ANALYSIS OF TRACK GEOMETRY INDEX MEASURMENT METHODS

Daniel H/Michael[1], Elias Kassa[1], Getu Segni[1]

School of Civil and Environmental Engineering, African Railway Center of Excellence

Corresponding author's email: dh5045@gmail.com

ABSTRACT

Degradation of railway track can be described by main geometry parameters such as profile, alignment, gauge, cant, and twist but track geometry quality index can be used for aggregating two or more geometric defects and represent health condition of track structure. This paper discusses different methods of quality indexes and analyzes numerically three methods based on real track geometry measurement data from Addis Ababa – Djibouti railway line and their advantages discussed for the purpose of recommending TQI method for predicting future state of track which will be used in Predictive maintenance. Data collected is from 25-27 of May 2020 for 215.8Km length. Results from analysis shows, track geometry index (TGI) represents track quality more reasonably. Chinese TQI method can also represent track quality but gives equal weightage for all types of degradation parameters on the other hand TGI allocated more weightage for parameters with higher effect on ride quality. J synthetic method can only represent two types of quality below and above threshold but the two other methods represent more quality levels. Theoretically, advantages and disadvantages of methods discussed can be referred but practically recommended method can be used in prediction models for implementing predictive maintenance.

Keywords: Track degradation, Track geometry defects, track quality Index, track quality level,

1. INTRODUCTION

1.1. Background

Railway track as a base element of railway system greatly and directly influences safety and cost efficiency of rail transport. In process of track management, maintenance-of-way departments have to try to balance cost associated with potential damages arising from unfavorable tracks and cost for Maintenance & Renewal activities to minimize life cycle cost of track. To attain minimization of life cycle cost, there are key issues which need to be addressed. One of them is the railway track condition forecast technology [1].

In order to forecast railway track condition it shall be defined first. There are different methods of defining track condition but most of track condition forecasting models use track geometry parameters.

In order to measure track conditions by using track geometry model, typically track is divided into several shorter sections and geometry statistics are performed to each of them. Geometry statistics are then summed up to give a measure of overall segment quality, which is commonly called Track Quality Indices (TQIs). Use of TQIs provides possibility to assess railway track performance indicators, to design interventions, and to compare track performances before and after intervention[2].Methods of calculating TQI varies by country. In China, TQI is calculated as the sum of the standard deviation of 7 track geometry measurement. In United States, TQI is calculated as ratio of traced space curve length to track segment length.

In Europe, J synthetic coefficient is used as an indicator of track quality based on standard deviation in Polish Railways. In India, a formula, called track geometry index (TGI), has been developed by Indian Railways to represent quality of track. This model is based on standard deviation of different geometry parameters over a 200m segment [3]. This paper discusses different methods used to represent track quality and analyses three of them based on real geometric measurement data from Addis Ababa-Djibouti railway for the purpose of recommending one method to be used for predicting the future state of track in the aim of implementing predictive maintenance.

1.2. Problem statement

Railway transport is the most economical transport next to water transport especially for freight transportation. To maintain the economic benefit of railway transport it is important to make the running cost as low as possible. One of the major running costs includes infrastructure maintenance cost which takes the greater share of infrastructure maintenance costs. To achieve minimization of maintenance cost it is important to implement predictive (condition based) maintenance which needs prediction of future state of infrastructure. Predicting needs prediction models and to have better models the condition of the structure shall be defined in a better indicator. In case of track infrastructure there are different methods representing quality of track geometry this paper focuses in discussing and recommending method of track geometry quality aiming to use it for predicting future state of track infrastructure. Prediction will help for implementation of predictive (condition based) track infrastructure maintenance.

1.3. Research purpose and objective

The purpose of the study is discussing different method of track quality index and recommending better method of quality index based on real track geometry measurement on existing railway line. The main objective is recommending track quality index method which will be used for prediction of future track condition and supporting the implementation of predictive track infrastructure maintenance.

2. Research methodology

The study method consists of explorative research and statistical quantitative data analysis, explorative approach is used in literature reviews and quantitative statistical data analysis is used for comparison and recommendations based on results.

