

ASSET CONDITION ASSESSMENT FOR RAILWAY ELECTRICAL & MECHANICAL ASSETS

Yip Wai TUNG¹, Elena KWAN¹,

¹Key Direction Limited

Corresponding Author: ywtung@key-direction.com

SUMMARY

This paper describes a methodology for conducting asset condition assessments (ACA) for railway electrical & mechanical (E&M) assets. ACA are to provide an overall health summary of the E&M assets, so that the maintenance management can realize the actual maintenance performance and related issues. In this work, a Condition Assessment Framework (CAF) is established to define the processes and artefacts for the ACA, which includes the definition of baseline for each individual asset and the Electronic Log Sheet (ELS) that is used to capture the asset condition during on-site assessment. The CAF consists of 3 types of assessments, namely, Physical Condition Assessment (PCA), Functional Condition Assessment (FCA) and Records Assessment (RA). The results are aggregated to obtain an Overall Aggregated Condition Score (OACS), which is used to determine the overall maintenance performance. Based on the assessment results, recommendations are provided to the maintenance management for necessary rectification actions, if deemed necessary, to restore the asset back to an acceptable baseline condition relative to the asset age; or alternatively, a practical asset replacement programme. This methodology was successfully applied to a real life condition assessment works conducted for Singapore's Mass Rapid Transit (MRT) E&M assets in 2021.

1 INTRODUCTION

E&M assets are considered to be among the most important operating assets. Daily MRT services rely on the normal performance of these E&M assets in order to provide a safe, smooth and pleasant journey for commuters. Therefore, ensuring the normal performance of E&M assets is a top priority of any MRT maintenance regime. Apart from daily maintenance, it is necessary for MRT maintenance to carry out asset condition assessments. The purposes of these assessments are (i) to assess the performance result of the maintenance practices; (ii) to identify any specific deviation from the normal operational patterns; and (iii) to explore any possibility of enhancing the overall reliability of the E&M assets.

To holistically assess the overall condition of operating E&M assets is a challenging exercise. A systematic approach must be adopted in order not to disrupt the daily operations of these E&M assets. In addition, a structural framework must be established so that all E&M assets can be objectively assessed within the same boundary of assessment.

This paper describes a Condition Assessment Framework and explains how this framework has been developed to carry out condition assessments for E&M assets for a MRT network in Singapore.

2 E&M OPERATING ASSETS

The condition assessment covers the following E&M operating assets:

- Rolling Stock
- Depot Equipment
- Signalling System
- Communications System
- Control System
- Power Supply & Electrical Services

- Mechanical Services
- Platform Screen Doors
- Automatic Fare Collection System

Obviously, these E&M assets all have individual system characteristics, operational profiles and maintainability requirements. Therefore when designing the CAF, one of the challenges was on how to provide a common assessment framework but at the same time cater for individual E&M assets' system characteristics. The following sections explain the development and rationale of the CAF.

3 CONDITION ASSESSMENT FRAMEWORK

The section describes the development of the Condition Assessment Framework (CAF) and its associated design principles and rationale.

3.1 Overview

The CAF in this work is defined as the collection of various types of asset assessments, which are used to measure the condition and performance of a particular asset. These assessments include the procedures of inspecting, reviewing and verifying assets and related information collection. The following Figure 1 illustrates the CAF.

