

Analysis of Wheel Tyre Replacement for LRT Jakarta 1100 Series

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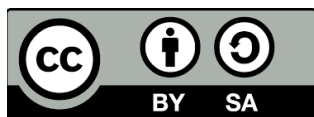
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Abstract

The Jakarta Light Rail Transit (LRT) 1100-series trainset, manufactured by Hyundai Rotem, has been operating for two years on a route that includes sharp R40 and R60 curves within the depot area. These operating conditions require careful wheel maintenance, particularly of the wheel tire (bandase), to ensure that the trainset remains classified as Ready for Operation (RFO) with wheel diameters maintained within the allowable tolerance range of 660–600 mm. This study analyzed the service life of the wheel tires on the LRT Jakarta 1100-series trainset and evaluated the influence of wheel behavior on R40 and R60 curves in relation to wheel–rail interaction and friction conditions. The methods included a literature review, field measurements using an underfloor wheel lathe at the LRT Jakarta depot, documentation before and after wheel reprofiling, and calculations based on four-month interval measurement data. The results showed average wheel diameter wear of 1.27 mm on the left wheel and 0.99 mm on the right wheel every four months. Flange thickness reached its allowable limit earlier than other wheel parameters, indicating that wheel tire replacement was projected to be required after approximately four years and three months of operation. Analysis of the free-running condition showed that, on both curve radii, the bogie wheelbase (2,310 mm) exceeded the calculated free-running limits (894.43 mm for R40 and 1,095.45 mm for R60). This condition caused the trainset to experience a tight/chord running condition (Spitzgang) due to the absence of cant and gauge widening, which also explained the presence of iron swarf observed during field inspections as a result of increased wheel–rail friction. These findings provide important considerations for preventive maintenance planning and spare-part procurement. This study recommends reviewing wheel and track technical specifications for curved sections and conducting further research on rail wear mechanisms and wheel–rail material characteristics to support the long-term operational reliability of the LRT Jakarta 1100-series trainset.



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INTRODUCTION

Light Rail Transit (LRT) has become an important urban transportation solution in many metropolitan areas due to increasing urbanization, traffic congestion, and the growing demand for sustainable mobility systems (Saeidizand et al., 2022). The development of rail-based transportation has been driven by the need for efficient, environmentally friendly, and reliable public transportation infrastructure (Le et al., 2022; Sun et al., 2019). According to the International Association of Public Transport (UITP), the expansion of automated and urban

rail transit systems continues globally as cities seek alternatives to private vehicle dependence and aim to improve urban accessibility (International Association of Public Transport [UITP], 2025). However, the operational reliability of rail transit systems depends heavily on the condition of mechanical components, particularly wheel and rail systems, because these components directly transmit operational forces during train movement (Tawfik et al., 2022; Wang et al., 2021).

The wheel–rail interaction system is one of the most critical factors affecting railway safety, operational efficiency, and maintenance costs (Bosso et al., 2022). Continuous contact between steel wheels and rails generates mechanical forces required for train movement, braking, acceleration, and guidance, but it also creates risks of wear, surface damage, cracking, and material degradation (Tawfik et al., 2022). Previous studies have demonstrated that wheel and rail wear are strongly influenced by operational factors, including axle load, running distance, wheel material properties, track geometry, and curve radius (Liu et al., 2024; Shi et al., 2021). In railway systems, sharp curves are particularly challenging because they increase lateral forces and friction between the wheel flange and rail, accelerating component degradation (Fang et al., 2024; Wang et al., 2021).

In Indonesia, the development of urban rail transportation has increased significantly, particularly in Jakarta as one of the cities implementing modern rail-based mobility systems. Jakarta operates two LRT systems, namely LRT Jabodebek and LRT Jakarta, with LRT Jakarta utilizing Hyundai Rotem 1100-series trainsets. These trainsets operate on routes containing specific track geometries, including sharp R40 and R60 curves located within the depot area, which require careful maintenance consideration due to their potential impact on wheel–rail interaction and friction. Therefore, accurate maintenance planning is required to ensure that all train components remain within safety and performance standards.

The wheel tire (bandase) is a fundamental component of the railway wheel system because it directly contacts the rail surface and influences wheel performance (Bosso et al., 2022). The LRT Jakarta 1100-series trainset must maintain wheel diameter and flange dimensions within the specified tolerance range of 600–660 mm to achieve Ready for Operation (RFO) status (Muhamedsalih et al., 2023). When wheel dimensions exceed allowable limits, maintenance actions such as wheel turning (reprofiling) or replacement are required to restore operational safety (Jia et al., 2024; Pires et al., 2021). Therefore, understanding wheel tire degradation patterns is essential for developing effective preventive maintenance strategies and minimizing unexpected operational disruptions (Shi et al., 2021; Zeng et al., 2025).

