Jurnal Sainstech Nusantara
https://nusantarajournal.id/sainstech

Vol.1 No.4 (2024) 40-53
ISSN: 3063-0657

Forecasting of MRT Railway Rail Lifetime on Fatmawati Curve Jakarta-Indonesia

Gifarly Muhammad Farrel Najendra*[1], Adya Aghastya[1], Muhammad Nurhadi[1]

[1]Railway building and track technology, Indonesian Railway Polytechnic Madiun, Tirta Raya street, Manguharjo, 63132, INDONESIA

Article Info

Article history:

Received 21 June 2024
Revised 2 October, 2024
Accepted 16 November, 2024

Abstract

This research analyzes the service life of rails on rail replacement on urban railway arches, with a focus on the Fatmawati MRT Jakarta arch. Due to the high frequency of train traffic in urban areas and curve radii that do not comply with standards, the rails on the Fatmawati curve experience significant wear. This research uses the AREA method to estimate the service life of rails based on the wear that occurs. The data collected includes the number of daily train trips and regular measurements of track wear. Analysis results show that rail wear on the Fatmawati curve is increasing, reaching a critical point in April 2029, where the rails are projected to have to be replaced. Using forecasting methods square train and least square, it is predicted that by April 2029, the numberof daily trips will decrease to 239 trips, and rail wear will reach 15.85 mm. This research provides recommendations for rail replacements to be carried out in accordance with predicted results to avoid further damage and maintain the operational safety of MRT Jakarta.

Keywords: Rail wear, Urban railway curve, AREA method, Wear prediction

Corresponding Author:

Name: Gifarly Muhammad Farrel Najendra
Email: gifarly.tbjp2110141@taruna.ppi.ac.id

1. Introduction

Rail is a critical component of railway infrastructure, playing a pivotal role in supporting and guiding trains as they move along the track. This essential part of the system ensures that trains operate safely by providing a stable and durable surface for the wheels to travel on. However, due to the constant interaction between the rails and train wheels, rail components are subject to significant wear and tear. The high frequency of train traffic, especially in urban rail systems, exacerbates the pressure on rails, resulting in more frequent maintenance needs. The situation is particularly acute in urban areas, where rail networks operate under the strain of dense traffic. This is often due to the close intervals between trains, which can lead to excessive friction and increased wear. An example of such a high-traffic system is MRT Jakarta, an urban rail network with a significant passenger volume and an extensive schedule of over 7,900 trips daily. In March 2024, MRT Jakarta recorded an impressive 2,876,356 passengers, reflecting the growing demand for public transport in the capital city of Indonesia [1] [2].

Urban rail systems, such as the MRT Jakarta, are under particular stress due to the high traffic frequency, which leads to the acceleration of rail degradation. The Fatmawati curve on the MRT Jakarta route, for instance, has been a focal point for maintenance concerns. The curve, with a radius of only

DOI: https://doi.org/10.71225/jstn.v1i4.60

180 meters, does not meet the minimum radius standard of 200 meters set by the Ministry of Transportation Regulation No. 60 of 2012. This is significant because railway curves that do not meet the minimum radius can put additional strain on both the rails and the trains that pass over them. The small radius of these curves causes more frequent and intense contact between the wheels and the rail, leading to higher levels of wear and increased friction. This issue is not unique to MRT Jakarta; other urban rail systems in Indonesia, such as the LRT Palembang on the Simpang Bandara route and the Jabodebek LRT on the Kuningan longspan, also feature tight curves that contribute to rail wear. The LRT Palembang curve has a radius of just 80 meters, while the Jabodebek LRT curve is slightly less than 115 meters. These characteristics suggest that urban rail systems, particularly those in metropolitan areas, face significant challenges when it comes to maintaining rail integrity and preventing rapid deterioration.

The increasing passenger numbers and the sheer frequency of train trips are among the main contributors to the wear experienced by the rails, particularly at sharp curves. As trains continuously navigate tight turns, the stress on the rails amplifies, leading to the development of issues such as rail corrugation and rail rolling contact fatigue (RCF). These problems are a direct result of the excessive friction and pressure placed on the rails during regular operations. The Fatmawati curve in MRT Jakarta, for instance, has shown visible signs of wear and tear, including corrugation, a condition where the rail surface develops undulations, making it less smooth and increasing the potential for further damage. In addition, RCF is a significant concern, as it can lead to cracks and premature rail failure. The cumulative effect of these issues suggests that the rails at critical locations, such as the Fatmawati curve, may require replacement to ensure continued safe and efficient operations. The necessity for such maintenance is underscored by the regulations and guidelines set by the authorities, which specify the need for replacement after a certain period, typically five years of operation, to prevent more serious structural problems [3] [4].

