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RELIABILITY ANALYSIS ON THE BOGIE SYSTEM AT INDONESIAN HIGH-SPEED TRAINS IN THE DESIGN PHASE TO IMPROVE SERVICE QUALITY

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ABSTRACT

High-speed train (HST) Indonesia is rail-based public transportation which is planned to be implemented in Jakarta - Surabaya. To maintain the HST for excellence service, it is necessary to conduct a study on the quality of the service. This paper tries to approach the Bogie system quality service from the reliability perspective in the design phase. The steps taken to maintain continuity of service quality are to identify critical sub-systems/components that affect the decline in reliability, Risk Analysis, build Reliability Block Diagram (RBD) from sub-system/components that have been identified in the bogie system, calculate initial reliability based on RBD, develop designs to minimize the potential for a decline in reliability, and compile procedure for evaluating and re-calculation the value for the reliability of the bogie system. Reliability is targeted at 0.9, which means that all service quality designs must always make the reliability value above the target. This paper is expected to provide an overview of potential that may occur based on predictions of decreasing reliability values until the operating period ends. So that anticipation of minimizing the decline in the value of reliability can be done.

Keywords: high-speed train; bogie system; reliability; quality of service

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INTRODUCTION

High-speed train (HST) Indonesia is rail-based public transportation that is planned to be operated in Jakarta - Surabaya to provide a choice of public transportation modes for the community. Before running on operation stage, the quality of service is the main factor to be concerned. Public transportation with good quality service will positively impact the user community. This paper will try to provide the results of the study related to efforts to maintain the service quality of the bogie system in terms of reliability. Reliability is one of the important parameters in service quality, as shown in **Figure 1** [1], the concepts of Reliability, Availability, Maintainability, and Safety (RAMS). by definition, Reliability is the ability of a system/component to operate at certain times and conditions, which have a large impact on costs of maintenance and repair and continuity of service [2]. Reliability analysis aims to identify the number and causes of failures and provide solutions to prevent the effects of failures systematically [3]. Reliability becomes a very important thing in the design of a product. This is due to several reasons such as customer satisfaction, operating and maintenance costs, repeat business, and competitive advantage [4], [5]. In addition, if we look at it from a maintenance perspective, reliability is very influential on the availability of a product [6].

In this paper, the focus of the study on one of the main systems is the bogie system using a qualitative approach based on target reliability. HST as public transportation must be able to maintain service quality by minimizing the occurrence of undesirable disturbances such as internal factors and external factors.

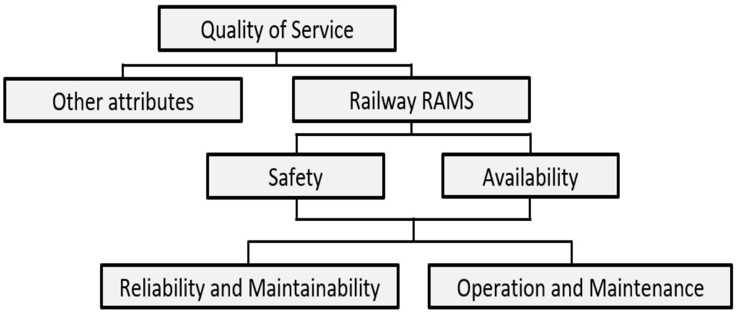


Figure 1. RAMS concept.

The study of service quality reviewed from the perspective of reliability is expected to increase trust for the industry to deliver products to operators, which ultimately increases customer satisfaction [7].

The purpose of this study is to maintain the service quality of the Bogie system from the perspective of reliability at the design stage using qualitative analysis.

METHODS

The steps taken in this study are as follows (as in **Figure 2**):

1) Data Collection & Sub-system definition
   Divide the bogie system into several sub-systems and components and find the failure rate of each component.
2) Risk Assessment
   Risk assessment is carried out to determine the risks that may occur and identify problems that may occur in the bogie system. This risk analysis uses the Failure Mode Effect Analysis (FMEA) tool.
3) Preliminary Reliability Analysis
   Designing Reliability Block Diagram (RBD) and calculate the initial reliability value of bogie using the Reliability Block Diagram (RBD)
4) Analysis of Service Quality in the Reliability Perspective
   Analysis of service quality has calculated the prediction of reliability values until the end of the operating period and the ability of systems/components to maintain reliability up to the operational period.
5) Evaluation and Re-calculation
   This step is to find out the changes that occur and anticipation that needs to be done