Several previous studies have investigated railway wheel and rail degradation from various perspectives. Research on railway wheel material development has examined improvements in wheel durability through alloy composition and heat-treatment processes to increase wear resistance. Other studies have analyzed rail geometry, curve design, and wheel–rail contact mechanisms to understand their relationships with operational safety and component lifespan. However, many existing studies have focused on conventional railway systems, material engineering, or general wheel–rail behavior, while specific investigations on wheel tire replacement prediction for modern urban LRT systems remain limited (Jiang et al., 2019; Lee et al., 2026; Lyu et al., 2026).

Previous research related to LRT Jakarta maintenance has primarily focused on technical planning, infrastructure development, and operational aspects rather than detailed prediction of wheel tire replacement based on actual field measurement data. This study differs by utilizing direct measurement data collected from the LRT Jakarta depot through underfloor wheel lathe inspections, documentation before and after wheel turning processes, and four-month maintenance cycle observations. This approach provides empirical evidence regarding actual wheel wear conditions rather than relying solely on manufacturer specifications or theoretical assumptions.

Although manufacturer maintenance schedules provide standard inspection intervals, differences may occur between planned maintenance requirements and actual operational conditions. The LRT Jakarta 1100-series trainset had been operating for two years, and variations between technical specifications and field conditions required further investigation to determine accurate replacement timing. Previous calculations based on operational assumptions estimated wheel replacement after six years, whereas field-based analysis may produce different predictions depending on actual wear rates and curve-related friction effects. This gap highlights the importance of integrating real operational data into railway maintenance decision-making.

The urgency of this research lies in supporting sustainable railway operations through improved preventive maintenance planning. Excessive wheel wear can increase maintenance frequency, reduce operational reliability, and potentially affect passenger safety if components exceed allowable limits. Field observations at the LRT Jakarta depot indicated the presence of iron swarf resulting from wheel–rail friction on R40 and R60 curves, providing evidence of material loss caused by wheel–rail interaction. Therefore, identifying dominant wear parameters and predicting wheel replacement timing are necessary to optimize maintenance schedules and spare-part procurement.

The novelty of this study lies in combining wheel wear measurement analysis with curve interaction evaluation specifically applied to the LRT Jakarta 1100-series trainset. This research not only estimates wheel tire service life but also analyzes the influence of R40 and R60 curves on wheel–rail friction conditions through evaluations of free-running and tight/chord running conditions. The analysis indicates that the trainset experiences a tight/chord running condition (Spitzgang) because the bogie wheelbase exceeds the calculated free-running limit on both curves. These findings provide practical insights for evaluating track specifications, wheel maintenance strategies, and future railway design improvements.

Based on these considerations, this study aimed to analyze the service-life prediction of the wheel tire (bandase) on the LRT Jakarta 1100-series trainset and examine the influence of R40 and R60 curves on wheel–rail friction conditions. The contribution of this research is to provide an empirical reference for railway operators in developing preventive maintenance programs, determining wheel replacement schedules, and improving spare-part procurement planning. Furthermore, this study provides technical insights into wheel–rail interaction mechanisms in urban LRT systems and supports future research on rail wear characteristics and wheel–rail material performance.

METHOD

A research method was applied to analyze wheel tire (bandase) replacement on the LRT Jakarta 1100-series trainset. The data collection methods used in this study included field observations, wheel measurements, documentation, and analysis of maintenance data related to wheel wear and replacement conditions.

Literature Study

The literature study method involves collecting data by reviewing literature related to the research topic. Its preparation is similar to other research approaches, but data are sourced and gathered from library materials through reading, note-taking, and processing of reference material. This method was used to obtain the formulas and theories needed to support the field study and the calculation method used in this final project report.

Field Study

The field study involved direct observation of the object under investigation to obtain primary data, namely wheel measurement data taken at the wheel lathe located at the LRT Jakarta depot. The equipment used for the field study included personal protective equipment (a helmet, to protect the head from impact and falling hard objects, as the lathe is positioned beneath the train; gloves, to prevent contact between the hands and turning swarf; safety glasses, to protect the eyes from turning swarf; a long-sleeved work uniform, to prevent cuts from turning swarf; and safety shoes, to prevent slipping and injury from falling objects during the turning process) as well as the wheel lathe itself. The lathe used is an underfloor-type wheel lathe, positioned beneath the maintenance track so that the wheels do not need to be removed from the train.

