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Evaluation of Railway Track Structural Conditions Using a Fuzzy-logic Method: A Case Study

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ABSTRACT

Despite the considerable number of indices developed and used of track geometry conditions, there is a lack of a reliable index representing track structural conditions. Although track structural conditions have considerable influences on track geometry conditions and consequently on safety of the track, there is a lack of sufficient studies on the development of methods by which track structural conditions can be evaluated. In this regard, a new structural index was developed in this research, using the fuzzy method. The new index objectively qualifies the overall condition of railway tracks by which precise maintenance strategy can be made. In order to evaluate the effectiveness and efficiency of the new index, its application in 163 track segments (each having one kilometer length) of a railway line was discussed. The results showed that the standard deviation (SD) of the new index is much lower than those of the currently used indices, indicating more accuracy of the new index. Moreover, the results obtained prove that the new index and the currently used index are very different in segments with severe defects. It was shown that the new index is more reliable compared to the conventional track structural condition index for short-and long-term track maintanance palnning.

KEYWORDS: Fuzzy track quality index, Railway, Maintenance.

INTRODUCTION

Although the budget allocated to maintenance and repair operations of railway lines is considerably high (compared to other types of transportation), the life cycle of railway assets is very short (Vanegas and Labib, 2001). It has been shown that this difference is due to the maintenance policies adopted in railways (Wang et al., 2015; Sadeghi and Askarinejad, 2009; Atashafrazeh and Shirmohammadi, 2016; Setiawan et al., 2019; Mousavi and Wong, 2015a, b). According to the literature, if the track superstructure is not repaired in an appropriate time, the cost of repair exponentially increases as the track deteriorates. Optimum repair and maintenance of railway tracks require a management system by which short-and long-term repair plans can be made. A key element in the establishment of a maintenance management system for railway tracks is the use of track quality index. It plays an essential role in Track Management Systems (TMSs) and helps maintenance programmers understand the quality of the track and select the most suitable and cost-efficient maintenance strategy (Duan et al., 2018, Ebadi et al., 2018).

In the last three decades, many attempts have been made to develop techniques for the evaluation of track quality conditions. Inspection and evaluation of railway track conditions are usually made by analysis of geometry data obtained from track-recording cars (Sadeghi and Askarinejad, 2011; 2012). In this regard, various track geometry indices have been developed in the literature. A summary of most widely used track condition indices is presented in Table 1.

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Table 1. Current track geometry indices (adapted from Sadeghi and Askarinejad (2011, 2012))

No.	Track Condition Index	Standard	Expressions
1	Five-Parameter Track Defectiveness (W_5)	Austrian Railway (Uzarski, 1993)	$w_5 = 1-(1-w_e)(1-w_g)(1-w_w)(1-w_y)(1-w_z)$
2	Geometry Index (TGI)	Indian Railway (Simonovic, 2001)	$TGI = \frac{2UI+TI+6AI+GI}{10}$ $UI, TI, AI, GI = 100 \times e^{-\frac{SD_m - SD_N}{SD_u - SD_N}}$
3	Q Index	Sweden National Railway (Shahin, 1994)	$Q=150- \frac{100}{3}[\frac{\sigma_H}{\sigma_{H\lim}}+2\frac{\sigma_S}{\sigma_{S\lim}}]$
4	J Index	Polish Railway (Uzarski, 1993)	$J = \frac{S_Z + S_Y + S_W + 0.5S_e}{3.5}$
5	Track Roughness Index	USA Railway (Sadeghi, 2010)	$R^2 = \frac{\sum_{i=1}^{n} d_i^2}{n}$
6	Standard Deviation	ORE (Europe) (Uzarski et al., 1993)	SD

Notes: In the first row, w_z *and* w_y *are the arithmetic averages for the vertical and horizontal irregularities, respectively,* w_g, w_w *and* w_e *represent the defectiveness of cant, twist and track gauge, respectively. In the second row,* SD_M, SD_N *and* SD_U *are the standard deviations of measured parameter, a newly laid track and a track needing urgent maintenance. In the third row,* σ_H *is the average of the standard deviations of left and right profile,* σ_s *is the average of the standard deviations of cant, gauge and horizontal deviation,* $\sigma_{H_{\lim}}$ *is the allowable value of* σ_H *based on track categories and* $\sigma_{S_{\lim}}$ *is the allowable value of* σ_s *based on track categories. In the fourth row,* S_e *is the standard deviation of vertical irregularities;* S_y, S_w *and* S_Z *are the standard deviations of horizontal irregularities, track twist and track gauge. In the fifth row, "n" is the number of measurements in the summation length and* d_i *is the mid-chord measurement for profile and alignment and the deviation for cross level and gauge. In the sixth row, SD is the standard deviation of data calculated for a* 1000-*m section.*

In the recent decade, some attempts have been made to improve the conversional track geometry indices and the current track maintenance approaches (Movaghar and Mohammadzadeh, 2019; Phanyakit and Satiennam, 2018). For instance, Sadeghi et al. developed an index which is a function of track defects and excess of ballast in the track (Sadeghi et al., 2012). A new maintenance approach was developed based on the new index, providing a possibility of quickly measuring ballast profile for a faster and more accurate ballast maintenance (Sadeghi et al., 2019). Yao et al. (2019) and Mariani et al. (2017) have used an automated ultrasonic method to detect/measure rail internal defects in railway tracks. In the Sadeghi's research, the statistical distribution of railway track geometry data is investigated using a significant amount of field data (Sadeghi, 2010). In another research, a new railway track condition index has been developed, which takes passenger ride comfort (PRC) into account (Sadeghi and Askarinejad, 2010). The influence of rail cant on the overall geometry condition of railway tracks has been investigated both experimentally and theoretically in the literature. The geometry condition assessment of the Iranian North-East LRT line is referenced for experimental investigation. Data obtained from the analysis of the track (using a rail–wheel contact model) is used for the theoretical part of the investigation (Sadeghi et al., 2012).

