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Evaluation of the Track Geometry Quality with Standard Deviation Method and Quality Indices: Case study of Kütahya-Afyonkarahisar Railway Line

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Railway; Alignment; Longitudinal Level; Track Geometry Indices; Track Geometry Quality

Abstract

In this paper, a specific part of the railway line between Kütahya and Afyonkarahisar cities was investigated. The track geometry parameters alignment, cant, longitudinal level, track gauge and twist investigated at this track section in accordance with the related standard EN:13848-5 and evaluations conducted about the track geometry defects. A fatal train accident occurred on the Kütahya-Afyonkarahisar railway line in 2008, besides the line was completely renewed in 2013. For this reason, measurements were carried out by the help of track geometry measuring devices on the Kütahya-Afyonkarahisar railway line having the opportunity to compare the improvements at the track geometry quality, within four years period. Owing to measurements performed on the track section, improvements, degradations and degradation trends were determined using the standard deviation method mentioned in the standard EN:13848-5. In addition, the effects of the track renewal performed on the railway line discussed by the help of the Track Quality Indices (TQI), Overall Quality Indices (OQI) and Tamping Indices (TI) concepts. In light of the case study conducted at this paper, the quality of the track renewal and maintenance works performed by Turkish State Railways (TCDD) was examined.

Yol Geometrisi Kalitesinin Standart Sapma Yöntemi ve Kalite Endeksleri İle Değerlendirilmesi: Kütahya-Afyonkarahisar Hattı Örneği

Anahtar kelimeler
Demiryolu; Fleş; Nivelman; Yol Geometrisi Endeksleri; Yol Geometrisi Kalitesi

Öz

Bu çalışmada, Kütahya-Afyonkarahisar şehirleri arasındaki konvansiyonel taşımacılık yapılan demiryolu hattı üzerinde belirli bir bölüm incelenmiştir. Söz konusu yol kesiminde, yol geometrisi parametreleri olan dever, ekartman, nivelman, fleş ve burulma hataları ilgili EN:13848-5 normu çerçevesinde incelenmiş ve bu yol geometrisi kusurları ile ilgili değerlendirilmeler yapılmıştır. Kütahya-Afyonkarahisar demiryolu hattında 2008 yılında ölümlü tren kazasının meydana gelmiş olup, ayrıca bu hatta 2013 yılında ise poz çalışması yapılarak hat tamamen yenilenmiştir. Bu nedenle hattaki iyileşmelerin karşılaştırılma imkanı bulunan Kütahya-Afyonkarahisar demiryolu hattında dört yıllık zaman dilimi içerisinde yol geometrisi ölçüm aletleri ile ölçüm çalışmaları yapılmıştır. Yapılan ölçümler sayesinde yol bölümündeki iyileşmeler, bozulmalar ve bozulma eğilimleri EN:13848-5 normunda da yer alan standart sapma yöntemi kullanılarak belirlenmiştir. Ayrıca Kütahya- Afyonkarahisar demiryolu hattı üzerinde yapılan poz çalışmasının yol geometrisi kalitesine etkileri yol kalite endeksleri (QI), toplam yol kalite endeksi (OQI) ve buraj endeksi (TI) kavramları ile irdelenmiştir. Bu çalışmada yapılan örnek olay incelemesi sayesinde, TCDD tarafından yapılmış olan yol yenileme ve bakım çalışmalarının kalitesi araştırılmıştır.

1. Introduction

As in the world in transportation sector huge investments are being made in recent years, among these high-speed rail investments are the leading investments in this area. Tracks were built for high-speed rail standards with the new high budgeted investments on railways but more importantly, is to fulfil the operation, maintenance and safety conditions while maintaining the standard of track under all conditions. As carrying out the timely maintenance activities, keeping under supervision track geometry defects incessantly is the most significant factor at preserving the track quality.

These vital maintenance, repair and track renewal activities are carried out and monitored by Track Maintenance and Repair Directorates at TCDD. Monitoring and quality control of the activities are also performed by the directorates with the help of the track geometry measurement machines (mpv7, krab, roger etc.). In order to reassure the quality of the maintenance, repair and track renewal activities carried out by the directorates, an independent double check process practised by this study.

In this study, a specific part of the Kütahya-Afyonkarahisar railway line was investigated in order to determine these track geometry defects, degradations, degradation trends and the effects of the maintenance works on track quality. At the case study, 2,5 km long railway section on the Kütahya – Afyonkarahisar railway line between Alayunt Railway Station (Km 66+874) and Çöğürler Railway Station (Km 86+505) was investigated which is located at the district of Turkish State Railways (TCDD) 71. Directorate Track Maintenance and Repair.

The results of the measurements performed semiannually by TCDD with track geometry measuring vehicle "Matisa MPV-7" obtained from related Track Maintenance and Repair Office. Moreover, unplanned measurements recorded by Czech Republic product "KRAB" track geometry measuring trolley, attained from the same institution. The results of measurements provided from these two measuring instruments were combined so as to monitor the quality of the track in time before and after the track renewal.

