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JAMEA

http://penerbit.uthm.edu.my/ojs/index.php/jamea

e-ISSN : 2716-6201

Journal of Advanced Mechanical Engineering Applications

Intercity Rail Maintainability Analysis: A Case Study on Rolling Stock Maintenance Compliance

Nuramira Najihah Baharin[1], Shahmir Hayyan Sanusi[1*], Nor Aziati Abdul Hamid[2], Amirul Afif Jumiran[3]

[1]Department of Mechanical Engineering, Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, MALAYSIA

[2]Department of Production and Operations Management, Faculty of Technology Management and Business
Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, MALAYSIA

[3]Department of Maintenance, Keretapi Tanah Melayu Berhad (KTMB) Depot, 31000 Batu Gajah, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/jamea.2022.03.01.007
Received 03 June 2022; Accepted 30 June 2022; Available online 20 July 2022

Abstract: Compliance to organizational standard is essential for maintaining high work performance within the appropriate timescale which can result in reduction of maintenance expenses. The purpose of this study was to analyze the compliance level of preventive maintenance activities based on job frequency and its working hours. Historical data of preventive maintenance from 2019 - 2020 obtained from a field study at Keretapi Tanah Melayu Berhad (KTMB) Depot Batu Gajah, Perak, was analyzed to investigate the frequency, manhours, and the cost involved for each type of preventive maintenance activities namely Exam A, B C and D involving ETS Class 91. The examination concerning manhours compliance was conducted in accordance with the organization's standard, as specified in the KTMB Operation and Maintenance manual based on the highest duration of maintenance and labors. From the results, Exam A contributed to the highest non-compliance practice compared to the other Exam where the highest non-compliance percentage (32%) was recorded in 2020 which results in losses of RM RM2,552.82. This study is beneficial for the organization as it determines irregular downtime and manhours compliance for rolling stock system maintenance to shape for a better future maintenance plan that will results in efficient operation and higher revenue.

Keywords: Intercity rail, rolling stock, preventive maintenance, manhours compliance, manhours cost

1. Introduction

Rolling stock (train) is one of the most important aspects that reflects the service quality of a rail system. It comprises several subsystems, such as the car body, bogie and braking system, power supply and signaling [1]. A well-functioning and well-maintained rolling stock system are essential to attaining the railway system's performance improvement objective. However, it is difficult to objectively measure the system's performance due to the many components and complex structures.

Generally, equipment that has deteriorated owing to a lack of maintenance or poor planning will need to be replaced at a higher cost. Rolling stock maintenance expenses represent 30% of the asset's total life-cycle costs; 60% of these costs are mostly attributed to labor, while 10% are dedicated to replacement parts [2]. Failure in the railway systems, whether

**Corresponding author: shahmir@uthm.edu.my*

caused by mechanical, electrical, or signaling faults, will lead to service disruption and result in injuries or, worst case, fatalities. Examples of incidents that are caused due to system failure in the Malaysia Intercity network possibly due to improper maintenance was reported in 2020, where several passengers were heavily injured [3]. This incident highlights the need for an effective maintenance plan to ensure the train and its whole system is in good condition for the safety of the passengers.

Previous studies have shown that brakes and wheels are the most worn components of the rolling stock [4]. Due to the constant strain of fast acceleration and deceleration and braking along the railway track, brakes and wheels on rolling stock are extremely susceptible to wear [5]. A vehicle performance issue, such as a breakdown, could result in an accident. In addition, rolling stock investment appraisal is a complex problem. There are also a variety of supply-side effects, including enhanced availability, lower operating costs, less track wear and tear, and less downtime [6]. A previous study has indicated that the cost of manhours is among the largest proportions of rolling stock's total cost of ownership. By comparing the actual maintenance practice to the organization's standard, the organization may be able to implement the best practices for maintaining the maintainability of the trains, thus lowering the manhours costs to the greatest extent possible. Few studies have been conducted on the impact of maintenance activities on lifetime value in the railway industry. Most research in this field has been on improving railway infrastructure management. Consequently, this study will determine irregular downtime and manhours compliance for rolling stock system maintenance. Since maintainability is based on the duration of maintenance and renewal activities, it is essential for maintenance management to comprehend maintainability [7]. This project lays the groundwork for Keretapi Tanah Melayu Berhad (KTMB) to manage the maintainability of their maintenance plan and improve train repair operations at the same time.

Preventive maintenance (PM) is the maintenance and service provided by maintenance teams to keep all equipment in good working order by systematically examining, recognizing, and repairing basic defects before they become major problems [8,9]. To attain a level of service, it is necessary to continually improve the performance of the rolling stock, which can be accomplished with proper maintenance. The complex integration of the rolling stock system can be redistributed and reformed into embedded systems combined to provide a high-quality transportation service. Short term benefits include low maintenance costs for non-essential system equipment, while long-term benefits include steady operation for more significant and critical equipment or systems [10]. Previous scholars mentioned that the highest rank of maintenance strategies was corrective and preventive maintenance [11]. In state-owned railroad companies, design and maintenance were once entirely separate procedures [2]. A maintenance job card is used as a reference for the maintenance team to perform preventative maintenance activities based on train distance traveled where the classification of preventive maintenance activities adopted by KTMB is shown in Table 1.