Although various methods have been developed for inspection and quantification of track geometry conditions, there are insufficient works for the development of a reliable method for evaluation of track structural conditions. Track structural conditions significantly influence track geometry conditions. In other words, track geometry defects may be a result of some structural defects in railway components, including rail, sleeper and ballast. While geometry conditions indicate the present condition and safety of running on the track, track structural conditions indicate a potential for failure. This means that track geometry condition evaluation can provide a possibility of making appropriate repair and maintenance for a short period, while track structural condition evaluation provides both short-and long-term maintenance planning. Evaluation of track structural condition aids in determining M&R needs on a categorical basis, developing work plans, measuring the effectiveness of work accomplishment, projecting condition trends, prioritizing M&R work and establishing deterioration rates (Pérez et al., 2015). Any efficient and cost-effective repair and maintenance strategy requires a long-term strategy which is built based on an accurate prediction of short-and long-term conditions. This indicates the necessity of having a model for evaluation of railway track structure.

The only study made for the development of track structural evaluation belongs to Uzarski from the Illinois University in 1990s (Uzarski, 1993). His research objective was to develop a repeatable condition index for the component groups of rail, joints, fastenings, wooden cross ties, ballast and subgrade. He also developed an overall Track Structure Condition Index (CTSI). His proposed technique for the evaluation of track structure has several limitations. It is limited to tracks with wooden sleepers and heavy traffic. The Uzarski model does not consider the differences between main line and branches, it is time consuming and very much dependent on individual judgments. Moreover, it does not consider turn-out in the railway lines.

To overcome the limitations of the current track structural index, a new index was developed in this research using the fuzzy method (Hemmati et al., 2018, Wang et al., 2018). This research is carried out based on an empirical method. First, a comprehensive field investigation on structural behavior of railway was made and as a result, the types and the extent of track defects (defect density), importance and defect severity, as well as the rate of railway defect progress were recorded/derived. Second, the fuzzy method was used to develop an index representing track quality conditions.

A railway track structure consists of several components, including rail, sleeper, ballast and turnout. In this research, the track structure is categorized into the four following defect groups: (1) rail, (2) sleeper, (3) ballast and (4) turnout (Table 2). A panel of experts was formed in order to define the dominant defects and their density and severity, as well as to determine the level of defect influences on the quality of the railway based on the results obtained from railway field. Track defects were classified into three severity levels including low, moderate and high. For development of the fuzzy track quality index (FTSI: the new index), a panel was formed, comprising 30 railway experts from a variety of track maintenance and construction services. This panel developed fuzzy membership functions for track defect density, defect severity and defect importance in track deterioration. The FTSI was developed based on the membership functions computed from FTSI values. In order to evaluate the efficiency of the current model, the fuzzy track quality index was tested in a railway line. Comparison of the new index with the currently used index indicates a better reliability of the new index in the presentation of track real conditions.

Fuzzy-based Track Structural Index

Fuzzy-based Track Structural Index (FTSI) is developed based on fuzzy mathematics in the following equation (Vanegas and Labib, 200l; Sadeghi and Askarinejad, 2009):

$$FTSI = \frac{\int_a^b FTSI(x)x\,dx}{\int_a^b FTSI(x)\,dx} \qquad (1)$$

where $FTSI$ is the track fuzzy index membership function representing the track qualitative index. In fact, *FTSI* is the centroid of *FTSI* function. This technique is well known in fuzzy mathematics (Vanegas and Labib, 2001; Simonovic, 2001). *a* and *b* are the two end base limits of *FTSI. FTSI* is a combination of density, importance and severity fuzzy membership functions for various track defects. This function is derived using New Fuzzy Weight Average (NFWA) technique presented in Eq. 2 (Vanegas and Labib, 2001; Sadeghi and Askarinejad, 2009).

$$FTSI = \frac{\sum_{i=1}^{3}\sum_{k=1}^{n} I_{ki} S_{ki} D_{ki}}{\sum_{i=1}^{3}\sum_{k=1}^{n} I_{ki} S_{ki}} \qquad (2)$$

where I_{ki}, S_{ki} and D_{ki} are the fuzzy numbers derived from the defect importance, severity and density membership functions, respectively. The *α–cut* techniques were used to calculate fuzzy numbers presented in Eq 2. "*i*" is the counter for three defect levels, including low, medium and high. "*k*" is the counter for defect type, varying from 1 to 22 (Table 2). Based on the main track structural defects investigated in the literature, 22 defects were used (Uzarski, 1993).

Table 2. Evaluation form for track fuzzy index

Track condition recoding form						
Name of rater:				**Date:**		
Kilometers:	Segment name:	Line name:		Length of the segment:		
Distress code	Severity			Density		
	High	Moderate	Low	High	Moderate	Low

As illustrated above, in order to use *FTSI*, importance, severity and density membership functions for each defect should be derived. In other words, in order to apply the fuzzy theory in the track evaluation process, three parameters of track defects (i.e., density, severity and importance) should be interpreted in the fuzzy domain (Hamal et al., 2018).

