3), in which I denotes the identity matrix. The element t_{ij} represents the indirect effects that ith criterion has on jth criterion, and the matrix T reflects the total relationship between each pair of system criteria:

$$T = \left[t_{ij}\right]_{n\times n}, i,j = 1, 2, \ldots, n$$

$$T = X + X^2 + X^3 + \cdots, +X^k = X\left(I + X + X^2 + \cdots, +X^{k-1}\right)\left[(I–X)(I–X)^{-1}\right]$$
$$= X\left(I–X^k\right)(I–X)^{-1}$$

then:

$$T = X(I–X)^{-1},\ \text{when}\ k \to \infty,\ X^k = [0]_{n\times n}$$

$$T = X(I–X)^{-1} \tag{3}$$

Step 4: determination of the sums of rows and columns of matrix T.

In the total-relation matrix T, the sum of rows and sum of columns are represented by vectors D and R, as derived using following equations:

$$D_i = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} = [t_i]_{n\times 1},\ i = 1, 2, ..., n \tag{4}$$

$$R_j = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n} = \left[t_j\right]_{n\times 1},\ j = 1, 2, ..., n \tag{5}$$

Step 5: set a threshold value (α).

This threshold value (α) is obtained from the average of the elements in matrix T, as computed using Equation (6), where N is the total number of elements in matrix T. This calculation is aimed to eliminate some minor effect elements in matrix T:

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}[t_{ij}]}{N} \tag{6}$$

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Since matrix T provides information on how one factor affects another, it is necessary for the decision maker to set up a threshold value to filter out some negligible effects. While doing so, only the effects greater than the set threshold value are chosen and shown in the digraph.

Step 6: development of a causal diagram.

The horizontal axis vector (D_k+R_k) named "prominence" is computed by adding D to R while $k=i=j=1$ which reveals how much importance the criterion has. Similarly, the vertical axis (D_k−R_k) named "relation" is calculated by subtracting D from R, which divides the criteria into a cause group and an effect group. If D_i is the sum of ith row in matrix T, then D_i summarizes both direct and indirect effects given by ith criterion over other criteria. Similarly, R_j indicates the sum of jth column in matrix T, and shows both direct and indirect effects given by jth criterion over other criteria. If $j=1$, it indicates the total effects given and received by ith criterion. Thus, (D_k+R_k) shows the degree of importance that ith criterion plays in the entire system. In the contrary, (D_k−R_k) determines the net effect that ith criterion contributes to the entire system.

Generally, when (D_k−R_k) is positive, the criterion belongs to the cause group. Otherwise, if (D_k−R_k) is negative, the criterion belongs to the effect group. Therefore, a causal diagram is developed while mapping the data set of (D_k+R_k, D_k−R_k), providing valuable insight for making decisions. Therefore, the decision maker can use the causal relationship of the variables and their interaction influence levels to find out the driving variables of the core problem in a complicated system, and plan for suitable decisions to solve the problem in accordance with attribute type and influence level.

4.2 Compromise ranking method

The basic concept of VIKOR method (Opricovic and Tzeng, 2004, 2007) lies in defining the positive and the negative ideal solutions. The positive ideal solution indicates the alternative with the highest value, while the negative ideal solution denotes the alternative with the lowest value. It was basically introduced as a multi-criteria ranking tool, based on the particular measure of closeness to the ideal solution using linear normalization procedure. It focusses on selecting the best alternative from a set of feasible alternatives in presence of mutually conflicting criteria while determining a compromise solution. It provides a maximum group utility for the "majority," and a minimum of individual regret for the "opponent." The compromise solution is a feasible solution, which is the closest to the positive ideal solution and farthest from the negative ideal solution. The following multiple attribute merit for compromise ranking is developed from the L_p-metric used in the compromise programming method:

$$L_{p,i} = \left\{ \sum_{j=1}^{n} \left(w_j \frac{\left[(x_{ij})_{\max} - x_{ij} \right]}{\left[(x_{ij})_{\max} - (x_{ij})_{\min} \right]} \right)^{p} \right\}^{\frac{1}{p}} \quad 1 \leqslant p \leqslant \infty; \;\; i = 1, 2, \ldots, m \tag{7}$$

In VIKOR method, $L_{1,i}$ and $L_{\infty,i}$ are used to formulate the ranking measure. The procedural steps for VIKOR method are enlisted as follows (Opricovic and Tzeng, 2004, 2007):

(1) From the developed decision matrix for the considered problem, determine the best, $(x_{ij})_{\max}$ and the worst, $(x_{ij})_{\min}$ values of all the criteria.

