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Reliability-Centered Maintenance (RCM) Application for 15-Ton Overhead Traveling Crane in Kuala Lumpur Additional Vehicle 27 (KLAV27) Project Facility at Hartasuma Sdn. Bhd. (HSB)

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Abstract: Reliability-Centered Maintenance (RCM) is a maintenance strategy that uses a systematic approach to identify and prevent failures in critical assets. The problem that occurred from this project is the 15-ton overhead traveling crane failure caused the Kuala Lumpur Additional Vehicle 27 (KLAV27) project to be delayed. Besides, the current preventative maintenance checklist that is used in Hartasuma Sdn. Bhd. (HSB) for overhead cranes, is not efficient as it only had monthly maintenance. The factor of failure for the crane was identified which the improper maintenance is the main factor for the crane failure. The analysis of the current preventative strategy showed that it is not tailored to the specific needs of the crane, and it does not consider the risks associated with each failure mode. The RCM analysis of the 15-ton overhead traveling crane has been conducted and identified several potential failure modes and a new preventative maintenance checklist was proposed to replace the current one. The new RCM strategy is expected to reduce the risk of equipment failure, improve the safety of the crane, and save costs. The findings of the research were used to improve the maintenance of the overhead traveling crane at HSB.

Keywords: RCM, FMEA, Overhead Traveling Crane, KLAV27, HSB

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1. Introduction

Reliability-Centered Maintenance (RCM) is a maintenance strategy that focuses on preventing failures of critical assets [1]. RCM involves a systematic approach to identifying potential failure modes in critical assets, analyzing the consequences of failures, and implementing maintenance tasks and procedures to prevent failures [2]. In the context of the Kuala Lumpur Additional Vehicle 27 (KLAV27) project at Hartasuma Sdn. Bhd. (HSB), RCM could be used to identify and prioritize maintenance activities for the 15-ton overhead traveling crane. The crane is a critical asset that is used to move heavy loads such as the train car body, and any unplanned downtime can have a significant impact on productivity. RCM can be used to identify and prioritize maintenance tasks that will help to prevent unplanned downtime and improve safety [3]. By using RCM, HSB can ensure that the crane is available when it is needed, and that workers are safe while operating the crane. This can reduce downtime, improve safety, and increase the overall efficiency of the facility.

The 15-ton overhead traveling crane at the KLAV27 project facility at HSB is experiencing several unplanned downtimes. This is causing significant delays and cost overruns on the project. Moreover, the current preventative maintenance only has monthly inspection which is not effective to ensure the crane to be always in good condition. The root causes of the unplanned downtime are due to a combination of factors, including lack of preventive maintenance. Preventive maintenance is important because it can help to identify and fix potential problems before they cause a failure. The implementation of an RCM program is expected to reduce the rate of unplanned downtime for the 15-ton overhead traveling crane. By identifying and addressing the root causes of failures, RCM can help to reduce downtime and improve the overall reliability of an asset [4]. The implementation of an RCM program is expected to lead to improved productivity and reduced costs for the KLAV27 project facility at HSB. This is because the crane will be available when it is needed, and there will be fewer delays due to unplanned downtime.

The objective of this paper is to investigate the factors that have caused the failures of the 15-ton overhead traveling crane in Kuala Lumpur Additional Vehicle 27 (KLAV27) project facility at Hartasuma Sdn. Bhd. (HSB). Next, it is to analyze the current maintenance strategy of preventative maintenance for the 15-ton overhead traveling crane. Lastly, the objective is to develop a Reliability-Centered Maintenance (RCM) strategy in minimizing failures of the 15-ton overhead traveling crane.

1.1 Implementation of RCM in China

This paper proposes the application of the RCM for sampling subsystem in continuous emission monitoring system (CEMS) in China [5]. CEMS is a system that continuously measures and records the emissions of pollutants from a stationary source. CEMS are used to comply with environmental regulations, to optimize plant operations, and to prevent exceedances of emission limits. In this paper, the RCM logic decision is implemented to identify the reasonable maintenance mode and the average availability model is proposed in order to determine the maintenance interval cycle. The implementation of RCM was carried out by gathering research object data, dividing subsystems, and selecting key components, performing Failure Mode and Effects Analysis (FMEA), using RCM logic decision diagrams for maintenance mode decision, and developing a maintenance plan strategy [6].