MRT Jakarta's elevated track, which uses slab track technology, further complicates maintenance efforts. Slab tracks, while offering the advantage of low maintenance, require precise monitoring because even minor defects can lead to significant consequences due to the track's rigid design. Unlike traditional ballasted tracks, slab tracks do not have the flexibility to absorb some of the stresses caused by track deformations or rail wear. Consequently, any visible signs of rail damage, such as corrugation or the onset of RCF, are closely monitored, as these issues can escalate more rapidly than they might in conventional rail systems. The elevated nature of the MRT Jakarta also makes it more difficult to perform maintenance, particularly when it comes to repairing or replacing the rails in hard-to-reach areas like curves. Therefore, timely interventions are crucial to avoid costly repairs or the need for more extensive replacements. The Fatmawati curve, with its small radius and history of rail wear, has become a focal point for rail replacement discussions. While the consultant’s work instructions during the MRT Jakarta construction called for rail replacement after five years, it is important to assess whether this plan is still necessary, given the current condition of the rails [5] [6] [7].

This study aims to evaluate the need for rail replacement on the Fatmawati curve in MRT Jakarta, based on the ongoing condition maintenance processes, including trackwork maintenance and rail examination. Despite the initial recommendations for replacement, the trackwork maintenance so far has yielded satisfactory results. This raises the question of whether the rail replacement plan is still required, or if the ongoing maintenance efforts have sufficiently addressed the issues without the need for drastic measures. The focus of this study is to determine whether the rails at the Fatmawati curve are still serviceable, or if replacement is indeed necessary to ensure the continued safety and efficiency

DOI: https://doi.org/10.71225/jstn.v1i4.60

of the MRT Jakarta network. By assessing the current rail condition and evaluating the effectiveness of the maintenance activities conducted thus far, the study seeks to provide a comprehensive answer to this question. Given the high traffic volume and the tight radius of the curve, it is crucial to establish whether the current maintenance efforts are enough to extend the life of the rails or whether more significant interventions, such as rail replacement, are inevitable [8] [9] [10].

Figure 1. Jabodebek LRT Kuningan Longspan, MRTJ Fatmawati Curve, Palembang LRT Airport Junction

The maintenance of rails in urban rail systems like MRT Jakarta is a complex and ongoing challenge, particularly in areas with high traffic frequencies and sharp curves. The Fatmawati curve, with its tight radius, exemplifies the strain placed on rails and the need for continuous monitoring and maintenance. Although the consultant's work instructions call for rail replacement after five years, the ongoing condition assessments suggest that this may not be necessary if the maintenance activities continue to meet the required standards. The findings of this study will be crucial in determining whether the rail replacement plan is still necessary or whether other strategies can be employed to maintain the integrity of the trackwork while minimizing disruption to the service. The results of this research will also provide valuable insights into the broader issue of urban rail system maintenance, offering guidance for future rail network developments in cities with similar operational demands [11] [12] [13] .

2. Research Method

2.1. Data Collection

Inspection and Maintenance Data

The data collection for rail service life planning conducted in this study includes daily trip data, rail wear data at the Fatmawati curve, damage conditions, and the necessary equipment data for calculating equivalent tonnage or daily crossing loads.

MRT Jakarta’s Daily Trip Data

The daily train movement data in the operation of MRT Jakarta can be read from the MRT Jakarta facility crossing table. The average circulation at each station for each track segment is summed, resulting in the total circulation of journeys for each corridor.

DOI: https://doi.org/10.71225/jstn.v1i4.60

Table 1. Number of Train Trip

	TRAIN TRIPS (Trip)					
	2019	2020	2021	2022	2023	2024
Month	Realization	Realization	Realization	Realization	Realization	Realization
January	-	8241	6611	7159	8035	8241
February	-	7671	6276	5368	7340	-
March	-	7063	6801	6559	8035	-
April	5724	2016	7122	6990	7270	-
May	8171	1519	6895	7047	8161	-
June	7560	5274	7170	7445	7688	-
July	8307	6225	4997	7663	8109	-
August	8241	5925	3837	7743	8253	-
September	7956	6090	4554	7550	7909	-
October	8307	6037	6569	7663	8229	-
November	7956	6642	7274	7742	8229	-
December	8133	6573	7447	8143	8124	-
Total	**70355**	**69276**	**75553**	**87072**	**95382**	**8241**

Rail Wear Data on Fatmawati Curve of MRT Jakarta

The measurement of wear on the curved rails at Fatmawati MRT Jakarta is conducted monthly to monitor whether the rails are still in accordance with the standards. This is related to the investigative activities on the Fatmawati curve. Measurements are taken at five points on the curve: BTC (MBA), BCC (MB), IP, ECC (AB), and ETC (ABA). The results of the measurements carried out periodically by the track team are as follows.