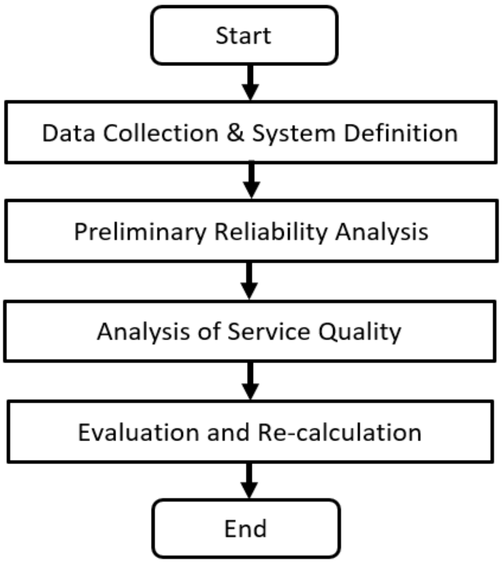
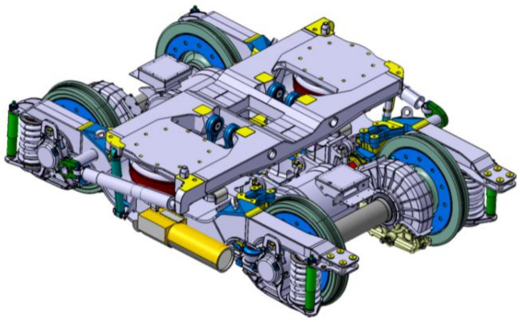


Figure 2. Reliability Flow Analysis.

RESULTS AND DISCUSSION

1. Data Collection & Sub-system Definition

Bogie is one of the important systems on the train (**Figure 3**), and Its function is to maintain the flexibility of the train so that it is always on the track, both when the train is going straight and when turning. When a train passes a turning or cornering rail, there will be an angle between the straight line of the train body and the rail. In this condition, there will be contact between the flange and the rail on one side of the wheel. On a train without a bogie, this angle is limited because the wheels will always line up with the train body so that the flanges are unable to hold the rail. The wheels will rise to the tracks and eventually a derailment or drop. With the bogie, the train wheels can form a certain angle to the car body so that the wheels can rotate to follow the rails without significant difficulty [8], [9].



Source: bombardier.com.

Figure 3. High-speed Train's Bogie System.

In addition to flexibility, the bogie can also reduce the effects caused by rails that rise and fall. The midpoint of the bogie called the Pivot Center will divide the deflection that occurs between the two wheels. This will cause the train to be more stable even though the rails are not flat/bumpy up and down [9], [10]. The HST bogie system consists of several sub-systems. Including complete bogie frame, wheelset assembly, primary suspension, secondary suspension, axle box assembly, bogie to car body connection. The bogie reliability system is a system that operates without interference at certain time intervals and conditions. The reliability of a system or component is also influenced by how preventive maintenance strategies are carried out. A bogie system is a collection of several sub-systems that have reliability value depending on the reliability of the forming sub-system. The bogie system's reliability is affected by sub-systems that are complete bogie frame sub-systems. Wheelset assembly, primary suspension, secondary suspension, axle box assembly, bogie to car body connection.

As a basis for calculating reliability, a detailed reference drawing of the HST bogie system design from PT. INKA & BPPT was used to produce the reliability block diagram (RBD).

2. Risk Assessment of Bogie System

2.1 Failure Mode Effect Analysis (FMEA)

FMEA is a tool for analyzing potential types of disorders, effects of disturbances, and preventive measures on systems. FMEA analysis at bogie system like **Table 1**. in **Table 1**, only critical components that are very influential are selected [11].

The results of FMEA's analysis of each sub-system are related to critical components that can reduce the bogie function and reduce the reliability of bogies, as described in **Table 1**.

Table 1. FMEA analysis at bogie system.

ID	Subsystem	Function	Potential Failure Mode(s)	Intermediate Effect(s)	System Effect(s)	Potential Cause(s) of Failure
2.1	Bogie Frame	Withstand and/or transfer vertical loads from trains and passengers	Cracked & Fracture	derailment	Train can Stop	Nonstandard material Overloading Impact from inside or Outside material porosity
			Bending	causes the body of the train to tilt/uneven load	The train still run	Nonstandard material Overloading Impact from inside or Outside Distorsion
2.2	Axle Box Assembly	transmit the load from the bogie frame to the axle and minimize friction between the axle and axle box	Noise at roller bearing	overheating on the bearing (bearing Jammed)	Train can Stop	Vibration Misalignment of shaft deflection insufficient lubricant dust, dirt
			Fatigue at roller bearing	cause bearing fracture	Train can Stop	Load too high or too low Misalignment of shaft deflection External Heat
			Skidding at roller bearing	the material to wear out quickly	The train still run	Rolling contact area insufficient lubricant
2.3	Wheelset Assembly	distributes the torque from the traction motor to the wheels and distributes the	Cracked & Fracture at Axle	derailment	Train can Stop	Nonstandard material Overloading Impact from inside or Outside
			worn wheel			Nonstandard material

