Progress in Engineering Application and Technology Vol. 4 No. 2 (2023) 1215-1223
© Universiti Tun Hussein Onn Malaysia Publisher's Office

PEAT

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/peat
e-ISSN : 2773-5303

Study of Track Quality Index (TQI) by using EM140 and KRAB 10 for Electrified Double Track Project (EDTP) Gemas to Johor Bahru

Nurul Hafizah Yussob[1], **Muhamad Faiz Abd Latif**[1]*, **Siti Zarini Mohamed Jizi**[1]

[1]Department of Transportation Engineering Technology, Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia, 84600 Panchor, Johor, MALAYSIA.

*Corresponding Author Designation

DOI: https://doi.org/10.30880/peat.2023.04.02.124
Received 02 July 2023; Accepted 13 July 2023; Available online 13 July 2023

Abstract: Track geometry, which includes parameters like alignment, rail surface, twist, cant, and gauge, is important in determining track quality and safety particularly for high-speed trains. The traditional approach of track maintenance, on the other hand, frequently depends on manual or static inspections, which can lead to potential inaccuracies, restricted coverage, and costly corrective actions. This study aims to address these challenges by developing and validating a track quality index (TQI) that incorporates both static and dynamic measurement techniques especially EM140 track recording car as a model in the Electrified Double Track Project (EDTP) Gemas to Johor Bahru. The TQI will enable a data-driven approach to track maintenance, facilitating proactive interventions, optimizing resources, and ensuring the long-term sustainability and safety of railway track. Through a comprehensive understanding of the TQI concept and its practical applications in this research, advanced measurement technology like the EM140 track recording car enables timely detection of any deviations or defects.

Keywords: EDTP, Track Quality Index, Track Geometry, EM140, KRAB 10

1. Introduction

The Electrified Double Track Project Gemas-Johor Bahru (GJBEDTP) is a project to construct a double-track electrified rail line connecting Gemas in the Negeri Sembilan state to Johor Bahru in the Johor state in the southern tip of Malaysia. Track geometry measurement is the process of measuring various geometric parameters of railway tracks. The geometric parameters include track gauge, cross level, alignment, curvature or twist and rail profile. There are various methods of track geometry measurement, including static measurement using hand-held tools and dynamic measurement using specialized equipment like track recording car.

**Corresponding author: mfaiz@organization.edu.co*

Static measurement method typically requires personnel to manually position the measurement equipment at predetermined locations and record the measurements. Dynamic measurement uses advanced technology and data processing algorithms to provide real-time data analysis and generate track quality index. These measurement systems offer the potential to revolutionize track maintenance practices by enabling more accurate assessments, early detection of defects, and predictive maintenance strategies.

The data obtained is only used to a limited level for analysis to identify fundamental causes of track deterioration and to analyse track behaviour over time. So, the problem is it lacks comprehensive assessment for the static measurement method. Measuring the track geometry quality plays an important role in rail administrations to safe operation and track maintenance [1].

The objectives for this paper are:

i. To identify the track geometry parameters involved related to track quality when inspection.
ii. To analyse the mechanism found in EM140 track recording car with static measurements KRAB trolley.
iii. To compare the data from EM140 and static method with the effective track quality number for determining the track quality standard.

This paper covers the measurement of track parameters in addition to detecting defects for track maintenance work that has been set after the construction has been carried out. This research is focused on analysing the ability of KRAB trolley and EM140 which allows easy and precise locating of defects in the field for maintenance plan and a better track quality index. This research is necessary because it is one of the other ways to help engineers in track geometry measurement system to avoid inaccuracy in assessing track quality index when inspection.

Among these methods, track recording car facilitates inspection work in addition to being able to identify defects on the rail more accurate than trolley-based method. This research also show that track recording car can give early signs to perform maintenance and further actions based on the Track Quality Index (TQI) generated in the on-board system of EM140.

1.1 Track Quality Index (TQI)

Track Quality Index (TQI) is typically a numerical value that represents the overall track condition, calculated based on various track geometry parameters and measurements [2]. The TQI of specific track geometry parameters is used to produce an overall track quality index (TQI-O), which provides an assessment of the overall track condition. The track quality level for railway track is categorized for the Class 1 as shown in the Table 1.