2. Research Methodology

This study focuses mostly on irregular downtime, a high number of personnel, the frequency of maintenance activities, and the compliance rate with working hours. In addition, the methodology offers ways for determining the frequency of maintenance tasks and compliance details. As illustrated in Fig 1, the study flowchart is separated into three phases (Phase 1, Phase 2, and Phase 3). Phase 1 consists of literature reviews and a study on the configuration of rolling stock. The second phase focuses on gathering maintenance information collected from job cards as well as the employees' payroll. The third phase examines and validates the frequency of preventive maintenance operations on rolling stock and the level of compliance standards based on an examination of working hours compliance and man hours cost.

2.1 Phase 1: Literature Review

Recognizing the current issue and determining the project's objectives were the first steps conducted for this study. To aid better understanding, research and related activities were undertaken using a variety of sources, such as books, journals, and technical papers. To gain a better grasp of the railway Reliability, Availability and Maintainability (RAM) standard, the EN50126 standard was first reviewed [12]. The KTMB Operation and Maintenance manual [13] was referred to acquire a better understanding on the configuration and operation of the rolling stock system.

2.2 Phase 2: Data Collection (Record Review)

In this phase, a field investigation was conducted at the KTMB Batu Gajah Depot to collect the maintenance team's historical data. To examine the preventive maintenance frequency, it is necessary to collect data of rolling stock examination such as job cards that involve Exam A, B, C, and D. The examination concerning manhours compliance was conducted in accordance with the organization's standard, as specified in the KTMB Operation and Maintenance manual based on the highest duration of maintenance and labors. The classification of preventive maintenance activities adopted by KTMB is shown in Table 1.

Table 1 - Classification of KTMB preventive maintenance based on mileage

Exam	Mileage
A	Examination every 5,000 km
B	Examination every 45,000 km
C	Examination every 90,000 km
D	Examination every 180,000 km

2.3 Phase 3: Analyzing and Validating Data

The preliminary findings were based on the data from job cards. The following parameters were required to analyze the data:

- Date and time of maintenance operations (Fig. 2a)
- Number of labors involved in maintenance activities (Fig. 2b)
- Distance traveled (Fig 2a)
- Maintenance activities' duration (Fig 2a)
- Observations reported by the maintenance crew (Fig 3)

These indicators were studied independently to determine the frequency of maintenance activities and the level of standard maintenance compliance (Fig 4). After examining the data provided by the company, multiple meetings and discussions were held with the maintenance team to confirm the findings.

