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A Study on Causes of Abnormal Noise That Affecting Ride Quality in MRT Putrajaya Line

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Abstract: MRT Putrajaya Line act as a means of public transport, really paying full attention to ride quality as it is a very crucial thing and acts as a key to success for any public transport. However, the team happened to find out an abnormal noise issue when their train is running on the mainline during the dynamic testing and this may affect the ride quality as it brings discomfort to passengers. Therefore, this paper aims to analyze the possible causes of abnormal noise using a cause and effect diagram and identify the root cause to propose a mitigation plan. By applying quality control tools, an inspection sheet was used to collect the data to find the root cause of abnormal noise. At the same time, the 5W1H method was used for the team to analyze the mitigation plan. Accordingly, the result shows that the Obstacle Device Detector (ODD) produces a loud knocking sound due to excessive vibration from the wheel out-of-roundness. The outcome from the 5W1H analysis resulted in a decision for modification works on the ODD spring where the spring's stiffness was increased from 6.1 *kgf/mm* to 7.8 *kgf/mm* to hold the ODD bar tighter hence reducing the vibration and noise. Next, modification work was made on a cam shaft to remove a plain washer that hits the junction box housing and produces a knocking sound, and lastly the installation of an additional holding bracket to hold the ODD bar from vibrating and causing a metal clicking sound. Hence, this modification is expected to be applied to all trains after they pass testing and receive an approval through Engineering Change Proposal (ECP).

Keywords: MRT Putrajaya Line, Abnormal Noise, Vibration, Obstacle Device Detector

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1. Introduction

Since Klang Valley is expected to have 7 million automobile journeys in 2020 [1], the MRT Putrajaya Line project was built as the 4th transit line in Klang Valley with Fully Automated Operation (FAO) with a rolling stock manufactured by Hyundai Rotem, Apex Communication and Posco Engineering (HAP Consortium). To achieve rail vehicles' success and popularity among passengers and transit operators, ride comfort is the crucial thing to put into account. Ride comfort can be influenced by noise, air humidity, lighting, temperature, ventilation, and, most notably, vehicle vibrations due to track irregularities and wheel untrueness [2]. Since train speed, axle loads, and traffic density is increasing including the maintenance debt due to the short rate of wheel and rail degradation, noise, and vibration issue are becoming more essential [3]. Therefore, to meet the noise requirement, a noise control design was made by HAP and the noise prediction is shown in Table 1 below.

Table 1: Saloon Noise Prediction Results in M-car when traveling at 80 km/h in free field [4]

Space	Air-borne	Structure borne	Static (VAC)	Overall	Average
M1 (Cab)	67.1	65.7	65.0	70.8	71.0
M2 (Door)	68.3	65.2	65.0	71.2	
M3	67.2	63.0	65.0	70.2	
M4 (Door)	67.7	64.0	65.0	70.6	
M5	66.6	62.3	65.0	69.8	
M6 (Door)	68.0	63.9	65.0	70.8	
M7	67.8	63.0	65.0	70.5	
M8 (Door)	69.2	65.2	65.0	71.7	
M9	68.5	65.9	65.0	71.5	
M10 (Gangway)	69.1	67.5	65.0	72.3	

1.1 Vehicle Dynamic

The vehicle body needs to have sufficient static stiffness to maintain the bearing capacity and reasonable dynamic characteristics to keep the vibration and noise under control. As [5] stated, the wheel–rail excitation and aerodynamic excitation in the bogie area are the main sources of vehicle vibration, therefore this study focuses on the underframe subsystem to be inspected. Variances in un-sprung mass and the related usual flaws contribute to extra-variation in vibration production. As a result, a well-designed primary suspension can decrease high-frequency vibrations caused by track irregularity, poor wheel conicity, and creep forces between the wheel and the rail in general [6].