Delphi method was used to generate membership functions in the fuzzy domain (Okoli and Pawlowski, 2004). It requires multiple investigations to achieve the consistency of expert opinions. Experts modify their opinions so as to meet the mean value and standard deviation of all the expert opinions taking part in the Delphi survey. However, Delphi method requires only a small number of samples and the derived results are objective and reasonable. For Fuzzy-based Track Structural Index (*FTSI*), the number of selected indicators using Delphi method was 30, having more than 5 years of experience in track maintenance activities. A suitable form was prepared for expert panel, (Fig. 1), including the level of track defect density, importance and severity. The experts were asked to quantify track defect density, importance and severity from 0 to 100 for the three categories of low, medium and high. They were also asked to present them in the rating forms. In other words, the experts expressed track defect density, importance and severity comparatively out of 100.

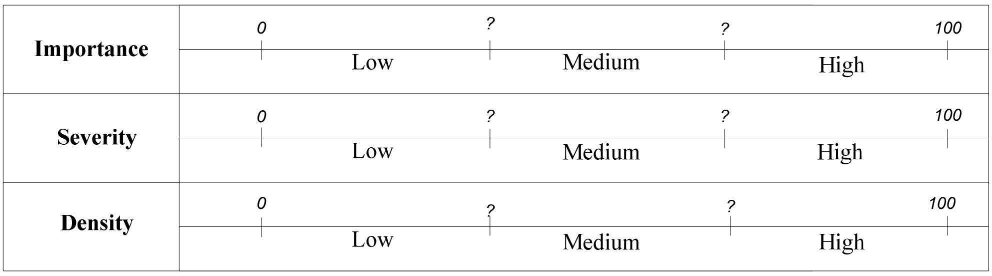

Figure (1): Forms prepared for experts to quantify track qualitative parameters' defects (density, severity and importance)

Table 3. Sample of evaluation form by the experts

	Rail group				Sleeper group					Ballast group							Turnout group					
Distress number (K_i, Equation 2)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Distress importance	Rail defect	Joint defect	Hold-down device	Tie plate	Single defective sleeper	Isolated defective sleeper clusters	Adjacent defective sleeper clusters	Missing sleeper	Improperly positioned sleeper	Dirty ballast	Vegetation growth	Pumping sleeper	Insufficient crib/shoulder ballast	Erosion of ballast	Inadequate trackside drainage	Inadequate water flow through drainage structures	Turnout rail distress	Plate slide and lock lever pin distress	Turnout central tool distress	Turnout traverse distress	Turnout joint distress	Turnout ballast distress
High	■	■				■	■						■				■					
Moderate			■		■			■	■	■	■			■	■			■	■		■	■
Low				■								■				■				■		

The rating sessions took place over several months and were conducted in an identical manner. Similar to the Shahin approach (Shahin, 1994), the raters were first given general instructions; then, they were given a copy of the rating guidelines and rating forms for each defect, one by one, in random order. The raters were not permitted to review completed forms while rating new forms, nor were they permitted to see the ratings given by other raters. After a given set of forms was completed, a research assistant reviewed the data. Any rating that deviated from the mean value more than twice of the standard deviation of the data was flagged to repeat the rating. This was done to allow the raters to correct ratings that may have been incorrectly recorded. After collecting the forms in the last stage, the density fuzzy membership functions from each expert for every defect were plotted (30×12 functions). The functions were averaged into one unique function, as presented in Fig. 2. This process was repeated again for severity and importance. The results are presented in Figs. 3 and 4.