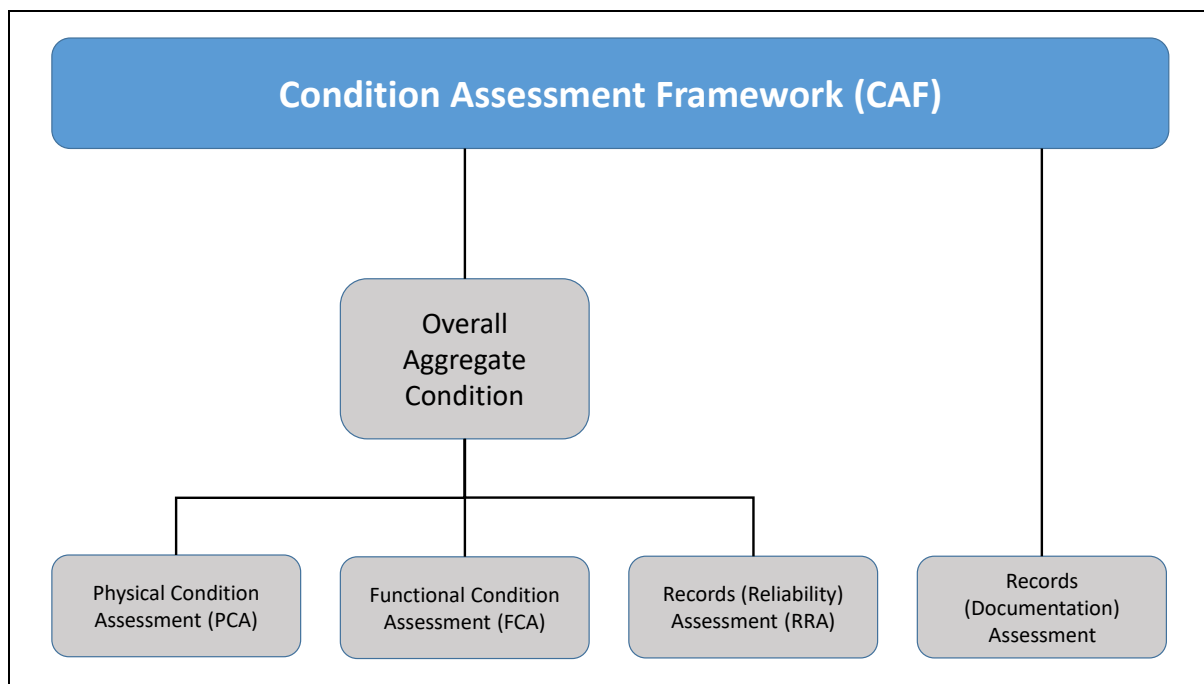


Figure 1: Condition Assessment Framework

The CAF consists of the following four major assessment types:

- a. Physical Condition Assessments (PCA);
- b. Functional Condition Assessments (FCA);
- c. Records (Reliability) Assessments (RRA); and
- d. Records (Document) Assessments (RDA).

PCA is to physically and visually inspect the conditions of each asset. The aim is to identify the areas of concern, using quantified measurements or criteria specified in associated maintenance work instructions.

FCA is to assess the functional conditions of each asset by conducting functional, system and operational performance checks. The aim is to identify the asset condition with respect to its intended functions that need to be performed.

The physical condition and functional condition are the two criteria to determine the “actual condition” of an operating asset; the “actual condition” of an operating asset means the asset’s on-site condition state at the point of time when the assessment is conducted. The on-site “actual condition” of an asset may or may not indicate the effort contributed by the maintenance regime to this asset, therefore, Records (Reliability) Assessment (RRA) and Records (Document) Assessment (RDA) are designed to assess the maintenance regime’s effort on the asset maintenance in order to preserve the asset’s “should be” condition. The Records (Reliability) Assessment focuses on reliability records and contributes to the Overall Aggregate Condition Score (OACS). The Records (Document) Assessment is focused on maintenance regime’s practices and is reviewed qualitatively.

3.2 Overall Aggregate Condition Score

The individual assessment criteria used in the CAF are quantitatively and qualitatively represented by their respective index scores from zero (0) to ten (10), with zero being the best score and ten being the worst score. The weightings to each criterion for individual E&M assets are assigned based on the functional and operational characteristic of individual E&M assets. Figure 2 below illustrates the generic weighting assignment for calculating the OACS of an E&M asset.

