The journey from RCM analysis to asset Management applied for railway industry

1 - Introduction

The maintenance engineering aims to define the type of maintenance task, which will be applied for each equipment/component along the operation phase in order to reduce the operational cost and increase the system performance.
In addition, safety is also a big issue in the railway industry in such way that the preventive maintenance task will try to avoid the unsafe failures, which may trigger a major accident, such as a derailment caused by bogie wheels axle fatigue, wheel cracks, brake caliper high wear out level and others.
Traditionally, the regulators in railway industry try to define the minimum kilometers in which an overhaul and test must be applied in the whole train system. Despite of the good intention, such approach does not assure any incident avoidance and in many cases, increase the maintenance cost and reduce the rolling stock's performance.
Therefore, the first step to define the proper interval of time to carry out preventive maintenance is to understand the equipment and component failure modes based on FMEA analysis. Further, the proper type of maintenance must be applied to detect the failure in enough time to carry out an intervention and avoid the failure.
Finally, the reliability performance for each asset must be achieved in order to have the failures occurring under expected interval and not too early in it's life cycle. This paper aims to discuss the maintenance aspects based on the RCM principles.

2 - Maintenance concepts applied for the railway industry

Basically, there are two types of maintenance that are corrective and preventive. Corrective Maintenance occurs always after equipment fails and preventive maintenance occurs always before failing happens. The objective to perform maintenance before equipment failure is to reduce failure downtime and cost.
Despite a good practice, it’s always hard to define precisely the best moment to perform preventive maintenance no matter how much historical and equipment condition information are available. However, by applying the proper predictive maintenance such as NDT or based on online monitoring data, a good interval prediction can be estimated.