The main reasons of the selection of this line are as follows: occurrence of a fatal train accident on 27 January 2008, complete renewal of the track on the summer of 2013, presence of the measurements recorded periodically with MPV-7 and Krab for the line. Due to derailment of Pamukkale Express travelling from İstanbul to Denizli operating on stated line, 8 passengers in addition to driver were killed and 37 others were severely injured. It was reported to be Turkey's one of the most serious accident occurring in the last two decades. (Int. Rsc. 1).

Eskişehir (Km 0+000) - Konya (Km 433+685) conventional railway line is totally 433,685 km and the project speed of the line is 120 km/h. The selected Km 67+750 – 70+000 section is located between Alayunt and Çöğürler stations at the Kütahya district. At the selected section the slopes of the line are as follows; For the increasing kilometer from 67+700 to 68+700 %3,3 upwards, from 68+700 to 69+500 %4,8 upwards, from 69+500 to 69+900 %6,0 upwards, from 69+900 to 70+240 %8,8 upwards. There are 2 railway crossings situated on Km 68+041 and Km 68+912. Moreover, a curve 962 meter radius is located between the Km 68+790 – 69+210.

Eskişehir – Afyonkarahisar conventional railway line was initally built in 1896. After that date the track had been maintained and repaired but the last known date of the complete renawal of the track was in 1989. Alayunt – Afyonkarahisar section of the line had been renewed section by section between the years of 1982-1989. Since completion of the economic life of the track section which had intensive transportation in years, complete renewal of the track had been performed at the summer of 2013. At this period, UIC 60 rail, HM type rail fastening and B70 concrete sleepers compatible with the new standards were used on the renewed track.

Krab and MPV-7 measurement results recorded on the dates 11.04.2011, 16.04.2012, 11.12.2012 and 15.04.2013 (before the track renewal performed on the summer of 2013 year) between Alayunt and Çöğürler stations located on this line are available. Besides, KRAB measurement results recorded on the line on the dates 09.01.2014, 09.02.2015 and 27.08.2015 (after the track renewal performed) are available. Similarly, MPV-7 measurement results recorded on the line by the Track Maintenance and Repair Office after the track renewal performed on the date 21.10.2014 are available. Since Krab the track geometry measuring trolley entering the TCDD inventory in 2012, no measurement could be provided before the year 2012.

A study is carried out to determine track geometry defects, degradations, degradation trends by comparing the above mentioned measurement results recorded before and after the track renewal the performed. In the light of this article, the quality of the track renewal performed by TCDD are intended to be evaluated by two different methods.

2. Material ve Method

At this paper, a track section between Km 67+750 – 70+000 is selected on the Kütahya-Afyonkarahisar railway line in order to investigate for the case study. On this selected track section variations at the track geometry quality were studied and the recorded data was evaluated by Krab8vNET software with quality indices (QI) and standard deviation (SD) as implemented at the EN:13848-5 standard. Map of the investigated route is shown at figüre 1.

Figure 1. Map of the investigated route (Int. Rsc. 2).

Quality Index (QI) formulations can be determined by the rail infrastructure managers in the world, according to the characteristics of their own railway networks. Quality index of the track is a significant indicator in terms of assessing the efficiency and deterioration rate of the track. Quality indices enable infrastructure managers to optimize work force, machine, equipment and financial resources and to plan the maintenance works to be carried out. For the alignment, cant, longitudinal level and track gauge parameters QI values can be calculated separately at the track segment selected by the railway manager. In addition to calculating QI values separately, an overall quality index (OQI) can be calculated as an indicator of the total track quality in order to monitor deteriorations and maintenance needs for the track segment.

Another criterion for determining the quality of the track geometry is standard deviation (SD) concept which is also mentioned in the EN: 13848-5 standard. As calculated for quality indices, standard deviation can be calculated for the alignment, cant, longitudinal level and track gauge parameters separately. For the alignment and longitudinal level parameters by the help of the limits defined in the EN: 13848-5 standard, deteriorations and maintenance needs for the track can be determined.

According to the EN:13848-5 standard, track quality levels are categorized to three main levels. Through these three quality levels the condition of the track can be directly identified and intervened by the railway infrastructure manager. These three quality levels are as follows:

- Immediate Action Limit (IAL): refers to the value which, if exceeded, leads to the Infrastructure Manager taking measures to reduce the risk of derailment to an acceptable level. This can be done either by closing the line, reducing speed or by correction of track geometry.
- Intervention Limit (IL): refers to the value, which, if exceeded, requires corrective maintenance in order that the immediate action limit shall not be reached before the next inspection;
- Alert Limit (AL): refers to the value which, if exceeded, requires that the track geometry condition is analyzed and considered in the regularly planned maintenance operations (CEN 2008).

By the help of the Track Quality Indices (QI), Overall Quality Indices (OQI) and Standard Deviation (SD) parameters quality level of the track geometry according to above mentioned limits can be determined and necessary precautions can be taken by railway infrastructure manager.