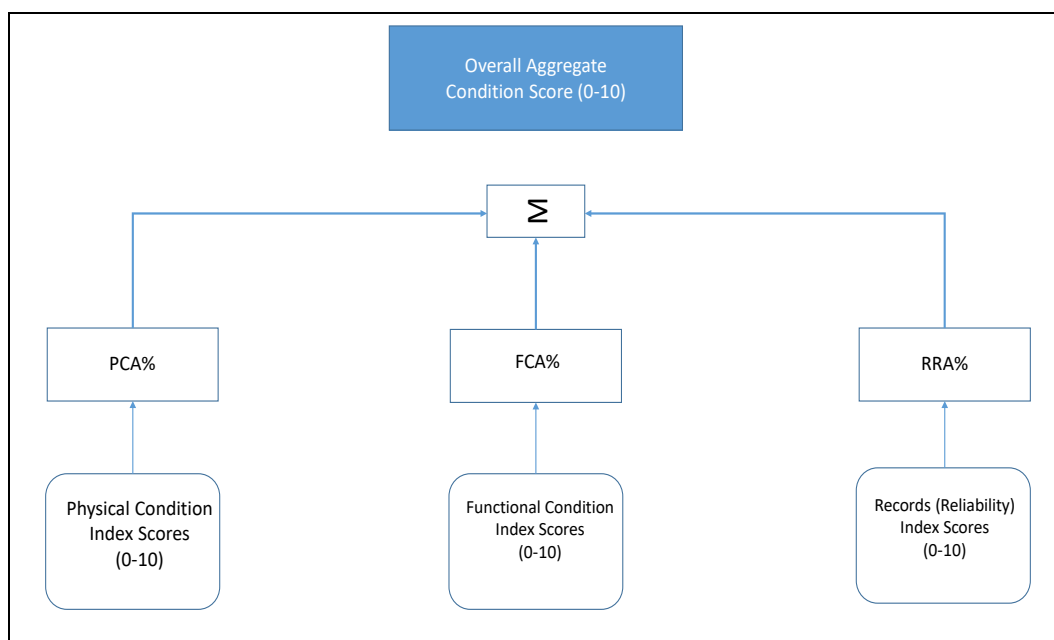


Figure 2: Generic Weighting Assignment

An Overall Aggregated Condition Score (OACS) for each asset is quantitatively expressed in the form of a score. Table 1 lists the details of the Overall Aggregated Condition Score.

Table 1: Details of Overall Aggregated Condition Score

Description	Index Score (OACS)	Condition Index Details
Very good condition	0	Generally a new asset with normal condition.
	1	A near new asset with no visible signs of deterioration.
Minor defect only	2	An asset in excellent overall condition, possibly with only very slight condition decline.

	3	An asset in very good overall condition but with some early sign of deterioration observed.
	4	An asset in good overall condition but with some obvious deterioration evident, serviceability would be impaired very slightly.
	5	An asset in fair overall condition, deterioration in condition is noticeable, and there would be some serviceability problem.
Maintenance required to return to acceptable level of service	6	An asset in fair to poor overall condition. The condition deterioration would be easily identified. Serviceability is impacted.
	7	An asset in poor overall condition. The deterioration is considered quite severe and serviceability is impacted.
Renewal needed	8	An asset in very poor overall condition with serviceability now being heavily impacted. Maintenance cost would be very high and the asset would be at a point where it needed to be rehabilitated.
	9	An asset in extremely poor condition with severe serviceability problems, there is an operational risk if the asset remains in service.
Asset unserviceable	10	An asset that is no longer serviceable and should be removed from service immediately.

The Overall Aggregate Condition Score represents an overall health of the asset for assets of the same age group, based on the combination of criteria as illustrated in the Figure 2, and it also reflects renewal or mitigations actions, if necessary.

3.3 Weighting Apportionment

The weighting apportionment for individual E&M assets varies depending on the E&M assets' physical and functional characteristics. The following Table 2 lists the weighting apportionment for individual E&M assets.

Table 2: Weighting Apportionment for Individual E&M Assets

E&M Assets	PCA%	FCA%	RRA%
Rolling Stock (Electric Multiple Unit)	40	15	45
Rolling Stock (Electrical Systems)	40	40	20
Depot Equipment	40	30	30
Signalling System	40	15	45
Communications System	35	35	30
Control System	35	35	30
Power Supply & Electrical Services (General)	45	25	30
Power Supply & Electrical Services (Overhead Catenary System)	45	15	40
Mechanical Services	25	25	50
Platform Screen Doors	35	35	30
Automatic Fare Collection	40	30	30

3.4 Baseline Condition

In addition to the weighting apportionment, another factor for the CAF is the asset baseline condition. The baseline condition is the ‘should be’ condition range corresponding to the E&M asset’s age, assuming that appropriate maintenance has been carried out during its lifecycle and the assets have been operated within its design conditions. The baseline condition takes into consideration the following four factors: 1) asset age, 2) maintenance frequency of the asset, 3) performance of the asset and 4) benchmarking against other MRT/systems. The OACS obtained (i.e., the current condition of the asset) is compared with the baseline condition; and hence recommendations are made on maintenance actions.

