International Journal of Railway Research, Vol. 7, No. 1, (2020), 73-84

Iran University of Science and Technology

International Journal of

Railway Research

ISSN: 2423-3838

Development of Track Geometrical Evaluation index using Power Spectral Density Method

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ARTICLE INFO

Article history:

Received: 12.04.2020

Accepted: 19.06.2020

Published: 26.06.2020

Keywords:

Geometrical indices

Track maintenance

Track recording car

A B S T R A C T

In order to reach a desired quality in railway tracks and to maintain this quality in an acceptable level, a systematic and regular maintenance plan must be performed. By proper management of track maintenance and codification of proper methods to evaluate the quality of railway tracks, a desired quality can be reached. For this purpose, some indices should be defined and maintenance limits of railway tracks should be determined based on these indices. Various geometrical indices have been defined in the railways and these indices are utilized by maintenance management systems. Each of these indices, because of their limitations or some special conditions, is not dependable in some tracks and their results are not acceptable. So, the main aim of this research is to develop a dependable geometrical index and the PSD[1] method is used to achieve this goal. This paper has been tried to utilize a recently developed index compared with other indices and the relationship between this index and other indices is expressed. That is, by developing the PSD index, the relationship between PSD and TGI, PSD and CTR geometrical indices has been expressed. It was found that either of mentioned indices (TGI and CTR) has a linear relationship with PSD index. By comparing the indices it is concluded that PSD index provides more details about the geometrical status of the track. Thus, using PSD index, track maintenance decision makers will be able to schedule the maintenance programs effectively.

1. Introduction

To reach a desired quality in railway tracks and to keep this quality in a constant level, a regular maintenance plan must be performed. By proper management of track maintenance and codification of proper methods to evaluate the quality of railway tracks, a desired quality can be reached. For this purpose, some indices should be defined and maintenance limits of railway tracks should be determined based on these indices. These indices are defined based on some parameters called track geometrical parameters. Some of these parameters are: Gauge, Cant, Profile, Alignment, and twist. Generally, developed geometrical indices are classified in several categories. Some of these categories include empirical indices such as combined track records (CTR), statistical indices such as standard deviation (SD), empirical-statistical indices such as track geometry index (TGI), statistical analysis indices such as ADA II, partial indices such as FRACTAL, spectral indices such as PSD [1,2].

SD is a statistical index and standard deviation of the track geometry parameters is used to investigate track quality. Fractal Analysis is an analytical technique that can be applied to characterize and to quantify irregular patterns that are chaotic and random; as track geometry data are classified [2]. Between all mentioned indices, because CTR and TGI are the indices which are commonly used in track maintenance programs, these indices are

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introduced. CTR index is obtained by considering different records of four track geometry parameters: gauge, twist, alignment, and profile. CTR is an empirical index and is one of the indices which are used in Iranian railways. This index will be defined in detail in the next sections of this paper.

TGI is an empirical-statistical index and is known as modified CTR index. In CTR index all geometrical parameters have the same value. But in TGI index, based on statistical analysis on different records of track geometrical parameters, each parameter is given a coefficient based on its importance. This index will be defined in detail in the future sections of this paper.

In power spectral density method (PSD), relationship between data along the track and frequency of data iteration is investigated. This method demonstrates that how the power of a time series is distributed by frequency. In this method, each parameter is derived as a wavelength and based on this wavelength the type of track defect and its elimination method is determined. PSD function demonstrates that how the variance or energy of a signal is distributed in a wavelength domain. Standard deviation of track geometrical irregularity is equal to square of area under the PSD curve. Total area under the PSD curve represents the track quality index. Long wavelength track irregularities can decrease ride comfort, while, track defects with some short wavelength cause vibrations with high frequencies that can result in risk of derailment and also produces loud noises. The advantages of this method are: the shape of defect can be observed to eliminate it, and an optimum maintenance planning for the track can be performed [1,2]. In this paper, for the maintenance of ballasted tracks using the PSD method, Chinese and Germany standards [3] are considered and finally the standard which is more consistent with the results is selected and the final equation is presented based on the selected standard. First geometrical indices and then their measuring methods are explained. Then, Using MATLAB and SPSS software's, an appropriate program for PSD geometrical index is written and finally an appropriate relation between PSD, TGI, and CTR geometrical indices is expressed and PSD geometrical index is developed [1, 2, 3].