Table 2. Rail Wear Measurement Results

MRTJ FTM CURVE ROLL WEAR MEASUREMENT DATA (mm)							
Year	**Point Patok**	**BTC (MBA)**	**BCC (MB)**	**IP**	**ECC (AB)**	**ETC (ABA)**	**Average**
2022	January	1,39	6,13	5,71	4,41	1,59	3,85
	February	1,46	6,39	6,2	4,54	1,67	4,05
	March	1,53	6,65	6,4	4,67	1,75	4,20
	April	1,6	6,91	7,19	4,8	1,83	4,47
	May	1,67	7,17	7,3	4,93	1,91	4,60
2023	June	1,74	7,43	7,5	5,06	1,99	4,74
	July	1,81	7,69	7,6	5,19	2,07	4,87
	August	1,88	7,95	7,8	5,32	2,15	5,02
	September	1,95	8,21	8,2	5,45	2,23	5,21
	October	2,02	8,47	8,3	5,58	2,31	5,34
	November	2,09	8,73	8,6	5,71	2,39	5,50
	December	2,16	8,99	8,85	5,84	2,47	5,66
	January	2,23	9,25	9,1	5,97	2,55	5,82
	February	2,3	9,51	9,35	6,1	2,63	5,98

DOI: https://doi.org/10.71225/jstn.v1i4.60

2024	March	2,37	9,77	9,6	6,23	2,71	6,14
	April	2,44	10,03	9,85	6,36	2,79	6,29
	May	2,51	10,29	10,1	6,49	2,87	6,45

2.1. Data Processing Methods

Train Travel Daily Trip Data

Daily trip data or train service delivery (TSD) used for analyzing rail service life on the Fatmawati curve, through calculations using the AREA formula derived from the equivalent tonnage formula, yielded results that will be used to calculate the rail service life. Additionally, forecasting methods using trend analysis will also be applied.

MRT Jakarta Rail Wear Data

The rail wear data were obtained from inspections using a digital rail wear measurement tool to assess the wear of the rails. This data is utilized to evaluate the service life of the rails on the Fatmawati curve, as rail wear can indicate the reliability of the rails. Subsequently, forecasting methods using trend analysis are employed to determine when the rails will require replacement.

3. Results And Discussion

3.1 Identification of Railway Routes

MRT Jakarta has one of the sections of the track that is still under study concerning curves with a small radius, specifically 180 meters, at an elevated position with an uptrack area. In conducting this research, the author selected the location on the Fatmawati – Cipete Raya section, which is situated between KM 2+440 and KM 2+759. This rail design includes several markers at specific locations for measuring rail wear at the Fatmawati curve. Information regarding the design of the Fatmawati curve can be found in Figure 2. below.