2.1. Research process

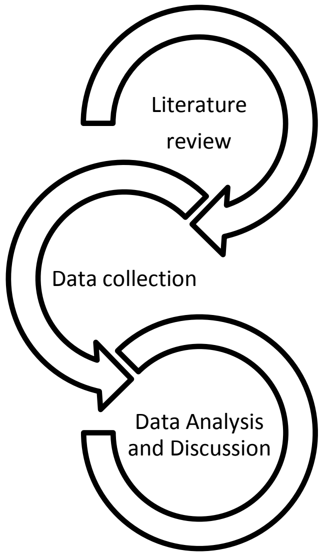

Figure 1 Research process flow chart

2.2. RESEARCH METHODS

Exploratory method used in literature review and statistical quantitative data analysis is used in data analysis. Literature study and survey is employed, the materials used include Journals, Thesis, Books, Manuals, conference papers. The lists of Key words used to search literatures:-*Track quality Index, Track geometry defects, track degradation, track quality level*

Secondary quantitative data is collected form Addis Ababa Djibouti railway line regarding the geometry of railway track from Track geometry measuring vehicle. Data analysis activities include data selection based on the line characteristics and classification by a section of 200m length, preliminary data analysis and detailed data analysis.

3. Railway track characteristics and degradation parameters

Changes in TQI, track settlement and average growth of track's irregularity are considered to be main track deterioration criteria from the aspects of track geometry, on tracks sub-structure and super structure, respectively[4].

Track geometry degradation is usually quantified by five track defects: the *longitudinal leveling defects*, the *horizontal alignment defects*, the *cant defects*, the *gauge deviations* and the *track twist*[5].

By looking to literature it can be observed that most of researchers considered short wavelength longitudinal level as crucial factor in degradation modeling[6]. This can be seen in

Figure **2**

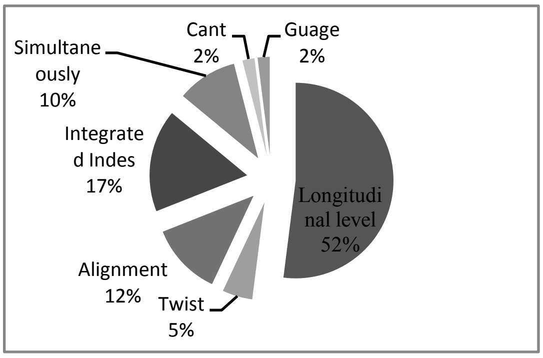

Figure 2 Distribution of applied track geometry measures [6]

3.1. LITERATURE REVIEW

Determining an indicator to represent track quality is an essential prerequisite for modeling track degradation. Indices for representing track quality condition are demonstrated in Figure 3[6].

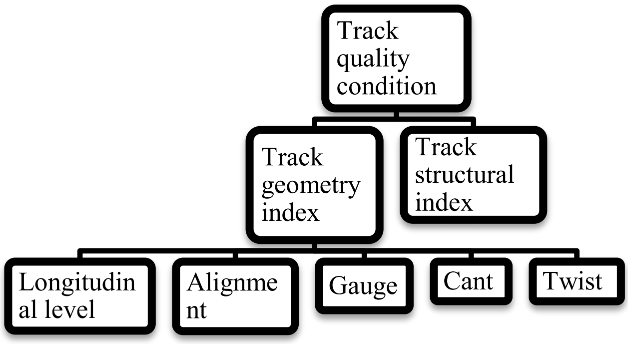

Figure 3 Track condition [6]

According to Xu [1],track condition is described by eight geometrical parameters : Gauge, Cross Level, Left/Right Surface, Left/Right Alignment, Twist, and Curvature[1].But in most cases, an artificial track quality index (TQI) has been created as a linear combination of geometry measurements to indicate track state. These have been used in a Markov model where TQI is calculated in a range of 0-100 based on unevenness, twist, alignment and gauge measurements [7]. Track Quality Index is defined as a numerical value that represents the relative condition of track surface geometries [2].American Railway Engineering and Maintenance-of-Way Association(AREMA) defined TQI as a number, derived from a formula that characterizes measured data collected from a Track Geometry Measurement Vehicle (TGMV) over a segment of track. It summarizes relatively large quantity of discrete measurements generated by a TGMV to allow characterization of an entire track segment [8].