One of the former works in the field of PSD geometrical index is a study which has been carried out by Zeng Zhiping and JIN Shouhua [4]. In this paper, merely the PSD analysis of the ballast-less slab-track is considered. This paper, using data analysis by PSD method finally concludes that the roughness condition of the ballast-less track is better than the ballasted track. The values of the PSD matching curve parameters for the roughness of the ballast-less slab-track are an appropriate source for studying the PSD of roughness for ballast-less track [1,2]. Another paper has been published by Zeng Zhiping and Yu Zhiwu [5]. In this paper, roughness of CWR tracks on a defined track is investigated using the PSD curve. Based on the static test on the samples, the FFT method (Fast Furrier Transform method) is used to evaluate the sample space whole spectrum. Using reverse analysis, it is specified that the characteristics related to the track vertical irregularities, track alignment defects, and track gauge defects for a CWR track (in the tested segment on Qinghai-Tibet railway) changes about 1 year after the construction completed and about 4 months after the operation started. Finally, using data analysis by PSD method it is concluded that vertical irregularities of CWR track is better than the vertical irregularities of non-CWR track [5].

In the University of Puerto, first the PSD is defined and then various standards about functional use of PSD in railways are introduced [3].

Another paper in the field of PSD has been published by Dan LU, et al [6]. The main purpose of this paper is to describe the defects of Beijing metro tracks. Some preprocessing data which are related to the Beijing track 10 are used in scaling. After all scientific discussions, the results are representing the PSD characteristic parameters. In addition, by comparing the Beijing metro with the national railways, an appropriate research function has been produced for the roughness of Beijing metro tracks. In this paper it is expressed that track roughness is the main reason for locomotive vibration and also the forces between rail and wheel [6]. Another paper in the field of PSD has been published by Liu et al [7]. This essay is about the Characteristic Analysis of the PSD of Track Irregularity on Ballastless Track in High-speed Railway. In this essay the PSD diagram of track irregularities on four different high speed railways has been compared to the low-level and high-level spectrum of the German high-speed railway. This paper concludes that PSD of track irregularity differs among ballastless tracks of the same type. This is because of different conditions in construction and tight alignment.

Also, this paper concludes that except several spectral peaks, the cross level, track alignment and profile PSD curves of the related ballastless track are all below the fitted curve of the low interference spectrum of the German high-speed railway, which means that the construction quality of the related ballastless track is well controlled.

The role of track geometrical indices in the maintenance of tracks possessing the quality index of the track superstructure is of special importance to recognize status of the track. When a structure is constructed and the operation is started the maintenance problems are raised. The superstructure and substructure of the railways are not exceptions and by passing the time and doing the operation the railway track is deteriorated because of the repetitive loads of the trains and environmental effects. Operation of the railway system and its profitability depends on the quality of railway tracks. The maintenance work load of the railway tracks is so high that all of them cannot be done in a limited period of time. For this reason, track maintenance engineers decided to prioritize maintenance works by defining geometrical indices. For this purpose, some indices should be defined and required limits of track maintenance should be specified based on these indices. PSD index is selected in a way that should state the geometrical status of the track with more details. Also, selection of this index should be coordinated with the financial power of the railway and readiness of the mechanized machinery [1].

1.1 Geometrical indices used in track maintenance

Geometrical index is a quantity which is calculated using an equation and is used to express the status of the track. This quantity can express the service level of the track. For this purpose, geometrical parameters of the track are measured using the recording cars and the track geometrical index is calculated based on these measured parameters. Track geometrical parameters are representatives of the rails position in the space. Given that each track consists of two rails and every rail in the space can move in two directions (vertically and horizontally), thus the location of the rails can be specified by four independent geometrical parameters. Given that these four parameters are measured in absolute terms and this is not a simple task, usually, track geometrical parameters consist of track gauge, track cant, track level, track alignment, and track twist [1, 22].

In other research, the authors described that the numerical procedure realizing the mentioned identification method can be based on theoretical Equations which determines the axle-box acceleration function with the knowledge of ballast stiffness function. [21]

1.2.1 CTR Index

By considering the status of the records related to the track geometry and considering the importance of the measured parameters, CTR index combines these parameters with certain coefficients and finally a quantity is calculated. This quantity is representative of general status of track. In India railways this method is used to investigate the geometrical quality of the track. To determine the CTR index the followings should be considered:

1-The coefficient of each parameter which has been measured by the track recording car should be proportional to the condition of the railways and the maintenance methods which are used.

