Comparison analysis of indonesian railway track quality index calculation results with european standards (EN) using multibody dynamic system simulation results (Case study: DAOP VIII Lawang - Malang)

H. Widyastuti, A.F. Sedayu
Institut Teknologi Sepuluh Nopember, Department of Civil Engineering, Kampus ITS, Sukolilo, Surabaya, Indonesia
e-mail: **amisani.sedayu@gmail.com**

Abstract

Train is one of the most popular modes of land transportation. With the increasing number of train enthusiasts in Indonesia, it must be supported by adequate facilities and quality. Therefore, it takes the value of the Track Quality Index which consists of geometric parameters such as alignment, longitudinal level, cross level, and track gauge. A review of the calculation of the TQI value can be used as a basis for repair and maintenance of railroads. The study was carried out using several methodologies to obtain the geometric quality values of the presented lines and compared them with each other, namely calculations using the railway method in Indonesia (KAI) as well as European standards (EN). Then compared with the simulation, the results show that the KAI TQI standard is less comprehensive, so it needs to be equipped with an assessment based on the maximum deviation of each rail geometry parameter. This research is expected to be an input in the calculation of comprehensive rail quality standards in Indonesia.

1 Introduction

The train is one of the most popular modes of land transportation and is quite popular with all levels of society. Generally, a train consists of a locomotive (vehicle with self-propelled power) and several series of trains or carriages that move on rails. As a means of mass transportation, trains are very efficient for a high number of passengers. In addition, the comfort and safety of passengers are important factors that must be considered in maintaining the quality of the train. With the increasing number of train enthusiasts in Indonesia, it should be supported by adequate facilities, improving the quality of good trains is of course one of the efforts that can be done.

Maintaining the quality of the train, it can be done by paying attention to two factors, namely the suspension of the train and the train tracks used. Railroad serves as a footing for rolling train wheels. In maintaining the quality of the track, it is necessary to have a requirement on the railroad that must be met from several parameters to create an ideal condition for the railroad. Several parameters affect the calculation of the quality of the railroad, including alignment, longitudinal level, cross level, and track gauge. In this case, the indicator is obtained from the assessment of the quality of the track based on the sum of the standard deviations of the four parameters. Thus, the result of the overall segment quality is called the Track Quality Index (TQI).

Track Quality Index (TQI) is a statistical summary of the track geometry parameters measured over a defined track length and effectively summarizes a large number of measurements of each parameter for a given track segment. The use of TQI provides the possibility to be able to assess the performance indicators of a railway line. In addition, TQI can also summarize and display the condition of most railroad tracks which can be used to monitor track quality degradation. Therefore, it is necessary to review the calculation of the TQI value to predict standard recommendations that can be used as a basis for repair and maintenance to maintain the quality of railway tracks.

Technological advances are very influential on the development of maintenance in the field of transportation, especially trains. Assistive applications, of course, have sprung up to make work easier. Bryansk State Technical University initiated a software system in the form of modeling the dynamics of railroad vehicles by representing the vehicle with a rigid and/or elastic object system (multi-body system, MBS).

The development of railway technology in Indonesia will continue to increase along with the development of the railway industry in the world. This is interesting to study as a recommendation to railway stakeholders in Indonesia to be able to compete by improving the quality of rail tracks. Currently, Indonesia uses the calculation standard by PT Kereta Api Indonesia (Persero). With the development of the times, further research and studies are needed on the application of TQI in Indonesia. Evaluation of rail quality is calculated using two methods, namely the Indonesian TQI standard used by PT. Kereta Api Indonesia (Persero) and the European Standards (EN 13848). The European Standards (EN) was created and used by most European countries which considers the geometric aspect as the main criterion. From the TQI calculation with the two methods above, the track quality criteria and speed recommendations will be compared with the vehicle respons from the multi-body dynamic simulation. With the data obtained, the correlation between the results of the TQI method and the results of the simulation obtained will be compared. Comparative analysis using quantitative & descriptive methods. This research is expected to determine the appropriate standard for calculating the quality of the track and can reduce the problem of decreasing the quality of the rail road.

2 Research methods

2.1 Parameter analysis

The analysis of the train measurement data refers to the measurements made by PT. Kereta Api Indonesia (Persero). The measuring train used by PT. Kereta Api Indonesia is the EM-120 type. The data obtained is in the form of raw data which will then be sorted based on the parameters needed for the calculation of the track quality index. In the TQI calculation, it takes five parameters for measuring the geometry of the rail road that must be reviewed, namely alignment, longitudinal level, cross level, track gauge, and twist. From some of the data taken by the measuring train, the five parameters of the railroad will be taken for calculations.