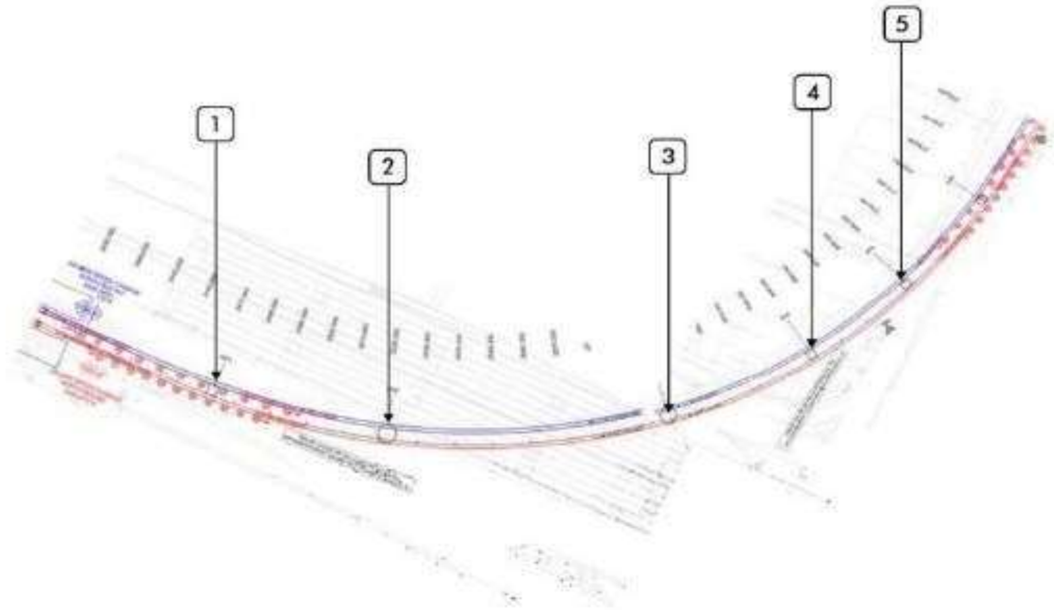

Figure 2. Design of Fatmawati curve

DOI: https://doi.org/10.71225/jstn.v1i4.60

3.2 Analysis of Projected Rail Service Life

In estimating the service life of the rails on the Fatmawati curve, calculations were performed using the AREA method. In this formula, it is necessary to calculate the length of the rail for each rail section and the radius for each curve present. The calculations conducted are as follows;

Step 1 Calculation of The Constant Value (K)

Table 3 . Details of Alternative Route Selection

Curve	Radius of curvature (m)	Curve (km)	Length	Kt (Lubrication)	K*
K	180	0,319	0,37		0,164
TOTAL		0,319			0,164

K = Curve Length x Kt x 1,393 (CWR)

K= 0,319 x 0,37 x 1,393

= 0,164

The value of (K) or the existing rail condition divided by the length of the area :

$$K = \frac{Total\ Value\ of\ K}{Total\ Distance}$$

$$K = \frac{0.164}{0.319}$$

$$= 0.514$$

Step 2 Calculation of Relay Weight Value (W)

W = Rail weight (lb/yd), where 1 kg/m = 2,015907 lb/yd. In MRT Jakarta Line, UIC54 rails are used with a weight of 54 kg/m, so:

54 kg/m = 54 x 2,015907 = 108,858978 ~108,857 lb/yd

Step 3 Crossing Capacity Calculation (D)

The result obtained from this calculation is expressed in tons per day, achieved by summing the total loads, each multiplied by their respective coefficients. Based on the calculation formula outlined in PM No. 60 of 2012, the calculation of TE is obtained using formula (1), which uniformly involves multiplying the load of the facility by the number of trips. The result TE indicates the load experienced by the Fatmawati curve in a single day.

TE = Total weight of the train set

DOI: https://doi.org/10.71225/jstn.v1i4.60

TE = Tc1 + M1 + M2 + M1′ + M2′ + Tc2

TE = 49.682 + 55.292 + 55.593 + 55.292 + 55.543 + 49.683

TE = 321,085 tons⁄day TEtotal = TE x daily trip TEtotal = 321,085 x 132

TEtotal = 42.383,22 tons⁄day

Then, when calculating the weight over one year based on the actual passing tonnage, the formula (2) is used as follows:

T = 360 x S x TE

T = 360 x 1,1 x 42.383,22

T = 16.783.755,12 tons⁄year

In the calculation, (T) represents the number of days in a year, indicating the load experienced in one year, multiplied by S = the coefficient, the magnitude of which depends on the quality of the track. In this case, for the Jakarta MRT track, the coefficient is set at 1.1 for tracks with a maximum passenger train speed of 120 km/h. From this, it can be determined that the Passing Tonnage (D) for Jakarta MRT is T = 16,783,755.12 tons per year. When converted to the unit mgt/ton, it is:

T = 16.783.755,12 ton⁄tahun : 0,909 $Juta\ ton$ = 18.463.977,03 mgt

Step 4 Calculation of Rail Lifespan (T)

In this case, the formula used is (3), where (K) represents the rail condition constant, which is specified according to the specifications and conditions of the MRT Jakarta rails, multiplied by (W), the rail weight in units of lb/yd, and (D), the passing tonnage in units of mgt. Thus;

$T = K\ x\ W\ x\ D$0,565

T = 0,514 x 108,871 x 18,4630,565

= 308,155 mgt

= 280,112 tons⁄year

Then, it was recalculated using formula (4) to determine the rail lifespan, where (T) represents the result of the tonnage in tons/year divided by (D). Thus, the lifespan of the Jakarta MRT rail is based on the AREA calculation."

$Ur = T/D$

= 280,155/18,463 = 15,171 ~ 15 Years

DOI: https://doi.org/10.71225/jstn.v1i4.60

From the calculations above, it is determined that the rail age at Lengkung Fatmawati is 15 years. The aforementioned method provides a rail age value that aligns with the existing conditions based on the wear predictions to be made in forecasting, making it one of the approaches still considered representative for use.