2.1 Standard Deviation Method According to EN 13848-5

Railway infrastructure managers used to combine all these mentioned defects (alignment, cant, longitudinal level and track gauge) into track-quality indices which would be a function of standard deviations of each defect and train permissible speed (as reported in Zhao et al. 2006 and El-Sibaie and Zhang 2004, Andrade and Teixeira 2013). Nevertheless the standard deviation for the short wavelength (3–25m) of longitudinal-levelling defects is still regarded as the main indicator for planned-maintenance decisions as it is confirmed by a recent guide on best practices for optimum track geometry durability (Andrade and Teixeira 2013).

As stated above track geometry defects obtained from the measurement results performed on a certain track section can be evaluated by using the standard deviation (SD) of the geometric variables. By the help of this statistical formulation the quality of the track section can be determined. The higher the value of standard deviation (SD) leads to the poorer the track quality; the lower values of standard deviation (SD) correspond to the opposite situation (Berawi 2013).

The standard deviation for each measured parameter is calculated using the following formula:

$$S = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(xi - \bar{x})}^{\,2} \quad (1)$$

Where;
S = Standart Deviation
x̄ = Average value of track defect (mm)
n = Number of track defects recorded at the track section studied
x_i = Value of the parameter at the point (mm)

According to EN 13848-5, standard deviation (SD)-Speed Zones tables are given below in table 1 and table 2. Evaluation of track can be performed with respect to Alert Limit (AL). Intervention Limit (IL) and Immediate Action Limit (IAL) are not determined at this approach.

Table 1 . Longitudinal level (AL) - standard deviation (SD) – speed zones table (CEN 2008)

Speed (in km/h)	Standard Deviation D1 (in mm)
V ≤ 80	2,3 to 3,0
80 < V ≤ 120	1,8 to 2,7
120 < V ≤ 160	1,4 to 2,4
160 < V ≤ 230	1,2 to 1,9
230 < V ≤ 300	1,0 to 1,5

Table 2 . Alignment (AL) - standard deviation (SD) – speed zones table (CEN 2008)

Speed (in km/h)	Standard Deviation D1 (in mm)
V ≤ 80	1,5 to 1,8
80 < V ≤ 120	1,2 to 1,5
120 < V ≤ 160	1,0 to 1,3
160 < V ≤ 230	0,8 to 1,1
230 < V ≤ 300	0,7 to 1,0

After the track renewal, the acceptable SD values would be the lowest SD values of each speed zone related. (e.g., for the aligment 80 < V ≤ 120 km/h speed zone 1,2 would be the acceptable SD value)

2.2 Quality Indices According to Krab Track Geometry Measurement System

Track Quality Index (TQI) is a numerical measure derived from the track geometry measurements to quantify the quality of the track condition. TQI has been widely used in track deterioration studies (El-Sibaie and Zhang 2004, Sharma et al. 2018) and has shown successful results. As summarized by Taciroğlu et al. (2020), Lasisi and Attoh-Okine (2019) there are some different track quality indices in the literature suggested by institutions and researchers. In this paper, the track quality index (TQI) of the Krab track geometry measurement trolley was studied. The formulations defined at Krab8vNET software were used for the evaluation of track geometry. These formulations are given below in formulas 2 and 3.

QI formulation determined on the basis of logarithmic transformation between standard deviation and QI, guarantees 80 percent of the QI values to be lower than 4 and having a mean of 3 (KZV 2002). The coefficients b' and m at the formulation are geometric variables related to standard deviation statistical values according to KZV (2002).

QI can be calculated with the following Eq. (2):

$$QI = \frac{ln\left(\frac{STD}{b'}\right)}{m} \quad (2)\ (KZV\ 2002)$$

The results of quality section evaluation of track according to quality indices are indicative (Izvolta and Smalo 2015). Measures, which are set for individual intervals of quality indices, are recommendatory tabulated at table 3.

Table 3 . The scale of the quality indices (QI) (Izvolta and Smalo 2015)

Interval of QI	Verbal assessment section a according to QI	Color of the QI in output
0 < QI ≤ 2	The state of the track geometry is satisfactory	No color marking
2 < QI ≤ 3	Recommended to plan the repair of the track geometry at the maintenance work plan	Green color
3 < QI < 4	Recommended to perform the repair of the track geometry at the nearest control	Violet color
4 ≤ QI ≤ 6	Recommended to perform immediate measures to ensure the safety of operation	Red color

Futhermore, Overall Quality Index (OQI) and Tamping Index (TI) are expressed as the sum of the geometrical variables; alignment, cant, longitudinal level and track gauge and they are used for the overall evaluation of the track quality (KZV 2002). OQI and TI summarizing the four basic geometric variables are expressed by the following Eq. (3):

$$OQI, TI = k\, max\,\{(W_{Al}\ SD_{Al} + W_{Ga}\, SD_{Ga}), (W_{Ct}\, SD_{Ct} + W_{Tp}\, SD_{Tp})\} + q \qquad (3)\ \text{(KZV 2002)}$$

Where;
SDAl-WAl Standard deviation and weight of alignment parameter
SDGa-WGa Standard deviation and weight of track gauge parameter
SDCt-WCt Standard deviation and weight of cant parameter
SDTp-WTp Standard deviation and weight of longitudinal level parameter
k multiplier factor
q cumulative constant

3. Results

The collected track geometry data were evaluated by the standard deviation method and quality indices mentioned at the material and method section.