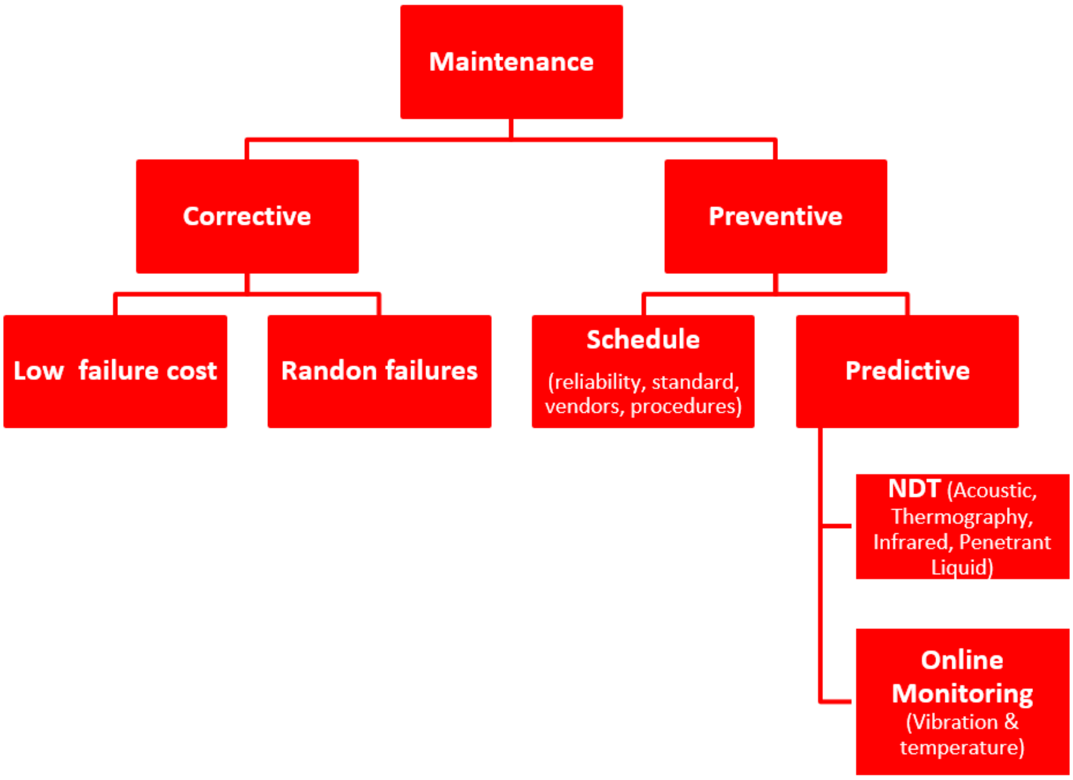


Figure 1 Maintenance Types. Source: Calixto: 2015

Based in figure 1 description, the preventive maintenance can be predictive (PdM) and Scheduled. The scheduled maintenance is carried out based on pre-defined interval of time, which consider reliability analysis or even vendor`s procedures. The predictive maintenance is based on Nondestructive test (NDT), which the main objective is to detections of variables which allows predicting equipment failures without stop the asset and helps to decide when the inspection or repair must be performed to avoid the failure. In fact, there are different predictive methods with different applications and technology to detect different type of failures as well as monitoring physical parameter, which are the root cause of failures such as vibration and temperature. The most applied Nondestructive tests (NDT) in the railway industry are:

- Infrared;
- Acoustic;
- Radiography;

In addition, monitoring methods can also apply as predictive methods such as:

- Vibration;
- Velocity;
- Rotation;
- Temperature.

Despite all the promising benefits, the predictive maintenance methods have also the limitation of effectiveness when is being applied too early and do not detect the failure or too late,

enabling to detect the failure when is too late to plan and carry out an intervention to avoid the failure.
The so-called P-F interval needs to be considered when predictive maintenance is implemented to avoid these problems. Therefore, as the first step, reliability studies may give a good clue about the frequency and the proper time to carry out the NDT. The Figure 2 illustrate the concept of P-F interval.

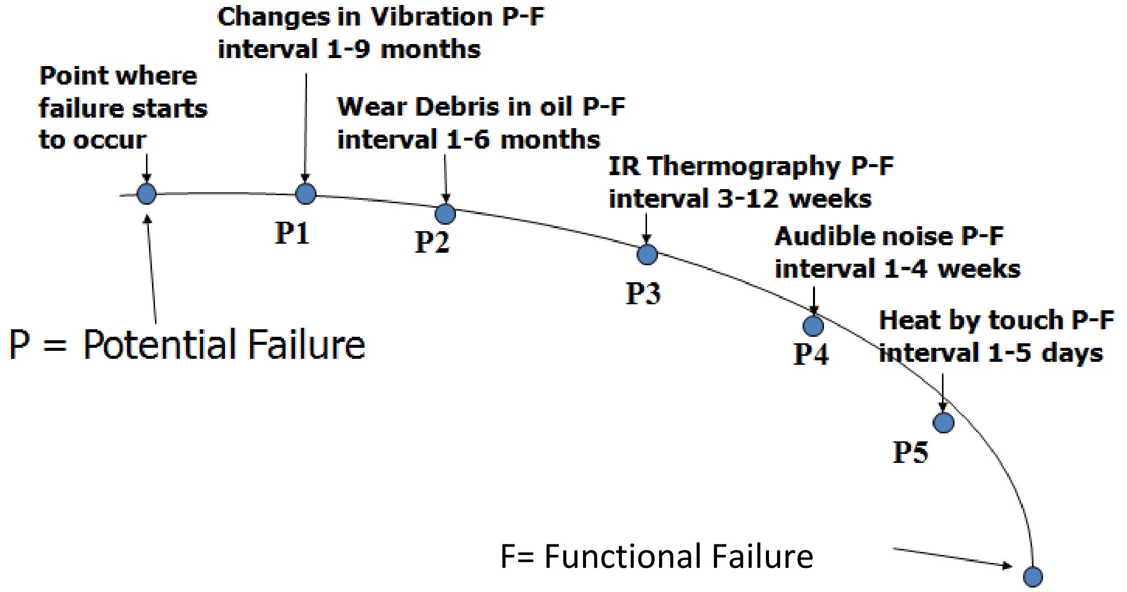


Figure 2 P-F interval (Potential and Functional Interval)

The additional issue about the predictive maintenance is the cost associated with the frequency of NDT as well as the number of sensors installed in railway asset to detect the asset physical health condition by monitoring online (velocity, RPM, temperature, vibration), which can increase the operational cost without bringing the real asset performance benefit. Even though, is still a very good solution to prevent failures.
Some examples of predictive maintenance methods applied to railway industry are demonstrated below:

The **infrared methods** detect the emission of radiant energy in the infrared wavelength to define the equipment condition. Therefore, it´s possible to check if it´s hotter than usual condition as shows figure 3.