3.3 Forecasting the Replacement of Fatmawati Curve in MRT Jakarta

Based on the analysis of rail lifespan using the AREA method, it has been found that the rail in the MRT Jakarta curve still has a remaining lifespan of 15 years. Forecasting was carried out to estimate the replacement of the Fatnawati curve based on the daily train trips and rail wear in MRT Jakarta, using quadratic trend and least squares methods.

Step 1 Forecasting Daily Trip Patterns of MRT Jakarta

Calculation of the coefficients a, b, and c in determining the sum of data ∑. For coefficients a, b, and c in the equation below, ∑Y is divided by n, which represents the number of actual data points.

To find the coefficient a,

$$\mathrm{a} = \frac{(\sum \mathrm{Y})(\sum \mathrm{X4}) - (\sum \mathrm{X2Y})(\sum \mathrm{X2})}{\mathrm{n}(\sum \mathrm{X4}) - (\sum \mathrm{X2})2}$$

$$\mathrm{a} = \frac{(190695)\ (121420) - \ (9781488)\ (1310)}{25\ (121420) - (1310)}$$

a = =7837,222

Coefficient b,

$$\mathrm{b} = \frac{\sum \mathrm{XY}}{\sum \mathrm{X2}}$$

$$\mathrm{b} = \frac{87152}{1310}$$

b =   = 66,528

Coefficient c,

$$\mathrm{c} = \frac{\mathrm{n}(\sum \mathrm{XY2Y}) - (\sum \mathrm{XY2})(\sum \mathrm{Y})}{\mathrm{n}(\sum \mathrm{X4})}$$

$$\mathrm{c} = \frac{25\ (9781488) - (1310)\ (190695)}{25\ (121420) - (1310)2}$$

$\mathrm{c} = -\ 1{,}7371$

Thus, the forecast value of TSD calculated for January 2024 using equation (5) is:

Y' (26) February 2024 $= a + Xt + cX$

DOI: https://doi.org/10.71225/jstn.v1i4.60

$= 7837{,}2 + 66{,}5\ (26) + -1{,}7371\ (26)2$

$= 8393$ Trip

Based on the calculations from the above equations and the data processed in Table (4.16), it can be determined that the value of TSD, or daily trips of the train, for the following two months is 8,393 trips in February 2024 and 8,367 trips in March 2024. Based on the forecasting data presented, it is indicated that in April 2029, there will be a low point in train trip capacity, or TSD, as the forecast suggests that the tracks on the Fatmawati curve will only be able to accommodate 239 train trips. This can be quantified in terms of equivalent tonnage, which represents the daily train load. The equivalent tonnage (TE).can be determined using formula (1).

The number of trips within one month 239 : 30 = 7,966 ~ 8 trips/day. Thus, in a single trip per day, only on the up track route, the data was obtained 3,983 ~ 4 trips/day

TE = 49.682 + 55.292 + 55.593 + 55.292 + 55.543 + 49.683

TE = 321,085 tons⁄day TEtotal = TE x daily trip

TEtotal = 321,085 x 3,983

TEtotal = 1,278,881 tons⁄day

The maximum allowable load is thus limited to 4 trips per day, with a load capacity of 1,278,881 tons per day.