Documentation

Documentation consists of the wheel measurement results recorded before and after the turning (re-profiling) process.

Calculation Method

The calculation method represents an effort to discover, develop, and verify the accuracy of a body of knowledge, so that a scientific work can achieve its intended outcome in a precise and well-directed manner through the application of scientific methods, using the following parameters.

Wheel Tyre Lifetime

Maintenance of the LRT Jakarta trainset follows the Manual Instruction (MI) issued by the manufacturer, Hyundai Rotem. As set out in the maintenance schedule, a three-yearly or 360,000 km inspection consists of Car Overhaul 1 (C1), and a six-yearly or 720,000 km inspection consists of Car Overhaul 2 (C2); both involve dismantling and measurement procedures that yield the condition of the wheel components, as summarized in Table 1.

Table 1. Train Wheel Maintenance Schedule

Title	Inspection Interval	Identification
Normal Maintenance Examination	15±2 days or 5,000 km	NME
Limited Inspection	60±7 days or 20,000 km	LI
General Inspection 1	360±7 days or 120,000 km	GI1
General Inspection 2	540±7 days or 180,000 km	GI2
Car Overhaul 1	3 years or 360,000 km	C1
Car Overhaul 2	6 years or 720,000 km	C2

Source: Hyundai Rotem Manual Instruction LRV 1100 (2018).

Effect of the Wheel on Curves

Rolling contact between a steel wheel and the rail is a characteristic phenomenon of rail vehicles and forms the basis for understanding vehicle behavior on both straight and curved track, since all forces used to stop, start, support, and guide the vehicle are transmitted through this wheel-rail contact—a condition that also makes the rail prone to damage such as corrugation, wear, cracking, and breakage. A wheelset consists of a pair of wheels rigidly mounted on a common axle, with a conical tread profile; this conical shape produces a sinusoidal (hunting) motion on straight track, while on curves it helps the wheelset negotiate the curve and reduces wear, and the wheel flange prevents the wheel from leaving the rail.

When a wheelset negotiates a curve, the left and right wheels travel different distances, as the outer rail forms a longer path than the inner rail; the wheelset therefore tends to shift toward the outer rail, producing a difference in rolling radius between the two wheels. When this difference in travelled distance exactly matches the difference between the inner and outer rail lengths, the wheelset negotiates the curve through pure rolling, a lateral position known as the equilibrium rolling line, expressed through the following relationships:

$$(R + l_0) / r_R = (R + l_0) / r_L \quad \dots(1)$$

$$r_R = r + \gamma y ; r_L = r - \gamma y \quad \dots(2)$$

where l_0 is half the distance between the wheel-rail contact points (mm), R is the curve radius (m), r_R and r_L are the right- and left-wheel rolling radii (m), and γ is the conicity of the wheel tread. From these two equations, the lateral displacement y required to reach the equilibrium rolling line is obtained as $y = l_0/\gamma R$, and since this displacement is limited by the wheel flange clearance ($y \leq \frac{1}{2}f_{wc}$), the resulting maximum rolling-radius difference is $\Delta r_{\max} = 2\gamma y_{\max} = \gamma \cdot f_{wc}$.

On straight track or large-radius curves, the wheel flange generally does not contact the inner face of the rail head except during hunting motion; continuous flange-rail contact instead occurs when a rigid bogie negotiates a sharp curve, under either a free-running condition (leading wheel against the outer rail, trailing wheel unrestrained) or a tight/chord condition (leading wheel against the outer rail, trailing wheel against the inner rail), with a free-running condition occurring when $a < \sqrt{2R(f_{wc} + e)}$, where a is the bogie wheelbase (mm), R is the curve radius (m), f_{wc} is the wheel-rail flange clearance (mm), and e is the track gauge widening (mm).

On large-radius curves the wheelset turns owing to creep forces acting on the wheel tread, whereas on sharp curves it is forced to turn by the rail itself, through what is termed the directive force—the lateral (horizontal) reaction force exerted by the rail on the wheel flange. This directive force P is the horizontal component of the normal force N acting on the flange, $P = N \cdot \sin \beta$, where β is the flange's angle of inclination to the horizontal plane (typically 60° – 70°); the resulting sliding motion of the flange in turn produces a friction force $F = \mu_f \cdot N = \mu_f \cdot P / \sin \beta$ opposing the sliding velocity, where μ_f is the coefficient of friction between the flange and the inner rail face.