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(2) Calculate the values of E_i and F_i:

$$E_i = L_{1,i} = \sum_{j=1}^{n} w_j \frac{\left[(x_{ij})_{max} - x_{ij} \right]}{\left[(x_{ij})_{max} - (x_{ij})_{min} \right]} \tag{8}$$

$$F_i = L_{\infty,i} = \text{Max}^m \text{of} \left\{ w_j \frac{\left[(x_{ij})_{\max} - x_{ij} \right]}{\left[(x_{ij})_{\max} - (x_{ij})_{\min} \right]} \right\} \quad j = 1, 2, \ldots, n \tag{9}$$

For non-beneficial criteria, Equation (8) can be rewritten as follows:

$$E_i = L_{1,i} = \sum_{j=1}^{n} w_j \frac{[x_{ij} - (x_{ij})_{\min}]}{[(x_{ij})_{\max} - (x_{ij})_{\min}]} \tag{10}$$

(3) Calculate P_i value:

$$P_i = v \left(\frac{(E_i - E_{i\ \min})}{(E_{i\ \max} - E_{i\ \min})} \right) + (1 - v) \left(\frac{(F_i - F_{i\ \min})}{(F_{i\ \max} - F_{i\ \min})} \right) \tag{11}$$

where $E_{i\ \max}$ and $E_{i\ \min}$ are the maximum and minimum values of E_i, respectively, and $F_{i\ \max}$ and $F_{i\ \min}$ are the maximum and minimum values of F_i, respectively. The parameter v is introduced as weight of the strategy of "the majority of attributes" ("the maximum group utility"). The value of v is usually set by the decision maker, ranging between 0 and 1.

Practically, if the decision maker assumes $v > 0.5$, he/she gives more importance to the first term in Equation (11) and hence, to the global performance of the alternative in respect to the whole of the criteria. While using a v value smaller than 0.5, he/she gives more weight to the second term that is related to the magnitude of the worst performance exhibited by the alternative with respect to each single criterion. When both these aspects are considered equally relevant, $v = 0.5$ should be used.

(4) Arrange the alternatives in ascending order, according to the values of P_i. The best alternative is the one having the minimum P_i value.

The VIKOR method is an effective MCDM tool, specifically applicable to those situations when the decision maker is not able, or does not know to express his/her preference at the beginning of the decision-making process. The computational procedure of VIKOR method is quite simple, and it offers a systematic and logical approach to arrive at the best decision. The main advantage of VIKOR method as compared to any other MCDM methods is that the final performance score in VIKOR is an aggregation of all criteria, their relative importance, and a balance between total and individual satisfaction. The compromise solution as provided by this method can be the groundwork for negotiations, involving the decision maker's preference on criteria weights.

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5. Performance evaluation of Indian Railway zones

The combined DEMATEL-VIKOR method is adopted here to find out the ranking of 16 zones of Indian Railways with respect to nine evaluation criteria. Kolkata Metro has been the last addition in the list of Indian Railway zones, but it is not considered here due to non-availability of pertinent information. Thus, the performance of 16 railway zones is evaluated with respect to nine decision criteria, as listed in Table II.