Each component's function, failure mode, and failure cause should be detailed, and then the criticality of each component should be calculated and sorted. The FMEA mode's frequency (O), detection (D), and severity (S) are all scored, with a 1–10-point scale. The more serious the degree, the higher the score. The following formula can be used to calculate: $RPN = O \times D \times S$ [17]. Table 1 shows the FMEA of the sampling system.

Table 1: FMEA of Sampling System [5]

Number	Components	Function	Failure mode	Failure cause	O	S	D	RPN	Compensation Measures
1	Sampling probe	Particulate matter more than 20μm in flue gas and sampling extraction	Blockage	High particulate matter in the flue gas or excessive accumulation of dust inside the probe	8	3	2	48	Check and clean regularly
2			Breakage	Damage to the filter element caused by long-term alternating heat and cold	7	5	4	140	Replace or reverse blow regularly
3				Corrosion of seal surface of probe	3	5	3	45	"O" type ring filling or silicone oil, regular replacement
4				Failure deformation of sealed O-ring	3	5	4	60	Choose high elastic sealing material, smear lubricant evenly over the grooves and seals
5				Unqualified probe quality	3	4	4	48	Check and replace regularly
6	Sampling tube	Sampling transport	Blockage	High particulate matter in the flue gas	5	5	5	75	Keep the filter core at constant temperature and dry
7			Flue gas condensation	Unreasonable temperature setting	5	2	5	50	Adjust the heat tracing temperature regularly
8				Poor heating effect of heating cable	5	2	4	40	Check and replace regularly
9			Leakage	Untightened pipe connections	3	4	2	24	Check the sealing condition of filter element and joint regularly
10				Aging pipeline	4	3	3	36	Check, clean and replace regularly
11	Solenoid valve	Back blowing on the probe and filter at a time	Non action of solenoid valve	Circuit breaker	2	3	5	30	Check the solenoid valve regularly
12				Coil damage	2	3	3	18	Check and replace regularly

Based on Table 1, the most serious failure causes filter element damage, followed by high particulate matter in the flue gas, and the least dangerous is solenoid valve non-action. The outcome of the preceding analysis is in accordance with the actual. The sampling system's weak link can be identified using the FMEA results, and the causes and modes of system failure are investigated. Then, different maintenance strategies for different components are implemented, which serves as the foundation for the RCM. Failure modes, maintenance modes, maintenance work content, and the maintenance interval cycle are the main contents of the maintenance strategy outline of important functional units. Table 2 shows the maintenance strategy for each component of the sampling system.

Table 2: Maintenance outline for the sampling system [5]

Part name	Failure Mode	Maintenance Method	Maintenance Content	Maintenance Cycle(h)
Sampling Probe	Blockage of probe filter	Periodical Inspection	Check and clean regularly/Replacement	272
	Sampling probe breakage	Periodical Inspection	Regularly replace/Use other heating measures to preheat the backflush	845
Sampling Pipe	Blockage of sampling tube	Periodical Inspection	Keep the filter element at a constant temperature and dryness/Clean it regularly	1962
	Condensation in sampling tube	Periodical Replacement	Adjust the heating temperature /Replace the fault heating cable, thermostat, etc.	3086
	Sampling tube leakage	Periodical Inspection	Check the filter element and seal at the joint regularly	3777
Solenoid Valve	Non action of solenoid valve	Periodical Replacement	Fasten the thread/ If it is damaged, replace the coil in time.	3735

In that there are different maintenance modes for different components, the results of the maintenance methods of the components from sampling subsystems decided according to the RCM theory are more targeted than the traditional maintenance method in the past. Previously, maintenance methods for CEMS were based primarily on manufacturer guidance and experience, rather than the fault consequences of actual equipment operation. In comparison, the results of this paper's maintenance method decision are more reliable.