3.1. Evaluation of the Track Geometry Quality with Standard Deviation Method

As stated before, a complete track renewal was performed in 2013 summer on the Kütahya - Afyonkarahisar Railway Line. Measurements recorded on the dates 11.12.2012 (Krab), 11.04.2011 (MPV-7), 16.04.2012 (MPV-7) and 15.04.2013 (MPV-7) (before the track renewal performed) are available. Moreover, after the track renewal performed, measurements recorded by the Krab on the dates 09.01.2014, 09.02.2015 and 27.08.2015 are present. Having the opportunity to combine and analyze the data recorded by track geometry measuring devices before and after the track renewal, a track segment between Km 67+750 – 70+000 near Alayunt Railway Station selected as case study of this paper.

At this part of the study standard deviation of alignment parameter recorded at all measurements performed by both Krab and MPV-7 was calculated in order to create a graph to visualize the deterioration trend. Standard deviation of alignment defects in 3-25 m. (D1) wavelength are presented in figure 2.

Evaluating the measurement results obtained from MPV-7 and Krab, according to figure 1 it can be seen that as an indicator of the deterioration of track, SD value increases gradually in time. The SD values of alignment parameter before the track renewal are quite over the limits given in table 2.

As seen on the figure 2, the first three measurement results are well above the limits defined as 1.2 – 1.5 mm at the 80 km/h < V ≤ 120 km/h speed zone. For this reason, the trains were operated with the speed restrictions at very low speeds on this track segment.

Due to speed restrictions applied on the track, an unplanned maintenance was performed after the inspection carried out on 11.12.2012. Following this unplanned maintenance activity a notable improvement on the track was detected according to the measurement results recorded by MPV-7 on 15.04.2013. After the track renewal performed on the summer of 2013, the increase in track quality can be observed clearly by the help of the SD value which is quite under the limits according to the measurement results recorded on 09.01.2014 by Krab.

After this period, SD value of track increased at the two inspections carried out until 09.02.2015. Due to initial settlements at the newly constructed track, quality of track deteriorated as expected within the two years after the track renewal.

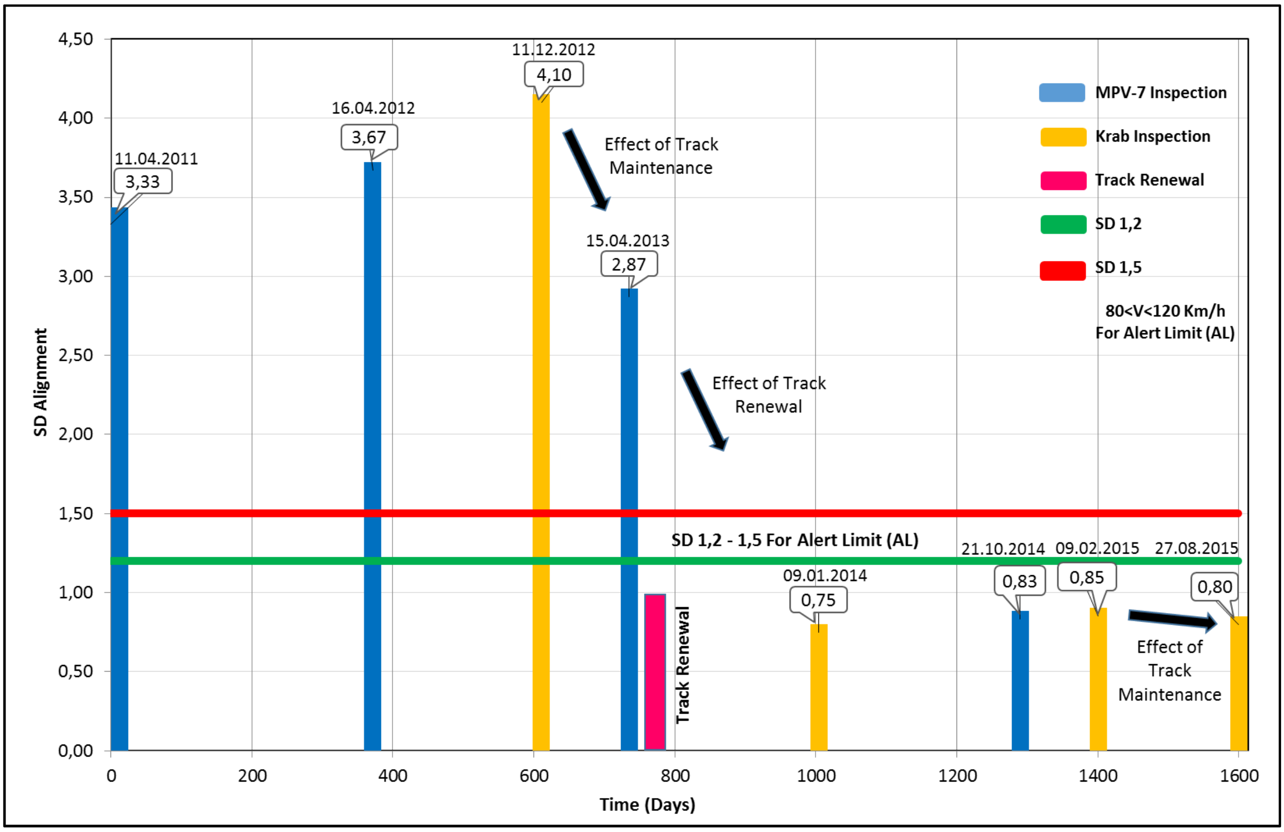

Figure 2. Standard deviation of alignment parameter vs time graph (İça 2015)