During the establishment of the baseline score of PCA and FCA, a pragmatic approach is adopted and the expected lifespan and the actual usage life are taken into consideration. The following Table 3 illustrates the general principle of assigning baseline score (PCA and FCA) to an asset; the baseline score is generally proportional to the asset’s usage life. However, it should not simply take score 10 for those assets with expected lifespan expired but still in good operational condition. Therefore, a baseline score of five (5) (fair overall condition) is assigned for those assets which have already in services for more than 60% of their expected lifespan. The following Table 3 shows the general principle of baseline score assignments with respect to asset life.

Table 3: General Principle of Baseline Score Assignments

Asset’s Current Age	Asset’s Expected Lifespan	Assigned Baseline Score		
		PCA	FCA	RRA
1 – 2 years	15	1	1	3 (please refer to Section 4.3)
3 – 4 years		2	2	
5 – 6 years		3	3	
7 – 8 years		4	4	
9 years and over		5	5	
1 year	10	1	1	
2 years		2	2	
3 years		3	3	
4 years		4	4	
5 years and over		5	5	
1 – 3 years	30	1	1	
4 – 6 years		2	2	
7 – 9 years		3	3	
10 – 12 years		4	4	
13 years and over		5	5	

4 ASSET CONDITION ASSESSMENT

4.1 Physical condition assessment

Site surveys and inspections are the direct approaches to obtain actual physical condition of the assets which must be checked to observe the physical conditions of equipment, and other areas for which worsening environmental conditions could impact the condition of assets.



The main purpose of the physical condition assessments is to provide an on-site visual inspection of each asset and to identify areas of concerns, using proven criteria from similar condition assessment exercises, or criteria specified in the maintenance work instructions where applicable.

To perform the physical condition assessment, the following three procedures are required:

- Procedure_1: Define asset information;
- Procedure_2: Inspect the asset physical condition; and
- Procedure_3: Document and calculate asset's Physical Condition Index Score.

The following Table 4 illustrates the details of each procedure.

Table 4: Procedures for Physical Condition Assessment

Procedures #	Purpose
1	To define the asset information needed to determine and evaluate asset condition against predefined condition indicators, expected results or specifications from the asset's Original Equipment Manufacturer (OEM). Asset information also includes those information generated by MRT operator, such as asset unique identifier, asset model information, and installed location.
2	To visually inspect the asset external / internal condition, installation, environmental and identify any areas of concerns, or potential problems that may cause degradation of the asset.
3	To document and calculate the asset's Physical Condition Index Score after all previous procedures are completed.

Each procedure is associated with a checklist (Electronic Log Sheet) for on-site implementation.

4.2 Functional Condition Assessment

Functional condition assessment is aimed to assess the functional, system and operational performance of the asset using proven criteria on similar condition assessment exercise, or specified in the maintenance work instructions, where applicable, to assess the condition of the asset under functional assessment.

To perform the functional condition assessment, the following five procedures are required:

- Procedure_1: Define asset information;
- Procedure_2: Verify asset diagnostic checking function, if applicable;
- Procedure_3: Verify asset functional and operational condition;
- Procedure_4: Check asset redundant condition, if applicable; and
- Procedure_5: Document and calculate asset's Functional Condition Index Score.

The following Table 5 illustrates the details of each procedure.

Table 5: Procedures for Functional Condition Assessment

Procedures #	Purpose
1	To define the asset information needed to determine and evaluate asset condition against predefined condition indicators, expected results or specifications from the asset's Original Equipment Manufacturer (OEM).