Step 2 Forecasting the Wear of MRT Jakarta Tracks

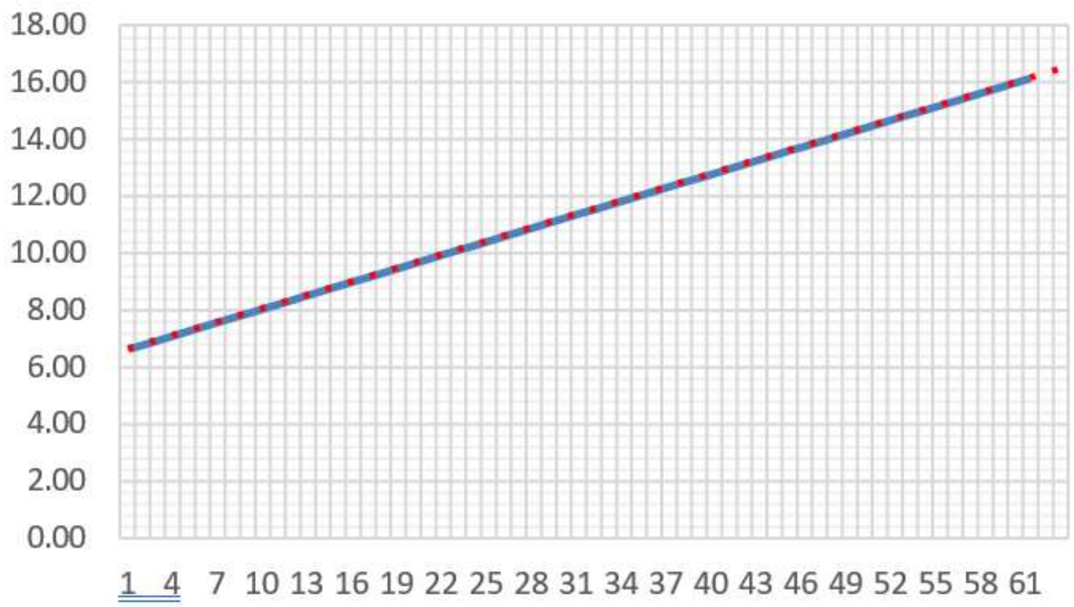

Figure 3. Forcasting Rail Wear

DOI: https://doi.org/10.71225/jstn.v1i4.60

The calculation of determining the coefficients a and b for computing the total amount of data (∑). For the coefficients a, b, and c in the equation below, it is known that ∑Y divided by n, which represents the number of actual data points.

$$a = \frac{\sum Y}{n}$$

$$a = \frac{88.2}{17}$$

A = 5,187

Next, to find the coefficient b, we refer to the calculation results in the table where the sum of ∑XY divided

by the sum of $\sum X2$ yields the result

$$b = \frac{\sum Y}{\sum X2}$$

$$b = \frac{64.948}{408}$$

b = 0.1591

Given the coefficients a and b, they are then substituted into the following equation to determine the forecast value:

Y' (17) June 2024 $= a + b\,X$

= 5,187 + 0,1591 (17) = 6,62 mm

From the calculations of the above equation, based on the data processed in Table (2), it can be observed that the Wear Value of the Fatmawati Arc Rel for the following two months, specifically June 2024 and July 2024, is 6.62 mm and 6.78 mm, respectively. Based on the forecast data above, it is indicated that in April 2029, the wear on the Jakarta MRT rails will reach its maximum point at 15.85 mm. According to the company's regulations or acceptance criteria for Jakarta MRT rails, the maximum allowable wear is 16 mm. This indicates that the condition of the rails will no longer be optimal and replacement will be necessary.

Step 4 Calculation of Forecast Accuracy for Daily Train Trip Journeys

$$MAPE = \frac{Y - Y'/Y}{N}\,100$$

$$MAPE = \frac{7159 - 6789/7159}{25}\,100$$

= 0,2 %

DOI: https://doi.org/10.71225/jstn.v1i4.60

Then, the results for each period were summed, yielding a total result of 4.0 or 4%. Thus, the forecasting error for the TSD or Daily Trip Forecast of MRT Jakarta's trains was calculated as follows:

Table 4. Forecasting Accuracy of MAPE in Time Series Data

Trend Forecasting Model	Error
MAPE	4%

Each method demonstrates results with error values from the accuracy calculations of Time Series Forecasting or Daily Train Trips within an excellent range, particularly with MAPE values of less than 10%.

Step 5 Accuracy Calculation of Rail Wear Forecasting

$$MAPE = \frac{Y - Y'/Y}{N}\ 100$$

$$MAPE = \frac{3.85 - 3.91/17}{3.85}\ 100$$

$$= 0{,}1\ \%$$

Then, the results from each period are summed, yielding a result of 0.5% or 1%. Based on the prediction of rail wear for the Fatmawati MRT Jakarta, the error value of the forecasting accuracy calculation is obtained as follows:

Table 5. Forecasting Accuracy MAPE TSD

Trend Forecasting Model	Error
MAPE	1%

The accuracy of the forecasting indicates that the error values obtained from the accuracy calculation for the Fatmawati MRT Jakarta curve rail wear fall within a very good range, with a MAPE value of less than 10%.