3.2. Space curve method

On study by Sharma, track geometry data for each 30.48cm is first aggregated into 160.934m segment, and each segment is L_0 in length. TQI is then calculated for each type of track geometry measurement individually using the following formula.

$$TQI = \left(\frac{L_s}{L_o} - 1\right) \times 10^6 \qquad (1)$$

where
TQI = track quality index; Ls = traced length of space curve (m);Lo = fixed 160.934mlength of track segment

$$L_s = \sum_{i=1}^{n} \sqrt{(\Delta y_i{}^2 + \Delta x_i{}^2)} = \sum_{i=1}^{n} \sqrt{(\Delta y_i{}^2 + 0.0929)} \quad (2)$$

where
Δy_i = difference in two adjacent measurements (m.);Δx_i = sampling interval along the track (=0.3048m.);i=sequential number.

In the presence of separate track geometry data for left track and right track, as in the case of surface and cant, we always choose the measurement (error) with higher absolute value[3].
As illustrated in Figure 4, for a specified track segment length, the rougher the track surface, the longer the space curve will be when stretched into a straight line[9].

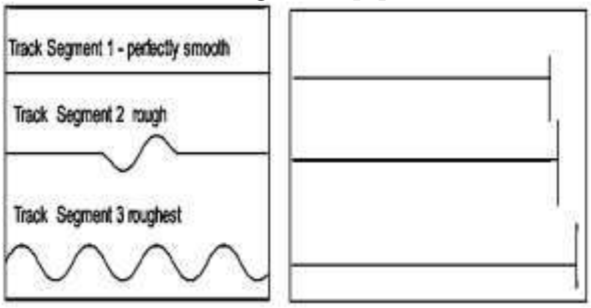

Figure 4 FRA Length-Base TQI Approach[9]

According to conclusions of this research "The TQIs developed were found to be able to quantitatively evaluate track quality and relate track quality to the Federal Track Safety Standards. These TQIs may be used to further evaluate vehicle and track interaction by incorporating vehicle characteristics. They may also be used as a tool to evaluate the effectiveness of track maintenance activities" [9].

3.3. J Synthetic Coefficient

In Europe, J synthetic coefficient is used as an indicator of track quality based on standard deviation in Polish Railways [3].Four track geometry parameters are considered in this index: vertical irregularities, horizontal irregularities, twist, and gauge [2]. The equation for calculating J synthetic coefficient is:

$$J = \frac{S_Z + S_y + S_w + 0.5 * S_e}{3.5} \quad (3)$$

where: - *Sz, Sy, Sw and Se,* are standard deviation of vertical irregularities, horizontal irregularities, twist, and gauge, respectively. Standard deviation for each measured parameter is calculated by the following equation: [2]

$$S = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i + \bar{x})^2} \quad (4)$$

Based on the above equation, *n* is identified as number of signals registered on track being analyzed, x_i represents value of geometry parameters at point *i* and $\bar{x}$is the average value of measured signals. J synthetic track quality coefficient also specifies allowable deviation of J [2]

Table 1.Allowable deviation of J coefficient based on line speed[2]

Speed [km/h]	J Coeff. [mm]	Speed [km/h]	J Coeff. [mm]
80	7.0	150	2.3
90	6.2	160	2.0
100	5.5	170	1.7
110	4.9	180	1.6
120	4.0	190	1.5
130	3.5	200	1.4
140	2.8	220*	1.1