2	If applicable or practical, verify asset diagnostic checking functions and identify any areas of concerns, or potential problems that may cause degradation of the asset.
3	Verify the asset intended functional and operational conditions and identify any areas of concerns, or potential problems that may cause degradation of the asset.
4	Check the asset redundant condition, if applicable; and identify any areas of concerns, or potential problems that may cause degradation of the asset.
5	Document and calculate the asset's Functional Condition Index Score after all previous procedures are completed.

During the on-site condition assessment, any observations will be captured in the Electronic Log Sheet to clearly state what kinds of issues are observed. Observations do not constitute defects in the physical or functional condition of the asset being assessed; they may or may not be related to the E&M assets being assessed. For example, an observation could be the failure of the air-conditioning in the equipment room where the asset is installed. In this example the observation is of something external impacting on the normal operation of the asset being assessed.

4.3 Record (Reliability) Assessment

The primary purpose of RRA is to assess the E&M assets' reliability. The aim is to evaluate the impact (positive or negative) of past maintenance actions in preserving the condition of the assets. The main purpose of this assessment is to assess the performance / reliability of the assets when they are in operation. The performance / reliability of the assets is reviewed and assessed based on maintenance and performance records. In general, this assessment covers the past three years of maintenance records and failure data. The following items, which are considered to be the key performance indicators of operational service, are reviewed, analysed and scored:

No Fault Found (NFF)

Reasons for failures which ended up with "NFF" could include erroneous reporting, and intermittent fault or some other failure where the root cause has not been identified. In any case, fault may recur. A high percentage of NFF failures could signify an inherent problem with the asset and indicates poor asset reliability. The ratio of no. of "NFF" to the total no. of faults reported will be analysed.

In general, it is acceptable to have a low percentage of NFF due to unknown conditions or mis-operations. However, a high percentage of NFF indicates that root cause has not been identified.

Repeated Failures (RF)

Repeated Failure is defined as the same fault occurring within 7 days of the original fault occurrence. Reasons for repeated failures could be many, such as system instability, or the root cause of the previous failure(s) has not been identified or rectified. A high percentage of repeated failures could signify an inherent problem with the asset and is detrimental to asset reliability. The ratio of the number of repeated failures to the total no. of faults reported is analysed.

In general, repeated failure means the root cause is not identified or the proper action is not taken, or a replacement component is substandard. Repeated failures may be caused by incompetent maintenance personnel.

Faults Distribution (FD)

Faults may be scattered or highly concentrated on a particular subsystem. In the latter case, it could mean a subsystem problem. The ratio of the number of faults in a single subsystem to the total number of faults reported is analysed. In cases with small data sets, it is not possible to determine the faults distribution.

Failure Trend (FT)

Up-to-date failure rates are compared with previous rates to ascertain if there is any degradation in performance or reliability over the assessment period indicating an increasing or decreasing failure trend. Failure trend is developed from failure records which are provided by the maintainer. Three years of maintenance records and failure data are assessed.

The following explanations and calculation are general guidelines for Records (Reliability) Assessment Checklist:

1. NFF: the calculation of NFF takes the ratio of number of NFF to the total number of faults reported.
2. RF: the calculation of RF takes the ratio of number of RF to the total number of faults reported.
3. FD: The calculation of fault distribution is the ratio of number of faults in a single subsystem to the total number of faults reported for the particular system within the reporting period.
4. FT: The calculation of failure trend takes into account of the total number of Line Replacement Units (LRU) of the asset, and will be calculated as follows:

$$\text{Failure Trend} = \frac{([\text{Fault count of most recent year} - \text{Average number of fault count over recent 3 Years}] / [\text{Total number of LRU of the asset}]) * 100\%}{}$$

5. The baseline value of RRA is assigned to three (3), which is a common norm from most benchmarking MRT operators.

4.4 Record (Document) Assessment

RDA is mainly used to ascertain the effectiveness of the maintenance regime, which covers maintenance documentation, maintenance records, training, obsolescence of spare parts or equipment and, configuration control and management. This is a qualitative assessment; however, a number of areas may not be practically assessed (for example, for as-built Drawings, the quantities and level of details cannot be practically assessed). Therefore, some areas will only be “reviewed”, without assessment and scoring, and documentation is one of these areas. The assessment includes a comparison table of the recommended maintenance regime in the Operation and Maintenance (O&M) manual by the Original Equipment Manufacturer (OEM) and the maintainer’s current maintenance records of the asset.