1.2 Rail Noise

As stated by [7] that rolling noise, impact noise, curve sounds, mechanical noise, airborne noise, and structure- and ground-borne noises are all typical noises and vibrations in railway systems. These noises were induced by the unevenness on the rolling surface, aerodynamic noise generated by airflow and turbulence around the train at high speeds, squeal noise due to frictional instability in the tangential wheel-rail contact in sharp radius curves, impact noise at discrete wheel-rail surface irregularities, brake noise, engine noise, etc. [8]. Wayside noise is influenced by auxiliary equipment such as VAC, traction inverter, auxiliary power supply, and air compressor. While for the traction motor noises are composed of most of the cooling system's aerodynamic noise [4]. While the driving gear noise is caused by residual unbalance of gear and contact between wheel gear and pinion gear teeth [4].

1.3 Effect of Wheel-rail Contact Interface

Successful railway transportation requires the optimal performance of the wheel-rail interface, which is why international multidisciplinary research efforts were made in this area [9]. Irregular wheel-rail surface defects or variations in the nominal wheel–rail contact geometry produce railway noise and ground-borne vibration due to wheel–rail impact loads. An abnormality on the wheel or rail might have a potential to be the result of surface wear brought on by rolling contact fatigue (RCF) cracking, which then results in loud knocking noises, or it could be a result of wheel sliding without rolling [3]. Additionally, as discussed by [10], several elements such as wheel and rail materials, lubricants, contact parameters (contact pressure, slip ratio, axle load, curve radius, etc.), and operating environment (water, snow, low temperature) all have a substantial effect on wheel and rail material wear and RCF.

An example of a worn and unworn wheel profile is shown in Figure 1 below. A poorly designed mix of wheel and rail profiles can cause a variety of railway issues. These issues, in turn, result in inefficiency and risk of exploitation. The flange and the tread are the two areas of the wheel that wear the most. The wheel profile varies as wear progresses. Even though this issue can be solved by re-profiling the wheel, there is still minor noise that occurs which leads the team to make a further investigation into other equipment.

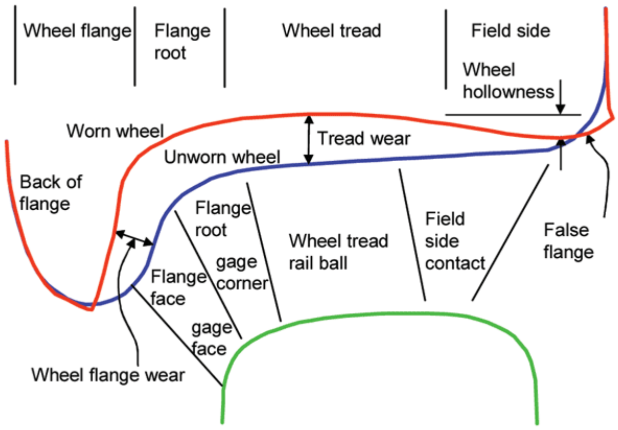

Figure 1: Worn and Unworn Wheel Profile [11]

2. Materials and Methods

2.1 Cause and Effect Diagram (Fishbone Diagram)

Cause and effect diagram, was used to graphically represent the underlying cause of abnormal noise. This diagram was used to analyze four types of possible main cause with another three sub-causes as shown in Figure 2 below. 12 potential sub-causes were identified based on the operators comment. From all the listed sub-causes, only four will be chosen to proceed with inspection as it have the closest possibility to cause the problem.