As a rigid bogie negotiates a curve, the direction of travel of the wheelset and the tangent to the curved track form an angle α , termed the angle of attack, given by $\sin \alpha = a/2R$; this angle must not exceed 2° in order to prevent derailment. The combined effect of the friction force F and the angle of attack α produces wear on both the wheel flange and the inner face of the rail head; Vogel expressed the product of the directive force P and the angle of attack α as a characteristic wear value, $C_a = P \cdot \alpha$, which represents the rate of flange wear (with P taken to represent the friction force F).

Train Wheel Wear Rate

Measurement data recorded on 7 September 2019, at a running distance of 29,157 km, showed an average wheel diameter of 656.12 mm, compared with data recorded on 10 January 2020, at a running distance of 38,805 km, showing an average diameter of 655.5 mm. These data were analyzed using two formulas: wheel wear per week, calculated as the average wheel wear over four months divided by the number of weeks in four months; and wheel wear per curve traversed, calculated as the average weekly wheel wear divided by the number of curves traversed by the train per week.

RESULTS AND DISCUSSION

Technical Specifications

Determining the minimum replacement threshold for the train wheel requires several supporting technical parameters. The LRT Jakarta trainset has a total length of 28 m, a car length of 2.7 m, a car height of 2.05 m, a bogie center spacing of 10.75 m, a trailer bogie mass of 4,370.37 kg, and a motor bogie mass of 5,947.11 kg. The wheel specifications range from 660 mm (new) to 600 mm (minimum) in diameter, 135–133 mm in width, 1,392.5–1,359 mm back-to-back, 32.5–27.5 mm in flange thickness, and 30–36 mm in flange height. The LRT Jakarta rail is of type EN 13674-1 (54E1), with a contact surface area of 69.77 m², a rail head height of 159 mm, and a mass of 54.77 kg/m.

Visual observation on the curved sections revealed iron swarf resulting from wheel material worn away through friction with the rail, distributed along both the R40 and R60 curves. Wear marks were also visible on the rail head from wheel-rail contact, though these were considered safe, as the rail surface showed no corrugation and remained smooth and free of defects. More swarf accumulated on the outer rail than on the inner rail. Trains negotiating the curve at 10 km/h experience considerable vibration; the operational speed of LRT Jakarta on curves has accordingly been limited to 10 km/h to slow the rate of wheel wear.

Measurement Data

Measurement data were obtained using measuring instruments before and after the wheel turning (re-profiling) process, using the LRV 1 trainset as the sample. Turning is carried out to equalize the diameter of one wheel with another, as differences in diameter and flange dimensions are commonly found between wheels, making turning necessary to standardize their dimensions; this process, however, accelerates subsequent wheel wear. New wheels also tend to wear faster, as they have not yet adapted structurally to a rail that has itself not yet been broken in; once the wheel and rail structures have adjusted to one another, wear continues to occur but at a lower rate under the same operating conditions.

Based on Minister of Transportation Regulation No. 13 of 2011 concerning "Standards, Testing Procedures, and Certification of Self-Propelled Train Roadworthiness," wheel turning is required when the diameter difference between the two wheels on a single axle exceeds 0 mm, the diameter difference between wheels on a single bogie exceeds 1 mm, the diameter difference between wheels across bogies exceeds 4 mm, or flange radius wear exceeds 8 mm, with flange width and height following the resulting flange radius structure.

Measurement samples were taken during the four-monthly maintenance cycle, comparing data recorded on 9 September 2019 with data recorded on 10 January 2020. The train runs in service four times per week, with one weekly maintenance cycle, corresponding

to 486 curve passes per week. The resulting average wear over four months, per week, and per single curve passage—for both diameter, flange thickness, and flange height, on the left and right wheels—is summarized in Table 2.

Table 2. Average Train Wheel Wear per Four Months, per Week, and per Curve Passage

Parameter	Per 4 Months Left (mm)	Per 4 Months Right (mm)	Per Week Left (mm)	Per Week Right (mm)	Per Curve Left (mm)	Per Curve Right (mm)
Diameter	1.27	0.99	0.075	0.058	0.0001537	0.00012
Flange thickness	2.11	0.33	0.124	0	0.0002559	0
Flange height	1.16	1.32	0.068	0.078	0.0001404	0.00016

Source: Primary data from wheel measurement results at LRT Jakarta Depot (2019–2020), processed by the authors.