2-It is essential to determine all allowable tolerances of all geometrical parameters of the track by considering the track classification, railway network tracks classification and existing standard. Track classification is specified based on the train tonnage, material which has been used in track construction, and the speed of freight and passenger trains. This method is based on the minimum and maximum number of the track defects. In order to investigate the track geometrical quality, the points at which the geometrical parameter has exceeded the allowable limit, are counted and combined registration index of the track is computed using Eq. (1) [1,2].

$$CTR=100-(U+G+T+A) \quad (1)$$

In order to calibrate the CTR geometrical index to the railway of Islamic Republic of Iran, Eq.(2) has been presented:

$$ICTR = 750 - (U+G+T+A) \quad (2)$$

Where:

U= number of the vertical deflections of the rail which are higher than 6 mm on 1 km of the rail length. For this purpose, the number of the deflections higher than 6 mm is counted and is divided on two rails.

G=number of the track gauge deviations which has amounts higher than 3 mm in 1 km of the track length.

T=number of the track twist deviation which has amounts higher than 5 mm in 1 km of the track length.

A=number of the track alignment deviations which has amounts higher than 5 mm in 1 km of the track length.

Also, the qualitative classification of the tracks using the ICTR index is displayed in Table 1 [10].

Table 1. Track classification using ICTR index

Qualitative description of track	ICTR
Excellent	ICTR >600
Very good	600> ICTR >525
Good	ICTR <525<450
Normal	ICTR <450<375
Weak	> ICTR 375

1.2.2 TGI geometrical index

TGI index developed by Indian railways. Because of the weaknesses of the CTR index (In CTR index all geometrical parameters have the same weight) and because of its insensitivity to some parameters, Indian railway currently utilizes the CTR modified method. This method is based on the statistical analysis and the weighted average is used to combine parameters. Qualitative classification of the tracks using TGI index is presented in Table 2 [1,2].

Table 2. Track classification using TGI index

	TGI Value	Track geometrical Status
1	$TGI > 80$	Excellent
2	$50 < TGI < 80$	Good
2	$36 < TGI < 50$	Normal
4	$TGI < 36$	Weak

In this method, the geometrical index is calculated for track segments which a length of 200 meters. This index is expressed using Eq.(3):

$$TGI = (6\times AL+2\times UI+TI+GI)/10 \qquad (3)$$

Where:

GI: track gauge index

TI: Track twist index

AI: track alignment index

UI: vertical level index

Advantages of TGI can be summarized as

Instead of specifying the location with bad conditions, a continuous illustration of the track length is presented and defective points can easily be identified.

Different weights for all parameters is considered and different parameters based on their importance are of different weights.

The range of values is so variable that a difference of 10 in TGI demonstrates a deterioration or a well-maintained track.

1.2.3 Development of PSD geometrical index

In this study, track data were obtained using track measuring machine. These data are related to the track geometrical parameters and are measured every 25 cm along the track so, these data are not continuous and recorded data are considered as a discrete signal. It is clear that the independent variable of this signal is the distance function (x). If the distance unit is considered to be 1 km, the sampling periodicity is $25/100000$ (sampling frequency will be equal to 4000). As mentioned earlier, spectral analysis of a signal demonstrates its fluctuations. Thus, using PSD analysis, track status can be investigated. In the following sections, the PSD analysis will be explained thoroughly.

Discrete signal Fourier Transform (DFT)

It can be shown that Fourier transform for a discrete signal is computed using Eq.(4).

$$H(\omega) = \sum_{k=-\infty}^{+\infty} x[n]e^{-j\omega k} \quad (4)$$

Where, ω is the frequency, H(ω) is the signal power at the frequency ω, and x[n] is the n-th sample of the signal. Another point to be noted in the above equation is that the ω is normalized in the above equation. In other words, x[n] samples have been defined in $n = 0, \mp 1, \mp 2, ...$While it is not clear that n-th sample is related to which time. Actually, the interval between two successive samples is not clear. The higher the sampling frequency compared to the real frequency (f_s), the samples are belonging to compacted intervals and the lower the sampling frequency, the samples are belonging to bigger intervals. Thus, the sampling frequency is an important factor in frequency interpretation of the DFT. Actually, the relationship between the actual frequency and the sampling frequency is as follow:

Fast Fourier Transform (FFT)