DOI: https://doi.org/10.71225/jstn.v1i4.60

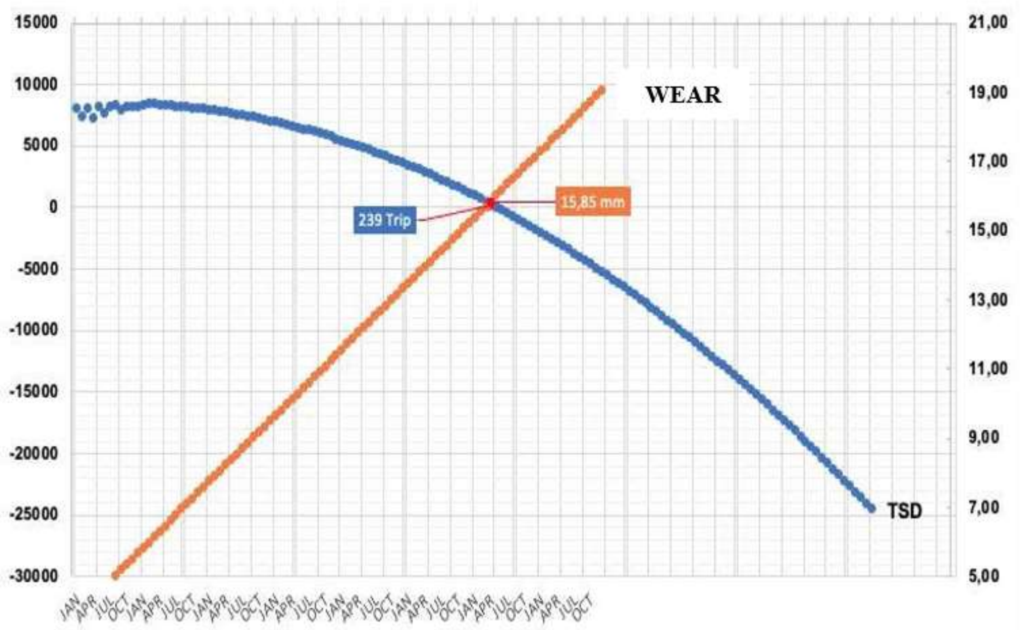

Figure 4. Combining Two Forecasting

Based on the forecast calculations for Train Service Delivery (TSD) and Rail Wear at the Fatmawati MRT Jakarta curve, the two lines in the graph above intersect. The frequency of train trips from February 2024 to April 2029 is projected to decrease, while rail wear at the Fatmawati curve from June 2024 to April 2029 is expected to increase. This intersection is indicative of the fact that the decline in the number of trips suggests that the rail can only support loads according to the daily tonnage calculation based on the number of train trips, which correlates with the increasing rail wear. It is noted that in May 2024, the forecasted number of passenger trips will decrease to 8,161, and rail wear will increase to 6.45 mm. The gradual decrease in daily train trips and the corresponding increase in rail wear are not drastic, as track maintenance efforts are effectively undertaken to preserve rail conditions. This aligns with ongoing activities for the MRT Jakarta's Fatmawati curve, where a study on rail replacement is planned. The load exerted by trains significantly affects rail wear; thus, the increase in wear indicates that the load on the rails is decreasing, as measured by the number of train trips or TSD. Given that the number of train trips is expected to decline from 2024 to 2029, along with rising rail wear, the maximum load capacity of the rails and the need for replacement are anticipated around April 2029. This prediction is based on the 5-year period from the Initial Knowledge (IK) provided by JMEC, which suggests that the rail replacement for the Fatmawati curve should occur when the number of trips reaches 239 or when the daily tonnage load is 1,278,881 tons/day, with rail wear reaching the tolerance limit of 15.85 mm [14] [15] [16].

4. Conclusion

In calculating the service life of the rail at the Fatmawati Curve of the Jakarta MRT, the AREA method and forecasting are used. The analysis is based on historical data, as the principle is that the current condition will also be influenced by past events. Therefore, the initial service life of the rail at the Fatmawati Curve, which was set to 5 years according to the Work Instruction (IK) by the consultant at the beginning of construction in 2019, was reevaluated. Considering the efforts made to maintain the

DOI: https://doi.org/10.71225/jstn.v1i4.60

condition through rail examination and optimal maintenance trackwork by MRT Jakarta, the service life of the rail, calculated using the AREA method, remains 15 years, extending to 2039. Research aimed at predicting when railway tracks will start to experience a decline in quality, necessitating replacement, involves making forecasts. The forecasting results, reviewed from two variables—daily train trips and rail wear—are plotted on a single graph over the same time period. An intersection of the lines is found in April 2029, with a total of 239 trips or a daily tonnage load of 1,278,881 tons per day, and wear reaching the tolerance threshold of 15.85 mm. According to the forecast based on the related variables, the track on the Fatmawati curve will need to be replaced starting in April 2029, which is 5 years from the IK JMEC MRT Jakarta in 2024.

Acknowledgments

I would like to express my sincere gratitude to the Politeknik Penerbangan Surabaya, Indonesian Railway Polytechnic for their support, resources, and opportunities throughout this research.