		load from the Bogie Frame to the wheels		reduce wheel dimension	The train still run	Skidding Overloading
2.4	Primary Suspension	to provide damping for the bogie frame and the wheel axle	Damage to the primary spring	no damping between axle and bogie frame	the HST system stops operating temporarily	degradation of the material housing effect or broken seal Thermal cycling effects fatigue and wear out
2.5	Secondary Suspension	to provide damping for the shocks experienced by the train to provide comfort for passengers and connects the bogie frame and car body	Damage to Air Spring system	air leakage in the air suspension	sloping at a body of the HST system	cracks in the canvas leaks/cracks in the rubber below
			Damage to lateral & vertical damper	shock load at the frame to a lateral and vertical direction	The train still run	housing effect or broken seal Thermal cycling effects fatigue and wear out
			Damage to bolster	Suspension Failure	The train still run	Nonstandard material Overloading
2.6	Bogie to Carbody Connection	Withstand vertical, horizontal, and longitudinal loads of the car body	Damage to Center pivot assy	causes the body of the train to tilt/uneven load	Train can Stop	fatigue and wear out overloading Nonstandard material

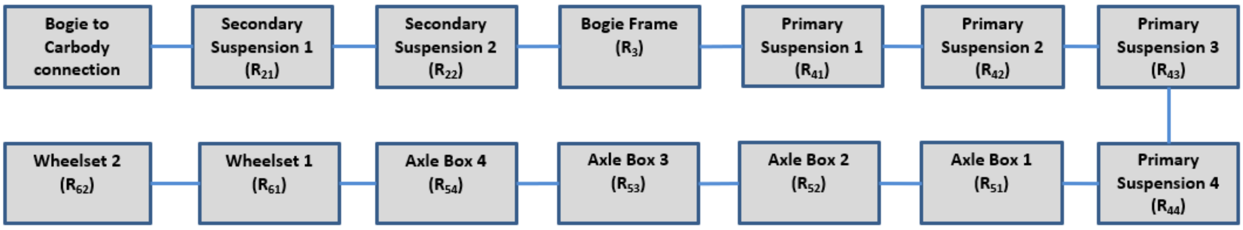


Figure 4. Reliability Block Diagram (RBD) for Bogie System.

2.2 The Bogie Critical System

The study results identified critical components in the bogie system, as in **Table 2.**

Table 2. Sub-systems and Critical components in the Bogie System.

No.	Subsystem
1	Bogie Frame Complete Components: Side Beam & Transom
2	Wheelset Assembly Components: Wheel & Axle
3	Axle Box Assembly Components: Housing, Roller Bearing, and Retaining Ring
4	Bogie to Carbody Connection Components: Center Pivot Assy &Force Transmitter
5	Secondary Suspension Components: Bolster Frame Assy, Lateral Rubber Stopper Installation, Vertical Damper Assy, Lateral Damper Installation, Traction rod installation, Lift Stop Assy & Air Spring Assy
6	Primary Suspension Components: Primary Spring

3. Preliminary Reliability Analysis for Bogie System

3.1 Reliability Block Diagram (RBD)

The reliability block diagram (RBD) system bogie shown in **Figure 4** is based on the schematic drawing of PT INKA's in terms of the complete head bogie.

3.2 Initial Reliability Calculation

To calculate Bogie's system initial reliability by using the reliability block diagram (RBD) in **Figure 4** [9], [12]. Failure rate data has not been obtained because the bogie system is still in the design phase. So to get the reliability value at this phase, comparative data is needed with data from the bogie system from HST in another country. This comparison data using data from China Railway High-speed (CRHX) from 2011 – 2015 [13], the failure rate values are obtained as follows (**Table 3**):

Table 3. The failure rate for bogie component.