According to the figure 2 it can be inferred that, SD of the alignment parameter is an important indicator for the overall quality of the track. The standard deviation of horizontal-alignment defects (filtered in the wavelength range 3–25 m – SD-HA) showed to be a statistically significant predictor for all maximum permissible speed groups and for the three quality levels (AL – alert limit, IL – intervention limit and IAL – immediate action limit) (Andrade and Teixeira 2013).

The three inspections having low initial track quality and the other three inspections having high initial track quality are compared and evaluated, in order to determine the effects of the initial track quality to the track deterioration. During this study, inspections carried out on the dates of 15.04.2013 and 27.08.2015 after the unplanned maintenance activities, were not taken into consideration for the evaluation of the results so as to eliminate the initial effects of track renewal and track maintenance.

Graphs of the standard deviation of alignment parameter obtained from the measurements carried out before the track renewal are given in figure 3 and 4. Standard deviation of the alignment parameter before the track renewal was studied by linear and exponential approaches.

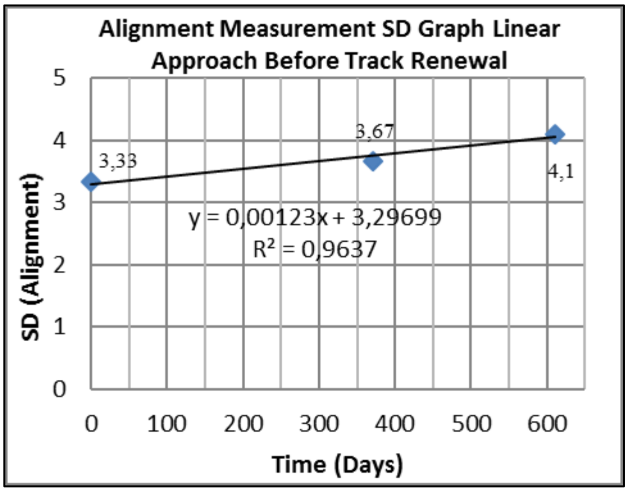

Figure 3. Alignment measurement-SD graph linear approach before track renewal

In the light of the present study, approximation models related to the deterioration of the track were developed with both linear and exponential approaches. Among these approximation models, exponential approach can be considered more appropriate for the real track condition since having closer R2 value to 1. As a result of this it can be concluded that the track deterioration model has an exponential trend before the track renewal which had a low initial track quality.

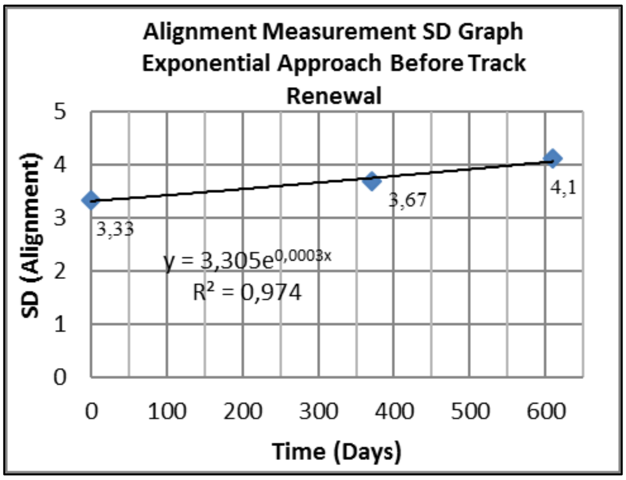

Figure 4. Alignment measurement-SD graph exponential approach before track renewal

In the same way, alignment parameter obtained from the measurements carried out after the track renewal was studied in order to develop an approximation model to monitor the rate of the track deterioration after the track renewal performed. As stated above, approximation models related to the deterioration of the track were developed with both linear and exponential approaches. Obtained graphs are presented in figure 5 and 6. Unlike the first case, since having closer R2 value to 1, this time linear approach can be considered more appropriate for the real track condition after the track renewal. Contrary to the previous situation it can be concluded that the track deterioration model has a linear trend after the track renewal, which had a high initial track quality.