2. Methodology

2.1 Methodology

The proposed solution to reduce unplanned downtime of the 15-ton overhead traveling crane is to implement the RCM program. RCM is a systematic approach to maintenance that focuses on identifying and mitigating the risks of failure. The RCM process will be based on the flowchart as shown in Figure 1. The first step is to acquire information about the crane, including its history of breakdowns and maintenance activities. This information will be used to identify the factors that could cause the crane to fail. Once the potential failure modes have been identified, a failure mode and effect analysis (FMEA) will be conducted [7]. The FMEA will assess the severity, likelihood, and detectability of each failure mode [8]. This information will be used to develop a new maintenance strategy that is tailored to the specific needs of the crane. The new maintenance strategy will be validated by the maintenance engineer to ensure that it is adequate to prevent failures and keep the crane in safe operating condition.

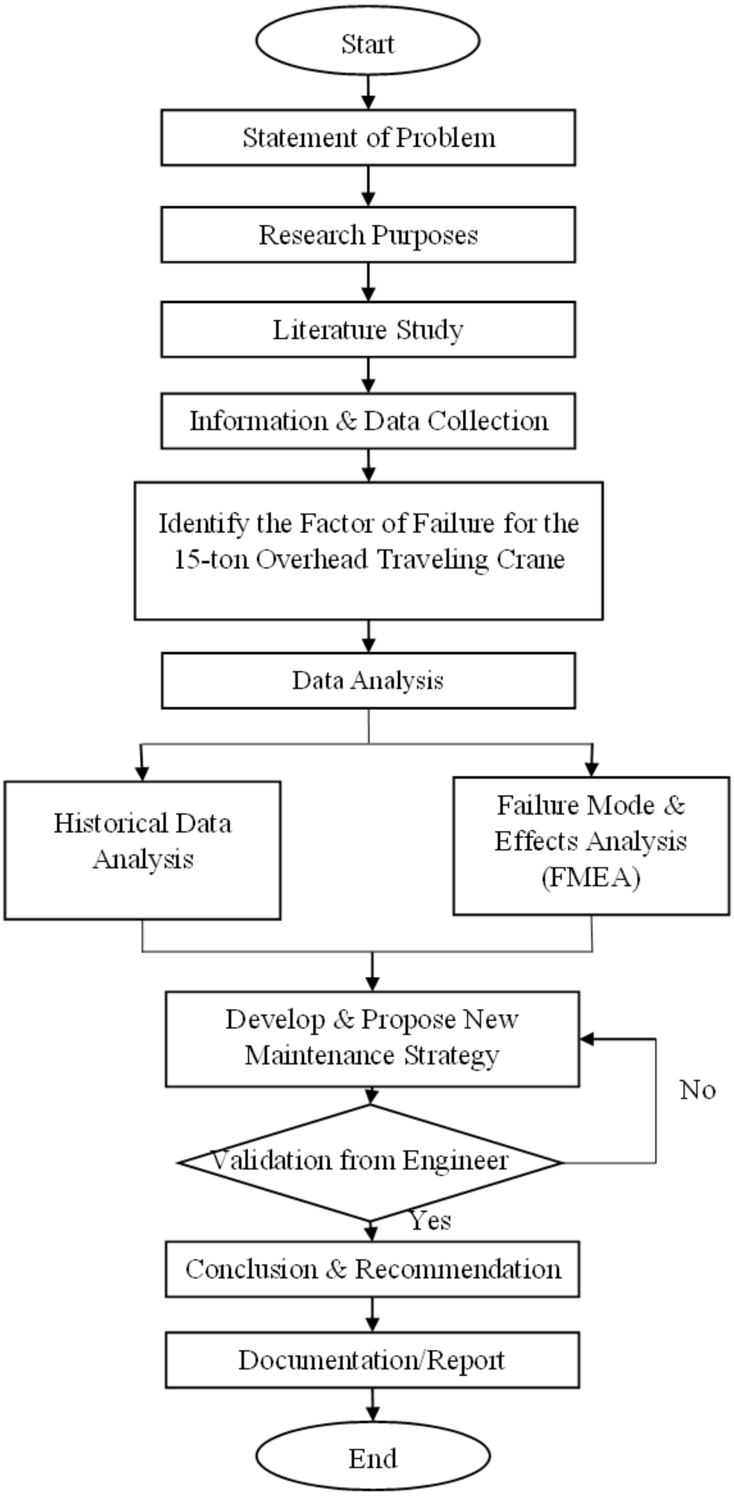

Figure 1: Methodology Flowchart

2.2 Failure Mode and Effects Analysis (FMEA)

FMEA is a commonly used method for conducting reliability analysis. It is applied to each system, subsystem, and component identified in the boundary definition. For every identified function, there may be multiple failure modes [9]. FMEA addresses each system function and all possible failures, as well as the dominant failure modes associated with each failure. It then examines the consequences of failure to determine the impact on the system's mission or operation and on the machine. During the