No.	Sub-system	Failure rate (λ)	Reliability component
1.	Bogie to Car body Connection	0.001325	$R_1 = 0.9934$
2.	Secondary Suspension	0.001397	$R_{21}=R_{22}= 0.9930$

3.	Bogie Frame	0.00067	R_3= 0.9967
4.	Primary Suspension	0.001095	R_{41}=R_{42}= R_{43}=R_{44}= 0.9945
5.	Axle Box Assembly	0.00115	R_{51}=R_{52}= R_{53}=R_{54}= 0.9943
6.	Wheel set Assembly	0.00151	R_{61}=R_{62}= 0.9925

To predict reliability values, we can use the equation of reliability shown in equation 1[14]:

$$R(t) = e^{-\lambda t} \qquad (1)$$

where:
R(t) : Reliability
t : time
λ : failure rate

Then we can calculate the reliability values from failure rate based on RBD in **Figure 4** with t = 5 years (from 2011 to 2015 in the data)

- Reliability for Bogie to Carbody Connection (R_1)
  $R_1 = 0.9934$

- Reliability for Secondary Suspension (R_2)
  $R_2 = R_{21} \text{ x } R_{22}$
  $R_2 = 0.9930 \text{ x } 0.9930 = 0.9861$

- Reliability for Bogie Frame (R_3)
  $R_3 = 0.9967$

- Reliability for Primary Suspension (R_4)
  $R_4 = R_{41} \text{ x } R_{42} \text{ x } R_{43} \text{ x } R_{44}$
  $R_4 = 0.9945 \text{ x} 0.9945 \text{x} 0.9945 \text{ x } 0.9945$
  $= 0.9783$

- Reliability for Axle box Assembly (R_5)
  $R_5 = R_{51} \text{ x } R_{52} \text{ x } R_{53} \text{ x } R_{54}$
  $R_5 = 0.9943 \text{x} 0.9943 \text{x } 0.9943 \text{ x } 0.9943$
  $= 0.9773$

- Reliability for Wheelset Assembly (R_6)
  $R_6 = R_{61} \text{ x } R_{62}$
  $R_6 = 0.9925 \text{ x } 0.9925 = 0.985$

- Reliability for bogie (R_B)
  $R_B = R_1 \text{ x } R_2 \text{ x } R_3 \text{ x } R_4 \text{ x } R_5 \text{ x } R_6$
  $R_B = 0.9934 \text{ x } 0.9861 \text{ x } 0.9967 \text{ x } 0.9783 \text{ x } 0.9773 \text{ x } 0.9850$
  $R_B = 0.9195$

Table 4. Bogie Initial Reliability System Value.

No.	Sub-system	Initial Reliability value
1	Bogie to Carbody Connection	0.9934
2	Secondary Suspension	0.9861
3	Bogie Frame	0.9967
4	Primary Suspension	0.9783
5	Axle Box Assembly	0.9773
6	Wheelset Assembly	0.9850
Bogie System		**0.9195**

4. Analysis of Service Quality in the Reliability Perspective

The service quality in this paper is an effort to minimize the decrease in the reliability value of the bogie system by using qualitative analysis.

4.1 Reliability Target

The target of reliability is a target in design so that the bogie system has a reliability value of at least 0.75 ≤ during the operational period of 10 years [15]. But in the design phase, our reliability target is 0.90. This target has been discussed and agreed upon with PT INKA as the manufacturer. The target was translated as an effort to maintain reliability so as not to experience a significant decline in performance during the operational period. Target reliability is used as a reference in carrying out further reliability analysis.

4.2 Quantitative Analysis

The following assumptions are used to carry out quantitative analysis in maintaining continuity of service quality in a reliability perspective:

a) The target of HST operations for 30 years
b) Age of system 50 years
c) Failure rate during the system age is stable (based on **Table 4**)

The accuracy of reliability predictions is very dependent on the selection of reliability prediction models and parameters of failure uncertain (such as the probability of failure etc.) [16]. Although the effectiveness of parameter estimates of failure affects prediction techniques, However there are also parameter estimates often relying on the experience of experts [5]. Reliability prediction models vary according to the type of parameter used. Parameters depend on the purpose of the analysis of the reliability model (for example; whether to predict system failure on demand, frequency of occurrence of failure, or only identifying critical components) [5].

To predict reliability values, we can use the equation of reliability shown in equation 1[14]. The failure rate is obtained from the initial reliability calculation for the total bogie component is 0.016788.

With equation 1, time (t) up to 50 years, the results as shown in **Figure 5**.

Table 5 shows that theoretically, if no steps are taken to minimize the decline in reliability, then after 20 years, the probability of a decline is significant.

Table 5. Reliability Predictions.