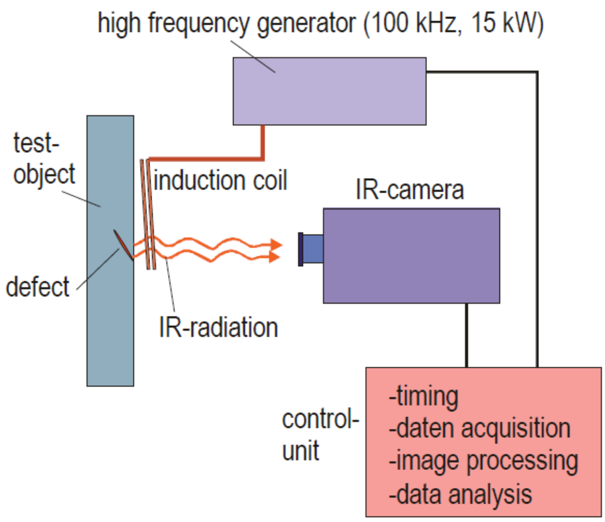


Figure 3 Infrared NDT process
Source: U. Netzelmann et al 2016

The infrared is applied to check different equipment condition such as overheated bearings, spindles and motors, loose electrical power connections, steam/Refrigerant leaks, insulation damage and moisture problems.

The **acoustic method** detects the equipment friction and stress waves produce distinctive sounds in the upper ultrasonic range. Therefore, the modification of such waves can suggest deteriorating conditions.
The Wayside Inspection in-service is one of the most common acoustic methods applied to detect cracks and other wheel defects. Basically, the transducers are installed in the rail in some specific situations. This method accuracy relies also on the train's speed that must be limited. The acoustic wayside inspection in-service measurement is shown in figure 4.

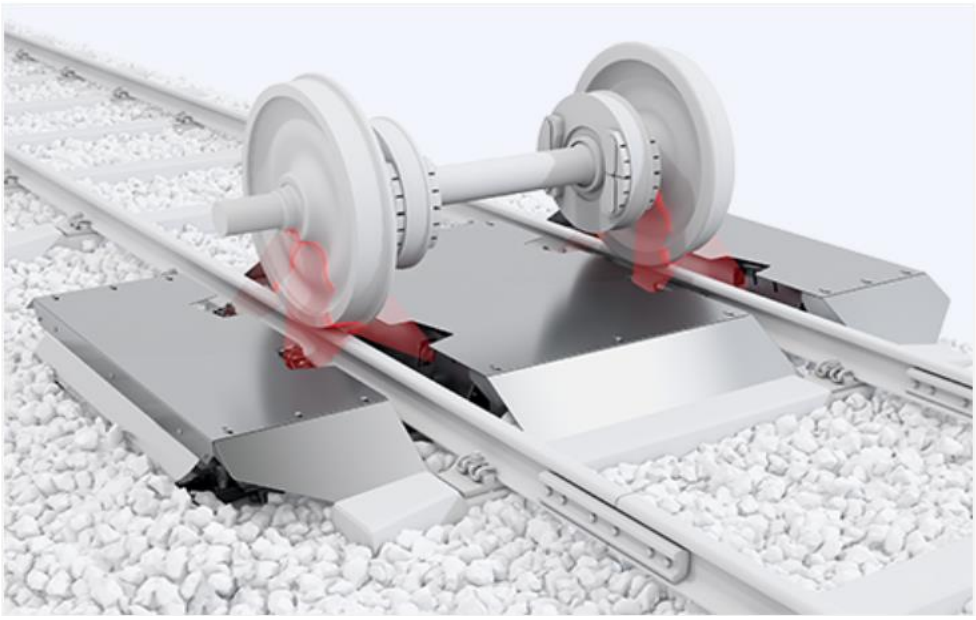


Figure 4 Ultrasound wayside NDT
Source: http://www.mermecgroup.com/inspect/train-monitoring/87/wheel-parameters.php

The **online monitoring** aims to monitor constantly the asset physical health condition based on the measurement of direct or indirect parameters, which indicate a failure or a potential failure. Usually, the parameters measured online are temperature, vibration, speed and difference load and forces in specific equipment areas.
The online monitoring system enables is applied to the train pantograph to prevent the carbon strip failure. Based on the measure of the carbon strip physical condition such as degradation and wear out, it enables the maintenance group to plan the best time to perform the replacement. The figure 5 shows the online detection system applied to carbon strips.