All these nine criteria are so selected that they are almost uncorrelated. The relevant data for these criteria are accumulated for the year 2010-2011, except the operating cost ratio, which is based on the figures from the year 2008-2009. Among these criteria, the first five are beneficial (higher the better) and the remaining four are non-beneficial in nature (lower the better). Route distance is an important criterion in this evaluation process because it covers both rural and urban places in India. The number of locomotives shows the strength of different Indian Railway zones to reduce the operational down time. The total number of locomotives encompasses all the diesel, steam and electric engines. The number of passengers carried in a specific year is also an important criterion. Indian Railways carried 24 million daily passengers and 8,900 million annually in the year 2010-2011. Indian Railways ranks ninth in the world in employment generation with almost 1.4 million employees. So, number of staffs in a particular zone is selected as another criterion. The number of major stations in each zone is selected as a beneficial criterion which is adjudged as quite important for performance evaluation of Indian Railway zones. Total number of accidents or derailment of trains is another criterion for which minimum value is always desired. Indian Railways is trying to develop a new technology so that train accidents or derailments can be substantially reduced. The total number of persons injured or deceased in railway accidents is treated as the next criterion for this performance appraisal process. More is the number of accidents or derailments, more will be the number of persons injured or died. The total expenditure of railway zones is treated here as another non-beneficial criterion. The last non-beneficial criterion is the operating cost ratio (percent), which is the ratio of total expenditure to total revenue for each railway zone. Table III shows the decision matrix as developed for performance evaluation of 16 zones of Indian Railways on the basis of nine criteria, where the relevant information for the railway zones with respect to different criteria are collected from various websites and published reports (www.wikipedia.com, Indian Railways Annual Statistical Report 2010-2011, etc.). The criteria weights are estimated using Shannon's entropy method (Rao, 2007), as shown in Table IV.

Sl. no.	Criteria	Symbol
1.	Route distance (in km)	C_1
2.	Total number of locomotives	C_2
3.	Number of passengers carried	C_3
4.	Number of total staffs	C_4
5.	Number of major stations	C_5
6.	Number of accidents/derailments	C_6
7.	Number of persons injured/deceased	C_7
8.	Expenditure (in Rs)	C_8
9.	Operating cost ratio	C_9

Table II. Criteria for performance evaluation of 16 Indian Railway zones

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Table III.
Decision matrix for performance evaluation of 16 Indian Railway zones

Sl. no.	Railway zone	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
1.	Central (CTL)	3,905	751	17,814,411	111,462	481	5	8	79,706,039	97.64
2.	Eastern (ESTN)	2,414	575	11,203,970	118,595	423	5	117	68,436,788	173.45
3.	East Central (ECTL)	3,628	531	4,078,384	74,123	399	15	21	59,496,882	99.48
4.	East Coast (ECST)	2,572	462	919,596	40,350	273	9	3	38,097,296	49.30
5.	Northern (NRTN)	3,968	898	8,693,161	152,956	812	23	28	111,329,174	115.26
6.	North Central (NCTL)	3,151	530	3,836,979	66,943	351	7	13	50,230,224	60.59
7.	North Eastern (NESTRN)	3,667	192	3,090,168	55,785	224	10	26	33,885,335	197.32
8.	North Frontier (NFTR)	3,907	259	981,960	65,675	281	3	47	43,514,630	148.69
9.	North Western (NWSTN)	5,459	191	1,805,780	55,137	391	8	28	35,937,142	120.23
10.	Southern (STRN)	5,098	671	7,856,587	93,925	562	6	17	64,678,479	126.06
11.	South Central (SCTL)	5,803	916	4,158,815	85,485	581	11	77	73,320,143	77.23
12.	South Eastern (SESTN)	2,631	715	2,579,012	83,450	323	13	274	51,838,609	62.24
13.	South East Central (SECTL)	2,447	250	1,835,563	40,899	178	1	1	33,673,671	53.23
14.	South Western (SWSTN)	3,177	314	2,023,758	32,807	280	5	7	28,288,195	77.11
15.	Western (WSTN)	6,182	641	17,052,992	105,907	609	6	20	76,399,494	93.25
16.	West Central (WCTL)	2,965	825	2,418,268	56,750	282	2	43	43,591,672	73.95

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As performance appraisal of Indian Railway zones and identifying the best performing zone is truly a complex MCDM problem, it is not appropriate to assume the elements within the evaluation system to be independent. As, all of the nine evaluation criteria are deemed to be significant and indispensable, hence, it becomes essential to find out the important criteria for the performance appraisal system and measure the relationships between the considered criteria. To achieve this, DEMATEL method is applied for capturing the profound relationships between those evaluation criteria causally and visually. Following the procedural steps of DEMATEL method, the relationships between different criteria are scored using an integer scale. Once the relationships between those criteria are measured, the initial direct-relation matrix (A) is developed, as shown in Table V. It is a 9×9 matrix, obtained by pair-wise comparisons in terms of influences and directions between the criteria.