2.2 TQI calculation based on Indonesian method

The calculation of the railroad quality index refers to the standard guidelines of PT. Kereta Api Indonesia The value of the track quality index is obtained by adding up 4 (four) parameters from the geometry of the railroad, namely alignment, longitudinal level, cross level, and track gauge. The track quality index has no units, it has a unit sum with different vectors. Measurement data collection is carried out continuously along 200 m segment. for alignment, longitudinal level, and cross level segment represents a length of 40 meters. In addition, for the width of the track, one segment represents a length of 20 meters. From each segment, the standard deviation is added up or calculated. The calculation segmentation is shown in the following figure:

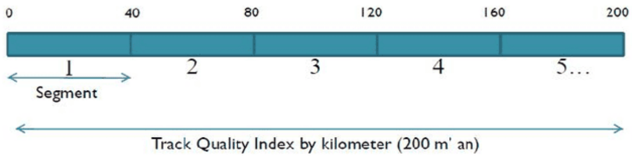


Figure 1: Segmentation of the calculation of the value of the Track Quality Index every 200 m

The calculation of the track quality index in this method uses the standard deviation of each parameter, with the following calculation formula:

$$SD = \sqrt{\frac{Xi^2 - \frac{Xi^2}{n}}{n-1}} \quad (1)$$

An explanation of the notation is as follows:

SD = Standard deviation value

Xi = Current value of data

n = Number of values in the data

The value of the track quality index is obtained by using the summation formula of the standard deviation value of each rail geometry parameter. (Widyastuti, 2019)

$$TQI = SD1 + SD2 + SD3 + SD4 \quad (2)$$

Where SD1,2,3,4 are the standard deviation values of the four geometric parameters, namely alignment, longitudinal level, cross level, and track gauge.

Determination of train speed limits on railroads refers to standard guidelines from PT. Kereta Api Indonesia (Persero). In determining the value of the track quality index of railroads there is a grouping of conditions, which are divided into four categories, namely:

- TQI < 20
- 20 < TQI < 35
- 35 < TQI 50
- TQI > 50

Based on the TQI value categorization above, PT. Kereta Api Indonesia determines the limits or recommendations for train speed based on the quality of the track. The data on Speed limits are listed in the following table.

Table 1: Standard Track Quality Index (TQI) values

No	TQI Range	Velocity (km/h)	Categories
1	<20	100-120	Very Good
2	20-35	80-100	Good
3	35-50	60-80	Sufficient
4	>50	<60	Bad

Source: (PT. Kereta Api Indonesia (Persero), 2012)

2.3 TQI calculation based on European standard (EN)

The calculation of the quality of the rail geometry in certain segments has also been evaluated by European Standards. In calculating the quality of railroads, three parameters of track geometry are required to be considered, namely the longitudinal level, alignment, and gauge. Longitudinal level and Alignment measurements were carried out based on the standard deviation of the irregularities on the 200 m long segment, while the irregularity on the Gauge was measured based on the average value of the 100 m long segment. In addition, the specification of geometric irregularities with a wavelength domain in the range of 3 m < 25 m is another parameter that needs to be taken into account in the standard deviation.

The European standards have a way of assessing the quality of railroads, namely by calculating isolated defects. Isolated defects are the difference between the average value and the peak value or referred to as the mean to peak value. But in practice, the average value is close to zero. The following is an illustration of calculating the zero value to the peak value.

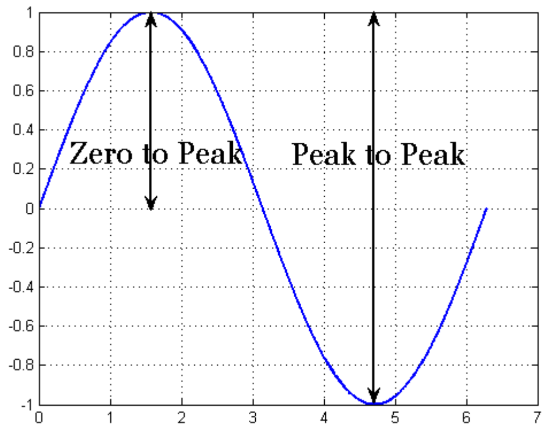


Figure 2 Graph of Zero to Peak. Value

In determining the speed limit, several categorizations between each parameter are needed. European standards specify several speed categorizations based on the quality of the rails taken into account. The assessment is carried out separately for each parameter, namely alignment, longitudinal level, twist, and track gauge every 3 meters. The assessment of the parameters of force and light between the right and left rails is carried out separately. The results of the assessment will be grouped according to the following three levels:

1. Alert Limit (AL): If the limit value of the AL level is exceeded, the railroad needs to be analyzed and considered to be scheduled into regular track maintenance operations.
2. Intervention Limit (AL): If the limit value of the AL level is exceeded, it is necessary to take corrective measures to prevent the railroad from entering a more severe or worse level.
3. Immediate Action Limit (IAL): If the limit value of the IAL level is exceeded, it is necessary to take action to reduce the risk of the train leaving the rail line. the actions taken can be in the form of closing the lane, reducing the speed of operation on the lane, or making the geometry correction of the railroad as quickly as possible.