*Calculated through extrapolation

3.4. Track Geometry Index (TGI)

Indian Railways developed a formula to represent quality of track called TGI. This model is based on standard deviation of different geometry parameters over a stretch of 200 m segment. TGI is calculated for each segment and average value of such segments in every km gives general TGI value. With respect to effect of each geometry parameter on ride quality, TGI has given different values for various geometry parameters as shown in the following formula:[2]

$$TGI = \frac{2UI + TI + GI + 6AI}{10} \tag{5}$$

where: - UI, TI, GI, and AI are index for unevenness, twist, gauge, and alignment respectively. For each measured track parameters, the index is calculated from the relation:

$$GI, TI, AI, UI = 100 \times e^{-\left(\frac{SD_{me\ s} - SD_{n}}{SD_{maint} - SD_{n}}\right)} \tag{6}$$

where:- *SDmes*is standard deviation of measured geometry parameters, *SDn*represents standard deviation prescribed for newly laid track and *SDmaint*is prescribed standard deviation for maintenance. *SDn*and *SDmaint*are given in table 2

Table 2 Standard deviation (SD) values[2]

Parameters	Chord Length	SD for newly laid track	*SDmaint*	
			Vmax ≥ 105 km/h	Vmax. < 105 km/h
Unevenness	9.60	2.50	6.2	7.2
Twist	3.60	1.75	3.8	4.2
Gauge	1.00	1.00	3.6	3.6
Alignment	7.20	1.50	3.0	3.0

Table 3 TGI Classification for maintenance [2]

No	TGI Value	Maintenance requirement
1	TGI > 80	No maintenance required
2	50 < TGI < 80	Need basic maintenance
3	36 < TGI < 50	Planned Maintenance
4	TGI < 36	Urgent Maintenance

The advantages of TGI are:

1. It gives an idea of health of continuous length rather than highlighting isolated bad locations.
2. It gives due weightage to different parameters as per their effect on the Ride Index.
3. The range over which it varies is much smaller and it does not get affected by minor changes from run to run. A variation of 10 in TGI shows a significant improvement/deterioration in the track quality [10].

3.5. Italian Railway Quality Indices

In order to calculate Rail quality indices RQI (Italian IQB), the Italian railway regulations on rail maintenance specify the following defectiveness indexes: *defectiveness index of longitudinal level*, equal to standard deviation on a 200m plane of longitudinal level; *defectiveness index of alignment*, equal to standard deviation on a 200m plane of alignment; *defectiveness index of transversal level*, equal to standard deviation on a 200m plane of transversal level; *wedging index*, equal to highest on a 200m plane, and therefore to the worst of the above-mentioned defectiveness indexes [11].

The regulations on rail maintenance survey, introduced by Italian Railway Network (*RFI, Rete FerroviariaItaliana*), impose three ***Rail Quality Levels*** which call for "full implementation of the line" and a level which requires such railway operational restrictions as slowing downs on the line and traffic blocks [11].

Table 4 Levels of Degradation for Rail quality Index RQI (Italian IQB) [11]

Degradation level	Threshold value	Required action
Optimal Level	1.2	excellent geometry conditions
Level of attention	1.8	geometry is to be monitored
Level of intervention	2.25	maintenance works is required
Level of safety	2.7	traffic slowing down or block required

3.6. Five Parameters of Defectiveness

Five parameters of defectiveness are noted as W_5, which is a quality measure of line segments developed by Polish Railways. The formula treats defectiveness of each geometry parameter as an independent event in practice [12]. Considering arrangement of parameters

$$W_5 = 1 - (1 - W_e).\left(1 - W_g\right) \times (1 - W_w).(1 - W_x).\left(1 - W_y\right) \quad (7)$$

where: - *We* – defectiveness of track gauge, *Wg*– defectiveness of cant, *Ww*– defectiveness of twist, *Wx*and *Wy*are arithmetic averages for vertical and horizontal irregularities, respectively, as determined from defectiveness of left and right rails. Coefficient of parameter defectiveness *W*in the approach is calculated using the following Eq.8 [12]

$$W = \frac{\sum_{i=1}^{n} l_i}{l} \quad (8)$$

where: -*W* has to be substituted with *We*, *Wg*, *Ww*, *Wx* and *Wy*respectively; $l_i$is a number of samples of assessment section which exceeded an allowed value of *We*, *Wg*, *Ww*, *Wx*or *Wy* respectively; l is a total number of section samples, n is a number of exceedances of allowed threshold for total measured section. Five-parameter defectiveness is calculated based on the exceedances of the maximum allowed limit values. The qualification for line maintenance which depends on defectiveness value is specified in Table 5 [12].