From the developed matrix A of Table V, the corresponding normalized direct-relation matrix (X) is obtained in Table VI. Table VII provides the related total influence matrix (T). Now, the sum of rows and sum of columns as represented by vectors D and R, respectively, are computed, and are shown in Table VIII. The causal diagram, as shown in Figure 1, is subsequently developed by mapping the data set of Table IX. The (D+R) and

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Weight	0.1465	0.1304	0.0642	0.1362	0.1372	0.1027	0.0075	0.1392	0.1362

Table IV. Criteria weights for performance appraisal of railway zones

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	0	0	3	4	2	4	3	4	4
C_2	0	0	2	1	0	0	0	3	4
C_3	3	4	0	4	4	3	3	4	4
C_4	2	1	2	0	1	0	0	4	4
C_5	2	3	2	3	0	0	0	4	4
C_6	0	0	2	1	0	0	4	3	1
C_7	0	0	2	0	0	3	0	3	2
C_8	1	1	2	2	2	2	2	0	4
C_9	1	1	1	3	3	0	0	3	0

Table V. Initial direct-relation matrix

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	0	0	0.0208	0.0278	0.0139	0.0278	0.0208	0.0278	0.0278
C_2	0	0	0.0139	0.0069	0	0	0	0.0208	0.0278
C_3	0.0208	0.0278	0	0.0278	0.0278	0.0208	0.0208	0.0278	0.0278
C_4	0.0139	0.0069	0.0139	0	0.0069	0	0	0.0278	0.0278
C_5	0.0139	0.0208	0.0139	0.0208	0	0	0	0.0278	0.0278
C_6	0	0	0.0139	0.0069	0	0	0.0278	0.0208	0.0069
C_7	0	0	0.0139	0	0	0.0208	0	0.0208	0.0139
C_8	0.0069	0.0069	0.0139	0.0139	0.0139	0.0139	0.0139	0	0.0278
C_9	0.0069	0.0069	0.0069	0.0208	0.0208	0	0	0.0208	0

Table VI. Normalized direct-relation matrix of criteria

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Table VII.
Total-relation matrix of criteria

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	0.0016	0.0016	0.0229*	0.0301*	0.0158*	0.0292*	0.0226*	0.0315*	0.0312*
C_2	0.0008	0.0008	0.0146*	0.0083	0.0014	0.0006	0.0006	0.0222*	0.0291*
C_3	0.0222*	0.0291*	0.0030	0.0306*	0.0295*	0.0224*	0.0224*	0.0324*	0.0323*
C_4	0.0148*	0.0080	0.0151*	0.0021	0.0086	0.0012	0.0011	0.0297*	0.0300*
C_5	0.0150*	0.0219*	0.0155*	0.0229*	0.0019	0.0012	0.0011	0.0305*	0.0308*
C_6	0.0006	0.0007	0.0148*	0.0079	0.0010	0.0012	0.0284*	0.0223*	0.0087
C_7	0.0006	0.0007	0.0147*	0.0012	0.0010	0.0215*	0.0012	0.0221*	0.0152*
C_8	0.0079	0.0080	0.0153*	0.0157*	0.0152*	0.0148*	0.0148*	0.0029	0.0299*
C_9	0.0079	0.0080	0.0082	0.0222*	0.0217*	0.0007	0.0007	0.0227*	0.0025

Note: $*t_{ij} > 0.0139$

Table VIII.
Computation of vectors D and R

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
D_k	0.1865	0.0785	0.2239	0.1105	0.1407	0.0857	0.0782	0.1245	0.0946
R_k	0.0713	0.0788	0.1240	0.1410	0.0961	0.0928	0.0930	0.2163	0.2096