Tables of grouping limits based on treatment were divided on each parameter. In the Force geometry parameters, light and twist have absolute values, while the gauge width parameters have minimum and maximum limits. Some of the limitations of the railroad geometry parameters from the European standards are as follows:

Table 2: Longitudinal Level - AL and IL Isolated Defect – Zero To Peak

Speed (in km/h)	**Zero to peak value [mm]** ***AL*** **Wavelength range**		**Zero to peak value [mm]** ***IL*** **Wavelength range**		**Zero to peak value [mm]** ***IAL*** **Wavelength range**	
	D1	***D2***	***D1***	***D2***	***D1***	***D2***
$V \leq 80$	12 to 18	*N/A*	17 to 21	*N/A*	28	*N/A*
$80 < V \leq 120$	10 to 16	*N/A*	13 to 19	*N/A*	26	*N/A*
$120 < V \leq 160$	8 to 15	*N/A*	10 to 17	*N/A*	23	*N/A*
$160 < V \leq 230$	7 to 12	12 to 16	9 to 14	14 to 20	20	24
$230 < V \leq 300$	6 to 10	8 to 12	8 to 12	10 to 14	16	18
$300 < V \leq 360$	6 to 8	8 to 10	7 to 10	8 to 12	14	16

Source: (European Stadard, 2017)

Table 3: Alignment - AL and IL Isolated Defect – Zero To Peak

Speed (in km/h)	**Zero to peak value [mm]** ***AL*** **Wavelength range**		**Zero to peak value [mm]** ***IL*** **Wavelength range**		**Zero to peak value [mm]** ***IAL*** **Wavelength range**	
	D1	***D2***	***D1***	***D2***	***D1***	***D2***
$V \leq 80$	12 to 15	*N/A*	15 to 17	*N/A*	22	*N/A*
$80 < V \leq 120$	8 to 11	*N/A*	11 to 13	*N/A*	17	*N/A*
$120 < V \leq 160$	6 to 9	*N/A*	8 to 10	*N/A*	14	*N/A*
$160 < V \leq 230$	5 to 8	10 to 14	7 to 9	12 to 16	12	18
$230 < V \leq 300$	4 to 7	8 to 10	6 to 8	10 to 12	10	14
$300 < V \leq 360$	3 to 6	6 to 8	5 to 7	8 to 10	8	12

Source: (European Stadard, 2017)

Table 4: Twist - Al And Il – Isolated Defect – Zero To Peak

Speed (in km/h)	**Zero to peak value [mm]** ***AL***	**Zero to peak value [mm]** ***IL***	**Zero to peak value [mm]** ***IAL***
$V \leq 80$	4	*5*	7
$80 < V \leq 120$	4	*5*	7
$120 < V \leq 160$	4	*5*	7
$160 < V \leq 230$	4	5	7
$230 < V \leq 300$	3	4	5
$300 < V \leq 360$	3	4	5

Source: (European Stadard, 2017)

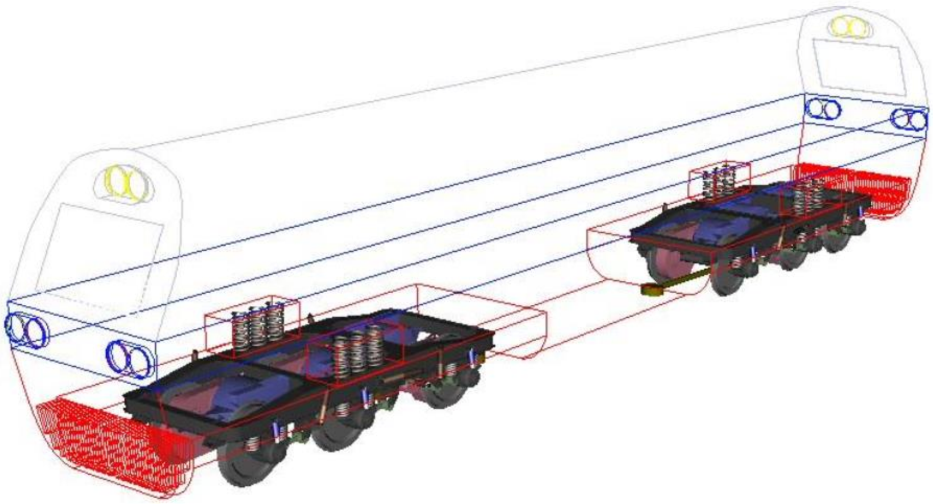
Table 5: Track Gauge - AL and IL - Isolated Defect – Nominal Track Gauge TO PEAK Value

