

Evaluation of Railway Infrastructure on Track Quality Index (TQI) Based Track Quality (Cross of Mandai-Garongkong) 2024

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ABSTRACT

Infrastructure quality greatly affects the speed, comfort, and safety of train travel. High speed can cause damage to the railroad track which can cause a decrease in the TQI value and increase the risk of train accidents. This study aims to analyze the factors influencing train speed, analyze the speed of railway facilities on track quality based on Track Quality Index, and analyze optimization strategies to keep the Track Quality Index (TQI) within the operating speed threshold in 2024. The method used in this research is mix method. The results showed that the factors affecting train speed across Mandai-Garongkong are the condition of the rail line and Track Quality Index (TQI), track geometry and rail infrastructure, characteristics of rolling stock, external environment, and operational management and speed regulation, so that the optimization strategy needed to enable optimal operational speed is the implementation of preventive and corrective maintenance strategies, real-time TQI monitoring with observation technology, and operational management based on observation results. Based on the calculation of the Track Quality Index (TQI) value on each track plot, it is found that the average TQI value is above 10, while the average operational speed is above 30 km/h, although the average TQI value is above 10, the operational speed can still be maintained above 30 km/h. It is recommended to immediately bring in facilities with speeds capable of maximizing the existing TQI value on the South Sulawesi crossing.

Keywords: railway infrastructure, train speed, track quality index.

INTRODUCTION

The progress of railway development in Sulawesi can be said to be developing slowly, the Directorate General of Railways has made plans to prepare the railway system and network between Makassar - Pare-pare. The problem that occurs on the Makassar - Pare-pare railway line is a decrease in train speed due to train travel so that efforts are needed to maintain the quality of the line. The performance of the railroad is directly proportional to the safety and smoothness of train travel [3]. Railway quality can be measured using the track quality index (TQI) [15]. TQI is an indicator that shows the condition and quality of the railroad track to assess the level of deviation of railroad geometry from the specified standards [7].

Track deterioration can have a direct impact on the speed, stability and safety of rail operations. This becomes more significant on new lines such as the Mandai - Garongkong Line which is part of the strategic network in the South Sulawesi region. The line is characterized by a mix of straight and curved rails and crosses regions with topographical variations and extreme weather, significantly affecting TQI values [6].

High TQI values indicate degraded track quality and have the potential to cause travel disruptions, both in terms of safety and reduced operating speeds [1], [6]. Therefore, a thorough evaluation of the factors that influence TQI values including geometric conditions, drainage systems, ballast, and rail joints is crucial [3].

The TQI value at several points on the Rancaekek - Haurpugur line exceeded the recommended threshold, in analyzing the quality of the railway track on the Cirebon-Cikampek line using the Track Quality Index (TQI) showed that 61.8% of the analyzed segments fell into the "Excellent" category with an average TQI value of 20.60, which allows for operational speeds between 100-120 km/hour. This second study emphasizes the importance of regular monitoring and assessment of track quality to ensure optimal operational standards.

The Ministry of Transportation in PM No. 60/2012 has set a tolerance limit for rail geometric deviations that can be used as a reference in measuring track quality. Several previous studies have suggested that extreme weather, traffic intensity, and wear of rail components are the main causes of track quality degradation, especially on tracks with sharp bends and medium speeds [6], [9].

The speed of the rolling stock is one of the factors that can affect the quality of the railroad. High speeds can cause damage to the railroad, such as warped rails, cracked rail pads, and loose rail joints. This damage can lead to a decrease in TQI values and increase the risk of railroad accidents [8], [14]. Therefore, it is necessary to evaluate the speed of railroad facilities against the quality of the railroad. This evaluation can help in determining the optimal train operating speed to maintain the quality of the railroad and improve the safety of train travel. So this research aims to analyze the factors influencing the speed of trains across Mandai - Garongkong, analyze the speed of railway facilities on Track Quality Index-based track quality, and analyze optimization strategies to keep the Track Quality Index (TQI) within the operating speed threshold.