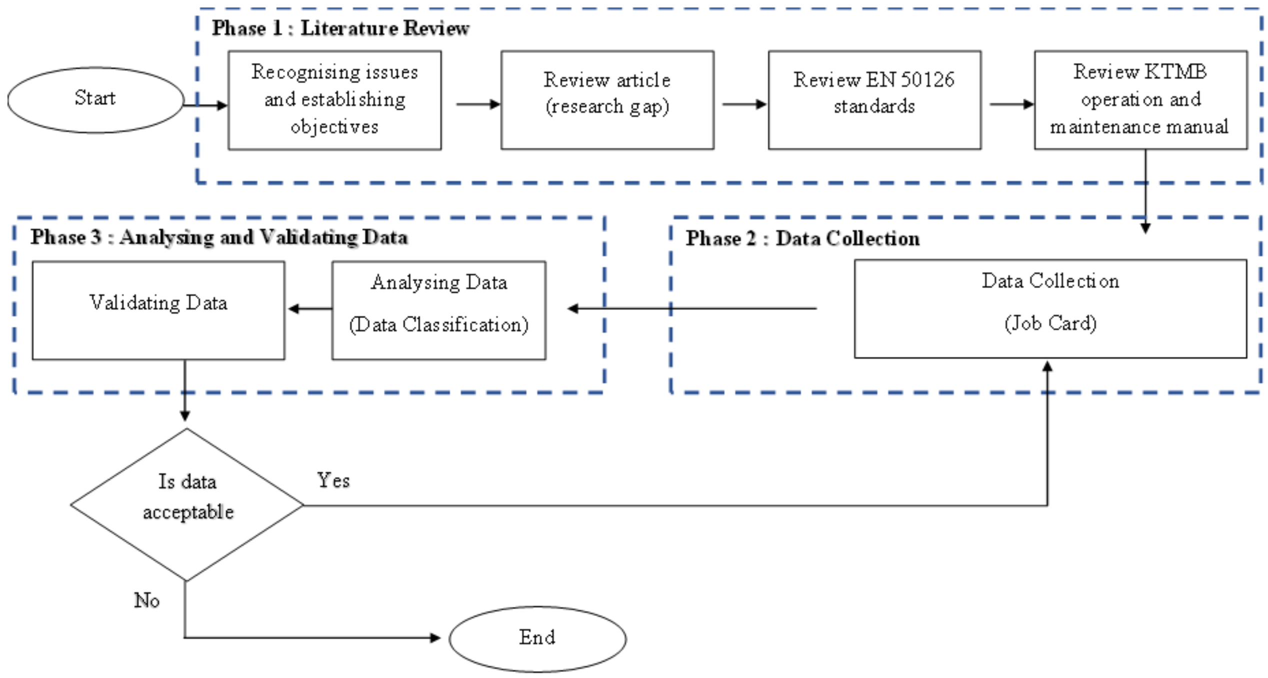
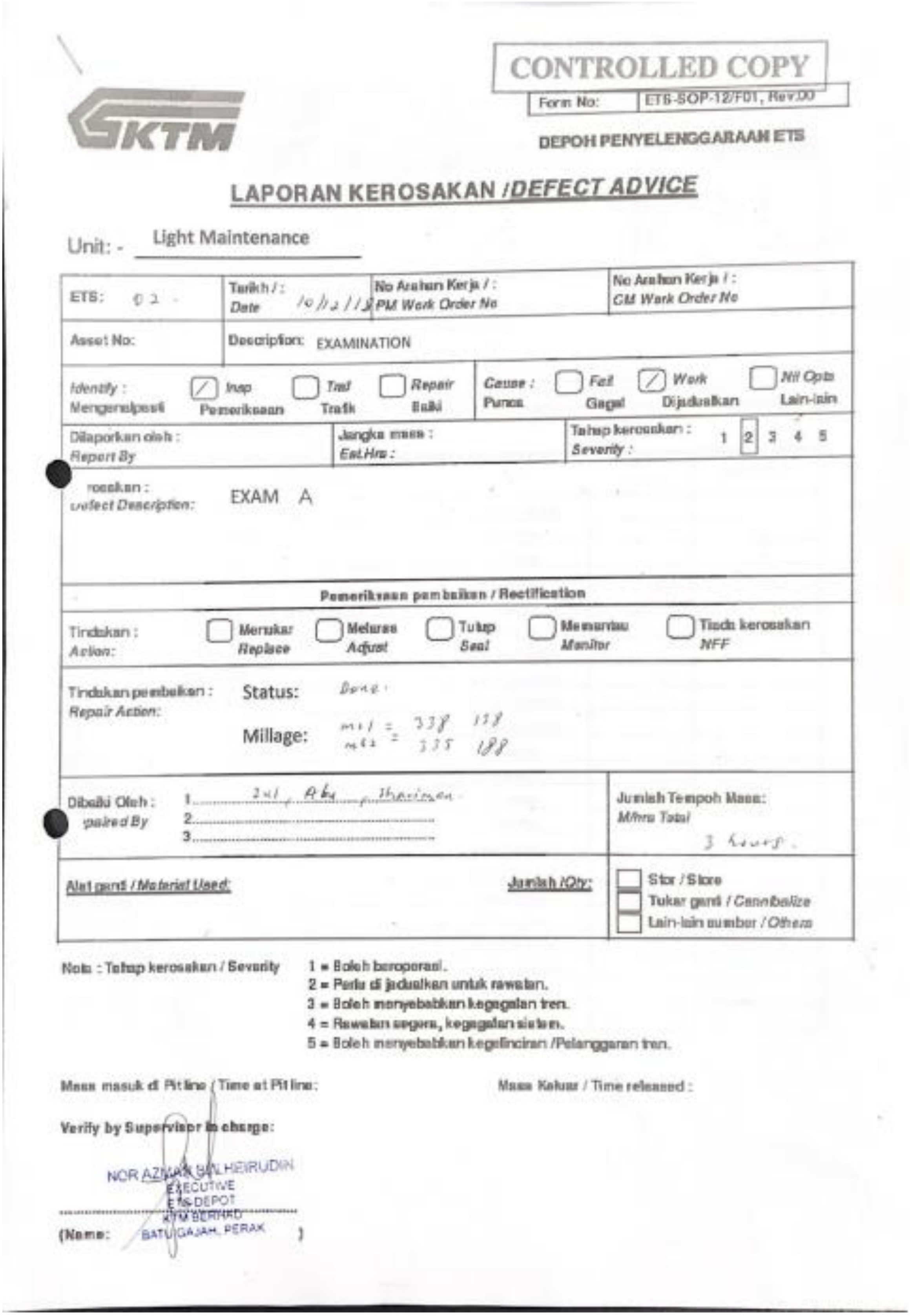


Fig. 1 - Study flowchart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Form No: ETS-SOP-12/F01, Rev.00