Speed (in km/h)	Nominal track gauge to peak value [mm] *AL*		Nominal track gauge to peak value [mm] *IL*		Nominal track gauge to peak value [mm] *IAL*	
	Min	**Max**	**Min**	**Max**	**Min**	**Max**
$V \leq 80$	−7	25	−9	30	−11	35
$80 < V \leq 120$	−7	25	−9	30	−11	35
$120 < V \leq 160$	−6	25	−8	30	−10	35
$160 < V \leq 230$	−4	20	−5	23	−7	28
$230 < V \leq 300$	−3	20	−4	23	−5	28
$300 < V \leq 360$	−3	20	−4	23	−5	28

Source: (European Stadard, 2017)

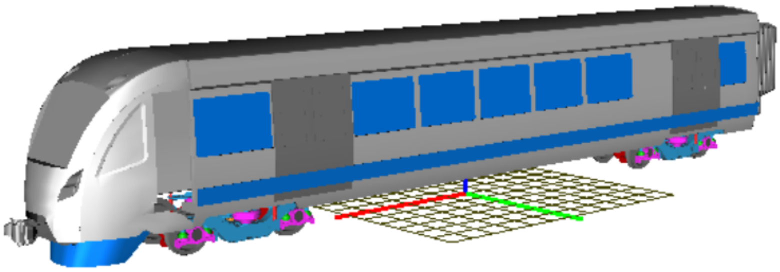
2.4 Universal mechanism train simulation

Modeling on the software is a train carriage operating in Indonesia. The specifications and dimensions of the simulated train using data obtained from PT. Industri Kereta Api (Persero). The bogie modeling of the train is following the original train made by PT. Industri Kereta Api (Persero). Here are some pictures of the train modeling on multibody dynamic software, namely Universal Mechanism.



Source : (Universal Mechanism, 2020)

Figure 3: Model of Bogie and Locomotive



Source: (Nugraha, 2017)

Figure 4: Modeling of Multiple Objects Trains

Dynamic testing is carried out to analyze 2 aspects, namely driving safety and the load on the railroad. Dynamic testing is carried out at several speeds following the provisions of the Universal Mechanism standard. Dynamic test simulations were also carried out on 15 straight rail segments with a track length per segment of 1 km. Each rail segment will have a different KAI and EN standards TQI value.

2.4.1 Driving safety

Driving safety is obtained from the large value of the lateral force on the railroad wheel device. The simulation variable taken is the sum of the lateral forces of the right wheel which is added to the left wheel to obtain the lateral force of each wheelset. All simulation results analyzed are the lateral forces of the wheels on each bogie. The simulation results are compared to the driving safety limit.

The driving safety limit is obtained from the calculation of the weight of the lateral load given by the train wheels to the rail with the following formula:

$$Driving\ Safety\ Limit\ = K2\ x\ (10\ kN + \frac{Pfo}{3}) \tag{3}$$

2.4.2 Track loading

Assessment of the load on the railroad can be done by using the maximum vertical force that occurs on the wheels. The variable taken from the simulation is the vertical force on each wheel. In the vertical style, the trained model has 8 wheels on each set. The results of the simulation of the vertical force obtained are compared with the maximum and minimum limits of the vertical force.

The driving safety limit is obtained from the calculation of the weight of the lateral load given by the train wheels to the rail with the following formula:

$$Track\ Loading\ Limit = 90.000 + \frac{Wtrain\ x\ SF}{number\ of\ train\ wheels} \tag{4}$$

Comparative analysis of the calculation of the track quality index was carried out between the calculation method of railways in Indonesia and the European Standards method. Comparative analysis is carried out by correlating the speed limits obtained from the calculation of the limits of the multibody dynamic simulation results. Theoretical comparisons are made in the form of tables and graphs in the discussion subsection.

3 Results and analysis discussion

3.1 TQI calculation results based on Indonesian method

In the Indonesian calculation, the first step is to calculate the standard deviation of each parameter based on data obtained by the Directorate General of Railways in the form of data distribution every 0.25 m. Standard deviation is a statistical value that is used to determine the distribution of data in a sample. Then do the manual calculations as in the following table.