To calculate Fourier transform using the H(ω), several multiplication and addition operations are required and this can be problematic for higher values of n. To calculate the Fourier transform of a discrete signal faster, an algorithm has been provided called FFT or Fast Fourier Transform. FFT using a particular method decreases the number of calculations related to the Fourier transform. Actually, the output of the FFT and DFT is the same but the computing speed of the FFT is higher than the DFT. Thus, FFT is the demonstrative of the signal frequency spectrum. The first output is related to the signal strength at the frequency of 0 and the last output (output $n^2 - th$) demonstrates the signal strength at the frequncy f_s. In other words, the k-th output is the signal strength at the frequency $k\frac{f_s}{2^n}$. MATLAB program can be easily used to calculate the FFT of a signal to compute its spectrum. The nature of the PSD and FFT is a little different. Actually, the PSD demonstrates the signal strength at each frequency. While, the FFT demonstrates the range of each frequency. But both of these provide a good view of frequency content. PSD is calculated using the Eq.(5).In this equation, $X(f_k)$ is the FFT and N is the number of samples.

$$p(f_k) = \frac{1}{N}|X(f_k)|^2 \quad (5)$$

PSD diagram and track frequency demonstrates that which frequency is dominant in the track. Actually, slow variations of track irregularities (defects with long wavelength) can cause the vibration of the wagon body and decrease the travel comfort. On the other hand, defects with short wavelength cause vibrations with high frequencies which can lead to derailment risks and noise emission.

In the PSD method, the relationship between data along the track and frequency of data iteration is investigated. This method demonstrates that how the power of a time series is distributed by frequency. In this method, each parameter is derived as a wavelength and based on this wavelength the type of track defect and its elimination method is determined. By increasing the track geometrical irregularities, this area increase and decreasing the track geometric irregularities has a reverse effect. Total area under the PSD curve represents the track quality index. Many researchers have mentioned that PSD can be an appropriate method to classify irregularities and defects of the track. Also, this method, using wavelength and amplitude, can be demonstrative of the indices related to the track irregularities. These quality indices are usually demonstrated on a power spectral graph. This graph consists of a continuous curve and the vertical axis represents the power density and the horizontal axis represents the spatial frequency. The lower power spectrum demonstrates the irregularities which are in a better status while the higher power spectrum demonstrates the reverse status. Variation in track irregularities in a specified span demonstrates that track has a particular problem. Slow variation of track irregularities (known as a defect with a long wavelength) can affect vertical and horizontal vibration of the car body and this can decrease traveling comfort. Conversely, a defect with a short wavelength can apply a vibration with a high frequency to the train body and this can cause derailment or noise emission. In this paper, first, the PSD method was coded using the MATLAB program, then the PSD was calculated for every one kilometer of track. Data which was used in this research is related to a 114 km long double track segment of Tehran-Mashhad railway. According to the standards introduced, Chinese standard is considered [3].

Chinese standard has been presented for three operation speeds: 200km/h, 160 km/h, and 120 km/h. For each speed, three spectral ranges are presented Eq.(6). This standard has been expressed equations of each spectrum and their coefficients for track gauge, track vertical level (longitudinal profile), track alignment, and track cross section parameters. Considering that the case study track is of operation speed of 120 km/h, coefficients defined in Table 3 are used:

$$s(f) = \frac{af^2 + b}{cf^2 + df^4 + ef^2 + k} \quad (6)$$

Using these coefficients, a graph is drawn for each spectrum and four limits are considered for geometrical indices data which are: excellent, good, normal, and bad.

These conditions are termed: Excellentpsd, badpsd, goodpsd, and verygoodpsd. Excellentpsd is shown by Expsd and is indicative of the percentage of data which their PSD status is lower than the lower status line (Red Line). The status of these data is considered Excellent. Verygoodpsd is shown by VGpsd and expresses that what weight of data is above the lower line and below the average line.