Table 5 Quality qualification of track lines [12]

Evaluation of line	New	Good Condition	Sufficient condition	Indicating insufficient condition
Value W_5	$W_5 < 0.1$	$W_5 < 0.2$	$W_5 < 0.6$	$W_5 > 0.6$

3.7. TQI Proposed by A. Chudzikiewicz et al

A paper by Andrzej [12]. developed a new method of determining TQI by conducting a complete dynamic analysis of railway vehicle/track system response. In this system, defect and degradation of track are estimated from vertical acceleration measured on an axle-box. Algorithm proposed in the paper specifies TQI as determined by inertial measurement. Inertial measurement is based on a simple law where double integration of acceleration indicates a position on an accelerometer. For example, a vertical position of a wheel can be computed by double integration of axle-box acceleration. The result provides longitudinal level due to a wheel being continuously in contact with a rail.TQI dependent on velocity takes form: -

$$TQI = W_{t,v}(v) = c_t.\left(\pi.\left(\frac{v}{v_e}\right)^6.\lim_{T\to+\infty}\left(\frac{1}{T}\int_0^T \dot{a}_e^2\left(\frac{v}{v_e}.t\right)dt\right)\right)^{0.15} \quad (9)$$

where: v_e-chosen reference velocity, v -current vehicle velocity, c_t-is constant value set on the basis of numerical research, t -time and a-axle box acceleration [12].

Table 6 Track quality qualification railway tracks by TQI coefficient [12]

Evaluation of line	New	Good Condition	Sufficient condition	Indicating insufficient condition
TQI Value	< 0.1	< 0.13	< 2.20	> 2.20

3.8. Australian Rail Track Corporation TQI

Australian Rail Track Corporation (ARTC) uses a 'Track quality index' (TQI) to provide an indication of track condition for specific sections of track. A TQI is derived from statistical analysis of track geometry car data for vertical alignment, horizontal alignment, twist and gauge over 100 m sections of track. Summation of four calculated indices provides a combined TQI for each 100 m section of track. Values are then averaged to give a TQI for longer sections of track or a rail corridor[13].

The intent of the TQI is not to provide a quantifiable pass/fail indication of track condition, nor is it used to identify specific track defects. TQI provides an overview of track quality and longer term trend analysis for strategic programming of track improvement works on the rail corridor. The ARTC typically reports on the percentage of track for each corridor that exceeds a TQI value of 25, considered (based on historical experience) as an optimal target maintenance level for concrete sleeper track. Specific track irregularities are identified through track inspection and track geometry car exception reports[13].

3.9. Track quality Index used in China railways

TQI is the summation of standard deviations of seven irregularities, that is vertical irregularities (left and right) alignment irregularities (left and right), gauge, cross-level irregularity, and warp, in each 200m long track section[14]

$$TQI = \sum_{i=1}^{7} \sigma_i \tag{10}$$

$$\sigma_i = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(x_{ij} - \overline{x_i}\right)^2} \quad and$$

$$\overline{x_i} = \frac{1}{n}\sum_{j=1}^{n} x_{ij} \tag{11}$$

where N (N=7) denotes irregularity number, σ_i is standard deviation of each irregularity, x_{ij} is the value of local irregularities, x_i is average value deviation, n is the number of sampling points.

Table 7 Track Quality Index Management Value [15]

Speed class	Left high low mm	Right high low mm	Left orbit mm	Right orbit mm	Gauge mm	Level mm	Triangle pit mm	TQI Value
V≤80 km/h	2.2~2.5	2.2~2.5	1.8~2.2	1.8~2.2	1.4~1.6	1.7~1.9	1.9~2.1	13~15
80km/h< V_{max}≤120km/h	1.8~2.2	1.8~2.2	1.4~1.9	1.4~1.9	1.3~1.4	1.6~1.7	1.7~1.9	11~13
120km/h< V_{max} ≤160km/h	1.5~1.8	1.5~1.8	1.1~1.4	1.1~1.4	1.1~1.3	1.3~1.6	1.4~1.7	9~11
160km/h < V_{max}	1.1~1.5	1.1~1.5	0.9~1.1	0.9~1.1	0.9~1.1	1.1~1.3	1~1.4	7~9