RESEARCH METHODS

Location and Research Design

The research location was carried out on the Mandai-Garongkong railway line in South Sulawesi Province, which includes Mandai-Maros Station (KM. 13+900-KM. 18+300), Maros-Rammang-Rammang Station (KM. 18+300-KM. 30+742), Rammang-Rammang-Pangkajene Station (KM. 30+742-KM. 37+248), Pangkajene-Labakkang Station (KM. 37 + 248-KM. 49+100), Labakkang-Mangilu Station (KM. 00+556-KM. 09+800), Mangilu-Ma'rang Station (KM. 49+100-KM. 60+700), Ma'rang-Mandalle Station (KM. 60+700-KM. 67+900), Mandalle-Tannete Rilau Station (KM. 67+900-KM. 81+996), Tannete Rilau-Barru Station (KM. 81+996-KM. 89+267), and Barru-Garongkong Station (KM. 89+267-KM. 05+250). This research started from July 2024 to September 2024. The research design used in this research is mix method.

Data Analysis

The quality of the railroad track can be seen in the Track Quality Index (TQI). This TQI measurement is carried out using the TGT (Track Geometry Trolley) measuring train. This measuring train has several sensors that function to check elevation, force, electricity, and track width. This reading method starts from recording data from sensors on the measuring train with the output in the form of sensor reading lines. Then the lines are converted into exception report data in the form of numbers. From this exception report data, the track quality index value is then obtained.

The data used in this study are measurements in 2023 obtained from the Directorate General of Railways. In general, the TQI value is calculated based on the average deviation of various rail geometry parameters against a predetermined standard value [12]. Track Quality Index (TQI) can be calculated using Standard Deviation. Parameter measurement data is taken every 0.25 m and processed in the amount of 800 data with the Standard Deviation formula:

$$SD = \sqrt{\frac{\sum xi^2 - \frac{(\sum xi)^2}{n}}{n - 1}}$$

The TQI value is the sum value of SD_{gauge} + SD_{alignment} + SD_{toprail} + SD_{cant} + SD_{twist}. In general, in calculating the TQI value, SD_{twist} is not included in the summation. The output of TGT is processed in a spreadsheet with the Standard Deviation formula, which will produce the TQI value within 200 m of spoor length. As for the TQI value for use in the Key Performance

Index (KPI), the value in the evaluation range (segment) is the average of TQI data per 200 m in the segment in question. Furthermore, it will be evaluated based on infrastructure against train speed to assess whether the quality of the track is in an optimum state according to train operational planning so as to produce safety and comfort in railroad services.

RESULT AND DISCUSSION

Factors Affecting Train Speed

Based on the observational method conducted in this study, the factors affecting train speed in the Mandai - Garongkong Crossing can be grouped into several main points:

1. Rail condition and track quality index (TQI)

Qualitative Research: A Guide to Design and Implementation states that in observation-based qualitative research, rail conditions and track quality index/physical infrastructure should be the main focus as they directly affect the system under study. Observations show that the main factors that increase TQI values are rail wear, bearing deformation, and ballast instability due to poor drainage [11].

Findings from interviews with line maintenance technicians:

"We found that at some points with less dense ballast, the TQI values tended to increase more quickly, especially after the rainy season. Therefore, ballast compaction and bearing adjustment became a major focus in maintenance." (MN)

Rail track condition refers to the physical and structural state of the railroad track, which includes track geometry, rail material quality, bearing stability, and ballast feasibility in supporting railroad travel operations safely and efficiently. The condition of the rail line greatly affects operational speed, travel safety, as well as the cost of maintaining railroad infrastructure.

Measurements using TGT showed that TQI values on some track segments exceeded the recommended threshold for maximum speed. Observations also show that the main factors that increase TQI values are rail wear, bearing deformation, and ballast instability due to poor drainage, not only that at some points with less dense ballast so that TQI values tend to increase faster especially during the rainy season.