In this case, the status of data is considered very well. Goodpsd is shown by GOpsd and expresses that what weight of data is above the average line and below the higher limit. In this case, the status of data is considered good (relatively). Finally, Badpsd which represents that what weight of data is above the higher limit. This status is known as bad Fig.1. After obtaining these four parameters for 1 km long track, a general equation is presented for PSD. This equation is based on the equation which has been presented by Maundrey 2003, Sadeghi 2006 [13].

$$TGI = \frac{6 * AI + 2 * UI + TI + GI}{10} \quad (7)$$

In Eq.(7), based on statistical analysis, the weighted average is used to combine different parameters. In this equation the weight of the alignment parameter, vertical deflection parameter, and twist-gauge parameters are 60 percent, 20 percent, and 10 percent respectively. Given that in Chinese PSD standard twist

Table 3. Spectral parameters for track speed of 120 km/h

Track irregularities		k	e	d	C	b	a
Trach gauge	Higher level	-0.0003	4.358	289.172	6524.50	0.42	640.74
	Average level	-0.0004	5.223	346.574	7819.64	0.16	255.97
	Lower level	-0.0015	18.995	1261.602	28425.14	0.21	325.92
Cross section (cant defect)	Higher level	0.008	30.938	1028.226	20908.35	7.38	1830.68
	Average level	0.00097	3.739	124.256	2527.1	0.44	110.62
	Lower level	0.027	103.956	3460.220	70234.04	4.34	1077.07
Track Alignment	Higher level	0.00003	0.018	1.0	0.0	0.026	0.0
	Average level	0.00003	0.018	1.0	0.0	0.008	0.0
	Lower level	0.00003	0.018	1.0	0.0	0.003	0.0
Longitudinal Profile	Higher level	0.0	0.006	1.0	0.0	0.013	0.0
	Average level	0.0	0.007	1.0	0.0	0.004	0.0
	Lower level	0.0	0.007	1.0	0.0	0.001	0.0

geometrical parameter has not been considered, then, in Eq.(8) cant parameter has been used instead.

$$PSD = \frac{6 * AL + 2 * UI + CL + GI}{10} \quad (8)$$

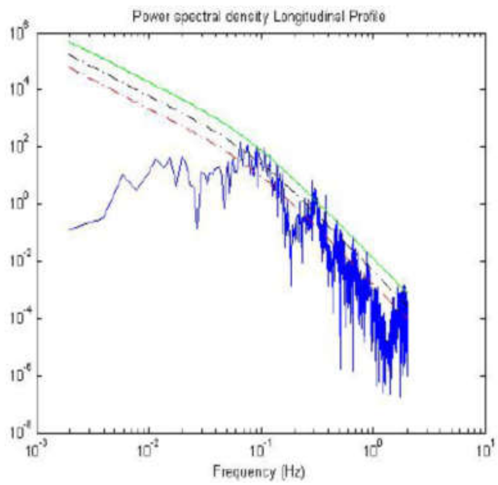

Fig.1. PSD status calculated for track longitudinal profile on a segment of case study track

Results of PSD analysis using MATLAB program are demonstrated in Table 4. This excel file is used as the input file for the SPSS software is carried out on it. To fit multiple linear regression, first, the data (such as Table 4) is entered into the software. Then, the linear regression is applied. TGI and CTR are the dependent variables and Expsd, Gopsd, VgPSD, and Badpsd are independent variables. Finally, the relationship between CTR and PSD and relationship between TGI and PSD is expressed. The result of the regression is an equation that demonstrates the best prediction of a dependent variable based on several independent variables. First, CTR dependent variable and Expsd, Gopsd, VgPSD, and Badpsd are introduced to the software.

Estimation of the PSD index equation for the case study

In this study, the outputs of the track recording car are used as the inputs of the MATLAB program. These measurements have been carried out in Tehran-Mashhad railway line in the railway blocks of Rey-Pishva (km9 to km52), Mashhad-Neyshabur (km783 to km 799), Semnan-Gerdab (km 229 to 276) and Esfarayen-Neghab (km 655 to km 675). Statistically, the best results are relevant to the Rey-Pishva block and these results are investigated in this paper. These results have been obtained by PSD analysis using the MATLAB program for every one km of the track and are demonstrated in Table 4.

Also, the Calculated TGI and CTR indices for the selected railway block are shown in Table 4. These indices have been obtained using MATLAB program. It should be noted that in the regression tables the variable Expsd which has no effect on the results is presented. This variable is eliminated in the final equation. The reason that this variable is presented in the excluded variables table is that the sig calculated for Expsd variable and TGI and CTR dependent variables is very big and this variable is eliminated by the software.