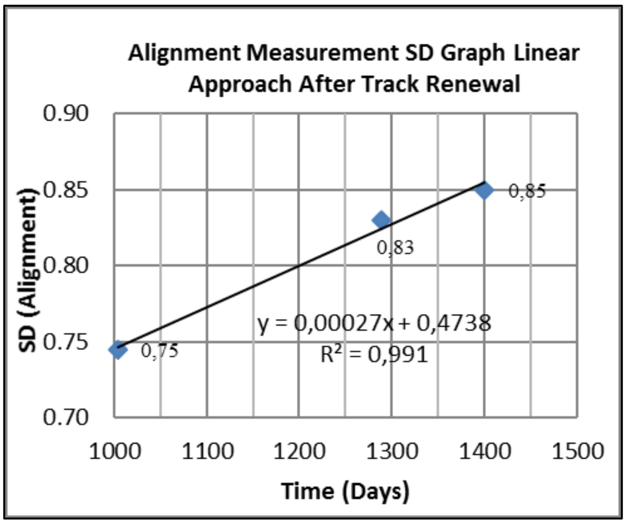

Figure 5. Alignment measurement-SD graph linear approach after track renewal

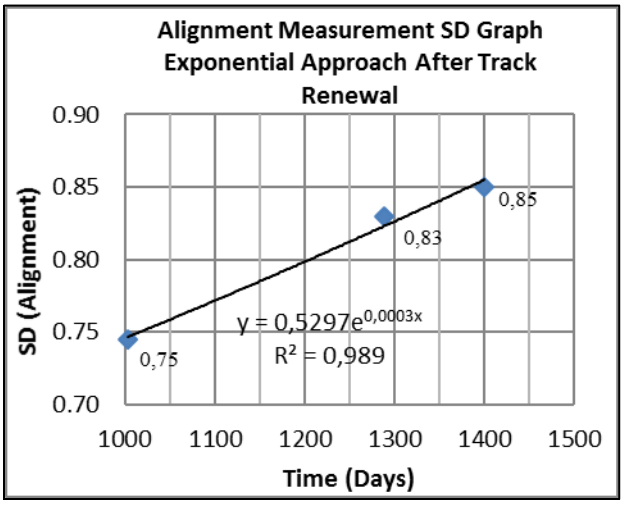

Figure 6. Alignment measurement-SD graph exponential approach after track renewal

As a result of the above conclusions;

- Average deterioration rates on the track having a low initial track quality before the track renewal were determined within the stated period (610 days) by the help of exponential approaches.
- Average deterioration rates on the track having a high initial track quality after the track renewal were determined within the stated period (396 days) by the help of linear approaches.
- In order to eliminate the initial effects of unplanned track maintenances performed, the duration between those period were not taken into consideration.

As summarized by Sasidharan et al. (2020), exponential (Quiroga and Schnieder 2011) and linear (Soleimanmeigouni, Ahmadi and Kumar 2018) are the two of the track deterioration models used in the literature. Using the mentioned models and according to the results obtained deterioration rates of the track before and after the renewal can be summarized at table 4.

Table 4. Deterioration rates of the track before and after renewal

Deterioration Rate Before Renewal		**Deterioration Rate After Renewal**	
(0 – 610 Days)		**(1004 – 1400 Days)**	
Exponential ($y = \alpha . e^{\beta x}$)		**Linear** ($y = \alpha + \beta x$)	
α	β	α	β
3,33	0,0003	0,468	0,00028
3,09	0,0005	0,598	0,00018
3,33	0,0003	0,496	0,00025
Avg. β = 0,000367		Avg. β = 0,000237	

As can be seen above on the table, before the renewal (within 610 days from the first measurement date) average track deterioration rate (β) was computed 0.000367 mm / 100 day. On the other hand, after the renewal (within 400 days from the first measurement date) average track deterioration rate (β) was computed 0.000237 mm / 100 day.

3.2 Evaluation of the Track Geometry Quality with Quality Indices

In this paper, apart from the evaluating the track quality with the standard deviation at the previous section, the track quality also investigated with the track quality indices concepts according to Krab software. The measurements recorded on the dates 11.12.2012 and 09.01.2014 between Alayunt-Çöğürler railway stations (Km 67+700 – 70+000) evaluated. The quality indices obtained from the software given in figure 7. and 8. Before the track renewal performed as it can be seen in figure 7. alignment, cant, longitudinal level and track gauge parameters were in Immediate Action Limit (IAL) (in red colour) and Intervention Limit (IL) (in violet colour) according to color scale given at the table 3.

80<V<120 Km/h	Horizontal				Vertical				Overall Quality Index (OQI)	Tamping Index (TI)
	Alignment		Gauge		Cant		Longitudinal Level			
Km	SD	QI	SD	QI	SD	QI	SD	QI		
67+750 - 67+800	2,16	4,43	1,27	2,83	1,02	2,27	3,08	3,82	3,59	4,32
67+800 - 68+000	1,82	3,90	1,55	3,49	1,35	2,97	1,47	2,07	3,53	3,71
68+000 - 68+200	0,91	1,97	1,12	2,43	1,24	2,74	1,68	2,35	2,23	2,25
68+200 - 68+400	1,36	3,01	1,09	2,35	1,03	2,30	0,84	1,18	2,46	2,74
68+400 - 68+600	1,14	2,51	1,19	2,60	1,18	2,63	0,89	1,25	2,25	2,21
68+600 - 68+800	1,08	2,38	1,42	3,19	0,75	1,62	0,91	1,28	2,41	2,07
68+800 - 69+000	1,26	2,79	1,48	3,34	2,08	4,21	2,00	2,74	3,24	3,24
69+000 - 69+200	3,87	5,72	1,38	3,08	1,99	4,09	1,27	1,79	4,59	5,83
69+200 - 69+400	7,05	6,00	1,08	2,32	1,52	3,31	1,51	2,13	4,42	6,00
69+400 - 69+600	8,28	6,00	1,30	2,89	1,87	3,90	1,47	2,07	4,69	6,00
69+600 - 69+800	6,80	5,99	1,13	2,46	1,57	3,40	1,30	1,84	4,49	6,00
69+800 - 70+000	13,48	6,00	1,97	4,35	1,64	3,53	1,91	2,63	5,37	6,00