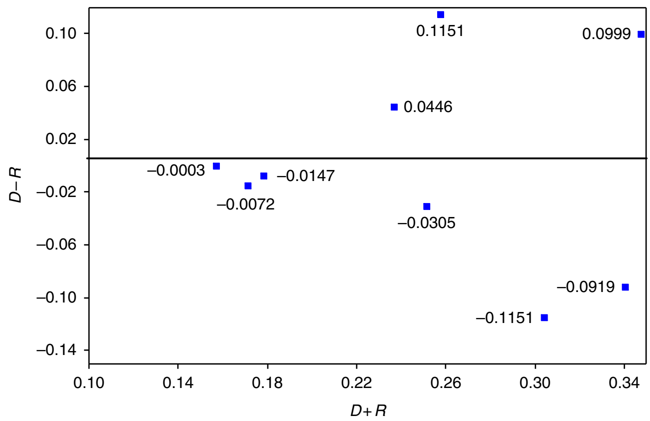

Figure 1.
DEMATEL causal diagram of criteria

Table IX.
Total and net effects for each criterion

Criteria	$D+R$	$D-R$	Criteria group
C_1	0.2578	0.1151	Cause
C_2	0.1574	−0.0003	Effect
C_3	0.3480	0.0999	Cause
C_4	0.2515	−0.0305	Effect
C_5	0.2368	0.0446	Cause
C_6	0.1785	−0.0072	Effect
C_7	0.1712	−0.0147	Effect
C_8	0.3408	−0.0919	Effect
C_9	0.3042	−0.1151	Effect

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(D–R) values of Table IX represent the total influence levels and net influence levels for different criteria, respectively, where the positive values indicate that it influences other criteria more than any other criterion influences it and the negative values denote that it is significantly influenced by the other criteria. Table IX indicates that C_1 (route distance) criterion has the largest net influence level, followed by criteria C_3 (number of passengers carried) and C_5 (number of major stations) in this performance evaluation problem.

Now, looking at the causal diagram of Figure 1, it becomes clear that the nine evaluation criteria are visually divided into cause and effect groups. The cause group consists of three criteria, i.e. C_1, C_3 and C_5, whereas, the effect group contains the remaining six criteria, i.e. C_2 (total number of locomotives), C_4 (number of total staffs), C_6 (number of accidents/derailments), C_7 (number of persons injured/died), C_8 (expenditure) and C_9 (operating cost ratio). It is quite obvious that C_1, C_3 and C_5 criteria are the main driving factors for the remaining six criteria. Among all the criteria, C_3 is identified as the most important one because it has the highest intensity of relation to other criteria for having the maximum (D+R) value, whereas, C_1 is the most influencing factor due to its maximum (D–R) value. Thus, C_3 and C_1 criteria play major roles in this performance evaluation problem of Indian Railway zones, and they have the greatest effects on the other criteria. On the contrary, criteria C_8 and C_9 are greatly influenced by the other criteria, having the lowest negative values of (D–R). The threshold value (α) is now derived from the average of elements in matrix T, as 0.0139. The values of t_{ij} in Table VII, which are greater than α (0.0139), are shown as t_{ij}*, which presents the interaction between two criteria, e.g. as the value of t_{13} (0.0229) > α (0.0139), an arrow in the diagraph, as shown in Figure 2, is directed from C_1 to C_3. Thus, this digraph portrays the contextual relationships among the elements of the considered performance appraisal model.

For performance evaluation and subsequent ranking of 16 Indian Railway zones using VIKOR method, at first, the best and the worst values of all the criteria are identified from the decision matrix of Table III. The relative weights of the nine evaluation criteria are already provided in Table IV. Now, the values of E_i and F_i are calculated in Table X. This table also exhibits the performance scores (P_i) for $v = 0.5$