The following Table 6 shows the general guidelines that are used for reviewing the documents.

Table 6: General Guidelines for RDA

Document to be Assessed	General Approach for Assessment
Maintenance Information	
Operation & Maintenance (O&M) Manuals	Verify existence of O&M Manuals. Identify sufficient information for the asset operation and maintenance. Compare the O&M Manuals and the maintenance records to ensure maintenance activities described in the O&M Manuals are carried out and recorded.
As-built Information	Verify existence and management of as-built drawings.
Work Instructions	Ensure preventive maintenance and corrective maintenance have proper procedures as guideline for maintenance activities as described in the O&M Manuals.
Maintenance Performance	

Preventive Maintenance (PM)	<p>Verify the assets are properly maintained in terms of PM schedule and PM completion rate. The PM schedule is compared with the OEM's suggested interval and schedule. The completion rate is checked to see if all PM have been conducted as per the planned schedule.</p> <p>Verify that the PM cycles of assets are derived properly, and no asset items are missed. This is checked in accordance with the OEM's suggested schedule.</p>
Corrective Maintenance (CM)	<p>Verify the assets are properly maintained.</p> <p>Verify that the CM requirements are evaluated properly and no asset items are missed. This is achieved by reviewing the CM records' contents to identify the affected asset items and the defect findings associated to the affected asset items.</p> <p>Verify the CM are duly performed. This is achieved by reviewing the completeness of the CM records, and whether it has included all necessary information.</p>
Maintenance Policy	
Maintenance Plans	<p>Verify existence of Maintenance Plan.</p> <p>Understand the maintenance philosophy for reviewing maintenance performance and maintenance activities.</p> <p>Check that maintenance activities are well defined.</p> <p>Check whether the maintenance activities are in line with O&M Manuals.</p>
Master Replacement Plan (MRP)	<p>Ensure the overall services of the railway will not be compromised due to ignorance of the asset usage lifecycle by reviewing the appropriateness of the provision of asset replacement planning activities for assets to be made obsolete.</p> <p>Review the MRP and assess whether the operator's replacement proposals for future implementation are supported by the findings from the condition assessment.</p>
Asset Replacement and Modification Plan	<p>Check that asset replacements and modifications are planned and have been implemented.</p> <p>Asset Replacement and Modification are the records of changes that have been done.</p>
Maintenance Support	
List of obsolete items	<p>Ensure that obsolete items are well managed.</p> <p>Ensure appropriate maintenance for the whole asset lifecycle.</p>
Operational Spares and Spares Under Repair	<p>Ensure sufficient spares are available to maintain the asset with the following data:</p> <ul style="list-style-type: none"> ■ Number of spares available for service against number of spares under repair; ■ Failure rate; ■ Spares criticality; ■ Workshop repair turn-round time; and ■ Procurement lead time.

Training Manuals and Training Records	Verify existence of Training Manual and Training Records and review the competence of training and maintenance staff.
Configuration Management	
Asset Configuration Management Plan	Ensure Configuration Management team roles and responsibilities are planned and understand how the team track, implement, and communicate configuration items and changes throughout the asset lifecycle.
Asset Configuration Change Control	Control and manage all steps of configuration change throughout the asset lifecycle.
Configuration Items and Records	Ensure all configuration management documents, configuration items and records are updated.

5 CONCLUSION

A holistic assessment of the condition of a MRT’s E&M operating assets to ensure serviceability and reliability is a challenging and resource-demanding exercise. To achieve an ACA that provides useful asset condition information for maintenance regime’s service planning, this work has developed a CAF with associated detailed implementation procedures and guidelines. The implementation of CAF discovers the assets condition of E&M operating assets in physical, functional and records/documentation aspects, depicting the overall health condition of the E&M assets. The assessment result provides a direction for the maintenance regime to cost-effectively allocate resources to better improve the service and reliability of E&M operating assets. The CAF has been implemented in conducting ACA work for a real-life MRT in Singapore, and successfully achieved the design outcomes.