DEPOH PENYELENGGARAAN ETS

LAPORAN KEROSAKAN /DEFECT ADVICE

Unit: - Light Maintenance

ETS: 02	Tarikh / : Date 10/12/19	No Arahan Kerja / : PM Work Order No	No Arahan Kerja / : CM Work Order No
Asset No:	Description: EXAMINATION		
Identify : Mengenalpasti	[/] Insp Pemeriksaan [ ] Traf Trafik [ ] Repair Baiki	Cause : Punca	[ ] Fail Gagal [/] Work Dijadualkan [ ] Nil Opts Lain-lain
Dilaporkan oleh : Report By	Jangka masa : Est.Hrs :	Tahap kerosakan : Severity :	1 [2] 3 4 5
...rosakan : Defect Description:	EXAM A		

Pemeriksaan pembaikan / Rectification

Tindakan : Action:	[ ] Menukar Replace	[ ] Melaras Adjust	[ ] Tutup Seal	[ ] Memantau Monitor	[ ] Tiada kerosakan NFF

Tindakan pembaikan : Repair Action:
Status: Done.
Millage: m1 = 338 138
m2 = 335 188

Dibaiki Oleh : ...paired By
1. 241, Abu, Ibrahim
2.
3.

Jumlah Tempoh Masa: M/hrs Total
3 hours.

Alat ganti / Material Used: Jumlah /Qty:
[ ] Stor / Store
[ ] Tukar ganti / Cannibalize
[ ] Lain-lain sumber / Others

Nota : Tahap kerosakan / Severity
1 = Boleh beroperasi.
2 = Perlu di jadualkan untuk rawatan.
3 = Boleh menyebabkan kegagalan tren.
4 = Rawatan segera, kegagalan sistem.
5 = Boleh menyebabkan kegelinciran /Pelanggaran tren.

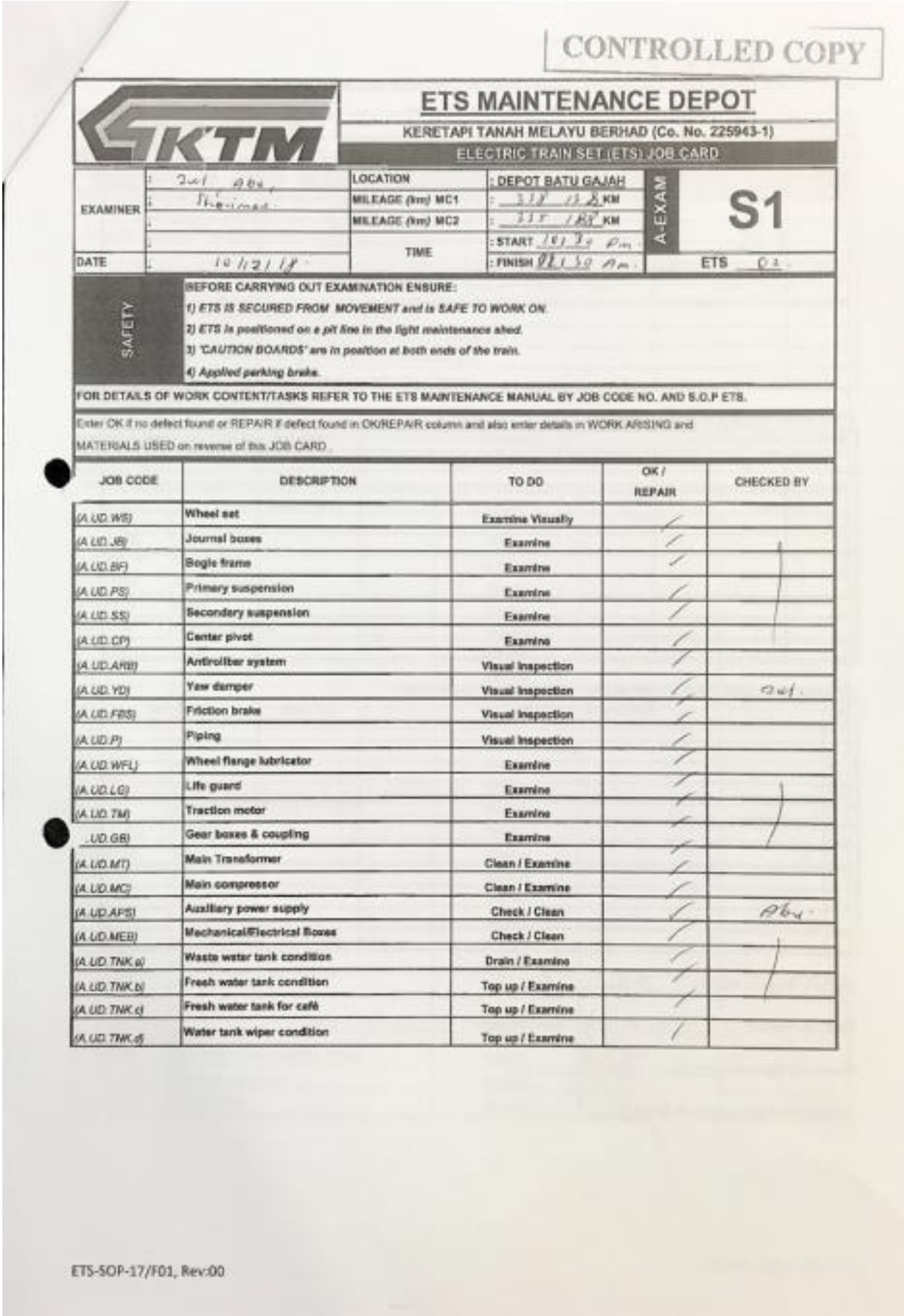
Masa masuk di Pit line / Time at Pit line: Masa Keluar / Time released :