Year	Reliability Predictions
0.5	0.9916
1	0.9834
2	0.9670
3	0.9509
4	0.9351
5	0.9195
6	0.9042
7	0.8891
8	0.8743
9	0.8598
10	0.8455
15	0.7774
20	0.7148
25	0.6572
30	0.6043
40	0.5109
50	0.4320

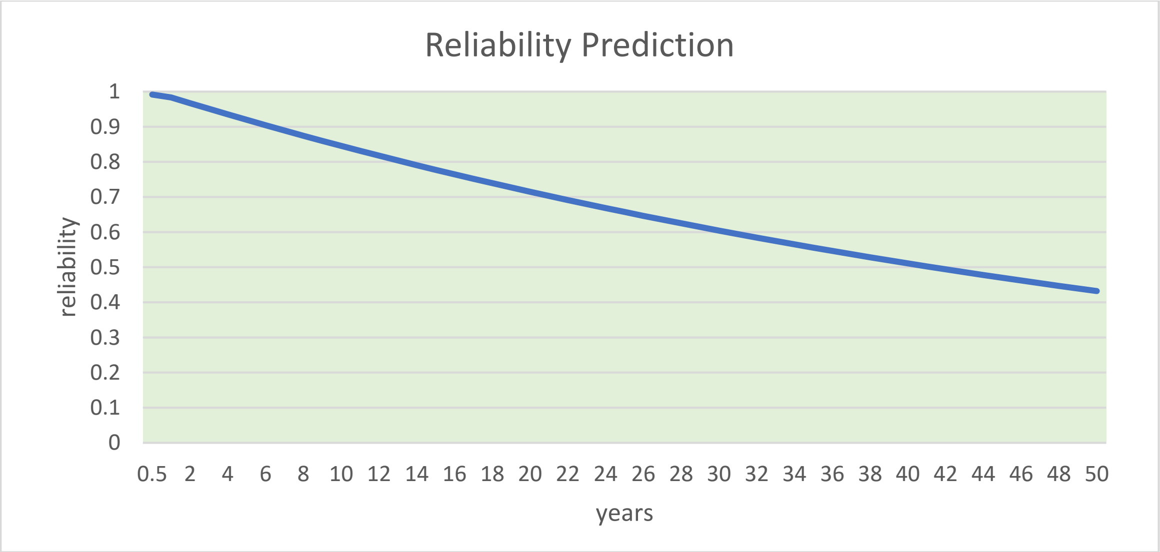


Figure 5. Prediction on the Bogie reliability.

This research conducts initial reliability and prediction of reliability values up to 30 years of operation period as the assumption in this design phase. The strategy is needed to be done so that the bogie system will not experience a significant decline. For this reason, steps need to be developed to minimize the decline in the bogie system, including the following steps:

a) The Bogie system identifies critical components that affect the decline in reliability values
b) Failure mode identifies potential failures that occur in the bogie system
c) Effects on the system. identify potential effects on the system
d) Qualitative analysis drawing up a design to prevent the possibility of a decrease in reliability.
e) Evaluation and calculation are conducted every year to determine the changes that occur in the value of reliability, based on the current data.

Table 5 shows the results of qualitative analysis at the bogie sub-system design stage, and after 30 years, the reliability value is 0.60.

The steps are needed to minimize the decline in reliability values by arranging periodic preventive maintenance procedure designs, designing corrective maintenance procedures, compiling material selection criteria.

5. Evaluation and Re-calculation

The design, evaluation, and re-calculation stages are taken in the evaluation and calculation process. This is to find out the changes that occur and the anticipation that needs to be done. Evaluation and re-calculation procedures need to be compiled by comparing current conditions with previous conditions.

Activities to maintain and increase reliability:

a) Designing preventive maintenance procedures periodically
b) Designing corrective maintenance procedures
c) Develop material selection criteria according to specification
d) Design SOP component installation

CONCLUSION

The conclusions of this study are:

a) The bogie system reliability value prediction in the 30th year is 0.6. its means that the bogie system has decreased reliability below the target.
b) If we target reliability of 0.90, it is necessary then the time (t) obtained is 6 years, meaning that in that period, preventive maintenance is required at least once
c) In the design phase, to maintain the excellence of service quality is to identify critical components that affect the decline in reliability values. Identify potential failures that occur in the bogie system. Identify potential effects of failure on the system and design to minimize the decline in reliability.
d) Procedure in carrying out data management is the main part that must be present in evaluating and re-calculating predictions of reliability value.
e) In the design phase, the steps taken to minimize the decline in reliability values. The steps are arranging preventive maintenance designs, arranging corrective maintenance designs, arranging material selection criteria, arranging the design of installation procedures, and evaluating and re-calculating reliability values.

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