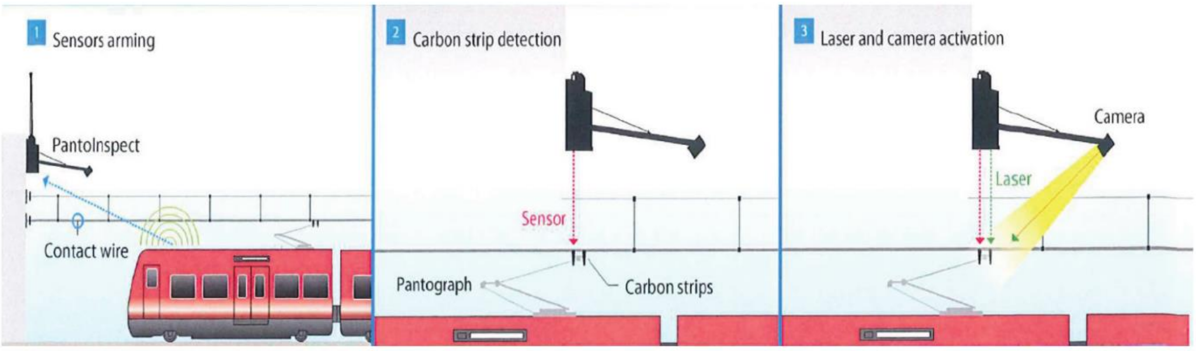


Figure 5 Pantograph online monitoring
Source: http:/www.ar-tech.com.au

3 – RCM concepts

In order to define which are the best maintenance task to each equipment and component the Reliability Centred Maintenance is necessary.
The term "reliability-centered maintenance" was first used in public papers authored by Tom Matteson, Stanley Nowlan, Howard Heap and other senior executives and engineers at United Airlines (UAL). The US Department of Defense (DOD) sponsored the authoring of both a textbook (by UAL) and an evaluation report (by Rand Corporation) on Reliability-Centered Maintenance, both published in 1978.
Today RCM is defined in the standard SAE JA1011 and other standards to Evaluation Criteria for Reliability-Centered Maintenance (RCM) method. The standard SAE JA1011, evaluation criteria for RCM Processes, sets out the minimum criteria that any process should meet before start RCM. They are:

⇒What is the item supposed to do and its associated performance standards?
⇒In what ways can it fail to provide the required functions?
⇒What are the events that cause each failure?
⇒What happens when each failure occurs?
⇒In what way does each failure matter?
⇒What systematic task can be performed proactively to prevent, or to diminish to a satisfactory degree, the consequences of the failure?
⇒What must be done if a suitable preventive task cannot be found?

The RCM methodology steps are summarized in figure 6 below. The maintenance task plan plays an important hole in the maintenance management and it will be discussed later in this book in the chapter 12 as part of asset management.