Verify by Supervisor in charge:

NOR AZMAN BIN HEIRUDIN
EXECUTIVE
ETS DEPOT
KTM BERHAD
BATU GAJAH, PERAK

(Name:)

a)



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KTM

ETS MAINTENANCE DEPOT

KERETAPI TANAH MELAYU BERHAD (Co. No. 225943-1)

ELECTRIC TRAIN SET (ETS) JOB CARD

EXAMINER		LOCATION	: DEPOT BATU GAJAH	A-EXAM	S1
		MILEAGE (km) MC1	: KM		
		MILEAGE (km) MC2	: KM		
		TIME	: START		
DATE	:		: FINISH		ETS

SAFETY

BEFORE CARRYING OUT EXAMINATION ENSURE:

1) ETS IS SECURED FROM MOVEMENT and is SAFE TO WORK ON.

2) ETS is positioned on a pit line in the light maintenance shed.

3) 'CAUTION BOARDS' are in position at both ends of the train.

4) Applied parking brake.

FOR DETAILS OF WORK CONTENT/TASKS REFER TO THE ETS MAINTENANCE MANUAL BY JOB CODE NO. AND S.O.P ETS.

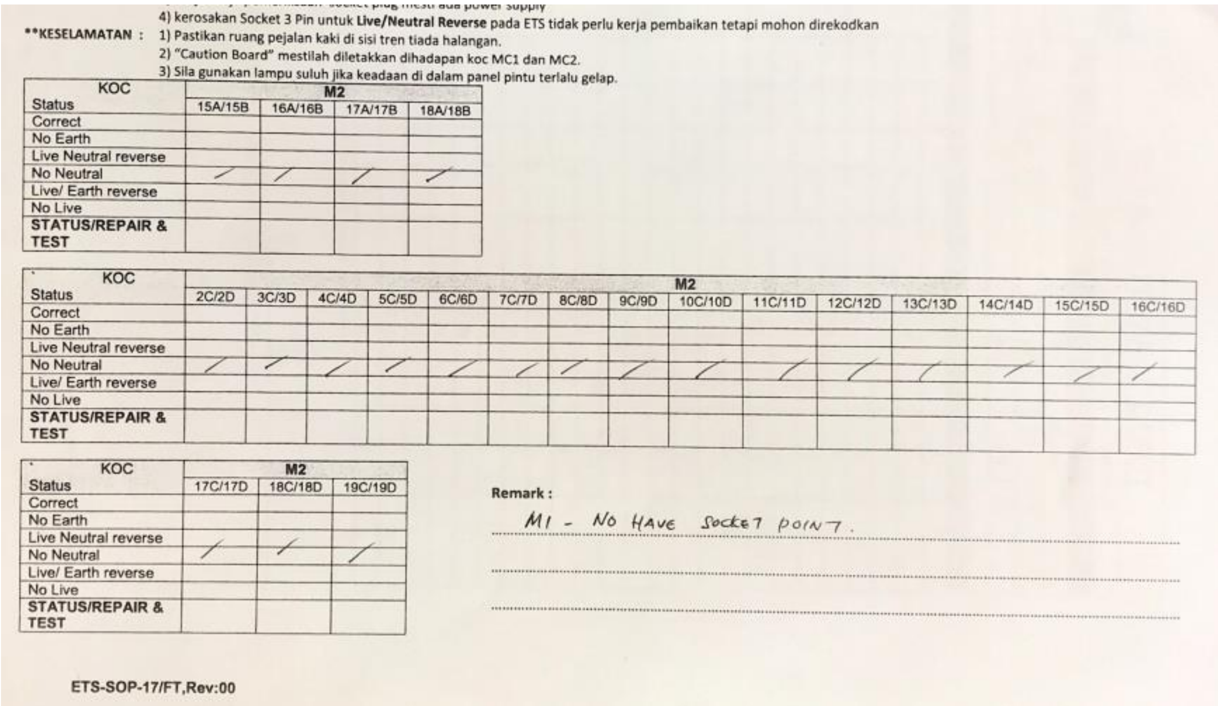
Enter OK if no defect found or REPAIR if defect found in OK/REPAIR column and also enter details in WORK ARISING and MATERIALS USED on reverse of this JOB CARD.