Table 6: Example of Manual Calculation of Standard Deviation

KM	M/4	XLEVEL	Total Xi	Xi^2
41	0	-8,96	-8,96	80,28
41	1	-7,35	-7,35	54,02
-	-	-	-	-
-	-	-	-	-
-	-	-	-	-
41	798	-6,85	-6,85	46,92
41	799	-7,44	-7,44	55,35
41	800	-8,06	-8,06	64,96
	Total		**-4905,09**	**37234,68**
		Total Xi^2	**24059907,91**	

$$SD = \sqrt{\frac{\sum Xi^2 - \frac{(Xi^2)}{n}}{n-1}} \tag{5}$$

$$SD = \sqrt{\frac{37234,6825 - \frac{24059907,91}{800}}{800-1}} \tag{6}$$

$$SD\ Longitudinal\ Level = \mathbf{2,999} \tag{7}$$

From the calculation above, the track quality index value on the elevation parameter in DAOP VIII 41 + 200 is 13.5. in the same way, it is also obtained that the SD Alignment = 3.787752, SD Cross Level = 3.757491, SD Track Gauge = 2.837692. From all these results added up, the TQI value is obtained at KM 41-000 – 41+200. The results of the track quality index value per 200 m' are as follows:

TQI = SD Alignment + SD Cross Level + SD Track Gauge + SD Longitudinal Level (8)

= 3.787 + 3.757 + 2.837 + 2.999 (9)

= 13,382 (10)

3.2 TQI calculation results based on European standard

In calculating the value of the rail quality index using the European method, it is based on geometric conditions. Several parameters that affect TQI European speed limits include longitudinal level, alignment, track gauge, and twist. The first step to determining the TQI speed limit with European standards is by measuring Zero to Peak or calculating from zero to the peak value of a parameter with a percentile of 99.85% and 0.15%. The railroad quality index is based on its geometric conditions. This index is obtained by looking at the peak values of the four measurement parameters. In the calculation of the zero to peak value using 99.85% to process and avoid errors in the data. So we will take the percentage of 99.85% for the top peak and 0.15% for the bottom peak.

Table 7: Example of Track Quality Index Calculation Results with European Standards Method

EUROPEAN STANDARDS								
Trip	Segment	KM	Longitudinal Level		Alignment		Track Gauge	Twist
			Left	Right	Left	Right		
Lwg - Mlg	I	41+000 - 41+200	14,386	10,484	8,956	13,206	0,742	3,570
Lwg - Mlg	II	41+200 - 41+400	14,058	11,880	15,034	13,984	0,049	4,811
Lwg - Mlg	III	41+400 - 41+600	14,94	14,110	20,178	21,024	-1,944	4,739
Lwg - Mlg	IV	41+600 - 41+800	15,568	12,542	8,564	9,062	-1,248	5,006
Lwg - Mlg	V	41+800 - 42+000	15,170	17,368	10,077	8,993	-0,914	4,848

3.3 Train simulation using universal mechanism

A train dynamic simulation was carried out to assess the feasibility of driving a train based on standards on 15 straight rail segments with 4 test speeds for each segment. The feasibility of train driving is obtained from the value of the dynamic response of the train to railroads with various irregularities. The dynamic response of the train is divided into 2 aspects, namely driving safety and the load on the railroad. Driving safety is judged by the large lateral force of each wheelset. The load on the railroad is assessed from the amount of vertical force on each wheel. Dynamic simulation testing will be carried out using Universal Mechanism software.

1) Driving Safety Test Results

   The driving safety limit is obtained from the calculation of the weight of the lateral load given by the train wheels to the rail with the following formula:

$$Driving\ Safety\ Limit = K2\ x\ (10\ kN + \frac{Pfo}{3}) \tag{11}$$

$$Driving\ Safety\ Limit = 0{,}75\ x\ (10\ kN + \frac{30.000\ x\ 9{,}81}{3\ x\ 4}) \tag{12}$$

$$Driving\ Safety\ Limit = 25.671\ N \tag{13}$$

The train driving safety limit is 25,671 N with absolute value. If in the simulation there is a force that exceeds the limit then the train is not safe. The maximum limit of lateral force is used to prevent damage to the structure of the railroad and as a safety limit from the occurrence of train accidents, such as trains going off the rails. The results of the vertical force simulation obtained can be seen in Figure 7