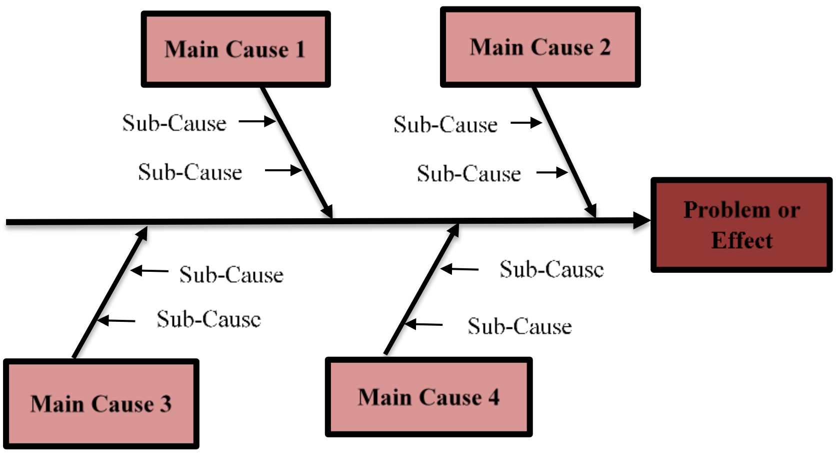

Figure 2: Cause and Effect Diagram (Fishbone diagram)

2.2 Data Collection via Inspection Sheet

In order to find the root cause of abnormal noise, the data collected using inspection sheet based on visual inspection, measurement and noise level observation. Data collection was focusing on the motor car. There are four types of inspection sheet (A/B/C/D), each is for different causes with different inspection checklist. There are visual inspection: torque mark checking, physical condition checking including loose screw, and leakage, measurement inspection and noise level observation. The inspection was made three times including corrective maintenance and recommendation work until zero noise is reported.

2.3 Mitigation Plan

To analyze the mitigation plan, the 5W1H questioning method was used. It is an acronym in which each letter stands for a different question: what, who, where, when, why, and how. The analysis questions produced from this method are presented in Table 2 below. To proceed, HAP team need to produces an Engineering Change Proposal (ECP) to get approval for modification work from the management.

Table 2: Analysis questions based on 5W's1H Method

5W's 1H QUESTION	
Root Cause	Abnormal Noise
Aim	Possible modification work for ODD to control excessive vibration
Description	**Finding**
1. Why	Why ODD receive excessive vibration and produce abnormal noise?
2. Who	Who detected the noise?
3. What	What trigger the ODD to cause abnormal noise?
4. Where	Where the point to be investigated that reported to have an issue?
5. When	When noise usually occur?
6. How	How to overcome the noise issue in short term and long term?

3. Results and Discussion

3.1 Cause and Effect Analysis

The final cause and effect diagram produced is in Figure 3 below. Based on the comment and observation from the operator, only four sub-causes were chosen to be inspected which are, obstacle device detector which seems to have some tolerance to cause vibration, primary suspension that was reported to have faulty, wheel out-of-roundness which is the primary suspect to initiate the vibration and noise as the wheel run on track due to slip and slide and knocking sound and lastly is the current collector that hanging near the wheel which may vibrate is there is any loose screw.