It can be argued that the impact of rail track condition on train speed is when good quality track (low TQI) allows for high speeds and a more stable journey; high rail wear (high TQI) requires a reduction in speed to maintain safety; and poor ballast conditions increase the risk of rail performance, which can lead to speed slowdowns and increased maintenance requirements.

2. Track geometry and rail infrastructure

Direct observation on the track:

"We found that on some of the sharp curves there were signs of higher rail wear on the outside due to increased centrifugal force, so the speed had to be adjusted to avoid the risk of further wear." (CA)

Track geometry refers to the physical characteristics of railroad tracks that affect travel comfort and safety. In line with research conducted [16] that track geometry (rail straightness, elevation, bend radius) greatly affects train speed, this study found that tracks with high Track Quality Index (TQI) values have lower speed limits due to increased vibration and instability during travel.

3. Characteristics of rolling stock

Interview with train operator:

"When passing through sections with deformed tracks, we often feel stronger vibrations in the cabin, so we need to reduce speed for the comfort and safety of passengers." (MI)

From the analysis of the Logride data obtained from the expert who rode the train above the cabin following the train journey, it was found that the vibration frequency increased in the segments with high TQI, resulting in instability at high speeds (vibration/wobble). Based on the interview results, segments with deformed track often have stronger vibrations in the cabin so the speed needs to be reduced for passenger comfort and safety. Train type, small locomotives or KRDs tend to tolerate higher values of TQI due to their lighter weight with

less traction. From the acceleration load analysis, it was found that heavily loaded trains experience a more significant speed reduction on high elevation tracks.

4. External environment (weather and environmental factors)
 In transportation research based on observational methods, the external environment is often a variable that influences operational speed [2].
 Technical observation in the field:
 "After heavy rain, we often find certain areas experiencing ballast movement, so drainage inspections and maintenance are a priority to keep the track stable." (DW)
 Analysis of historical rail operational data shows that operating speeds are often reduced during rain or after periods of high rainfall. Monitoring results using observations at points that are prone to landslides and flooding contribute to increased TQI. [1] in their research also explained that extreme temperatures cause rail expansion, which can increase TQI values and limit operating speeds. Heavy rain can disrupt ballast stability and accelerate track degradation, thus affecting operational speed.

5. Operational management and speed regulation
 Analysis of recorded operational data and signaling systems shows that train operating speeds are heavily influenced by traffic management factors and safety regulations.
 Interview with operational supervisor:
 "At some points with high traffic, we have to adjust the speed so as not to interfere with other train schedules, especially near the station area.." (MY)
 Speed limit rules based on track conditions in the data show that operating speeds are often adjusted according to track geometry conditions identified in routine inspections. In terms of traffic frequency, the denser the timetable, the more frequent the speed reductions to manage the spacing between trains, especially at junction areas or near stations. Some segments of the Mandai-Garongkong section still use mechanical signaling systems, which limits the flexibility of operational speeds compared to digital communication-based signaling systems. At some points with high traffic, speeds will be adjusted so as not to interfere with other trains' schedules, especially near station areas.

Track Quality on the Speed of Railway Facilities Based on Track Quality Index Value

The Track Quality Index calculation can be obtained from the summation of the four parameters obtained from the output data of the measuring train or Track Geometry Trolley. The four parameters that affect the TQI value are Force, electricity, elevation and track width. Track Quality Index (TQI) can be calculated using Standard Deviation.