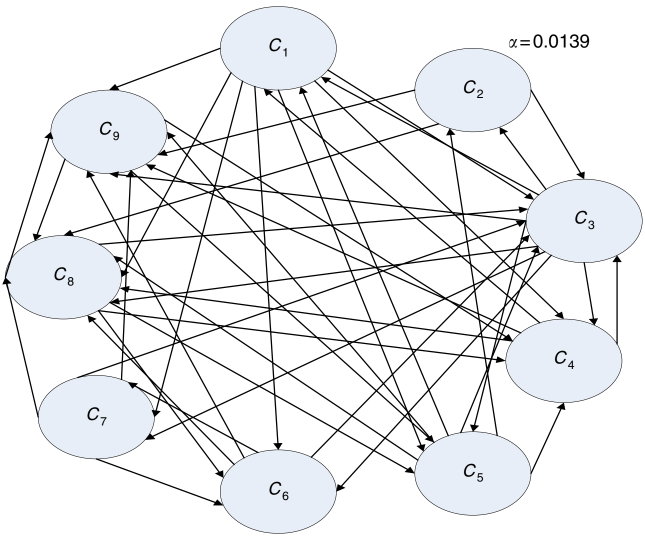

Figure 2.
DEMATEL diagraph for performance evaluation of Indian Railway zones

Railway zone	E_i	F_i	P_i	Rank
Central (CTL)	0.3864	0.0885	0.2286	4
Eastern (ESTN)	0.5595	0.1465	0.8191	14
East Central (ECTL)	0.5639	0.0993	0.5133	5
East Coast (ECST)	0.5843	0.1404	0.8086	13
Northern (NRTN)	0.4273	0.1392	0.6118	8
North Central (NCTL)	0.5132	0.1178	0.5745	6
North Eastern (NESTRN)	0.7096	0.1362	0.9321	16
North Frontier (NFTR)	0.6120	0.1182	0.6957	10
North Western (NWSTN)	0.5328	0.1304	0.6809	9
Southern (STRN)	0.4005	0.0706	0.1276	3
South Central (SCTL)	0.3431	0.0765	0.0970	2
South Eastern (SESTN)	0.5316	0.1381	0.7300	11
South East Central (SECTL)	0.6026	0.1452	0.8626	15
South Western (SWSTN)	0.5809	0.1362	0.7770	12
Western (WSTN)	0.2946	0.0806	0.0660	1
West Central (WCTL)	0.4779	0.1251	0.5796	7

Table X.
E_i, F_i and P_i values for 16 railway zones

and the compromise ranking of 16 Indian Railway zones. The candidate railway zones are then arranged in ascending order, according to their P_i values. The best performer amongst these 16 Indian Railway zones is Western zone, followed by South Central zone. North-Eastern zone is identified as the outperformer in this evaluation process. Using VIKOR method, the compromise ranking of 16 railway zones is thus obtained as WSTN > SCTL > STRN > CTL > ECTL > NCTL > WCTL > NRTN > NWSTN > NFTR > SESTN > SWSTN > ECST > ESTN > SECTL > NESTRN. From the decision matrix of Table III, it is observed that Western zone has the maximum route distance of 6,182 km amongst all the competing railway zones. It had also carried the second highest number of passengers (17,052,992) in the year 2010-2011 and it has also 619 major railway stations in its entire route, which is just next to Northern zone (812). It is also observed that during the year 2010-2011, there were only six major accidents/derailments occurred in this zone in which altogether 20 persons were seriously injured/died. The smaller values of these two non-beneficial criteria may be the reasons behind Western zone taking the top position in the ranking list of railway zones. On the other hand, the high-operating cost ratio of 197.32 (where the average is approximately 93), and smaller values of number of passengers carried (3,090,168), number of major stations (224) and number of staffs (55,785) drive North-Eastern zone to be the outperformer in the context of Indian Railways scenario.

The Pareto analysis results based on P_i values of 16 Indian Railway zones are presented in Figure 3. It is observed from this figure that Western, South Central, Southern and Central zones can be considered as the benchmarks for other railway zones so as to improve their performance.