Table 1: Track quality standard for class 1 line track

TQI - O	Track Quality
< 24	Very Good
25 – 35	Good
36 – 50	Fair
51 – 65	Poor
≥ 66	Very Poor

The formulas below shows on how to get the overall TQI value:

$$\text{Track Quality Index, TQI} = \sum_{i=1}^{7} \sigma_i \qquad \textit{Eq. 1}$$

$$\text{Standard Deviation, } \sigma_i = \sigma_{Gauge} + \sigma_{L.SFCr} + \sigma_{R.SFCr} + \sigma_{ALL} + \sigma_{ALR} + \sigma_{SUP} + \sigma_{TWS} \qquad \textit{Eq. 2}$$

$$\text{Standard Deviation Index, } \sigma_i = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}} \qquad \textit{Eq. 3}$$

where: σ_i is the standard deviation of a single geometrical parameter (Gauge, left rail surface, right rail surface, left alignment, right alignment, superelevation/ cant and twist) and i represents the number of geometrical parameter.

1.2 Standard Deviation Index (SDI)

The standard deviation is used to show the dispersion of track geometry measurement data. A low standard deviation indicates that the track geometry measurements are close to the mean and a high standard deviation indicates that the track geometry measurements have a high dispersion around the mean value. The SD index is made up of seven standard deviations, each of which is related with a track quality metric and is derived based on measurement results for the parameter across a track segment, as defined in formula below.

$$\text{Standard Deviation Index, SDI } \sigma_i = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i^2 - \bar{x}_i^2)} \qquad \textit{Eq. 4}$$

$$\text{Mean, } \bar{x} = \sum_{i=1}^{n}\frac{x_i}{n} \qquad \textit{Eq. 5}$$

Where σ_i is the standard deviation of a quality parameter in mm, x_i is the parameter measurement value in mm at the i_{th} sampling point in the track segment, and n is the number of sampling points in the track segment. $\sum$ represents the summation symbol which mean sum over all data on track geometry parameters.

2. Research Methodology

In actual use, the track geometry car, track geometry trolley, and a few more manual instruments are used to assess track irregularities. The other two types of equipment evaluate the quality of the track without wheel loading, whereas the track geometry car measures the condition of the track under wheel loading conditions.

2.1 Design Parameters

The gauge, cross level, left and right surface (also known as longitudinal level in European nations), left and right alignment, and twist of rail locations in a three-dimensional space differ from their intended positions [3]. Track irregularities can have a significant impact on the safety, reliability, and efficiency of railway operations.

Advanced measurement technologies, such as track recording cars, can also be used to identify track irregularities, and help railway operators to develop targeted maintenance and repair strategies. The following Table 2 summarizes the EM140 Track Recording Car method of measurement of track geometry parameters and the abbreviation used.

Table 2: Method of measurement of track geometry

Parameter	Description	Measurement Base	Method of Measurement
L.SFCr	Profile Left Rail, Vertical Surfacing	10 m	Contact-transducer
R.SFCr	Profile Right Rail, Vertical Surfacing	10 m	Contact-transducer
TWS	Twist	1.75 m	Contact-transducer and Inclinometer
GAUGE	Track Gauge	Continuous	Contactless-Laser
SUP	Superelevation/ Cross Level/ Cant	Continuous	Contact-transducer and Inclinometer
ALL	Alignment Left Rail, Lateral Alignment	10 m	Contactless-Laser
ALR	Alignment Right Rail, Lateral Alignment	10 m	Contactless-Laser

2.2 Methods

Inspection by foot, trolley, locomotives, and rear vehicles enable Permanent Way Inspector (PWI) to carry out assessment of the quality of the track. These inspections, though important are qualitative and enable assessment based on the individual experience. That is how the data can be gained by inspection.

2.2.1 Static data collection

Manual or static track geometry measurement typically involves a process of physically measuring the key parameters of railway tracks using specialized tools and equipment [4]. The measurements taken at each location must be recorded in a consistent and organized manner using paper forms or electronic data entry to document the measurements. The data collected by the KRAB trolley is typically less comprehensive than the data collected by the EM140 track recording car, but it can still provide valuable information for railway managers and the project team. The Figure 1 below shows the flowchart on data collection by KRAB 10.