Average TQI Score

Table 1. Average TQI Score

Track Quality Index (TQI)			
Station	July	August	September
Mandai – Maros	15,97	12,44	13,78
Maros – Rammang Rammang	12,28	12,67	13,16
Rammang Rammang – Pangkajene	13,99	13,25	14,62
Pangkajene – Labakkang	11,71	11,59	11,52
Labakkang – Ma’rang	8,51	7,63	8,88
Ma’rang – Mandalle	9,49	10,29	11,09
Mandalle – Tanete Rilau	10,34	11,36	11,56
Tanete Rilau – Barru	11,53	11,85	12,17
Barru – Garongkong	10,11	8,77	13,71

(Source: Primary Data, 2024)

Table 1. shows that in July the average value of TQI at the mandai-maros station was 15.97; in August 12.44; and in September 13.78. For the maros-rammang rammang station the average TQI value in July was 12.28; in August 12.67; and in September 13.16. For the rammang rammang - pangkajene station the average TQI value in July was 13.99; in August 13.25; and in September 14.62. For the pangkajene - labakkang station the average TQI value in July was 11.71; in August 11.59; and in September 11.52. For the labakkang - ma'rang station the average TQI value in July was 8.51; in August 7.63; and in September 8.88. For ma'rang - mandalle station the average value of TQI in July 9.49; in August 10.29; and in September 11.09. For mandalle - tanete rilau station the average value of TQI in July 10.34; in August 11.36; and in September 11.56. For the tanete rilau - barru station the average TQI value in July was 11.53; in August 11.85; and in September 12.17. For the barru - garongkong station the average value of TQI in July 10.11; in August 8.77; and in September 13.71.

Average Speed Score

To calculate speed data in the context of railways, it is obtained using the following formula:

$$v = \frac{s}{t}$$

Table 2. Average Velocity Values for July 2024

July 2024				
Station	Distance	Time (minutes)	Time (hour)	Speed
Mandai – Maros	3,796	7	0,117	32,54
Maros – Rammang Rammang	11,786	14	0,233	50,51
Rammang Rammang - Pangkajene	6,592	9	0,150	43,95
Pangkajene – Labakkang	12,185	13	0,217	56,24
Labakkang – Ma’rang	9,787	12	0,200	48,94
Ma’rang – Mandalle	6,991	8	0,133	52,43
Mandalle – Tanete Rilau	12,184	14	0,233	52,22
Tanete Rilau – Barru	6,591	11	0,183	35,95
Barru – Garongkong	0,799	9	0,150	5,33

(Source: Primary Data, 2024)

Travel time is obtained from Gapeka Realization data, Table 2. shows that in July the speed value for mandai-maros station is 32.54 km/h; maros station - rammang rammang 50.51 km/h; rammang rammang station - pangkajene 43.95 km/h; pangkajene station - labakkang 56.24 km/h; labakkang - ma'rang station 48.94 km/h; ma'rang - mandalle station 52.43 km/h; mandalle - tanete rilau station 52.22 km/h; tanete rilau - barru station 35.95 km/h; and barru - garongkong station 5.33 km/h.

Table 3. Average Velocity Values for August 2024

August 2024				
Station	Distance	Time (minutes)	Time (hour)	Speed
Mandai – Maros	3,796	7	0,117	32,54
Maros – Rammang Rammang	11,786	14	0,233	50,51
Rammang Rammang - Pangkajene	6,592	9	0,150	43,95
Pangkajene – Labakkang	12,185	13	0,217	56,24
Labakkang – Ma’rang	9,787	12	0,200	48,94

Ma'rang – Mandalle	6,991	8	0,133	52,43
Mandalle – Tanete Rilau	12,184	14	0,233	52,22
Tanete Rilau – Barru	6,591	11	0,183	35,95
Barru – Garongkong	0,799	9	0,150	5,33

(Source: Primary Data, 2024)

Table 3, shows that in August the speed value for the mandai-maros station is 32.54 km/h; maros station - rammang rammang 50.51 km/h; rammang rammang station - pangkajene 43.95 km/h; pangkajene station - labakkang 56.24 km/h; labakkang - ma'rang station 48.94 km/h; ma'rang - mandalle station 52.43 km/h; mandalle - tanete rilau station 52.22 km/h; tanete rilau - barru station 35.95 km/h; and barru - garongkong station 5.33 km/h.