JOB CODE	DESCRIPTION	TO DO	OK / REPAIR	CHECKED BY
(A.UD.WS)	Wheel set	Examine Visually	✓	
(A.UD.JB)	Journal boxes	Examine	✓	
(A.UD.BF)	Bogie frame	Examine	✓	
(A.UD.PS)	Primary suspension	Examine	✓	
(A.UD.SS)	Secondary suspension	Examine	✓	
(A.UD.CP)	Center pivot	Examine	✓	
(A.UD.ARB)	Antiroliber system	Visual Inspection	✓	
(A.UD.YD)	Yaw damper	Visual Inspection	✓	
(A.UD.FBS)	Friction brake	Visual Inspection	✓	
(A.UD.P)	Piping	Visual Inspection	✓	
(A.UD.WFL)	Wheel flange lubricator	Examine	✓	
(A.UD.LG)	Life guard	Examine	✓	
(A.UD.TM)	Traction motor	Examine	✓	
.UD.GB)	Gear boxes & coupling	Examine	✓	
(A.UD.MT)	Main Transformer	Clean / Examine	✓	
(A.UD.MC)	Main compressor	Clean / Examine	✓	
(A.UD.APS)	Auxiliary power supply	Check / Clean	✓	
(A.UD.MEB)	Mechanical/Electrical Boxes	Check / Clean	✓	
(A.UD.TNK a)	Waste water tank condition	Drain / Examine	✓	
(A.UD.TNK b)	Fresh water tank condition	Top up / Examine	✓	
(A.UD.TNK c)	Fresh water tank for café	Top up / Examine	✓	
(A.UD.TNK d)	Water tank wiper condition	Top up / Examine	✓	

ETS-SOP-17/F01, Rev:00

b)

Fig. 2 - Job Card Sheet



4) kerosakan Socket 3 Pin untuk **Live/Neutral Reverse** pada ETS tidak perlu kerja pembaikan tetapi mohon direkodkan

**KESELAMATAN :
1) Pastikan ruang pejalan kaki di sisi tren tiada halangan.
2) "Caution Board" mestilah diletakkan dihadapan koc MC1 dan MC2.
3) Sila gunakan lampu suluh jika keadaan di dalam panel pintu terlalu gelap.

KOC	M2			
Status	15A/15B	16A/16B	17A/17B	18A/18B
Correct				
No Earth				
Live Neutral reverse				
No Neutral	✓	✓	✓	✓
Live/ Earth reverse				
No Live				
STATUS/REPAIR & TEST				

KOC	M2														
Status	2C/2D	3C/3D	4C/4D	5C/5D	6C/6D	7C/7D	8C/8D	9C/9D	10C/10D	11C/11D	12C/12D	13C/13D	14C/14D	15C/15D	16C/16D
Correct															
No Earth															
Live Neutral reverse															
No Neutral	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Live/ Earth reverse															
No Live															
STATUS/REPAIR & TEST															

KOC	M2		
Status	17C/17D	18C/18D	19C/19D
Correct			
No Earth			
Live Neutral reverse			
No Neutral	✓	✓	✓
Live/ Earth reverse			
No Live			
STATUS/REPAIR & TEST			

Remark : M1 - NO HAVE SOCKET POINT.

ETS-SOP-17/FT,Rev:00

Fig. 3 - Job Card Checklist

Preventive Maintenance	Unit	Downtime	Man Power	Duration (Hours)	ManHour (Include OT if required)	Total ManHours	Remarks
Daily Inspection	Shift 1	2 set operation	4	2	8	18	1. Work regarding to set will stable at depot while waiting next train operation
	Shift 2	1 set operation	2	1	2		
	Shift 3	2 set Operation	4	2	8		
A Exam	Shift 1	-			0	9	1. Work will perform at night only and depend on manpower on that day
	Shift 2	-			0		
	Shift 3	3 hours	3	3	9		
B Exam	Shift 1	-			0	25	1. Work will perform at night and continued due to extra job from A Exam
	Shift 2	3 hours	2	5	10		
	Shift 3	5 hours (Start)	3	5	15		
C Exam	Shift 1	2 days	3	19	57	96	1. Due lack floating spare readiness, several works unable to perform. (Air System & Propulsion) 2. Required more time for proceed service on the spot.
	Shift 2		2	12	24		
	Shift 3		3	5	15		
D Exam	Shift 1	2.5 days	3	27	81	128	1. Due lack floating spare readiness, several works unable to perform. (Air System & Propulsion) 2. Required more time for proceed service on the spot. 3. Required commissioning test work
	Shift 2		2	16	32		
	Shift 3		3	5	15		

Fig. 4 - KTMB Maintenance Standard [13]

Calculating the Revenue Percentage:

$$Revenue\ Percentage = \frac{Revenue}{Organization's\ Standard\ Cost} * 100\%$$

$$Revenue\ Percentage = \frac{-RM2552.82}{RM8073.61} * 100\%$$

$$Revenue\ Percentage = -32\%$$

3. Result and Discussion

Four types of PM activities were conducted by KTMB to ensure that repairs and replacements are performed in a timely manner to ensure optimal operation which consist of Exam A, B, and C as depicted in Fig. 5, with a total of 76 activities recorded. Based on the results, it can be deduced that the frequencies of Exam A recorded among the highest compared to Exam B and C. This is because Exam A was conducted every 5,000-kilometer mileage whereas Exam B and C are conducted every 45,000 kilometer and 90,000-kilometer mileage respectively. Through these discoveries, a comparative analysis was undertaken between the maintenance team's actual practices and the organization's standards. The percentage compliance chart for the maintenance team's man hours was displayed in a dark blue line.