At present, the Railways Ministry is ignoring the fundamental changes required to transform Indian Railways to suit the twenty-first century demands. The way forward is to dismantle the archaic organizational structure set up of the nineteenth century and establish a more efficient mechanism to operate all its zones. Indian Railways must reach the remote and underserved areas of the country to bring them into the national mainstream of development. It will accelerate economic growth, open up new avenues for employment in the primary, secondary and tertiary sectors, and also promote

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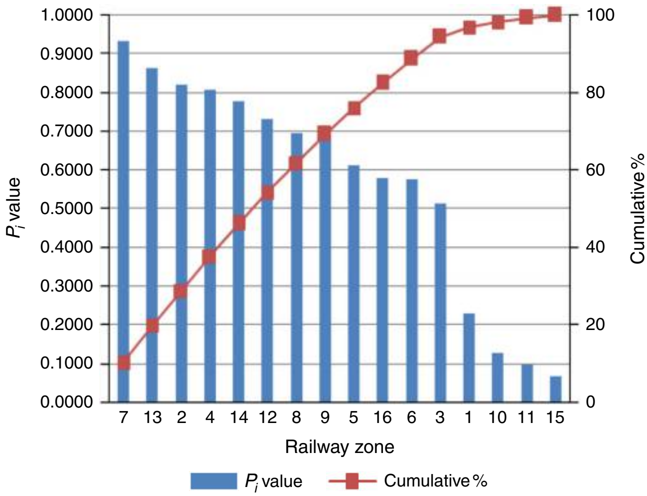

Figure 3.
Pareto analysis of P_i values for 16 railway zones

geographically and socially balanced growth. By carrying more people and goods than other modes of transport, it can help protect the environment while promoting balanced development. It shall provide efficient, affordable, customer-focussed and environmentally sustainable integrated transportation solutions. The reach and access of its services would be continuously expanded and improved by its integrated team of committed, empowered and satisfied employees and by use of cutting-edge technology. Advanced technologies in all spheres, including track, rolling stock and signaling would be used to make railway operations free of accidents, be it derailment, collision or fire on trains. High-quality training to improve the skills of employees to manage new technology is critical, and steps would be taken to provide the same. In the coming years, not a single-level crossing in the country would remain unmanned or unprotected. Thus, based on the DEMATEL-VIKOR method-based analysis, it can be revealed that Indian Railways must address four strategic goals, i.e. inclusive development, both geographically and socially; strengthening national integration; large-scale generation of productive employment; and environmental sustainability.

It is also advised that each railway zone would be the final decision maker on operation, management and development of its own zone. For instance, each zonal head can decide about constructing stations and platforms, adding or removing trains, upgrading rolling stock, regulations for safety, cleanliness and hygiene. Each zone also would prepare an annual budget to govern itself and its divisions. This would enable individualistic growth of each zone based on its requirement. The Indian Railways should review the performance of its zones annually and provide feedback for improvements. Periodic review and modification of policies are also required to facilitate further development of railway. These suggestions are indicative of the railway reforms to revamp and modernize Indian Railways into a world class mode of transportation to cater to the needs of the twenty-first century and to support the inclusive growth of the nation.

6. Conclusions

The adopted combined methodology provides a systematic approach in apprising and evaluating the performance of 16 Indian Railway zones and hence, may become

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a valuable tool to the decision makers/railway administrators. Using DEMATEL method, the interaction relationship and impact level between different selection criteria are analyzed. It is also used to analyze the causal relationships and interaction influence levels between those criteria. Based on the DEMATEL results, it becomes apparent that route distance plays a pivotal role in performance evaluation of Indian Railway zones and it has the greatest influence on the remaining criteria. On the other hand, total expenditure and operating cost ratio are significantly influenced by the other criteria. The VIKOR method aggregates the performance score under different criteria into an overall performance value of each railway zone. However, the evaluation criteria need to be selected carefully as they play a crucial role in performance evaluation and subsequent ranking of the railway zones. Although, Indian Railways has constantly been innovating new ways to make travel easier for passengers across the country by connecting remote areas while providing luxurious comforts, still based on these results, it may be recommended that the railway administrators should focus on developing proper railway infrastructures for improving passengers' satisfaction and comfort during their travel. This combined approach is quite generic in nature and can be applied for resolving the problems of evaluating the performance of other service sectors too.

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