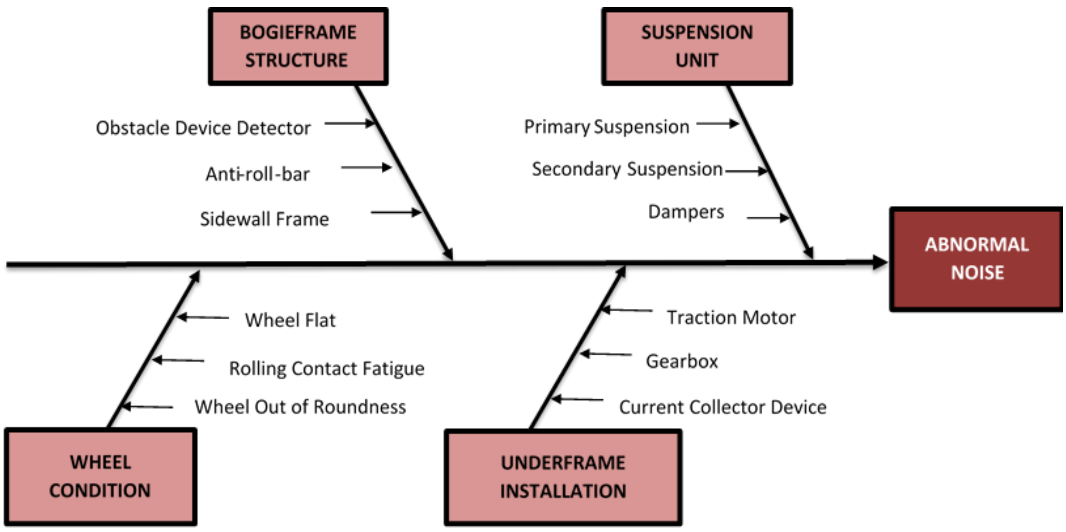

Figure 3: Cause and Effect Diagram for Analysis of Abnormal Noise issue

The main purpose of this table is to tabulate the inspection data and find out the root cause of abnormal noise. From the inspection form, it was summarized into two type of inspection namely; visual and measurement. At the end of all inspection, there will be noise level observation which was done by turnkey contractor. There are three level of noise where 0 = no abnormal noise, 1 = minor noise, and 2 = major noise.

Table 3: Summary of Inspection 1 for ET204

Summary Inspection on ET204						
Issue:	**Abnormal Noise**					
Inspection No.	**1**					
Type	**Inspection Code**	**M1**		**M2**		**Action Taken**
		1 (front)	2 (rear)	1 (front)	2 (rear)	
Visual	**A1**	Ok		Ok		-
	A2	Ok		Ok		-
	A3	Ok		Ok		-
	B1	Ok	Ok	Ok	Ok	-
	B2	Ok	Ok	Ok	Ok	-
	B3	Ok	Ok	Ok	Ok	-
	B4	Ok	Ok	Ok	Ok	-
	C1	Ok	Ok	Ok	Ok	-
	D1	Ok	Ok	Ok	Ok	-
	D2	Ok	Ok	Ok	Ok	-
	D3	Ok	Ok	Ok	Ok	-
Measurement	**A4**	Ok	Ok	Ok	Ok	-
	B5	Ok	Ok	Ok	Ok	-
	B6	Ok	Ok	Ok	Ok	-
	C2	Not Ok	Ok	Not Ok	Not Ok	CM
	C3	Ok	Ok	Ok	Ok	-
	D4	Ok	Ok	Ok	Ok	-
Noise Level	0 - 1 - 2					
Recommendation	Suggestion to machine all wheel and observe noise level on next inspection.		Result	ACCEPTED		
Temporary Countermeasure	Wheel re-profiling					
Permanent Countermeasure	-					

Prepared by	Qasrin Najiha	Checked by	Ir. Nor Effendi Yusof

Table 3 shows an abnormality was founded for inspection 1 at M1 and M2 car, which is wheel run out. It shows the action taken is wheel re-profiling to improve the noise level. However, even after the corrective action, the noise level was still in abnormal condition. From here, wheel run-out is assumed not to be the main issue as there is still minor noise. Further, the team may need to reinspect the design of sub-system used.

Table 4: Summary of Inspection 2 for ET204

Summary Inspection on ET204						
Issue:	**Abnormal Noise**					
Inspection No.	**2**					
Type	**Inspection Code**	**M1**		**M2**		**Action Taken**
		1 (front)	2 (rear)	1 (front)	2 (rear)	
Visual	**A1**	Ok		Ok		-
	A2	Ok		Ok		-
	A3	Ok		Ok		-
	B1	Ok	Ok	Ok	Ok	-
	B2	Ok	Ok	Ok	Ok	-
	B3	Ok	Ok	Ok	Ok	-
	B4	Ok	Ok	Ok	Ok	-
	C1	Ok	Ok	Ok	Ok	-
	D1	Ok	Ok	Ok	Ok	-
	D2	Ok	Ok	Ok	Ok	-
	D3	Ok	Ok	Ok	Ok	-
Measurement	**A4**	Ok	Ok	Ok	Ok	-
	B5	Ok	Ok	Ok	Ok	-
	B6	Ok	Ok	Ok	Ok	-
	C2	Ok	Ok	Ok	Ok	-
	C3	Ok	Ok	Ok	Ok	-
	D4	Ok	Ok	Ok	Ok	-
Noise Level	0 - 1 - 2					
Recommendation	Suggestion to remove ODD to observe if the design may contribute to noise and continue to re-measure the wheel as it seems that ODD is hanging closest to wheel which have the highest possibility to vibrate if the wheel do not have smooth surface.			Result	ACCEPTED	
Temporary Countermeasure	-					
Permanent Countermeasure	Design review					
Prepared by	Qasrin Najiha		Checked by	Ir. Nor Effendi Yusof		