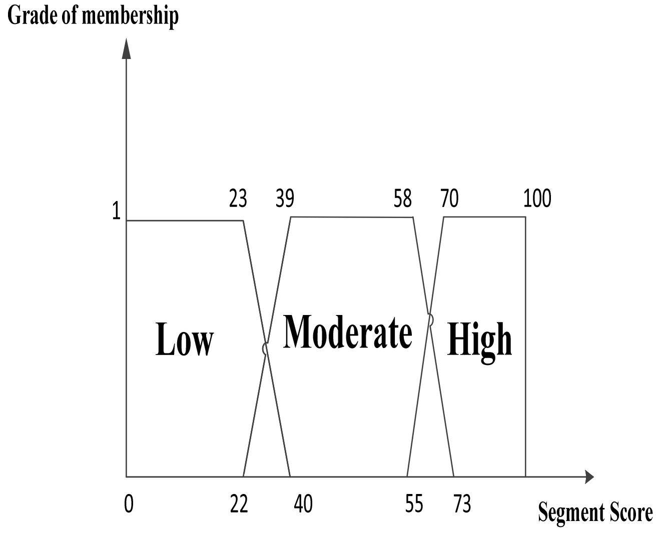

Figure (2): Fuzzy membership functions for defect density

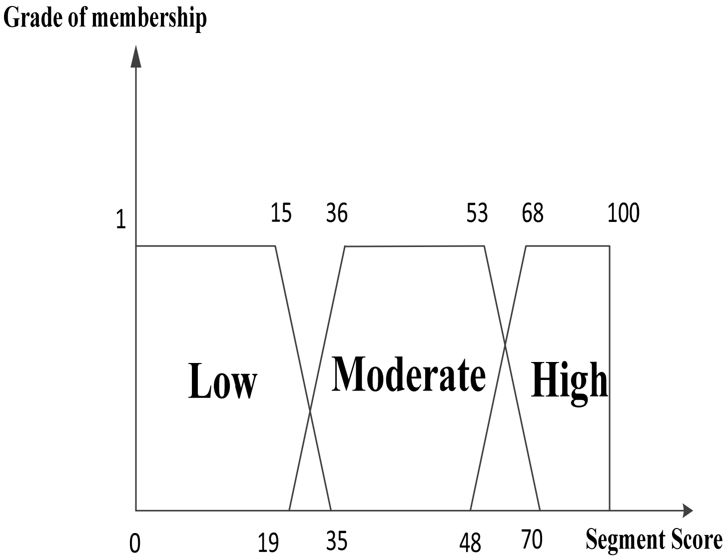

Figure (3): Fuzzy membership functions for defect severity

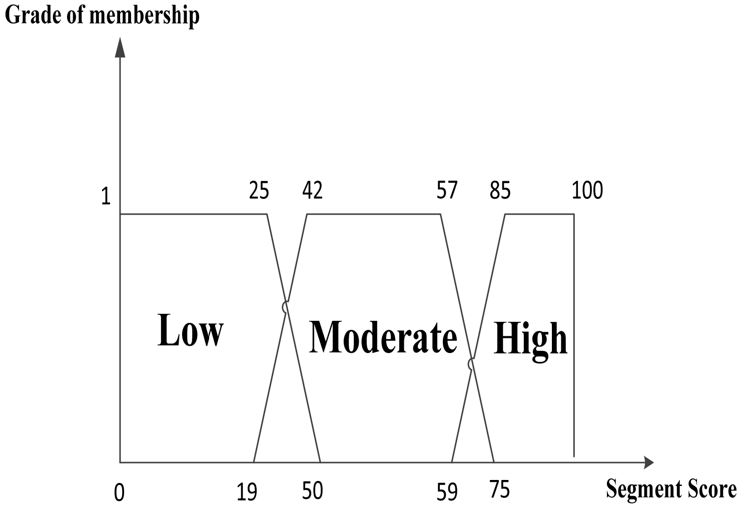

Figure (4): Fuzzy membership functions for defect importance

Field Investigation

The model was tested in a crowded railway line (which includes both freight and passenger ones 30 years old) to examine the practicality and applicability of the new track quality index. A total track length of 258 km, which includes Tehran–Garmsar double track with 114 km and Tehran-Ghazvin track with 144 km (Fig. 5), was investigated in the field tests. These are tangent tracks with the average gradient of 1.5%, carrying a tonnage in the range of 8-12 million gross tons per year. Several studies were conducted in 2012, 2014, 2016 and 2017 in this site with the aim of selecting a suitable and cost-efficient maintenance strategy (Zakeri, 2012; Esmaeili et al., 2014; Mosayebi et al., 2016; Heydari-Noghabi et al., 2017). The site is in average condition and comprises pre-stressed concrete sleepers (type B70), UIC60 rail, 30-cm ballast layer and a Vossloh fastening system. A schematic diagram of the site zone is presented in Fig. 5. The test zone was divided into 163 segments with an average length of 1200 meters, including tangent, curved and turnout sections. The developed quality index was computed in these segments (Zakeri, 2012; Esmaeili et al., 2014; Mosayebi et al., 2016; Heydari-Noghabi et al., 2017).

In order to evaluate the efficiency of the current model, CTSI (the most widely used track condition index) developed by Uzarski et al. (1993) was also computed in all the segments and compared with the FTSI. The records were repeated during day and evening, on feet and by a camera which was installed on a car (Fig. 6 and Fig. 7). The checklists prepared to compute the CTSI and the FTSI are presented in Table 2.

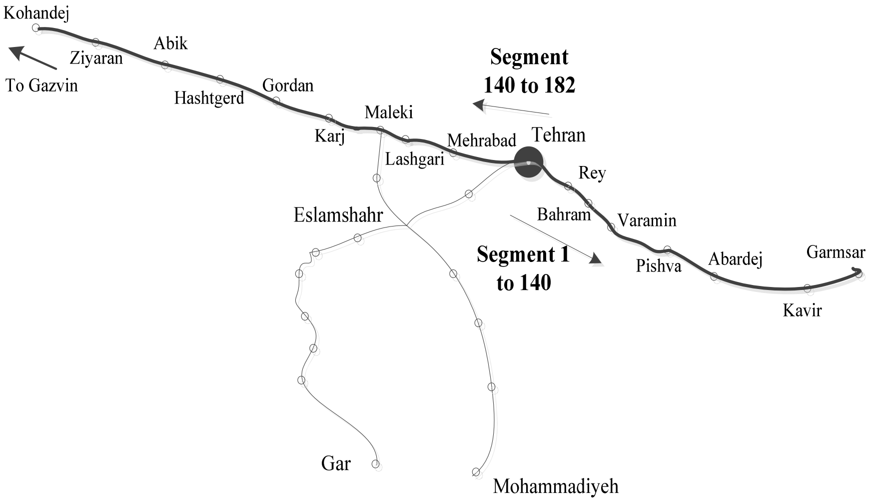

Figure (5): Schematic view of the segmented test zone, Tehran-Garmsar and Tehran-Ghazvin

Figure (6): Track survey on foot (Tehran-Qazvin)

Figure (7): Track survey by car and camera (Tehran-GARMSAR), train speed of 20 to 30 km/h

Computation of the New Index (FISI)

To derive/compute the Fuzzy Track Structural Index (FTSI), 30 track inspectors who have various experiences of more than 5 years in track maintenance were asked to record the defects of the track components (i.e., rail, sleepers, fastening system and ballast) in all the track segments.