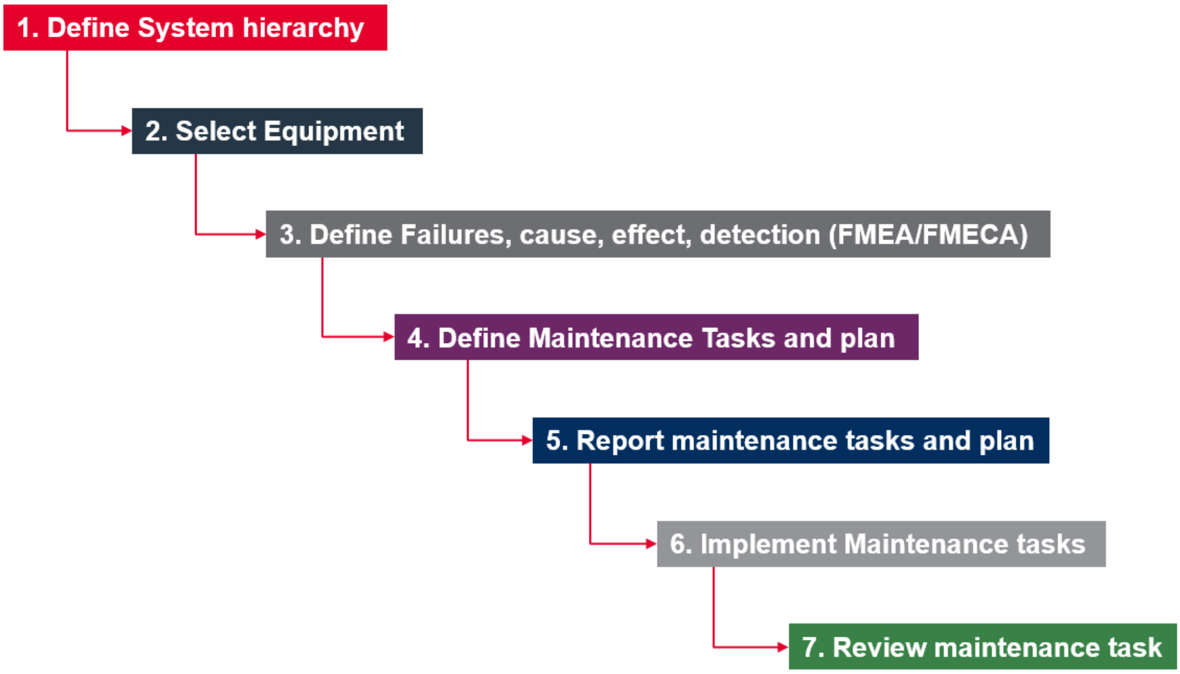


Figure 6: RCM steps

As described in figure 4, the FMEA is the main input for the RCM. The RCM analysis has as main objective to define equipment maintenance tasks based on the best maintenance practices concerning equipment reliability, safety and task cost.

The maintenance is a task, which has as main objective to re-establish equipment Availability /reliability or part of such availability/reliability. Whenever it's possible, maintenance try to reestablish 100% of reliability, but in most of cases, due to equipment's wear a long time or even to human error in maintenance task that´s not possible.

In fact, the difference between carrying out corrective maintenance and predictive maintenance is not always clear in terms of activity cost. Therefore, the LORA (Level of Repair analysis) goes deep in assessing the level of repair analysis and compare different type of maintenance task cost including the logistic effect on system LCC and availability. The LORA is part of the ILS program that will be presented in the next coming paper.

Despite some limitation, the RCM mostly concerns the best practice to detect and avoid the equipment failure. Therefore, during RCM analysis, the frequency of failure and the impact on system availability are the two main parameters, which are taken into account. The figure 7 summarizes the type of decision that the maintenance specialist takes into account during the RCM workshop meeting to define the maintenance task for a specific component.