Estimated Wheel Replacement Time

Based on the technical specification, wheel maintenance—including reprofiling or replacement—is scheduled at six years or 720,000 km. Using the measurement interval between 9 September 2019 and 10 January 2020 (representing one four-month maintenance cycle) as a basis, and taking the actual distance travelled over that period (38,805 km – 29,157 km = 9,648 km) projected across 18 four-month cycles (six years), the estimated distance travelled over six years is calculated as $(38,805 - 29,157) \times 18 \text{ months} = 173,664 \text{ km}$, indicating that the trainset will reach its scheduled Car Overhaul 2 at six years or 173,664 km, whichever occurs first.

Plotting the wear trends for diameter, flange thickness, and flange height over an 18-year projection shows that, of the three parameters, flange thickness reaches its maximum allowable wear limit soonest. Using the flange thickness recorded at three years (18.99 mm) against the maximum allowable flange thickness (27.5 mm), the estimated time to reach the replacement threshold is $x = (27.5 \text{ mm} \times 3 \text{ years}) / 18.99 \text{ mm} \approx 4 \text{ years } 3 \text{ months}$, indicating that flange thickness—not wheel diameter—is the governing parameter for determining wheel replacement timing.

Free-Running Condition on the R40 and R60 Curves

Sharp curves affect the running behavior of trains negotiating the R40 and R60 radius curves located at the depot. A wheelset is considered to run freely when the bogie wheelbase (a) is smaller than the free-running limit $\sqrt{(2R(fwc + e))}$; conversely, when the wheelbase exceeds this limit, the wheelset runs in a tight/chord condition (Spitzgang) (Subiyanto, 1982). With a track gauge of 1,435 mm, a wheel back-to-back distance of 1,392.5 mm, and a flange width of 32.5 mm, the flange-rail clearance is calculated as $fwc = \text{track gauge} - (\text{back-to-back} + 2 \times \text{flange width}) = 1,435 - (1,360 + 2 \times 32.5) = 1,435 - 1,425 = 10 \text{ mm}$.

For the R40 curve, with a bogie wheelbase of 2,310 mm, the free-running limit is $\sqrt{(2 \times 40,000 \times (10 + 0))} = 894.43 \text{ mm}$; since 2,310 mm exceeds this limit, the trainset cannot run freely on the R40 curve. Applying the same calculation to the R60 curve gives a free-running limit of $\sqrt{(2 \times 60,000 \times (10 + 0))} = 1,095.45 \text{ mm}$; since 2,310 mm again exceeds this limit, the trainset likewise cannot run freely on the R60 curve. In both cases, the trainset therefore runs in a tight/chord (Spitzgang) condition, as neither curve incorporates cant (superelevation) or gauge widening.

CONCLUSION

The wheel tire (bandase) condition of the LRT Jakarta 1100-series trainset was significantly influenced by operational conditions, particularly wheel–rail interaction on sharp curves. Based on four-month measurement data, the average wheel diameter wear was 1.27 mm on the left wheel and 0.99 mm on the right wheel, while flange thickness became the primary parameter determining wheel replacement intervals. The estimation results indicated that wheel tire replacement would be required after approximately 4 years and 3 months of operation, which differed from the standard maintenance schedule based on manufacturer specifications. Furthermore, the analysis of the R40 and R60 curves showed that the trainset operated under a tight/chord running condition (Spitzgang) because the bogie wheelbase of 2,310 mm exceeded the calculated free-running limits of 894.43 mm for R40 curves and 1,095.45 mm for R60 curves. This condition contributed to increased wheel–rail friction, material loss, and the formation of iron swarf observed during field inspections.

Future research should conduct more comprehensive evaluations of wheel and rail degradation by incorporating longer operational periods, larger measurement datasets, and additional parameters, such as wheel–rail material characteristics, contact stress, lubrication conditions, and rail wear patterns. Further studies should also examine the effects of track geometry improvements, including cant application and gauge widening on curved sections, to reduce tight/chord running conditions and optimize wheel service life. Such investigations are expected to support the development of more accurate predictive maintenance models and sustainable maintenance strategies for urban rail transit systems, particularly LRT Jakarta operations.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to the conduct of the research, preparation, or publication of this article.

AUTHOR CONTRIBUTIONS

All authors contributed to the preparation of this article. The first author, Ahmad Sahlul Khuluq, was responsible for the conceptualization of the study, data collection and analysis, interpretation of the results, and manuscript preparation. The other authors contributed to the review, editing, and final approval of the manuscript.

GENERATIVE AI STATEMENT

The authors declare that no generative artificial intelligence was used in the preparation of this article.

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