FMEA analysis stage, a critical assessment is performed to determine how important a system function is in relation to the identified mission. The effects of failure are ranked from lowest (1) to highest (5) [10]. The probability of occurrence is determined based on the criticality assessment ranking, providing a method of quantifying the probability of failure. Historical data is a valuable resource in establishing the ranking. Table 3 shows the rating of severity, Table 4 shows the rating of occurrence and Table 5 shows the rating of detectability.

Table 3: Severity rating [1]

Rating	Effect	Description
1	Negligible	A failure that does not result in any significant impact
2	Minor	A failure that results in inconvenience or minor cost
3	Major	A failure that results in minor downtime or loss of production
4	Critical	A failure that results in significant downtime or loss of production
5	Catastrophic	A failure that results in death, injury, or environmental damage

Table 4: Occurrence rating [1]

Rating	Effect	Description
1	Extremely unlikely	A failure that is extremely unlikely to occur
2	Remote	A failure that is unlikely to occur
3	Occasional	A failure that can be expected to occur occasionally
4	Frequent	A failure that can be expected to occur frequently
5	Almost certain	A failure that is almost certain to occur

Table 5: Detectability rating [1]

Rating	Effect	Description
1	Certain to detect	A failure that is certain to be detected before it causes an impact
2	Easy to detect	A failure that is easy to detect before it causes an impact
3	Difficult to detect	A failure that is difficult to detect before it causes an impact
4	Very difficult to detect	A failure that is very difficult to detect before it causes an impact
5	Impossible to detect	A failure that cannot be detected before it causes an impact

3. Results and Discussion

The result identified the factors and causes of the overhead traveling crane failures through the FMEA. A new maintenance strategy for preventive maintenance was developed and proposed. This improvement can help to improve work efficiency, reduce overhead traveling crane downtime, and reduce project delays and costs. Both FMEA and the new maintenance strategy were validated by the maintenance engineer in HSB.

3.1 Factor of Failure of the 15-ton Overhead Traveling Crane

Overloading, improper maintenance, operator error, and environmental factors can all contribute to crane failure. The historical data of the crane downtime and services were analyzed to identify the main factor of the crane failure. Past data shows that the main factor of crane failure is improper maintenance. The failure due to improper maintenance can be prevented using the RCM method. Figure 2 shows the number of 3 different 15-ton overhead traveling crane downtime and part replace since 2017 until May 2023 that was extracted from past data.