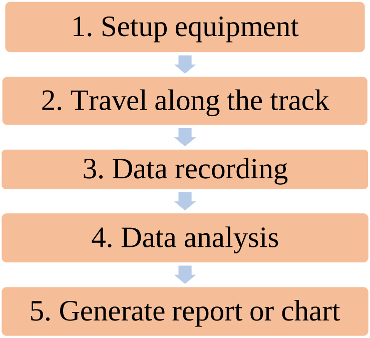

Figure 1: Flowchart for KRAB 10 operation

2.2.2 Dynamic data collection

The EM140 collects data using a variety sensors and instruments that are mounted on the vehicle. These sensors and instruments are designed to measure various parameters related to the condition of the railway track. Overall, the operation of the EM140 involves a combination of advanced technology and specialized software, which together provide valuable insights into the condition of the railway track. Figure 2 shows the flowchart on how the EM140 collects data.

Figure 2: Flowchart for EM140 operation

3. Results and Discussion

Heavy train loads and high speeds that are regularly paired eventually lead to a degradation of the track geometry [5]. Variations in the track geometry quality were investigated on this particular track section, and the software used to analyse the collected data applied quality indices (QI) and standard deviation (SD) that were in line with the EN:13848-5 standard. By examining the results obtained from both static and dynamic measurements, a more comprehensive understanding of the track's condition and performance can be achieved.

3.1 Results

The systems do not directly display the actual numerical values of track geometry parameters. Instead, it provides indices or indicators that represent the relative condition or deviation of the track geometry parameters from reference values or standards. Table 3 and 4 show the typical readings generated by KRAB 10 trolley-based measurement and EM140 track recording car from KM 572.500 to KM 578.000 for 4.5 km length of track.

Table 3: Readings generated by KRAB 10 trolley-based measurement

From	To	Gauge	L.SFCr	R.SFCr	ALL	ALR	SUP	TWS 1.75m
572,500	573,000	1.44	3.81	3.77	1.97	2.76	1.23	1.26
573,000	574,000	1.39	3.74	3.51	3.27	3.62	1.66	1.55
574,000	575,000	1.42	3.47	2.67	2.22	2.67	1.87	1.69
575,000	576,000	1.35	2.32	2.31	7.41	8.16	1.43	1.29
576,000	577,000	1.33	5.33	4.61	3.00	2.99	2.45	2.05
577,000	578,000	1.39	5.92	3.69	2.93	3.04	2.48	2.05

Table 4: Readings generated by EM140 track recording car

From	To	Gauge	L.SFCr	R.SFCr	ALLr	ALRr	SUPr	TWS 1.75m
572,500	573,000	2.52	4.66	4.20	2.08	2.39	2.32	1.55
573,000	574,000	2.08	5.07	4.27	3.19	3.45	3.12	2.28
574,000	575,000	2.01	5.23	3.82	2.41	2.62	3.10	2.30
575,000	576,000	1.95	3.28	2.60	2.41	2.16	2.88	2.53
576,000	577,000	2.68	7.99	6.14	3.86	3.65	4.72	2.58
577,000	578,000	2.38	9.84	5.51	5.39	5.38	6.84	3.26

By comparing table 3 and table 4, EM140 track recording car recorded the most accurate reading of track condition as it can detect more defects on the same area rather than using KRAB 10.

TQI is determined for each section, and the average of such sections in each kilometre produces the overall TQI value. The TQI, which is used to assess the overall quality of track irregularity of the unit, is the sum of the standard deviations. Table 5 shows the Overall Track Quality Index (TQI-O) from KRAB 10 while table 6 shows the Overall Track Quality Index (TQI-O) from EM140.