Note: - the reference is translated from Chinese version to English by Google translate

3.10. Track quality Number MDZ

The MDZ number comprises both horizontal and vertical deviations in track together with speed and lack of super elevation. This measurement is developed to capture changes in acceleration over a certain distance from a passenger point of view by direct mathematical analysis of real track geometry data, recorded by measuring wagon. The variation of acceleration is regarded as main criteria for comfort. Therefore, the sum of all changes in acceleration over a certain distance (charged with some corrective parameters) reflects the MDZ number for this section. This quality number reflects the riding comfort [16]. The MDZ number is defined as

$$MDZ = c \times \frac{1}{L} \times v^{0.65} \times \sum_{i=1}^{\frac{L}{\Delta x}} \sqrt{(\Delta vert.level)^2 + (\Delta horiz.level + \Delta cant)^2} \tag{12}$$

where: - Δvert. level and Δhoriz. level, is the difference in track deviation from one measurement point to the next. Here, Δ*cant* is the difference in cant level from one measurement point to the next.

3.11. Q Index

Pro rail of Netherlands converts SD index into a more universal form across different classes of tracks, as shown in (13). Q index ranges from 10 to 0. The larger the Q index, the better track quality [17].

$$N = 10 * 0.675^{\sigma_i / \sigma_{i80}} \tag{13}$$

where: - N denotes Q index for quality parameter over 200m track segment,
σ_i is standard deviation for the quality parameter, and

σ_i^{80} represents 80th percentile of standard deviations for 200m segments in maintenance section ranging from 5 to 10 km.

3.12. Canadian National Railway's TQI

Canadian National Railway Company uses 2nd order polynomial equation of standard deviation σ_i of measurement values for quality parameter over track segment to assess its partial quality, as formulated in (14). The overall quality assessment is achieved by averaging six partial quality indices for gauge, cross level, left (right) surface, and left (right) alignment[17].

$$TQI_i = 1000 - C * \sigma_i^2 \quad (14)$$

where$C$-is a constant and takes value of 700 for main line tracks

A larger track quality index implies track segment has better quality.

4. Analysis of TQI measurement methods

In this section, three methods of TQI measurements are analyzed based on real track geometry measurement data from conventional railway line. The data is taken from Track geometry measuring vehicle record of Addis Ababa Djibouti standard gauge railway line on May 25-27, 2020. The section of reading on the line is from Adama (KM 114) to Mieso (Km 329+057)

The methods analyzed are J synthetic coefficient, track geometry index (TGI), and TQI used in Chinese railway.

4.1.Study area for the case comparison

The study area used for data collection is in Ethiopia and starts from Sebeta,10Km distance from Addis Ababa passes through Debrezeyt, Mojo dry port, Addama, Metehara, Awash, Mieso, Dire Dawa and Dewale cities.

Figure 5 study area (Addis -Djibouti Railway line) source ERC website

Data collected from Addis Ababa – Djibouti railway line under operation is used for analysis. This line is about 656km in length and it is Chinese class II standard gauge railway. Track inspection vehicle checks dynamic partial unevenness (peak management) of track; involving track gauge, level, height, track-alignment, twist, vertical acceleration and horizontal acceleration.

The dynamic quality of overall unevenness (mean value management) at line section is assessed through track quality index (TQI).From these detailed data this study focuses on five of the track geometry data only 1) longitudinal profile: vertical unevenness 2) Horizontal alignment 3) Gauge 4) Cant (supper elevation) and 5) twist: the difference between supper elevation of the rail in two consecutive measurements (change in supper elevation) The track geometry measuring vehicle collects four of this basic data namely longitudinal profile, horizontal profile, Gauge, and cant others are derived from these basic data. From the whole line data used for the comparison of the selected three methods of track quality index is the section from Adama (KM 114) to Mieso(Km 329+057) which is shown by the rectangular box on figure 5. This covers about 215Km length.