References

[1] Adi, W. T. (2019). Kajian Umur Jalan Rel Berdasarkan Keausan dengan Metode dari AREA dan Perjana. *Jurnal Perkeretaapian Indonesia (Indonesian Railway Journal)*, *3*(2). https://doi.org/10.37367/jpi.v3i2.84

[2] Azman, M. M. (2019). Analisa perbandingan nilai akurasi moving average dan exponential smoothing untuk sistem peramalan pendapatan pada perusahaan XYZ. *Jurnal Sistem Dan Informatika*, *13*(2), 36–45.

[3] Ding, H. H., Fu, Z. K., Wang, W. J., Guo, J., Liu, Q. Y., & Zhu, M. H. (2015). *Investigation on the effect of rotational speed on rolling wear and damage behaviors of wheel / rail materials*. *331*, 563–570. https://doi.org/10.1016/j.wear.2014.12.043.

[4] Gultom, E., & Kaelani, Y. (2017). Studi Eksperimen dan Analisa Laju Keausan Material Alternatif pada Sepatu Rem Lokomotif. *Jurnal Teknik ITS*, *5*(2). https://doi.org/10.12962/j23373539.v5i2.20765

[5] W.J. Wang, J. Guo, Q.Y. Liu, M.H. Zhu, Z.R. Zhou, Study on relationship between oblique fatigue crack and rail wear in curve track and prevention, Wear 267 (2009) 540–544.

[6] J.W. Ringsberg, Shear mode growth of short surface breaking RCF cracks, Wear 258 (2005) 955–963. [3] A. Bevan, P. Molyneux-Berry, B. Eickhoff, M. Burstow, Development and validation of wheel wear and rolling contact fatigue damage model, Wear 307 (2013) 100–111.

[7] A. Ekberg, B. Akesson, E. Kabo, Wheel/rail rolling contact fatigue-probe, predict, prevent, Wear 314 (2014) 2–12.

[8] L. Ren, G. Xie, S.D. Iwnicki, Properties of wheel/rail longitudinal creep force due to sinusoidal short pitch corrugation on railway rails, Wear 284–285 (2012) 73–81.

[9] W.J. Wang, W. Zhong, J. Guo, Q.Y. Liu, M.H. Zhu, Z.R. Zhou, Investigation on rolling contact fatigue and wear properties of railway rails, Proc. IMechE, Part J: J. Eng. Tribol. 223 (7) (2009) 1033–1039.

[10] A. Ekberg, E. Kabo, H. Andersson, An engineering model for prediction of rolling contact fatigue of railway wheels, Fatigue Fract. Eng. Mater. Stuct. 25 (2002) 899–909.

DOI: https://doi.org/10.71225/jstn.v1i4.60

[11] B. Dirks, R. Enblom, Prediction model for wheel profile wear and rolling contact fatigue, Wear 271 (2011) 210–217. [9] F.J. Franklin, I. Widiyarta, A. Kapoor, Computer simulation of wear and rolling contact fatigue, Wear 251 (2001) 949–955.
[12] J. Sandstrom, Subsurface rolling contact fatigue damage of railway wheels—A probabilistic analysis, Int. J. Fatigue 37 (2012) 146–152. [11] G.F. Mi, H.Y. Nan, Y.L. Liu, B. Zhang, H. Zhang, G.X. Song, Influence of inclusion on crack initiation in wheel rim, J. Iron Steel Res. (Int.) 18 (2011) 49–54.
[13] Aghastya, A., Wardana, A., Adi, W. T., Imron, N. A., & Wirawan, W. A. (2023). Geometry Design of Railway Track for High-Speed Railways Bandung-Cirebon KM 00+ 000-KM 33+ 850. *Journal of Railway Transportation and Technology*, *2*(2), 34-45.
[14] Wirawan, W. A., Wahjono, H. B., Rachman, F. R. N. F., & Rhamadhani, A. (2023, July). Macrostructural and mechanical properties of rails cladded by automatic flame treatment. In *AIP Conference Proceedings* (Vol. 2689, No. 1). AIP Publishing.
[15] Aghastya, A., Prihatanto, R., Rachman, N. F., Adi, W. T., Astuti, S. W., & Wirawan, W. A. (2023, March). A new geometric planning approach for railroads based on satellite imagery. In *AIP Conference Proceedings* (Vol. 2671, No. 1). AIP Publishing.
[16] Aghastya, Adya, et al. "The effect of heating surface treatment by oxy-acetylene gas on the microstructure and hardness of the UIC R42 rail." *AIP Conference Proceedings*. Vol. 2592. No. 1. AIP Publishing, 2023.

DOI: https://doi.org/10.71225/jstn.v1i4.60