Figure 7. Standard deviation (STD) and quality indices (QI, OQI) values before the track renewal on the date 11.12.2012 (İça 2015).

Overall Quality Index (OQI), being the sum of these four track geometry parameters, was in Immediate Action Limit (IAL) and Intervention Limit (IL) in certain track sections. According to the Overall Quality Index (OQI) track segment needed an immediate maintenance action between Km 69+000 and 70+000 indicated in red color. As stated at the standard deviation method at previous section, Overall Quality Index (OQI) by itself can indicate the real condition of the track, likewise standard deviation of horizontal-alignment defects. By the help of the OQI, the quality and the condition of the track can be determined directly.

As can be seen in figure 7, since the track renewal performed in 1989 until the measurement date (11/12/2012), longitudinal level parameter had less degradation when compared to other parameters. Accordingly, it may be inferred that the degradation rates of the track geometry parameters over time appears to be different for all parameters. For instance, while degradation is rapid at cant and alignment parameters, longitudinal level parameter is having a slow degradation according to the measurements.

80<V<120 Km/h	Horizontal				Vertical				Overall Quality Index (OQI)	Tamping Index (TI)
	Alignment		Gauge		Cant		Longitudinal Level			
Km	SD	QI	SD	QI	SD	QI	SD	QI		
67+750 - 67+800	0,69	1,40	0,52	0,83	1,04	2,30	0,90	1,27	1,48	1,48
67+800 - 68+000	1,04	2,26	1,22	2,70	0,95	2,09	1,25	1,78	2,13	1,96
68+000 - 68+200	1,48	3,26	0,55	0,91	0,81	1,77	1,74	2,42	2,01	3,00
68+200 - 68+400	0,61	1,21	0,49	0,78	0,93	2,06	1,42	2,00	1,72	1,72
68+400 - 68+600	1,30	2,89	0,63	1,11	1,14	2,53	1,22	1,72	1,87	2,60
68+600 - 68+800	0,39	0,67	0,53	0,86	0,89	1,97	1,49	2,09	1,72	1,72
68+800 - 69+000	0,59	1,15	0,60	1,04	1,31	2,89	1,99	2,73	2,52	2,52
69+000 - 69+200	0,77	1,62	0,67	1,23	0,88	1,93	1,45	2,05	1,68	1,68
69+200 - 69+400	0,58	1,13	0,55	0,91	0,94	2,08	1,51	2,12	1,79	1,79
69+400 - 69+600	0,43	0,77	0,46	0,69	0,91	2,00	1,92	2,64	2,01	2,01
69+600 - 69+800	0,58	1,13	0,49	0,78	1,02	2,26	1,79	2,49	2,07	2,07
69+800 - 70+000	0,51	0,97	0,52	0,84	0,52	1,08	1,32	1,88	1,18	1,18

Figure 8. Standard deviation (STD) and quality indices (QI, OQI) values after the track renewal on the date 09.01.2014 (İça 2015).

Analysis obtained from the inspections performed on the track has the similar results with the studies carried by Khouy *et al.* (2012) on the Swedish heavy haul railroad. According to the analysis performed by Khouy *et al*. (2012), the longitudinal level failure rate has a clear linear trend over time while the rates of failures for other parameters (cant, alignment and twist) increases over time, possibly indicating an aging effect.

The positive effects of the track renewal performed can be directly seen when the measurements recorded after the renewal on the same track segment examined. After the renewal, IAL and IL alerts at this part of the track have turned into AL with the green color. As can be seen in figure 8, there is only alignment defect between Km 68+000 – 68+200 with intervention limit and tamping index (TI) alert is available at the same section in order to repair the indicated alignment defect.

Two years later after the track renewal, a new measurement is performed on 09.02.2015 at the same track section. Evaluation of the measurement recorded is given in figure 9. When compared the two evaluations given in figure 7. and 8., it can be reached that deteriorations on the track remained minimum between Km. 67+700 – 70+000. As can be seen in figure 9., alignment defect at Km 68+000 – 68+200 still exists and cant parameter has IL alert level between Km. 68+200 - 68+600 in this two years period. When compared the two evaluations given in figure 7. and 8., it can be reached that deteriorations on the track remained minimum between Km. 67+700 – 70+000. Since having high initial track quality, track geometry parameters have not been affected notably except these two defects.