Table 5: Overall Track Quality Index (TQI-O) from KRAB 10 trolley

KM From	KM To	GAUGE	TWST 1.75m	ALL	ALR	SUP	L.SFCr	R.SFCr	Total TQI
572,500	573,000	1.44	1.26	1.97	2.76	1.23	3.81	3.77	16.24
573,000	574,000	1.39	1.55	3.27	3.62	1.66	3.74	3.51	18.74
574,000	575,000	1.42	1.69	2.22	2.67	1.87	3.47	2.67	16.01
575,000	576,000	1.35	1.29	7.41	8.16	1.43	2.32	2.31	24.28
576,000	577,000	1.33	2.05	3.00	2.99	2.45	5.33	4.61	21.76
577,000	578,000	1.39	2.05	2.93	3.04	2.48	5.92	3.69	21.51

Based on the data in the table, readings from KRAB 10 shows that the track is in very good condition where it records readings below threshold 24 except for one location that is slightly more than thresholds 24 which is at KM 575,000 to KM 576,000. High deviations from the desired alignment can cause rough rides for passengers and increase wear and tear on train equipment.

Table 6: Overall Track Quality Index (TQI-O) from EM140

KM From	KM To	GAUGE	TWST 1.75m	ALLr	ALRr	SUPr	L.SFCr	R.SFCr	Total TQI
572,500	573,000	2.52	1.55	2.08	2.39	2.32	4.66	4.20	19.69
573,000	574,000	2.08	2.28	3.19	3.45	3.12	5.07	4.27	23.43
574,000	575,000	2.01	2.30	2.41	2.62	3.10	5.23	3.82	21.44
575,000	576,000	1.95	2.53	2.41	2.16	2.88	3.28	2.60	17.77
576,000	577,000	2.68	2.58	3.86	3.65	4.72	7.99	6.14	31.59
577,000	578,000	2.38	3.26	5.39	5.38	6.84	9.84	5.51	38.57

From KM 577.000 to KM 578.000, the TQI-O shows the condition of track is in fair condition between 36 to 50 of range. The readings indicate potential defects as it can be poor condition of track if does not take any action. From the deviation of each track parameter, the parameter alignment, superelevation, and rail surface show higher index which exceeding those thresholds.

Figure 3 shows the bar chart on TQI-O calculated from KRAB 10 and EM140.

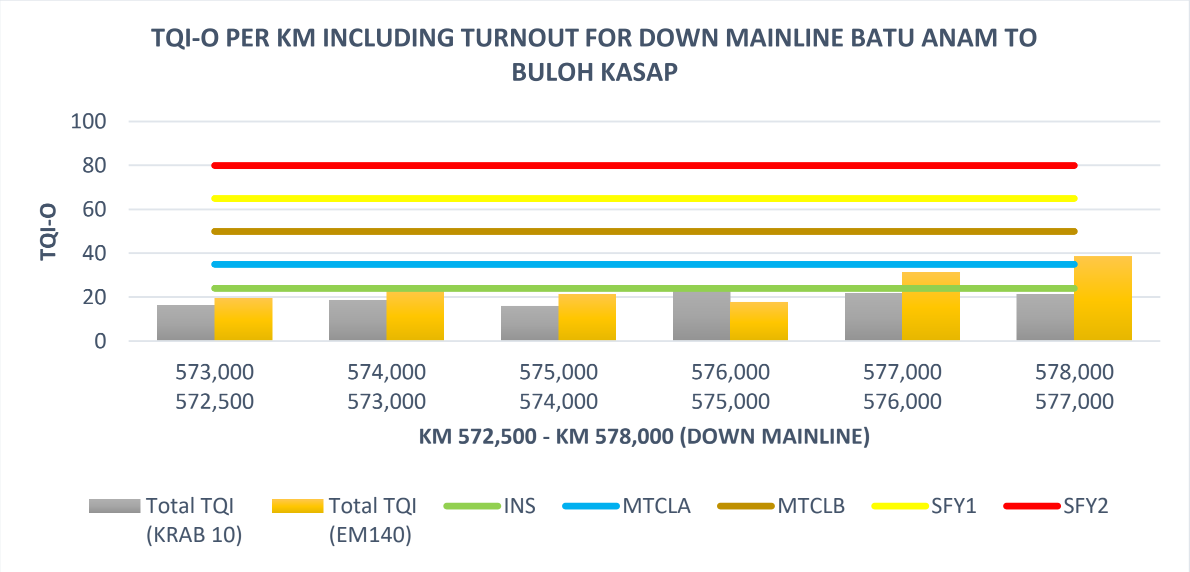

Figure 3: TQI-O per KM including turnout for down mainline Batu Anam to Buloh Kasap

From the above figure, INS stands for Installation/ Construction Stage which means the track is in very good condition and does not need maintenance. The thresholds value is less than 24. MTCLA is Maintenance Level 1 which means the track is in good condition, but inspection and monitoring is required to identify any area that required basic maintenance.