The results obtained from completed forms were used to develop membership functions (importance, severity and density). Then, the Fuzzy Track Structural Index (FTSI) was computed based on the derived fuzzy membership functions (applying fuzzy technique) for all the 163 segments. The membership functions were decomposed into rectangular membership functions, using $\alpha - cut$ techniques (Eq. 3).

Alpha cut is the horizontal representation of fuzzy sets by their α-cuts. Let $\mu \in F(X)$ and $\alpha \in [0,1]$. Then, the sets $[\mu]\alpha = \{x \mid \mu(x) \geq \alpha\}$ and $[\mu]\alpha = \{x \mid \mu(x) > \alpha\}$ are called the α-cut and strict α-cut of μ (Klir and Yuan, 1995).

The concept of an $\alpha - cut$ of a fuzzy set is useful for defining the arithmetic operations on fuzzy numbers. The $\alpha - cut$ of a fuzzy set A is the (crisp) set A of elements x, such that their degree of membership in the set A is at least equal to $\alpha\,(0 \le \alpha \le 1)$; $\alpha - cut$ is then expressed by Eq. 3 (Klir and Yuan, 1995), where $\mu_A(x)$ is the fuzzy membership.

$$A_{\bar{\alpha}} = \{X \mid \mu_A(x) \ge \alpha\}, \alpha \in (0,1] \qquad (3)$$

After identifying $\alpha - cut$, fuzzy memberships were derived. Then, rectangular membership functions were combined with New Fuzzy Weighted Average (NFWA).

As can be seen, the minimum and maximum values of the FTSI were computed for three selected segments when $\alpha - cut$ equals 0 and 1. Then, using the fuzzy technique, the FTSI was obtained (using the MATLAB toolbox). For example, the outputs of membership functions were 51, 69 and 43 for the first, second and third segments (Figs. 8, 9 and 10).

Table 4. Defect severity levels (adapted from Uzarski et al. (1993))

Severity level	Description
Low	Defects that do not affect train operation
Moderate	Defects that may or may not cause an operation restriction on the track
High	Defects that cause operation restrictions on the track and may prevent train operation

Table 5. FTSI computed for three selected segments

FTSI			$\alpha - cut$ type
22	44	28	Minimum FTSI in $\alpha - cut = 0$
63	86	72	Maximum FTSI in $\alpha - cut = 0$
39	60	42	Minimum FTSI in $\alpha - cut = 1$
52	82	63	Maximum FTSI in $\alpha - cut = 1$
43	69	51	FTSI