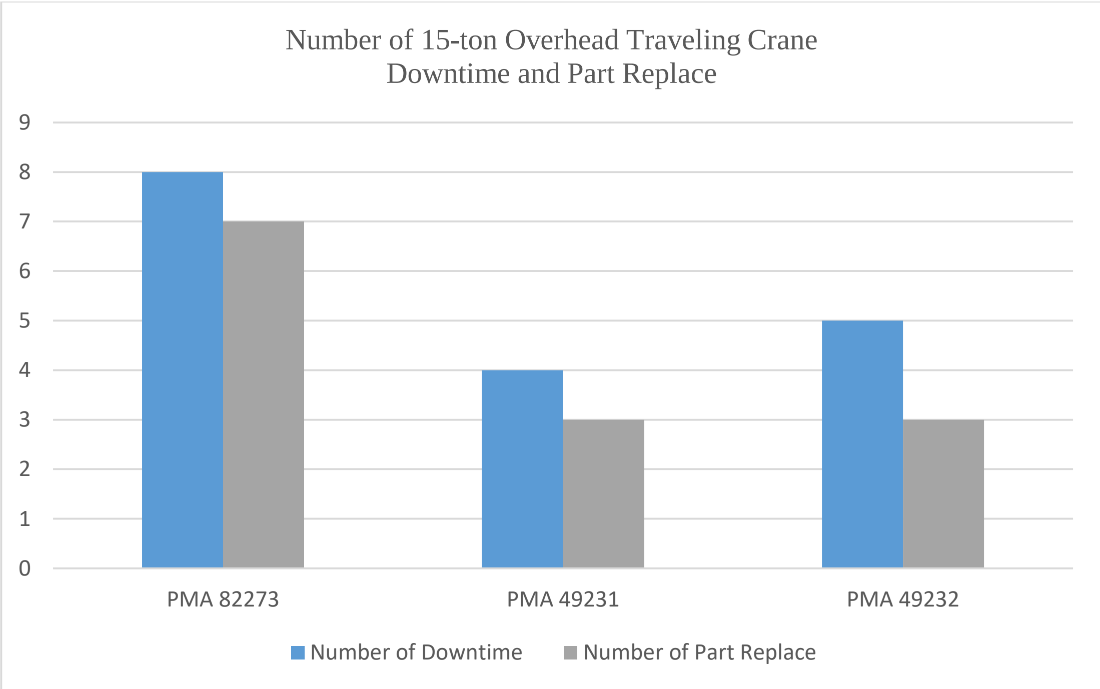

Figure 2: Number of 15-ton Overhead Traveling Crane Downtime and Part Replace

The parts that were replaced showed that most of the downtimes occurred because parts were broken and needed to be replaced or repaired out of scheduled service. These caused the crane to experience downtime at unwanted times, possibly during crucial moments, which could lead to delays for KLAV27. The parts that were broken and needed to be replaced, occurred because of improper maintenance.

3.2 Analysis of Current Maintenance Strategy for 15-ton Overhead Traveling Crane

Table 6: Current maintenance strategy for monthly inspections

No.	Area		Condition	Remark
1	Supporting Structure	Weld		
		Bolt/nuts		
2	Bridge	Rail & alignment		
		Trucks & wheel		
		Motor & drive train		
		Stop & limit control		
3	Trolley	Rail & alignment		
		Wheel		
		Motor & drive train		
		Stop & limit control		
4	Hoist	Wire rope condition		
		Brakes & ratchets		
		Equalizer sheaves		
		Hoist unit control		
		Functional operation		
5	Electrical	Switch control panel		
		Warning alarm		
6	Load Block	Sheaves		
		Pins		
		Swivel		
		Hook		

Based on Table 6, the current maintenance strategy has a several weaknesses.

i. It only consists of monthly inspections and does not specify the failure that may occur on the overhead traveling crane. The current maintenance strategy does not consider the different failure modes that can occur on the overhead traveling crane. As a result, it is possible that some potential failures may not be identified, which could lead to unplanned downtime and costly repairs.
ii. It is ineffective. Monthly inspections do not identify all potential failure modes, and they do not consider the severity of each failure mode. For example, a monthly inspection may not be able to identify a crack in a wire rope that could eventually lead to a catastrophic failure. Additionally, the severity of each failure mode is not considered, so it is possible that some critical failures may not be prioritized for maintenance.
iii. It is inefficient. It is because some of the equipment and parts may only need yearly inspections, or some may need more frequent inspections such as daily or weekly. This means that the current maintenance strategy may be wasting resources by inspecting some equipment and parts more frequently than necessary. Additionally, it may be leading to missed opportunities to identify and repair potential failures before they occur.
iv. It is unclear on the action or task to do during the crane inspection for preventative maintenance. The inspection process will take longer time when the task is not clear on what actions or tasks to do, they may spend more time trying to figure out what to do, which could reduce the efficiency of the inspection.

3.3 Failure Modes and Effect Analysis (FMEA)

The Risk Priority Number (RPN) is calculated by multiplying the severity, occurrence, and detectability ratings of the failure mode as the formula below:

$$RPN = severity \times occurrence \times detectability$$

A higher RPN indicates a higher risk of failure. Failure modes with higher RPNs are higher risk and should be prioritized for corrective action. Corrective action can include preventive maintenance, design changes, or training. By identifying and prioritizing high-risk failure modes, organizations can reduce the risk of unplanned downtime, injuries, and property damage.