In January and March of 2019, the maintenance department successfully adhered to the organization's maintenance standards. This can be demonstrated when both months accomplished 100 percent compliance in respect to the manhour's standards. In December and May, the respective percentages were 86% and 75%, respectively. Even though August 2019 recorded the highest frequency of maintenance activities, the percentage of compliance in that month was at the third lowest level. Factors that contributed to the low compliance percentage were due to long maintenance periods or large numbers of manpower or both. However, the lowest percentage of maintenance standards compliance was recorded in September, with a compliance percentage of 25%. This has contributed to increased maintenance costs and decreased train availability due to the comparatively long repair time and noncompliance with the organization's standards.

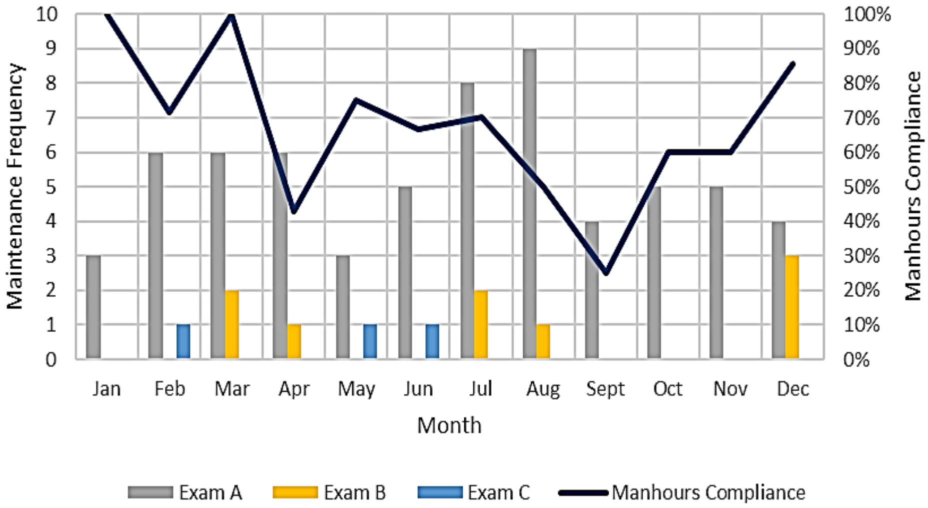


Fig. 5 - Preventive maintenance 2019

The frequency of maintenance activities performed in 2020 is depicted in Fig 6. In 2020, 57 maintenance actions were recorded compared to 76 maintenance activities in 2019. Compared to the preceding year of the COVID-19 epidemic, train service has decreased substantially [14]. As a result of the Movement Control Order (MCO) implemented to prevent the outbreak from spreading [15], there are limited trains in operation. In 2020, due to the COVID-19 pandemic, the least amount of maintenance work was performed. PM Exam A in 2020 recorded the fewest frequency compared to Exam A in 2019. Based on the findings, no maintenance works were documented as of April 2020. This is due to the MCO being implemented in March 2020. As a result, fewer trains are operating to meet passengers' n,eeds and the maintenance operations resumed back in May onwards. As a result, many trains began operating to accommodate the demands of the passengers. Exam A was taken less frequently in October 2020.

Based on the frequency of PM's actions, an additional study was conducted to investigate the level of maintenance compliance with the organization's standard. The percentage compliance chart for the maintenance team's man hours was displayed in the green line. According to the results, the level of adherence to the organization's requirements was 100% in May 2020, with only a single maintenance activity was documented, and the maintenance staff successfully adhered to the maintenance standard. From January through March 2020, a reduction in maintenance compliance rates was observed. This is mainly due to the lack of maintenance actions during the relevant period. Therefore, there was a modest reduction in man hours. In April 2020, there were no maintenance operations recorded. The proportion of compliance with maintenance man hours is therefore not reported. Nonetheless, as of November 2020, no compliance level with respect to maintenance operating hours was documented. Yet, two maintenance actions were performed over the period. Nevertheless, neither activity meets the organization's maintenance specifications.