The results of regression analysis obtained by the SPSS software for the Rey-Pishva railway block are presented in the following. These results are the best results obtained by the SPSS software. First the results related to the TGI geometrical index are presented. These results are displayed in tables 5-7. ANOVA test or one-way variance analysis is used to compare the average of a variable among more than two independent groups. The significance level that is called p-value is a level which is known as the sig-value in statistical reports of the SPSS. This level is a criterion which is known as the significance base. ANOVA table shows that whether the regression model can predict the variations of the dependent variable meaningfully and investigate the model statistically or not. Sum of squared degrees of freedom and squared average for two sources of the variation (regression and residue) is from contents of this table. The regression output demonstrates the information about the variations which are considered for the model. The residue output demonstrates the information about the variations which are not considered for the model and the summation output is related to the total information about the regression and average. Coefficients table provides the required information to predict the dependent variable. In the following, the results of the case study for the CTR geometrical index are presented. These results are obtained using the SPSS software. These results consist of the ANOVA tables for the Coefficients and model summary which are presented in tables (8 to 10) [10]. The regression equation is used to predict the values of the

Table 4. General results obtained by MATLAB program for the case study

row	CTR	TGI	Expsd	Badpsd	VGpsd	GOpsd
1	741	62	0.66	0.067	0.18	0.09
2	745	62	0.6	0.07	0.18	0.10
3	739	63	0.57	0.08	0.23	0.12
4	728	62	0.63	0.07	0.20	0.11
5	749	63	0.65	0.07	0.18	0.10
6	738	63	0.59	0.08	0.22	0.11
7	750	62	0.63	0.08	0.19	0.10
8	710.5	56	0.44	0.10	0.31	0.15
9	750	64	0.634	0.07	0.20	0.09
10	726	60	0.66	0.07	0.18	0.09
11	734	58	0.56	0.08	0.24	0.11
12	735	61	0.61	0.07	0.20	0.11
13	743	62	0.46	0.11	0.26	0.17
14	719.5	58	0.65	0.07	0.18	0.09
15	733	63	0.60	0.07	0.20	0.12
16	717	59	0.65	0.06	0.19	0.10
17	733	60	0.56	0.08	0.23	0.13
18	550	46	0.52	0.13	0.19	0.16
19	635	51	0.50	0.12	0.21	0.17
20	747	62	0.64	0.07	0.18	0.10
21	748	64	0.64	0.07	0.18	0.11
22	723	61	0.65	0.07	0.19	0.10
23	731	63	0.62	0.08	0.19	0.11
24	736	63	0.52	0.1	0.25	0.14
25	745	62	0,60	0.08	0.21	0.11
26	714	60	0.60	0.08	0.21	0.12
27	740	61	0.54	0.09	0.25	0.13
28	724	61	0.59	0.08	0.20	0.12
29	722	58	0.53	0.09	0.24	0.13
30	728	59	0.62	0.08	0.20	0.11
31	689	60	0.62	0.08	0.19	0.11
32	705	60	0.60	0.08	0.20	0.12
33	750	65	0.62	0.08	0.20	0.10
34	732	60	0.66	0.08	0.17	0.09
35	723	60	0.55	0.08	0.24	0.13
36	715	59	0.56	0.09	0.23	0.12
37	703	51	0.59	0.09	0.19	0.13
38	510	42	0.45	0.13	0.24	0.18
39	539	44	0.51	0.13	0.20	0.16
40	731	59	0.60	0.08	0.20	0.12
41	713	59	0.63	0.085	0.19	0.11

dependent variable accurately and its equation is as follows:

$$Y = a + bx \quad (9)$$

The predicted values of the dependent variables TGI and CTR are “a” which is the intersection point of the regression line and the y axis and is known as the constant in the regression table. “b” is the gradient of the not standardized regression line and X is different values of the independent variables Badpsd and VGpsd. The presented CTR and TGI models are as equations 10 and 12 [10].

$$CTR = \beta_0 + \beta_1 Badpsd + \beta_2 VGpsd \quad (10)$$

$$\mathrm{CTR} = 822.452 - 3177.142\mathrm{Badpsd} + 764.000\ \mathrm{VGpsd} \quad (11)$$

$$TGI = \beta_0 + \beta_1 Badpsd + \beta_2 VGpsd \qquad (12)$$

$$TGI = 70.955 - 277.427\ Badpsd + 56.274\ \ VGpsd \qquad (13)$$

Eq. (11) and Eq. (13) can be used in Iranian railways to predict and evaluate the PSD geometrical index using TGI and CTR indices.