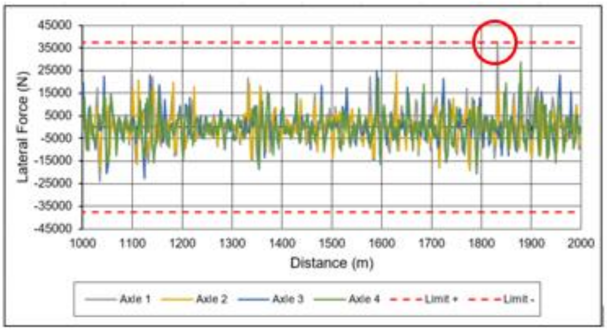


Figure 5: Test Results on Lateral Loads on Segment 2 DAOP VIII

2) Load Test Results on Track

The driving safety limit is obtained from the calculation of the weight of the lateral load given by the train wheels to the rail with the following formula:

$$Track\ Load\ Limit = 90.000 + \frac{Wtrain\ x\ SF}{number\ of\ train\ wheels} \tag{14}$$

$$Track\ Load\ Limit = 90.000 + \frac{30.000\ x\ 9{,}81\ x\ 0{,}7}{2\ x\ 4} \tag{15}$$

$$Track\ Load\ Limit = 94.273\ N \tag{16}$$

The safety limit for train driving is 94,273 N with absolute value. If in the simulation there is a force that exceeds the limit then the train is not safe. The maximum limit of the vertical force used to prevent damage to the rail structure. Meanwhile, the minimum vertical force limit is used as a safety limit for train accidents. The results of the vertical force simulation obtained can be seen in Figure 8.

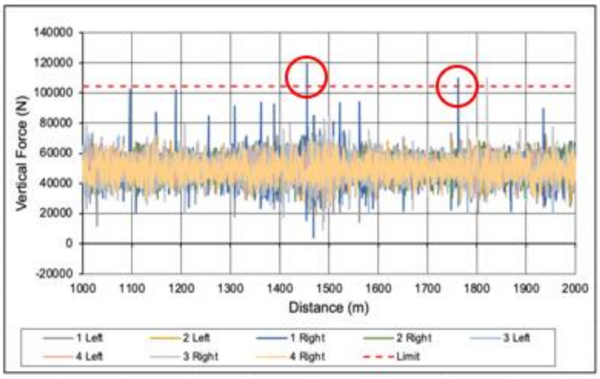


Figure 6: Test Results on Vertical Loads on Segment 2 DAOP VIII

3.4 Comparison of the results of the three TQI calculation methods

Comparison numbering is done as a whole and several points. The results of the comparison of TQI calculations and speed limits based on the assessment of Indonesian Standards, European Standards, and Universal Mechanism Simulation can be seen in Table 8 as follows.

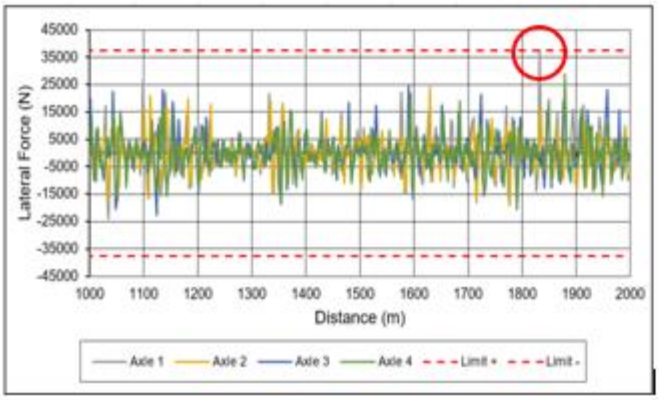


Figure 7: Test Results on Lateral Loads on Segment 2 DAOP VIII

The simulation results of the lateral force at the DAOP VIII test point (Lawang - Malang) in segment 2 along the 1000 Meters have passed the safety limit at a test speed of 80 km/hour. It can be seen from Figure 9 that the simulation results of the lateral force have a large value and have exceeded the safety limit which is 37,972 N in the range of 1800 meters to 1900 meters. This is because in this range there is a fairly large irregularity. Therefore, the simulation results of the train model state that the operating speed of the train is recommended below 80 km/hour. This segment has a TQI value of 22.72 (Cat. Good) on the Indonesian Standards and AL on the European Standards.

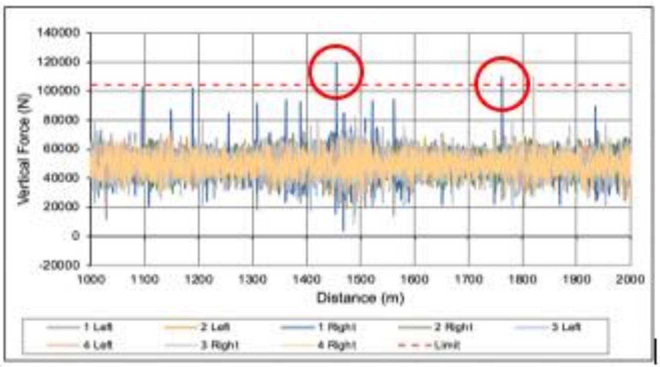


Figure 8: Test Results on Vertical Load Segment 2 DAOP VIII

Figure 10 shows the simulation results in segment 2 of DAOP VIII with a test speed of 60 km/hour, there is a vertical force that has passed the minimum vertical force in the range of 100 m to 800 m at a test speed of 60 km/hour. From these results, some things are not reasonable, namely the simulation results of a large vertical force that exceeds 94,273 N. This is because in that range there is a fairly large track irregularity. Therefore, the simulation results of the train model state that the recommended train operating speed is below 60 km/hour in segment 2 which has a TQI value of 14,556 (Cat. Very Good) on the Indonesian Standards and IAL on the European Standards so that the train can operate safely.