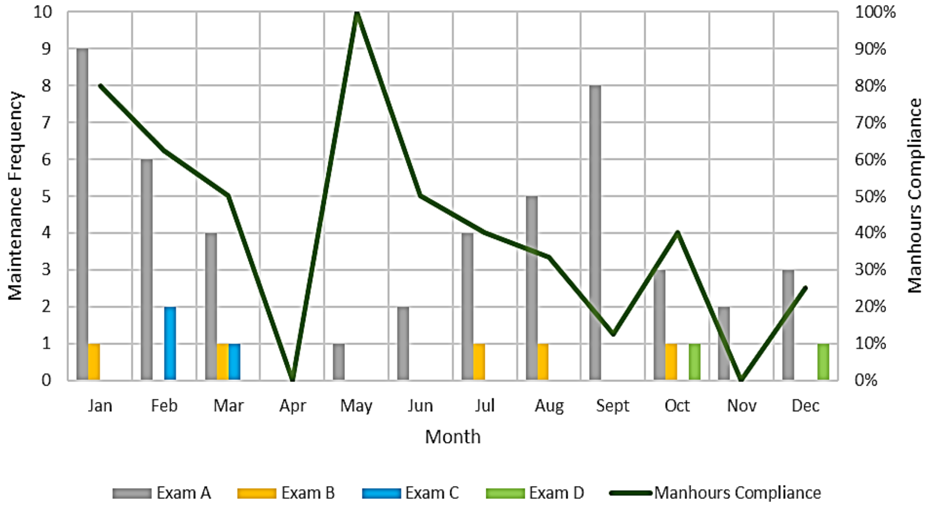


Fig. 6 - Preventive maintenance 2020

Table 2 - Summary of maintenance compliance for 2019 and 2020

2019								
Exam	Quantity	Non-Compliance (%)	Actual Practice		Organization's Standard		Revenue	Revenue Percentage
			Manhours	Cost	Manhours	Cost		
A	64	39%	588.5	RM11,232.43	576	RM10,993.85	-RM238.58	-2%
B	9	0	63.5	RM1,212.00	135	RM2,576.68	RM1,364.69	53%
C	3	0	7	RM133.61	171	RM3,263.80	RM3,130.19	96%
Total	76		659	RM12,578.03	882	RM16,834.33	RM4,256.30	25%
2020								
Exam	Quantity	Non-Compliance (%)	Actual Practice		Organization's Standard		Revenue	Revenue Percentage
			Manhours	Cost	Manhours	Cost		
A	47	62%	556.75	RM10,626.43	423	RM8,073.61	-RM2,552.82	-32%
B	5	40%	64	RM1,221.54	75	RM1,431.49	RM209.95	15%
C	3	0%	14	RM267.21	171	RM3,263.80	RM2,996.59	92%
D	2	0%	23.5	RM448.53	162	RM3,092.02	RM2,643.49	85%
Total	57		658.25	RM12,563.71	831	RM15,860.91	RM3,297.20	21%

Overall, compliance with standards is essential and has been the focus of this study. The summary of maintenance compliance for 2019 and 2020 was tabulated in Table 2. Exam A in 2019 and 2020 does not meet the defined implementation standards based on the findings. This has resulted in losses of revenue of RM 238.58 in 2019 and RM 2552.82 in 2020 where 2020 has recorded the highest percentage of losses (32%) since the cost of the maintenance activity exceeds the standard cost. Therefore, it can be inferred that complying with the standard is essential for reducing unscheduled downtime, which in turn reduces the cost of manhours.

4. Conclusion and Recommendation

The maintenance data and information for 2019 and 2020 were evaluated to determine the frequency of each type of maintenance activity. Train maintenance is performed in stages proportional to the distance traveled by train. According to the study's findings, Exam A was conducted more frequently than the other Exams in both 2019 and 2020. Based on the frequency of maintenance activities, further examination of the maintenance workforce's compliance was conducted.

The purpose of the study was to evaluate the maintenance team's actual practices to the organization's established guidelines. Based on the findings, within 2 years (2019 – 2020), only 3 times 100% compliance was recorded which was in January 2019, March 2019, and May 2020. September 2019 recorded the lowest manhours compliance percentage due to a combination of factors, including a lengthy maintenance duration, a significant volume of labor, or both. Compared to 2019, findings from 2020 indicate that the frequency of maintenance actions has dropped significantly. This is due to the global outbreak caused by the Covid-19. Thus, train operations are limited because of MCO enforcement. Overall, Exam A does not meet the set implementation standards which result in total losses of RM 2791.40 in terms of man-hours cost.

This study proves that the train maintainability may be determined by analyzing the frequency of maintenance activities performed, and the train availability and manpower can be determined by comparing the number of manhours in compliance. As a result, it can be deduced that adhering to the standard is critical for decreasing downtime, which minimizes the cost of manhours. However, the analysis of the train's maintainability, including the replacement cost, requires significantly more effort. It is anticipated that the outcome of this study will aid local railroad operators by improving train quality through time-consuming maintenance procedures. Simultaneously, the suggested method would provide a rapid and cost-effective strategy in which disruptions and downtime in train operations may be minimized when the train is in good condition following maintenance.

Acknowledgement

This research is supported by the Ministry of Higher Education through Konsortium Kecemerlangan Penyelidikan (KKP) No K346 and Universiti Tun Hussein Onn Multidisciplinary Research Grant (MDR) No H475. Sincere gratitude to the Maintenance Department of KTMB Malaysia for all the support and assistance they provided throughout the period of this project.

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