RESULTS

Table 8 Comparison between Chinese TQI, J synthetic value and TGI

Mileage (KM)	TQI		J synthetic		TGI	
	Value	Exceed standard	Value	Exceed standard	Value	Exceed standard
114	15.75	More than 10%	3.884	Not Exceed	54.27	basic maintenance
114.2	16.42	More than 10%	3.966	Not Exceed	52.86	basic maintenance
248.2	11.86	Not exceeded	3.04	Not Exceed	66.9	basic maintenance
300	14.64	exceeded	3.494	Not Exceed	64.53	basic maintenance
320.4	15.48	More than 10%	3.493	Not Exceed	79.88	basic maintenance
323.2	19.88	More than 20%	4.901	Not Exceed	45.48	Planned maintenance
324	16.21	More than 10%	3.854	Not Exceed	64.81	basic maintenance
324.2	20.34	More than 20%	5.061	Not Exceed	43.74	Planned maintenance

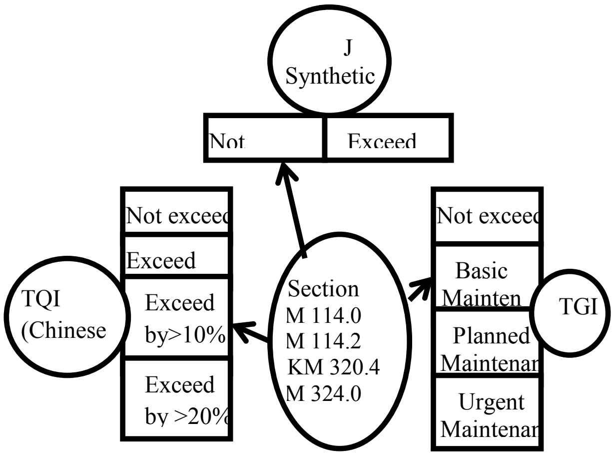

Figure 6, Comparison of TQI, TGI, and J Synthetic methods by severity level, case 1

As we can see from figure 6 in this situation the Chinese TQI measurement method seems more conservative than the other two methods this is because TGI method gives wider range for the "Basic maintenance" level of severity. J synthetic method only reflects two categories of track quality one above the threshold and the other below the threshold value which makes the categorization more difficult in understanding the progress of deterioration in several levels of quality.

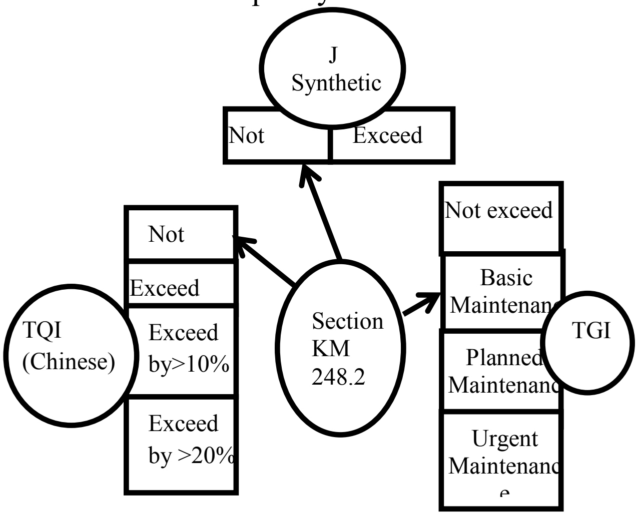

Figure 7 Comparison of Chinese TQI, TGI and J Synthetic methods case 2

On this case the reverse of case one above becomes evident. TGI categorizes this section in to more Sevier stage than any of the two methods, this happens because TGI gives more weightage to track geometry parameters which have more serious effect on ride quality and less to those having less effect on ride quality during the calculation of TGI value.

However the Chinese TQI method gives equal weight for all parameters of track geometry degradation. We can say that TGI method is safer for this case.