Table 4. Average Velocity Values for September 2024

September 2024				
Station	Distance	Time (minutes)	Time (hour)	Speed
Mandai – Maros	3,9	7	0,117	33,43
Maros – Rammang Rammang	11,96	14	0,233	51,26
Rammang Rammang – Pangkajene	6,749	9	0,150	44,99
Pangkajene – Labakkang	10,4	13	0,217	48,00
Labakkang – Ma'rang	11,35	12	0,200	56,75
Ma'rang – Mandalle	7,05	8	0,133	52,88
Mandalle – Tanete Rilau	13,6	14	0,233	58,29
Tanete Rilau – Barru	8,15	11	0,183	44,45
Barru – Garongkong	6,419	9	0,150	42,79

(Source: Primary Data, 2024)

Table 4. shows that in September the speed value for the mandai-maros station is 33.43 km/h; maros station - rammang rammang 51.26 km/h; rammang rammang station - pangkajene 44.99 km/h; pangkajene station - labakkang 48.00 km/h; labakkang - ma'rang station 56.75 km/h; ma'rang - mandalle station 52.88 km/h; mandalle - tanete rilau station 58.29 km/h; tanete rilau - barru station 44.45 km/h; and barru - garongkong station 42.79 km/h.

Table 5. Average TQI & Speed Score Per 3 Months

Average Value Per - 3 Monthly		
Station	TQI	Speed
Mandai – Maros	14,1	32,8
Maros – Rammang Rammang	12,7	50,8
Rammang Rammang – Pangkajene	14,0	44,3
Pangkajene – Labakkang	11,6	53,5
Labakkang – Ma'rang	8,3	51,5
Ma'rang – Mandalle	10,3	52,6
Mandalle – Tanete Rilau	11,1	54,2
Tanete Rilau – Barru	11,9	38,8
Barru – Garongkong	10,9	17,8

(Source: Primary Data, 2024)

Table 5. Shows the results of the average calculation of the TQI value and speed per 3 months where it is found that the TQI value for the Mandai-Maros station is 14.1 and the speed value is 32.8 km/h; Maros Station – Rammang Rammang TQI 12.7 and the speed is 50.8 km / h; Rammang Rammang Station - Pangkajene TQI 14.0 and the speed is 44.3 km/h; Pangkajene Station - Labakkang TQI 11.6 and the speed is 53.5 km / h. Labakkang Station - Ma'rang TQI value 8.3 and speed 51.5 km / h; Ma'rang Station - Mandalle TQI value 10.3 and speed 52.5 km / h; Labakkang - Ma'rang Station TQI 8.3 and speed 51.5 km/h; Ma'rang - Mandalle Station TQI value 10.3 and speed 52.6 km/h; Mandalle - Tanete Rilau station TQI 11.1 and speed 54.2 km/h; Tanete Rilau - Barru Station TQI 11.9 and speed 38.8 km/h; and Barru - Garongkong station TQI 10.9 and speed 17.8 km/h.

Based on the results of the calculation of the Track Quality Index (TQI) value on each track plot, it is found that the average TQI value is above 10, stating that the track condition is in very good condition, while the average operational speed is above 30 km/hour. From the results of the study, although the average value of TQI > 10, capable of being passed at a speed of 120 km / h but at this time the operation is still at 30 km / h due to the availability of facilities that are currently operating only capable of maximum speed at 80 km / h, also indicates that the condition of the track is not in the optimal category but still allows operations at certain speeds, although there are indications of the need for periodic maintenance, also because the distance between the plots is too short and the ability of the facilities to reach top speed in a certain distance is not capable.