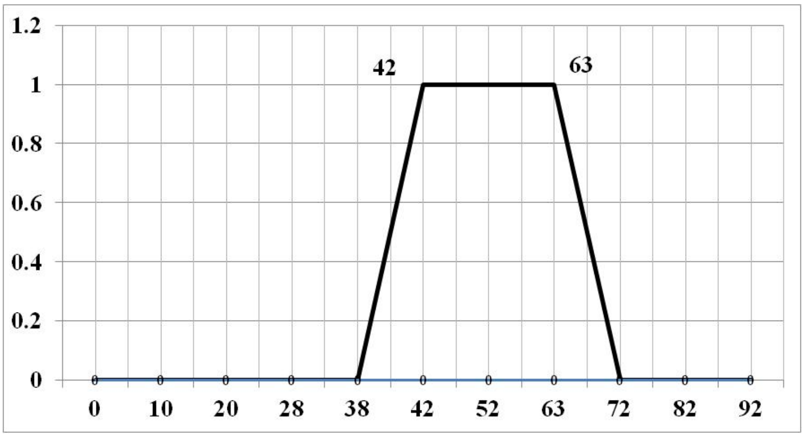

Figure (8): Membership function calculated by MATLAB for the first segment

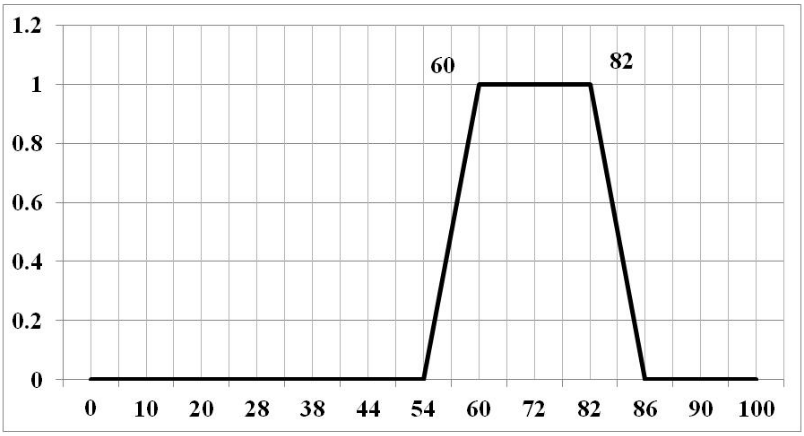

Figure (9): Membership function calculated by MATLAB for the second segment

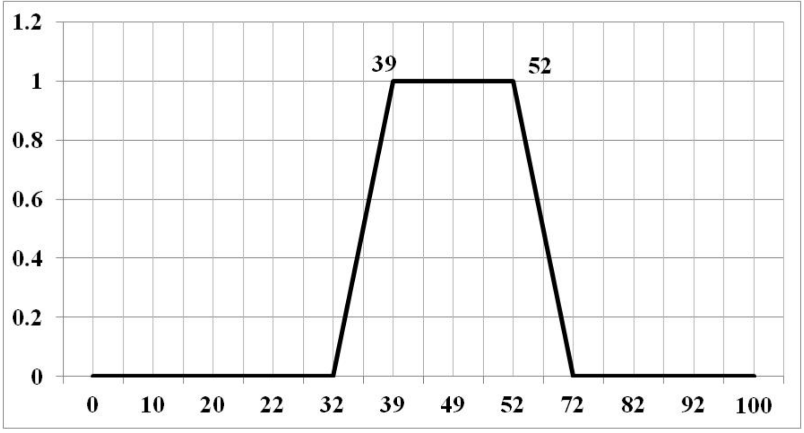

Figure (10): Membership function calculated by MATLAB for the third segment

Computation of Conversional Index

In order to compare the results of the FTSI and the CTSI (the most widely used Track Structure Index), the CTSI was derived/computed for the 163 segments of 1200-meter length (Wang et al., 2015). Equation 4 was employed to compute the convention quality index for each track component group. The calculated indices for each segment were then averaged to obtain the quality index for rail (RCI), sleeper (SCI) and ballast (BCI) for each segment (Uzarski, 1993b).

$$(BCI, SCI, RCI) = C - \sum_{i=1}^{p}\sum_{j=1}^{mi} \alpha(Ti, Sj, Dij) F(t,d) \tag{4}$$

where C is a constant (equal to 100), α( ) is the deduct weighting value depending on defect type T_i, severity level S_i and defect density D_{ij}. I is the counter for defect types, j is the counter for severity levels, p is the total number of defect types for the component groups under consideration, m_i is the number of severity levels for the i^{th} defect type, F(t,d) is the adjustment factor for multiple defects that vary with total summed deduct value and t is the number of individual deducts over an established minimum value (d). The indices for each segment were then averaged to obtain the quality indices for rail (*RCI*), sleeper (*SCI*) and ballast (*BCI*) in each track long segment (track line). That is, the *CTSI* was computed from Eq. 5 (Uzarski, 1993b):

$$CTSI = 0.5CI(low) + 0.35CI(mid) + 0.15CI(high) \tag{5}$$

where *CI (low), CI (mid)* and *CI (high)* are the indices for *RCI, SCI* and *BCI*, sorted out from the lowest value to the highest value (Uzarski, 1993a).

RESULTS AND DISCUSSION

The CTSI and the FTSI obtained for the three selected segments are presented in Table 6. For comparison of the FTSI and the CTSI, all the 163 segments were categorized into 3 groups of moderate condition (69 segments), good condition (65 segments) and poor condition (29 segments). Figs. 11, 12, 13 and 14 present comparisons of the FTSI and the CTSI for the 163 segments in the 3 conditions.

Figs. 11 to 14 present the differences between the FTSI and CTSI values in the 163 segments with good, moderate and poor conditions. As indicated in Fig. 12, the differences between the FTSI and CTSI values are at least 5% and up to 18% in 65 segments with good condition. The difference between the FTSI and the CTSI are in the range of (0-12%) in the segments with moderate condition (Fig. 13) and in the range of (2-22%) in tracks with poor condition (Fig. 14). The FTSI and the CTSI values are in good agreement in most of the segments in good condition. This indicates that as the condition of the track gets worse, the difference between the indices enlarges.

To investigate the influence of inspection method in the evaluation of track quality, the FSCI and the CTSI were obtained from inspection made in the evening time (when there is no sun) and during the day. Also, the influence of the method of inspection (including inspection on foot and inspection by car) was evaluated.

Fig. 15 shows the FTSI and CTSI values obtained in 30 selected segments computed from the results of track inspections made in different conditions (i.e., during the day and in the evening time, on foot and by a camera installed on a car). According to Fig. 15, the differences between the CTSI and the FTSI are less during the day compared to those in the evening time. This can be due to more accurate inspection of the segment defects when there is sun. This figure also indicates that there is negligible difference between the FTSI and the CTSI when using a railway car (derezin) during the inspection of the segments.

Table 6. Comparison of CTSI and FTSI for the three segment

CTSI index	RCI	46	59.6	30
	SCI	82	96.5	24
	BCI	43	85.5	62
	TSI	50	74.17	32.78
	Condition of track, based on a judgment of CTSI	Medium	Good	Low
FTSI index	Minimum FI in $\alpha-cut=0$	28	44	22
	Maximum FI in $\alpha-cut=0$	72	86	63
	Minimum FI in $\alpha-cut=1$	42	60	39
	Maximum FI in $\alpha-cut=1$	63	82	52
	FTSI	51	69	43