The second inspection in Table 4 was done after wheel re-profiling. Even so, there is still an abnormal noise found even though all item is in good condition. These shows the issue may be from the equipment's design or the installation. But not to forget that the wheel profile runout below 0.4mm was considered OK, whereas 0.3mm runout still may cause minor vibration. Therefore, the operator should keep on measuring the wheel run-out value. Suggestions were made to remove the Obstacle Device Detector (ODD) from the bogie frame and see the noise observation level results.

Table 5: Summary of Inspection 3 for ET204

Summary Inspection on ET204						
Issue:	**Abnormal Noise**					
Inspection No.	**3**					
Type	**Inspection Code**	**M1**		**M2**		**Action Taken**
		1 (front)	2 (rear)	1 (front)	2 (rear)	
Visual	**A1**	Ok		Ok		-
	A2	Ok		Ok		-
	A3	Ok		Ok		-
	B1	Ok	Ok	Ok	Ok	-
	B2	Ok	Ok	Ok	Ok	-
	B3	Ok	Ok	Ok	Ok	-
	B4	Ok	Ok	Ok	Ok	-
	C1	Ok	Ok	Ok	Ok	-
	D1	Ok	Ok	Ok	Ok	-
	D2	Ok	Ok	Ok	Ok	-
	D3	Ok	Ok	Ok	Ok	-
Measurement	**A4**	Ok	Ok	Ok	Ok	-
	B5	Ok	Ok	Ok	Ok	-
	B6	Ok	Ok	Ok	Ok	-
	C2	Ok	Ok	Ok	Ok	-
	C3	Ok	Ok	Ok	Ok	-
	D4	Ok	Ok	Ok	Ok	-
Noise Level	0 - 1 - 2					

Recommendation	-	Result	ACCEPTED
Temporary Countermeasure	-		
Permanent Countermeasure	Design review		
Prepared by	Qasrin Najiha	Checked by	Ir. Nor Effendi Yusof

The third inspection in Table 5 was made after ODD at M1 and M2 car were removed with no out of roundness issue (considering that the 'not ok' out of roundness is above 0.4mm). Based on the result, it shows that abnormal noise issue was solved and this proves that ODD is the root cause of abnormal noise while the wheel out of roundness become the main suspect of vibration.

From here, the team needs to scheme how to solve the ODD issue without removing it as it is a crucial part of train operation. Hence that is why the 5W1H method was used to find the mitigation plan for ODD.

3.3 Mitigation Plan

Based on the question defined above, the finding was made by the operator and turnkey contractor. The findings for each question are presented in Table 6 below:

Table 6: Finding based on 5W1H Method

5W's 1H STRATIFICATION

Root Cause	Abnormal Noise
Aim	Possible modification work for ODD to control excessive vibration
Description	**Finding**
Why	• The vibration was transferred from wheel out of roundness to the ODD. • The ODD spring that holds the bar from swinging is not strong enough.
Who	• The noise was detected by the operator
What	• ODD bar vibrates vertically and hit the bar holder • ODD bar swings excessively and hit the stopper pin • ODD cam shaft swings excessively and hit the ODD junction box housing
Where	• ODD Stopper Pin • ODD Cam Shaft • ODD Junction Box Housing • ODD Bar Holder
When	• During train movement at the mainline
How	• Try to implement new spring with higher compression. • Implement additional holding bracket to hold the bar firmly towards existing bar holder. • Added a rubber at the bar holder to prevent metal collision sound.