The results show that higher TQI values (above 10-12) cause a decrease in train stability due to increased vibration and dynamic forces between wheels and rails. At TQI values > 15, speed limitation becomes a necessity as the risk of wheel wear and potential derailment increases. The results of the study on the Mandai-Garongkong crossing show a similar pattern, where TQI values above 10 still allow speeds above 30 km/hours, but with the risk of increased track instability, concluding that without maintenance measures, tracks with high TQI will degrade faster [17].

On the Mandai-Garongkong crossing, maintenance strategies such as Rail Grinding and Continuous Welded Rail (CWR) can be applied as recommended [16] study to control TQI improvement. By regularly monitoring TQI, operational speed planning can be more adaptive to track conditions.

Optimization Strategy to Keep Track Quality Index (TQI) Within the Operating Speed Threshold

Observation of Pathway Physical Condition and TQI Value

In the initial stage of the research, direct measurements of track geometry parameters were made using a TGT (Track Geometry Trolley) equipped with accelerometer and laser sensors to detect rail irregularities. The observation results showed that high TQI was found on segments with ballast conditions that began to degrade, especially at points with poor drainage, rail wear was faster on tracks with geometric rates that had more vertical alignments and horizontal alignments (bends/inclines), and rail pads at several points experienced a decrease in carrying capacity due to changes in road/tire structural conditions due to weather and unstable levels of centering or subsidence. Based on the results of this observation, the strategies that can be carried out are:

1. Implementation of preventive and corrective maintenance strategies

Based on the field findings, several maintenance strategies were identified and implemented to maintain the quality of the pathway, namely:

- a. Scheduled ballast tamping, Observations show that segments with less dense ballast experience higher TQI values. Therefore, periodic ballast tamping is required to maintain the density and carrying capacity of the track against the dynamic loads of trains.
- b. Replacement of rails and sleepers in segments with high TQI, Visual inspections and rail thickness measurements showed that segments with rail wear above standard limits experienced a significant increase in TQI. As an optimization measure, selective replacement of rails and sleepers was carried out to restore track stability.
- c. Improvement of the drainage system, it was observed that standing water at some points of the track accelerated ballast degradation. Therefore, drainage cleaning and

improvement are carried out to ensure that the track remains dry and stable. Based on the results of research conducted [5] that ballast compaction and drainage system optimization can reduce the increase in TQI values by 20-40% under extreme climatic conditions.

2. Real-time TQI monitoring with observation technology
The results of the research with observational methods based on the utilization of TGT (track geometry trolley) and manual monitoring technology. The results of research with TQI monitoring in real time are in line with research conducted [16] which can identify track segments that require maintenance before significant quality degradation occurs.
3. Operational management based on observation
 - a. It was also observed that managing the speed of operations has a direct influence on TQI scores. Therefore, operational management strategies were implemented, including:
 - b. Speed adjustment based on TQI value;
 - c. More even load distribution;

Application of Rail Grinding and Continuous Welded Rail (CWR), The combination of these two methods can reduce long-term maintenance costs and improve travel efficiency and safety on the Mandai-Garongkong crossing. This is also in line with the results of research conducted [10], [17] that both rail grinding and continuous welded rail methods are recommended strategies.

CONCLUSION

Factors affecting train speed across Mandai - Garongkong are the condition of the rail line and Track Quality Index (TQI), track geometry and rail infrastructure, characteristics of railroad facilities, external environment (weather and environmental factors), and operational management and speed regulation. Based on the calculation of the Track Quality Index (TQI) value on each track plot, it is found that the average TQI value is above 10, while the average operational speed is above 30 km/h, although the average TQI value is above 10, the operational speed can still be maintained above 30 km/h due to several supporting factors. Optimization strategies are needed to ensure that the TQI value remains within the limits that allow optimal operational speed, namely the implementation of preventive and corrective maintenance strategies (scheduled ballast tamping, replacement of rails and sleepers in segments with high TQI, and improvement of drainage systems), real-time monitoring of TQI with observation technology, and operational management based on observation results.

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