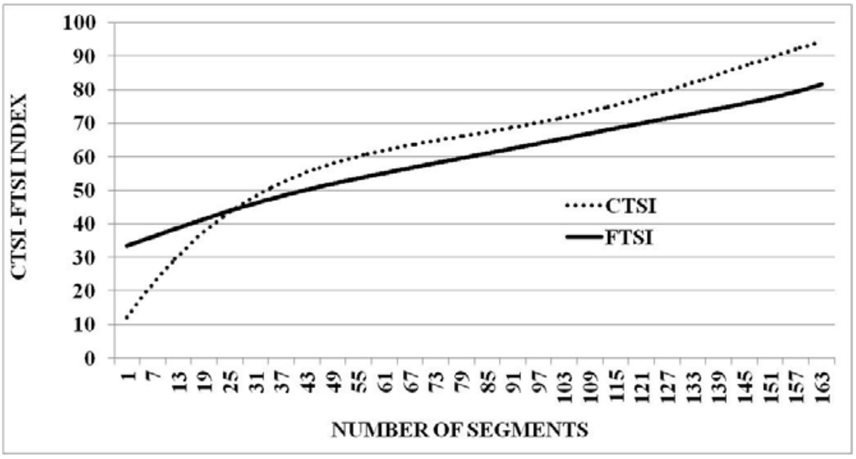

Figure (11): Comparison of FTSI and CTSI in all segments

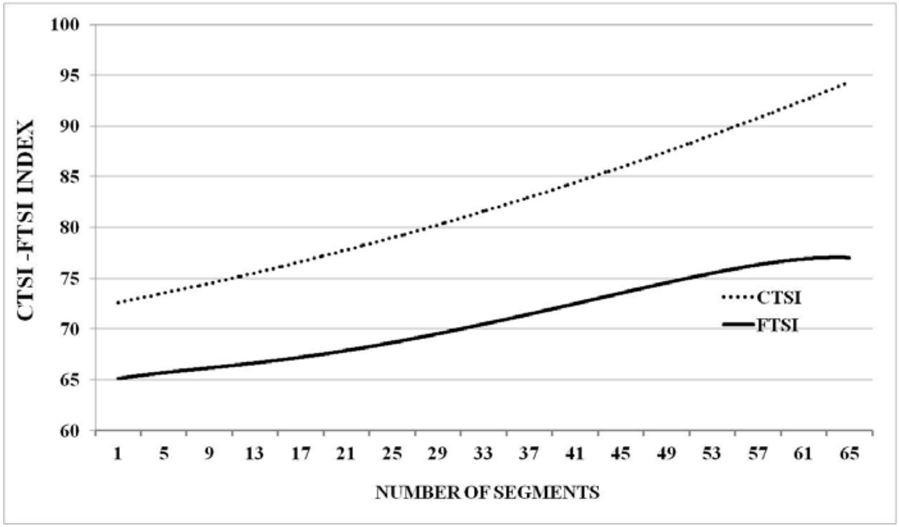

Figure (12): Comparison of FTSI and CTSI in segments with good condition

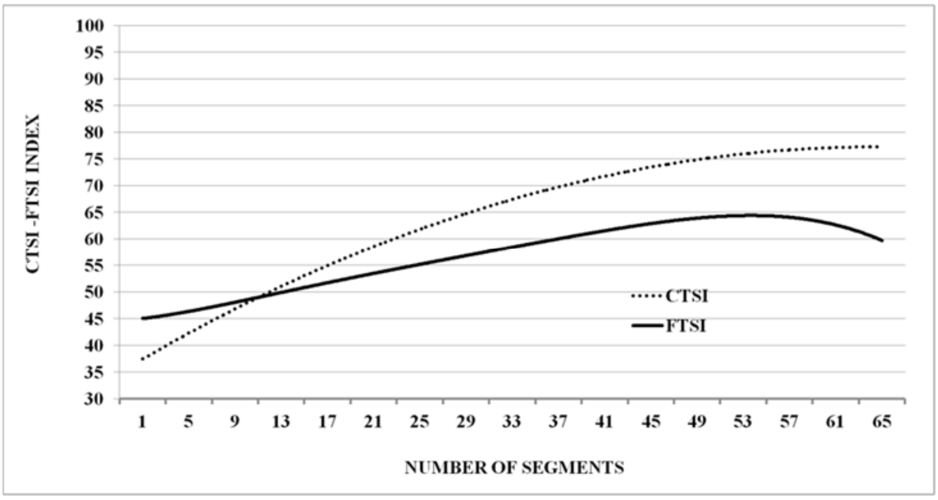

Figure (13): Comparison of FTSI and CTSI in segments with moderate condition

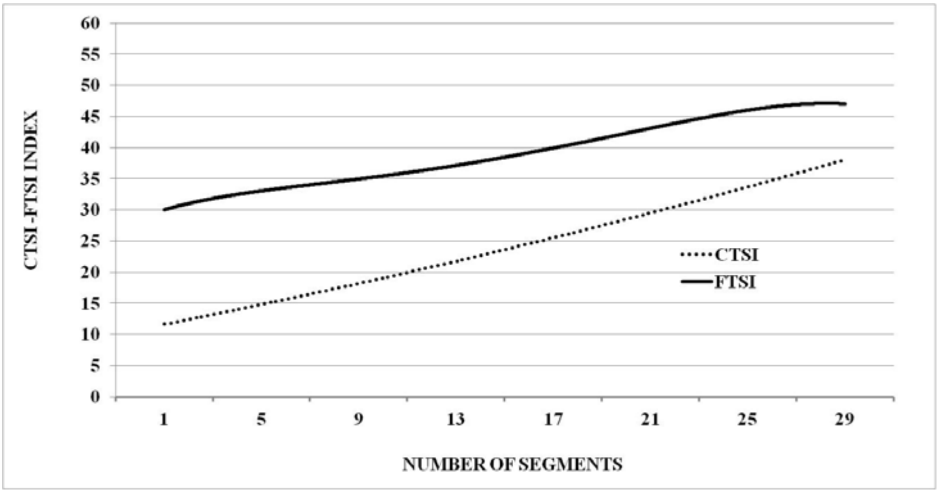

Figure (14): Comparison of FTSI and CTSI in segments with bad condition

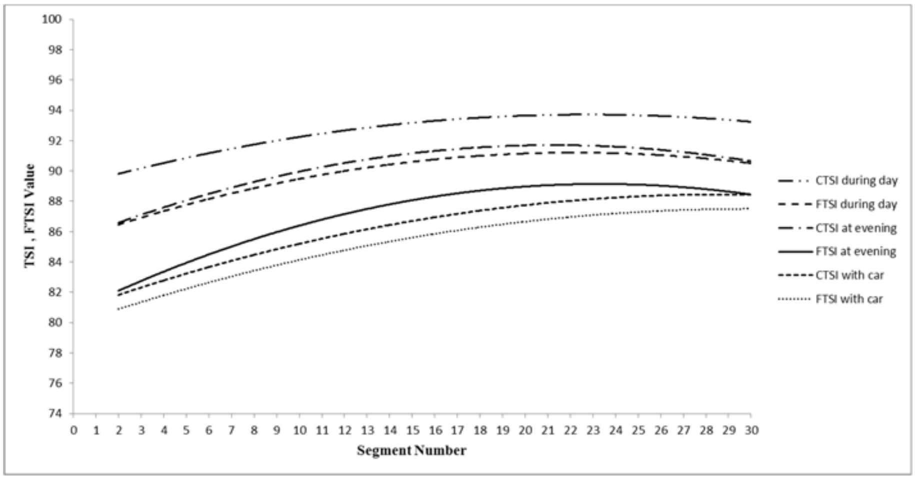

Figure (15): Comparison of FTSI and TSI values in some selected segments

To illustrate the improvement made by the new fuzzy index in the presentation of the track quality conditions, the derived indices (FTSI and CTSI) for all the segments were evaluated by a group of experts. They investigated all of the defects during 1 year. The experts rated the quality of each of the 163 segments. They rated the quality out of 100. For this purpose, a questionnaire was designed and distributed to the experts. They were asked to rate the overall quality of each segment. The investigation was made using the Delphi method. The results are presented in Figure 16, where the CTCI and the FTCI are compared with the expert judgments.

Figure 16 presents a comparison of the FTSI and the CTSI with the expert judgments in the segments. As indicated in this figure, the new index is more close to the judgments of the experts in all conditions of the segments. The difference in the CTSI and the expert judgments is in the range of 20% to 30%, while this difference is in the range of (2-8%) for the FTSI. This indicates that the new index (developed based on the fuzzy method) improves the accuracy of the prediction of track conditions by 20%.

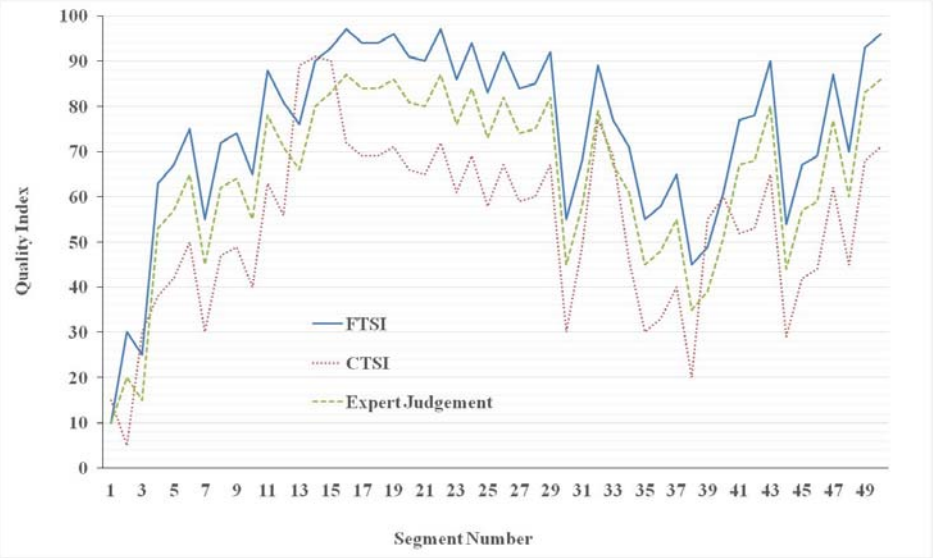

Figure (16): Comparison of the new index and conventional index with the expert judgments

CONCLUSIONS