After a thorough observation based on the 5W1H method, there are a few suggestions for modification that can be made for ODD, such as:

i. Spring modification as shown in Table 7 below:

Table 7: Spring Modification for Obstacle Device Detector (ODD)

Parameters of Spring	Original	New	Unit
Stiffness	6.106	7.874	*kgf/mm*
Free Height	148	152	*mm*
Detection Height	134.1	131.6	*mm*
Obstacle Detection Force (static)	170	187	*kgf*

ii. Cam modification to remove plain washer to ensure there is a gap between the shaft and the junction box housing as Figure 4 and Figure 5 below.

Figure 4: Defect on junction box housing due to shaft's bolt

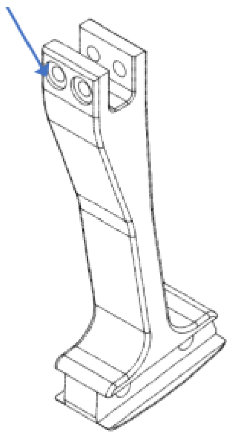

Figure 5: Removal of washer at camshaft

iii. Installation of additional holding bracket to control the vibration between the bracket and bar holder as shown in Figure 6 below.

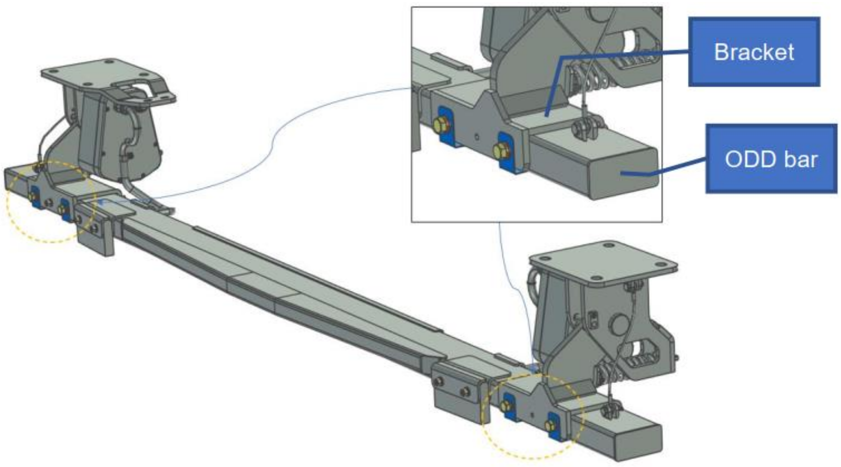

Figure 6: Installation of holding bracket to hold ODD bar from vibrating

4. Conclusion

The potential causes of abnormal noise were successfully analyzed and narrowed down the scope using the cause and effect diagram. At the end of the analysis, four sub-causes were chosen to proceed with the inspection to find the root cause of the abnormal noise issue. The data of inspection based on the maintenance work done was collected using an inspection sheet. The result from the inspections shows that the Obstacle Device detector (ODD) experiencing excessive vibration due to wheel out-of-roundness and producing a loud noise. The mitigation plan was also successfully proposed based on the discussion using the 5W1H method where the team made modification works on ODD such as spring modification, cam shaft modification, and installation of an additional holding bracket. The modification was done on the spring after analyzing the condition of the ODD bar vibrating excessively where the spring's stiffness will be increased from 6.1 kgf/mm to 7.8 kgf/mm to hold the ODD bar tighter which then reduces the swinging of the ODD bar. While on the cam shaft, the washer needs to be removed after founding a damage at the junction box housing where the team suspected that the cam shaft swings and hit the box which results in a knocking sound. Lastly, suggestions were made to reduce the noise by controlling the vibration by using additional holding brackets to hold the ODD bar from moving freely.

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