The thresholds value is between 25 and 35. MTCLB is Maintenance Level 2, which means the track is in fair condition and required to do maintenance. The thresholds value is between 36 to 50. For poor track condition, it can be categorized to SFY1 which means Safety Level 1 which needs to do planned maintenance like tamping. Lastly, SFY2 stands for Safety Level 2, which means the track is in very poor condition and required maintenance as soon as possible since it enters the Intervention Limit.

From the current data of deviation and TQI, the defect’s location can be identified from exception report for EM140 and local defects report for KRAB. Table 7 and 8 show some of the defect’s location detected by the KRAB 10 and EM140.

Table 7: Local defect location from KRAB 10

Item	Defects Location	Length (m)	Parameter	Maximum Value	Category
1	572.696	2	Gauge	-2	Installation
2	573.167	0	Left Rail Surface	-5	Maintenance
3	573.854	3	Alignment Right	5	Maintenance
4	574.937	2	Cant	-3	Maintenance
5	575.627	2	Alignment Right	-12	Intervention
6	576.082	3	Right Rail Surface	-8	Maintenance
7	576.491	0	Twist	4	Installation
8	577.411	5	Cant	-7	Maintenance
9	577.418	3	Alignment Left	-7	Maintenance
10	577.729	3	Left Rail Surface	6	Maintenance

Table 8: Defect location from exception report of EM140

Item	Defects Location	Length (m)	Parameter	Maximum Value	Severity	Category
1	572.691	2	Gauge	-2	4	Installation
2	573.163	2	Left Rail Surface	-5	2	Maintenance
3	573.507	11	Cant	-5	4	Maintenance
4	573.874	4	Alignment Right	6	3	Maintenance
5	574.515	3	Twist	-4	4	Intervention
6	574.965	4	Right Rail Surface	-5	2	Maintenance
7	576.082	5	Left Rail Surface	11	4	Intervention
8	577.406	15	Cant	10	4	Intervention
9	577.424	6	Alignment Left	14	4	Intervention
10	577.896	4	Right Rail Surface	-8	4	Maintenance

From table 7 and 8, most of the defect located is for parameter rail surface, cant and alignment. However, the data given by EM140 is more detailed since it provides more locations that have potential defects categorized in maintenance and intervention stage. The data also consist with the severity of defect so the team can prioritize which area that need immediate maintenance based on the severity.

When the measured TQI value exceeds the specified limit, it indicates that the track condition requires attention and intervention. These limits may be defined as a maximum allowable TQI value or as specific thresholds for individual track parameters. Regular monitoring of the track condition using methods such as track geometry measurement systems like the EM140 track recording car can help identify when the TQI values exceed the intervention limits. In summary, if the readings indicate potential defects such as excessive gauge widening or alignment issues, immediate maintenance actions may be necessary.

3.2 Discussion

By accurately measuring parameters such as alignment, gauge, cant, cross-level, and vertical profile, potential hazards and deviations from desired track conditions can be identified. This enables timely interventions to address issues such as misalignments, irregularities, or wear that could compromise track stability and increase the risk of derailments or accidents.

KRAB 10 involves collecting track geometry data when the track is not under train load. It provides a snapshot of the track's condition at a given moment, allowing for detailed analysis and assessment of individual track geometry parameters. While EM140 captures track geometry data while the track is under train load and in motion. It provides real-time measurements that consider the dynamic forces and interactions between the train and the track. Table 9 shows the summary of comparison between KRAB 10 and EM140.