An FMEA analysis was done based on the collected data of the failures of overhead traveling crane HSB from 2017. The failure mode with the highest RPN is the controller failure in the electrical system, with a score of 60. This is because the failure is catastrophic, meaning that it could lead to the crane becoming inoperable and causing injuries or property damage. The failure is not very common, but it is difficult to detect. Therefore, the controller failure due to the electrical system is the failure mode that needs to be prioritized for corrective action.

On the other hand, the failure of the motor in the hoist subsystem has the lowest RPN of 18. This is because the failure is not as severe as the controller failure, and it is more likely to be detected. However, the hoist motor failure could still lead to delays or productivity loss, and in some cases, it could also lead to injuries. Therefore, it is still important to inspect the hoist motor regularly to prevent failures.

3.4 Proposed Maintenance Strategy Plan

New checklists for preventative maintenance were developed to replace the current checklist. They were developed based on the FMEA results. The newly proposed checklists are divided into 5 different checklists which are tailored to the specific needs of the equipment, and it is more efficient than the current maintenance checklist. The checklists are the weekly checklist in Table 7, monthly checklist in

Table 8, quarterly checklist in Table 9, semi-annual checklist in Table 10 and annual checklist in Table 11. The checklists are then validated by the maintenance engineer at Hartasuma.

Table 7: Weekly Preventative Maintenance Checklist

No	Area	Type of activity	Condition (✓/X)	Remarks
1	Check the wiring and electrical connections for any signs of damage or wear	Electrical		
2	Check the electrical connections for tightness and corrosion.	Electrical		
3	Inspect the crane for any loose or damaged parts especially on the bridge system.	Mechanical		
4	Check the crane's safety systems for proper operation.	Mechanical		

Table 8: Monthly Preventative Maintenance Checklist

No	Area	Type of activity	Condition (✓/X)	Remarks
1	Test the safety devices, such as the overload relays and limit switches	Electrical		
2	Clean the electrical components as needed.	Electrical		
3	Inspect the electrical components for any signs of overheating.	Electrical		
4	Lubricate the electrical components as needed.	Electrical		
5	Lubricate the crane's moving parts as needed.	Mechanical		
6	Inspect the crane's load block and hoist for wear and tear.	Mechanical		
7	Check the crane's brakes for proper operation.	Mechanical		
8	Inspect the crane's tires for wear and tear.	Mechanical		

Table 9: Quarterly Preventative Maintenance Checklist

No	Area	Type of activity	Condition (✓/X)	Remarks
1	Conduct a more in-depth inspection of the electrical components, checking for wear and damage that may have been missed during routine inspections.	Electrical		
2	Replace any electrical components that are found to be damaged or worn.	Electrical		
3	Conduct a more in-depth inspection of the crane, checking for wear and damage that may have been missed during routine inspections.	Mechanical		
4	Replace any worn or damaged parts.	Mechanical		

Table 10: Semi-annually Preventative Maintenance Checklist

No	Area	Type of activity	Condition (✓/X)	Remarks
1	Have the electrical components inspected by a qualified electrician.	Electrical		
2	Have the crane inspected by a qualified crane inspector.	Mechanical		
3	Have the crane's load block and hoist serviced by a qualified crane service technician.	Mechanical		

Table 11: Annually Preventative Maintenance Checklist

No	Area	Type of activity	Condition (✓/X)	Remarks
1	Have the electrical components serviced by a qualified electrician.	Electrical		
2	Have the crane’s brakes serviced by a qualified technician.	Mechanical		
3	Have the crane’s tires rotated and balanced.	Mechanical		

4. Conclusion

The objectives of this study were to investigate the factors that have caused the failures of the 15-ton overhead traveling crane at HSB, to analyze the current maintenance strategy, and to develop a Reliability-Centered Maintenance (RCM) strategy to minimize failures of the crane. The study found that the main factor of crane failure is improper maintenance. The current maintenance strategy is not as effective as it could be in preventing critical failures because it is not tailored to the specific needs of the crane and does not consider the risks associated with each failure mode. The RCM analysis identified several potential failure modes and recommended maintenance tasks to prevent or detect and correct these failure modes. The checklists include weekly, monthly, quarterly, semi-annually, and annual checklists for the preventative maintenance on the overhead traveling crane. In conclusion, the study found that the RCM strategy is more effective than the current maintenance strategy in preventing failures of the 15-ton overhead traveling crane.

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