Table 5 demonstrates the values of R, R^2, and the adjusted R^2. The value of the adjusted R^2 demonstrates that how much of the total variance of TGI variable have been justified by other four variables. R is the multiple correlation coefficient and R^2 is the multiple determination coefficient. Larger quantities of the R show a strong correlation. Smaller quantities of the R^2show that whether the regression model is able to fit the data well or not. Using the R^2 the best models to fit the data can be found. In models which do not have many variables, the larger the value of the R^2, the better the model is compared with other models. But, in models which have many variables, interpretation is carried out using justified R^2. In this study, the value of the justified R^2 is considered 0.76 which in engineering sciences is an appropriate value. R^2 determination coefficient demonstrates that what percentage of the variations of the dependent variable are determined by the independent variables. Table 6 is called the Anova table. This table demonstrates that whether the regression model is able to anticipate the variations of the dependent variable and to investigate the statistical acceptance of the model. Total squared degrees of freedom and average Square for two sources of the variation (regression and residue) are included in this table. Regression output demonstrates the information about the variations in your model. Residue output

Table 5. Summary of the TGI final model for the case study

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.834a	.695	.679	2.92
a. Predictors: (Constant), VGpsd, Badpsd				

Table 6. TGI ANOVA final table for the case study

ANOVA[b]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	740.07	2	370.04	43.37	.000a
	Residual	324.18	38	8.53		
	Total	1064.26	40			
a. Predictors: (Constant), VGpsd, Badpsd						
b. Dependent Variable: TGI						

Table7. Final table of the TGI coefficients for the case study

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	70.95	3.52		20.14	.00
	Badpsd	−277.42	30.20	-.93	−9.18	.00
	VGpsd	56.27	18.75	.30	3.00	.005
a. Dependent Variable: TGI						

Table 8. The summary of the CTR final model for the case study

Summary of model				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.882a	.778	.760	27.11
a. Predictors: (Constant), GOpsd, VGpsd, Badpsd				

Table 9. Final table of the CTR ANOVA for the case study

ANOVA[b]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	95565.14	3	31855.05	43.31	.000a
	Residual	27209.40	37	735.38		
	Total	122774.54	40			
a. Predictors: (Constant), GOpsd, VGpsd, Badpsd						
b. Dependent Variable: CTR						

Table 10. Final table of the CTR coefficients for the case study

Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	820.03	32.97		24.86	.000
	Badpsd	−2887.42	583.73	-.90	−4.94	.000
	VGpsd	822.21	202.25	.41	4.06	.000
	GOpsd	−286.26	505.85	-.11	-.56	.575
a. Dependent Variable: CTR						

demonstrates the information about variations which are not considered in your model. The total output is all the information about regression and residue. Table 7 is called the Coefficients table. This table provides the essential information to anticipate the dependent variable.

2. Results and Discussion

As it is seen in the Table 4, by considering the CTR index, the geometrical status of the track in this railway block is excellent except in kilometers 18, 38 and 39. Geometrical status of the track by considering the TGI index is good except in kilometers 38, 39 and 18. As it is seen, the weight of the PSD on each kilometer of the track for VGpsd, Badpsd, and Expsd has been presented. In this block, on kilometers 38, 39, and 18, the status of the TGI and CTR geometrical indices has been changed from good to average, from excellent to very good and good, respectively. As it is seen in Table 4, on kilometer 18 the Badpsd status is equal to 0.130713 and the Expsd is equal to 0.520459, which the value of the Badpsd on this kilometer has been increased eventually. This status is also visible on kilometers 38 and 39. Expsd parameter in PSD index shows that what percentage of the track is in an excellent situation and in this block the highest weight is related to the Expsd. It means that the geometrical status of the track is relatively excellent and on the mentioned kilometers the geometrical status of the track somewhat has been deteriorated and the status of the track in these kilometers is average.

3. Conclusions

Generally, it can be mentioned that TGI index shows a status of track which is similar to the status by PSD index while the CTR index shows a better status of the track and each of these indices are showing an appropriate status of the track in this block. But, it is evident that the PSD index, by considering four parameters (Expsd, VGpsd, Badpsd, and Expsd), shows the geometrical status of the track with more details compared with CTR and TGI indices. Thus, using PSD index, a better judgment can be made about the quality of the track compared with the TGI and CTR indices. Considering the importance of the PSD equation in this paper, one equation between CTR and PSD and another equation between TGI and PSD has been presented. This equation can help decision makers in the field of track maintenance to make better decisions.

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