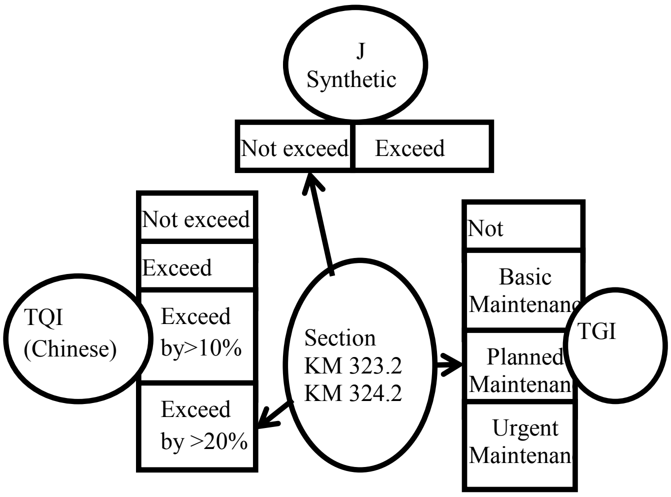

Figure 8 Comparison of TGI, Chinese TQI and J Synthetic methods case 3

In this case, similar to the case one above, TQI seems more conservative than the other two methods. This happens also because of giving the same weightage for all parameters of degradation during the calculation process of the aggregated TQI value.

DISCUSSIONS

Because the line in consideration for the case study is a conventional track and the design speed for freight is 80Km/hr. A speed of 80Km/hr value is taken for the limits of the track quality index values in three of the methods under consideration. Even if the data used for analysis is taken on 215Km length of track, only some important sections are presented on the result.

As we can see from Table 8, J synthetic coefficient method is not effective in indicating detailed values of track quality. It can only show those two levels of track quality, one exceeding threshold value and the other not exceeding, because it has only one threshold value. Because of this J synthetic method is indicating safe values for all of the seven track quality values which are above the acceptable limit in both of the other methods.

On the other hand most of the track sections considered out of the threshold value by the Chinese TQI method is also above the threshold by TGI (track geometry index) method too. Except one point at KM 248.2 at this section the Chinese TQI method shows the section is safe for operation and does not exceed the threshold value but TGI method shows that the section needs basic maintenance. This result shows that TGI is more conservative and safer to use than the two other methods of track quality index.

Regarding maintenance priority and definition of damage severity, both the TGI and Chinese TQI give different interpretations. For example if we take the section at KM 323.2 and KM 324.2 graphically represented on figure 8, the Chinese TQI method defined the damage as more serious by labeling the damage exceeded by more than 20% of the threshold level, which implies; this sections need more priority for maintenance but TGI method labels these two sections in medium level of severity, labeling them as they can be considered in planned maintenance.

These different interpretations come from the difference of calculation methods. The Chinese TQI method gives equal weights for all of the defects i.e. horizontal unevenness (right and left), Vertical unevenness (right and left), level, gauge and twist. But TGI gives different weight for those geometric defects by allocating higher weight for more serious effects on ride quality and lower weight for those having less effect on ride quality. In these regards TGI is more reliable than the Chinese TQI method.

To the contrary on the section at KM 114, KM 114.2, KM 300, KM 320.4, and KM 324 the Chinese TQI method labels the defects as medium Severity defects by indicating "*more than 10% exceeded*" from the threshold, for all sections except KM 300 which is labeled as lower level severity damage. But TGI labels the section in "*Basic maintenance*" which indicates lower level of severity. In this regard the

Chinese TQI method seems more conservative than TGI. The reason behind is again on the calculation method of the aggregated TQI in which TGI gives more reasonable weightage for track geometry parameters rather than giving same coefficient for all.

CONCLUSIONS

From the above results and discussion it can be concluded that both TGI and the Chinese TQI can give more categorization of track quality than J Synthetic method. But TGI gives a more reasonable track quality value than all of the three methods analyzed.
Ethio-Djibouti railway line uses Chinese TQI method for characterizing track geometry quality index which gives more categorization of track quality but it's advisable to include TGI method.

LIMITATIONS OF THE STUDY

This paper analyzed three methods of track quality measurement even if it discussed more than ten methods of track quality measurement this is because most of the methods reviewed need a more advanced track geometry data and the data which can't be found easily and needs a more advanced track geometry measuring vehicle or special equipment for data collection. Hence it is recommend other researchers to compare more options of track geometry measurement methods.

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