From several comparisons of TQI calculation data, the following is an example of comparison data for all speed limit calculations from several railroad segments that have been tested.

Table 8: Comparison of Speed Limits on Railroad DAOP VIII (Lawang - Malang)

Trip	Segment	KM	TQI Indonesia (km/h)	European Standards (km/h)	Universal Mechanism Simulation (km/h)
Lwg - Mlg	I	39+000 - 39+200	100 - 120	80	80
Lwg - Mlg	II	39+200 - 39+400	80 - 100	80	80
. . .	. . .	. . .	. . .	. . .	. . .
Lwg - Mlg	IV	45+600 - 45+800	80 - 100	80	80
Lwg - Mlg	V	45+800 - 46+000	80 - 100	80	80

The results of the comparison of calculations in the table are followed by visualization in the form of graphs to facilitate comparison. The following is a graph of the results of the comparison of the three methods of calculating the track quality index.

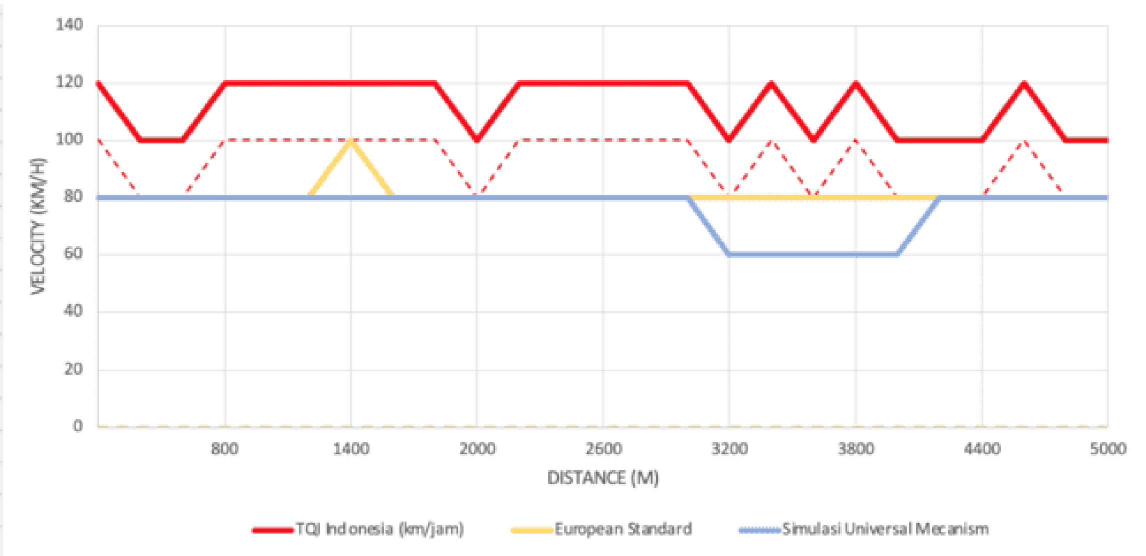


Figure 9: Comparison of the Speed Limits of the Three Methods on the DAOP VIII Railway (Lawang - Malang)

4 Conclusions and suggestions

4.1 Conclusion

The conclusions that the author can draw after completing this undergraduate assignment are as follows:

1. Calculation of the quality of railroads based on Indonesian standards has been carried out. Based on the TQI value on the railway line, namely DAOP VIII (Lawang - Malang) it shows that the railroad is dominated by the "Very Good" category followed by the "Good" category, and one segment with the "Medium" category for the rail range. so that the train speed limit is between 80 - 120 km/hour.
2. The calculation of the quality of the railroad based on the European Standards (EN) has been carried out. The results of calculations on the DAOP VIII railway line show that the railroad is dominated by the "IAL" category and followed by the "IL" and "AL" categories for the rail range with the recommended train operating speed of <80 km/hour.
3. Evaluation of the dynamic response of trains on 5 rail segments and 4 test speeds for each TQI value has been carried out by dynamic simulation in Universal Mechanism software using running safety and track loading tests. The train model used is a passenger train model operating in Indonesia. The dynamic simulation test followed the Universal Mechanism guide and obtained the recommended operating speed between 60-80 km/hour in the three segments.
4. A comparison of the assessment of the quality of the standard rail of Indonesian railways against the European Standards using a simulation has been carried out. The results of the calculation of the Indonesian standards are better than the results of EN and simulations. The results of this comparison show that Indonesian railway standards are less comprehensive when used to assess the quality of railroads, compared to the European Standards. Therefore, using only the TQI value of Indonesian railway standards is not sufficient in assessing the quality of railroads and the maximum deviation of each parameter of the geometry of railroads in Indonesia. The results of the comparison with the simulation show that the recommended train operating speed is in the range of 60 km/hour – 80 km/hour.