Although track geometry conditions indicate railway track safety at the present condition, it does not indicate track long-term behavior/conditions for which a maintenance programmer can make a long-term maintenance planning. This shows a need for a track structural condition index which reflects track structural conditions (the main cause of track geometry defects).

The only available track structural condition index (called CTSI) has several important limitations. Addressing the CTSI limitations, a new structural index was developed in this research, using the fuzzy method. The new fuzzy track structural index (FTSI) was developed to objectively and qualitatively present the overall condition of track segments. In order to evaluate the effectiveness of the new index, the new index was tested in a crowded railway line and compared with the conventional index (currently used in the railway industry).

The results/findings obtained in this research include:

- The currently used track structural index has considerable errors in perdition/representation of track structural conditions, particularly when track inspection is made at night time or on foot or the track structural condition is in a critical condition (having severe defects).
- The fuzzy technique is an effective tool to improve the current techniques for development of railway

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track structural condition index.

- The fuzzy index (developed in this research) has a better estimation (up to 20%) of the track quality conditions, indicating an improvement in the prediction and presentation of real structural conditions of railway tracks.
- The difference in the FTSI and the CTSI increases when the inspection is made in the evening (when there is no sun), but the difference considerably reduces if the inspection is made by a railway car (derezin).
- The new index provides maintenance programmers with a possibility of making more accurate decisions on track maintenance approach for the short and long terms.

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