Table 9: Summary of comparison between KRAB 10 and EM140

Aspect	KRAB 10	EM140
Coverage	Conducted at specific points of track	Cover entire length of track which train travel.
Time taken	Time-consuming	Less time taken
Speed	Can operate at very low speed up to 15 km/h	Can operate at normal operating speeds up to 140 km/h
Data collection	Collects measurements at discrete location of track	Collects data in real-time providing continuous measurements
Data Generation	Generate TQI-O report, graph and local defects report	General TQI-O report, graph, exception report, data report and summary
Data Integration	Requires additional steps for data processing and analysis	Provides advanced software and algorithms for analysis
Cost	Low	High
Maintenance	Low maintenance cost	High maintenance cost

Combining both sets of results allows for a more holistic assessment of the track's condition, considering both static and dynamic aspects. The combined analysis of static and dynamic measurement results helps prioritize maintenance interventions. Static measurements identify localized defects or deviations, while dynamic measurements highlight areas of dynamic response or where forces and wear may be more pronounced.

4. Conclusion

The results obtained from static and dynamic measurements of track geometry provide complementary insights into the condition, behavior, and maintenance needs of the railway track. Static measurements offer detailed analysis and identification of localized defects, while dynamic measurements capture real-time responses and transient anomalies. By identifying and addressing issues early on, such as track misalignments or excessive wear, maintenance activities can be scheduled strategically to minimize downtime, reduce the risk of major failures, and optimize maintenance costs. By combining the results from both approaches, railway operators can gain a comprehensive understanding of track performance, prioritize maintenance interventions, and ensure the safe and reliable operation of their rail networks. In summary, track maintenance plays a vital role in ensuring safety, reliability, asset longevity, cost efficiency, passenger comfort, and regulatory compliance in railway systems.

Acknowledgement

This research was made possible by the cooperation given by SIPP-YTL team and grant provided by the Ministry of Higher Education, Malaysia. The authors would also like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for its support.

References

[1] Peng, L., Zheng, S., Li, P., Wang, Y., & Zhong, Q. (2020). A comprehensive detection system for track geometry using fused vision and inertia. *IEEE Transactions on Instrumentation and Measurement*, *70*, 1–15. https://doi.org/10.1109/tim.2020.3039301

[2] El-Sibaie, M. & Zhang, Y. (2004). Objective Track Quality Indices. Proceedings of 83rd TRB Annual Meeting, Washington, D.C.

[3] Liu, R.-K., Xu, P., Sun, Z.-Z., Zou, C., & Sun, Q.-X. (2015). Establishment of Track Quality Index Standard Recommendations for Beijing Metro. *Discrete Dynamics in Nature and Society*, *2015*, 1–9. https://doi.org/10.1155/2015/473830

[4] Madejski, J. (2014). Track Geometry Measurement as Preventive Maintenance Data Source. *CETRA 2014 - 3rd International Conference on Road and Rail Infrastructure*. https://doi.org/10.13140/2.1.3549.5047

[5] Offenbacher, S., Neuhold, J., Veit, P., & Landgraf, M. (2020). Analyzing major track quality indices and introducing a universally applicable TQI. *Applied Sciences*, *10*(23), 8490. https://doi.org/10.3390/app10238490

[6] Camacho, D., Le, T. H., Rapp, S., & Martin, U. (2016). Light rail ballasted track geometry quality evaluation using Track Recording Car Data. *WIT Transactions on The Built Environment*. https://doi.org/10.2495/cr160281

[7] Constantin. (2016, December 8). *Evaluation of the track quality*. A railway track blog. https://pwayblog.com/2016/09/11/evaluation-of-track-quality/

[8] Florian Auer, D.-I. D. techn. (2013). *Multi-function Track Recording cars*. Multi-function track recorder cars - Plasser India. Retrieved from https://www.plasserindia.com/fileadmin/user_upload/Mediathek/Publikationen/32_36_Auer.pdf

[9] Hutchinson, F. E., & Zhang, K. (2020). The Gemas-Johor Bahru Railway Electrified Double-Tracking Project: Steady Progress towards Completion. *RESEARCHERS AT ISEAS – YUSOF ISHAK INSTITUTE ANALYSE CURRENT EVENTS*, (2020), 1–9.