4.2 Suggestions

Based on the undergraduate research that has been done, the authors find several suggestions that can be made for further research, namely:

1. Studies on the calculation of rail quality standards in developed countries such as Europe need to be reviewed on railroads in Indonesia so that they can be used more precisely as an evaluation of KAI standards in assessing the quality of railroads.
2. Dynamic simulations on the Universal Mechanism software are expected to be used in the calculation components of rail quality standards in Indonesia by using a passenger train model that has been operating.
3. The requirements for the maximum deviation from the measurement results of the railroad in the dynamic simulation or the maximum limit for the irregularity of the railroad need to be evaluated further to determine the acceptable standard for the maximum train operating speed along the rail segment.

Aknowledgements

The author would like to thank PT. Industri Kereta Api (Persero) has helped the authoring process and obtain the data needed in this study.

Finally, we can only thank those who have helped us during the process of writing and compiling this journal, either directly or indirectly. We hope this journal can be useful for people who read it both now and in the future.

References

[1] A.R.B. Berawi, R. Delgado, R. Calçada, and C. Vale, “Evaluating Track Geometrical Quality Trough Different Methodologies,” *International Journal Of Technology*, vol. 1, no. 1, pp. 38-41, 2010.

[2] W. Kurniawan, and R. Rulhendri, “Tinjauan Volume Pemeliharaan Tahunan Jalan Rel Berdasarkan (TQI),” *Jurnal Rekayasa Sipi ASTONJADRO*, vol. 4, no. 2, pp. 1-17, 2015

[3] D.I. Karunianingrum, and H. Widyastuti, “Kualitas Indeks Track Geometry Sebagai Indikator Penlilaian Kualitas Track Melalui Metode Yang Berbeda,” *Jurnal Transportasi: Sistem, Material, dan Infrastruktur*, vol. 2, no. 1, pp. 6-10, 2019.

[4] R.R.A. Lubis, and H. Widyastuti, “Penentuan Rekomendasi Standar Track Quality Index (TQI) Untuk Kereta Semicepat Di Indonesia (Studi Kasus: Surabaya - Cepu),” *Jurnal Aplikasi Teknik Sipil*, vol. 18, no. 1, pp. 39-44, 2020.

[5] PT. Kereta Api Indonesia (Persero), *Evaluasi Geometri Jalan Rel Atau Kereta Ukur*, 2012.

[6] *European Standards, P., Railway Applications — Track — Survey Of Track Geometry Quality. BSI Standards Publication*, 2014.

[7] *European Stadard, B., Railway Applications - Track - Track Geometry Quality Part 5: Geometric Quality Levels - Plain Line, Switches, And Crossings. BSI Standards Publication*, 2017.

[8] *European Standards, B. E., Railway Applications — Track — Track Geometry Quality Part 6: Characterisation Of Track Geometry Quality. BSI Standards Publication*, 2014.

[9] P. A. Nugraha, *Analisis Dinamik Sistem Benda Jamak Kereta LRT*, Bandung: Fakultas Teknik Mesin Dan Dirgantara Institut Teknologi Bandung, 2017.

[10] Universal Mechanism. *User's Manualsimulation Of Rail Vehicle Dynamics*. Portugal: UM Loco, 2020.

[11] W.A., Fistcar, H. Widyastuti, and C.A. Prastyanto, “Pengaruh Parameter Track Quality Indeks (TQI) Terhadap Perilaku Bantalan Beton,” *Jurnal Aplikasi Teknik Sipil*, vol.18, no. 1, pp. 131-138, 2020.

[12] M. R. Abyan, *Pengembangan Perangkat Lunak Pengolahan Data Hasil Pengukuran Jalan Rel Dan Perhitungan TQI Untuk Kereta Api Semicepat Melalui Analisis Respon Dinamik Kereta*, Bandung: Institut Teknologi Bandung, 2021.

[13] H.V. Poor, *An Introduction To Signal Detection And Estimation*. New York: Springer-Verlag Ch. 4, 1985.