80<V<120 Km/h	Horizontal				Vertical				Overall Quality Index (OQI)	Tamping Index (TI)
	Alignment		Gauge		Cant		Longitudinal Level			
Km	SD	QI	SD	QI	SD	QI	SD	QI		
67+750 - 67+800	1,32	2,92	0,59	1,01	1,28	2,84	2,17	2,93	2,60	2,64
67+800 - 68+000	0,68	1,37	0,60	1,05	0,74	1,59	1,33	1,88	1,43	1,43
68+000 - 68+200	1,60	3,50	0,67	1,22	1,07	2,38	1,94	2,67	2,29	3,27
68+200 - 68+400	0,61	1,20	0,60	1,03	1,76	3,74	1,66	2,32	2,75	2,75
68+400 - 68+600	0,95	2,04	0,60	1,03	1,75	3,71	1,56	2,19	2,67	2,67
68+600 - 68+800	0,72	1,49	0,57	0,97	0,72	1,56	1,35	1,91	1,43	1,43
68+800 - 69+000	0,98	2,13	0,53	0,88	1,05	2,32	0,89	1,25	1,48	1,82
69+000 - 69+200	1,26	2,78	0,49	0,78	0,93	2,07	1,62	2,27	1,86	2,49
69+200 - 69+400	0,43	0,77	0,47	0,73	0,72	1,55	1,47	2,08	1,51	1,51
69+400 - 69+600	0,52	0,98	0,50	0,80	0,91	2,00	2,11	2,86	2,13	2,13
69+600 - 69+800	0,64	1,29	0,52	0,85	0,68	1,44	1,68	2,35	1,59	1,59
69+800 - 70+000	0,54	1,03	0,56	0,93	0,68	1,46	1,28	1,81	1,34	1,34

Figure 9. Standard deviation (STD) and quality indices (QI, OQI) values after the track renewal on the date 09.02.2015 (İça 2015).

As it is understood, having high initial track quality preserves the quality of the track much longer and takes more time to reach the limits for deteriorations (Sato 1997). The initial track quality has increased significantly with the high quality materials, track maintenance equipment and machines used at the track renewal. It can be referred that high initial quality of track enabled it to keep the standards of track under 9 million tonnes of freight carried in about two years' time.

4. Discussion and Conclusion

The importance of repair, maintenance and optimization concepts has grown in recent years with the rapidly developing high-speed rail network in the world. The first priority of the maintenance and repair concept is to keep the quality of track geometry quality within the existing standards. Therefore, in this paper the five geometric variables (alignment, cant, longitudinal level, track gauge and twist) effecting the track geometry quality discussed in accordance with the standard EN:13848-5 used by TCDD. Track geometry defects, improvements, degradations, degradation trends and overall quality of the track investigated through the measurements at the Kütahya-Afyonkarahisar railway line by the help of track geometry measuring devices using the standard deviation and quality indices approaches.

According to the measurements performed on the track, as mentioned at the study of Andrade and Teixeira (2013), the standard deviation of horizontal-alignment defects is showed to be a statistically significant predictor for all maximum permissible speed groups and for the three quality levels (AL – alert limit, IL – intervention limit and IAL – immediate action limit). Therefore, degradation trends on the track were determined using the approximation models by the help of standard deviation of horizontal-alignment defects.

The average degradation rate of track within the 610 days from the first measurement date is computed (β) 0.000367 mm/100 days. On the other hand, the average degradation rate of track within the 396 days from the date of first measurement after the track renewal is calculated 0.000237 mm/100 days. Accordingly, the rate of deterioration of the track before the track renewal having low initial track quality can be evaluated as exponential, whereas the rate of deterioration of the track after the track renewal having high initial track quality can be defined as linear.

Moreover, track geometry parameters and overall track quality index (OQI) were determined using the software of the krab track geometry measuring trolley. The positive effects of the track renewal performed were directly presented by the improved quality of the track and quality index values measured. After the track renewal performed, significant improvements determined in overall quality of the track and in all track geometry parameters respectively. Track geometry parameters being at the Immediate Action Limit (IAL) level before track renewal, were observed to be even below the Alert Limit (AL) after the track renewal performed. Track geometry parameters in deterioration trends determined after track renewal in two years period. In this two years period approximately 4.5 million tons/year freight is carried on the line and according to the measurements performed, freight carried leaded to further deterioration especially on the horizontal-alignment and cant parameters.

In the light of this study it can be reached that initial track quality is a significant factor for determining the quality of the track as both at the quality index method and at the standard deviation method. Moreover, it can be concluded that track deterioration rate may develop linear or exponential depending on the initial track quality.

In this study it can be seen that generally track deterioration rate grows linearly and deformations remain at a certain level since having low operating speeds on Kütahya - Afyonkarahisar conventional line. Limits of the standard are tolerable for the track geometry defects at low operating speeds. Therefore, regular inspection of the track is crucial for the quality, safety and efficiency of the line at high-speed railway lines. Considering the deterioration of the track to progress exponentially at high operating speeds, even the minor track geometry defects on the alert limit should be carefully examined. Under available budget constraints the optimum maintenance policy should be pursued in order to provide high levels of quality, safety, comfort and efficiency.

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