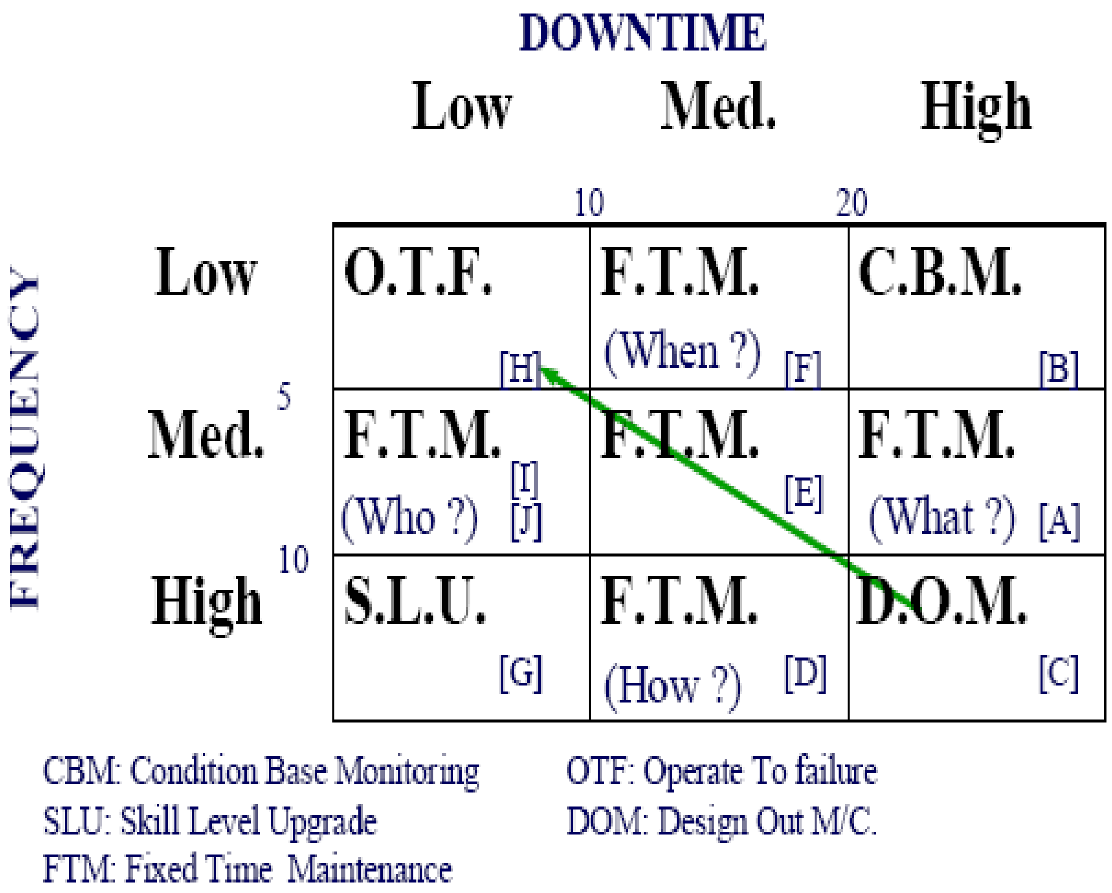


Figure 7: Title: Decision Map
Source: Ashaf W. labib, Euromaintenance 2011

The Skill level upgrade is the type of maintenance, which can be carried out by the operator such as replace a simple component. Design out of M/C is when the preventive action does not avoid or reduce the failure frequency and the effect of failure is high which request a new design of the equipment or component.

THE RCM analysis supposes to be carried out during the design phase to define not only the main maintenance tasks, but also the impact of such maintenance task on the asset life cycle cost and operational availability as input for the RAM analysis (which will be discussed in the next coming paper). The figure 8 shows an example of RCM analysis applied to some bogie equipment.

Figure 8: Bogie RCM (Bogie Frame and Whell)

Reliability Centered Maintenance (RCM)														
RCM Leader: Dr. Eduardo Calixto			**Document: DE-101223-001 Rev01**		**Date:18-05-2015**									
System: Locomotive			**Subsystem: Bogie**		**Equipment: Bogie Frame**		**Component: Bogie Frame and Wheel**							
N0	**Component**	**Failure mode**	**Phase**	**Cause**	**Consequence**	**R**	**Mitigate Action**	**Risk Post**	**Task**	**Task Type**	**Freq**	**Resp**	**Remark**	**Status**
1	Bogie Frame	Crack	Op	Overload by short circuit moment of traction motor	Train Derailment	CI	Define preventive maintenance	EII	Ultrasonic test and visual inspection	Pdm	300000 (Km)	Maint Team	N/A	OK
			Op	Overload by blocking traction motor or gearbox		CI	Define preventive maintenance	EII	Ultrasonic test and visual inspection	Pdm	300000 (Km)	Maint Team	N/A	OK
		Fracture	Op	High overload		CI	Define preventive maintenance	EII	Ultrasonic test and visual inspection	Pdm	300000 (Km)	Maint Team	N/A	OK
			Op	External Impact			Define preventive maintenance		Ultrasonic test and visual inspection	Pdm	300000 (Km)	Maint Team	N/A	OK
2	Wheel	Fracture	Op	High overload	Derailment	CI	Define preventive maintenance	EII	Wayside Online monitoring	OM	cte	Ma	N/A	Ok
			Op	External Impact		CI	Define preventive maintenance	EII	Wayside Online monitoring	OM	cte	Ma	N/A	Ok
		Corrosion	De	Wrong Material specification		CI	V&V software test	EII	Wayside Online monitoring	OM	cte	Ma	N/A	Ok
		Fatigue	Op	Overload			Define preventive maintenance	EII	Wayside Online monitoring	OM	cte	Ma	N/A	Ok

4 - What to do after design phase? Is it necessary, again and again, RCM analysis during the operation phase?

The answer is no. Some decades ago, without the possibility to have all maintenance and performance data online, it was necessary to review again and again the RCM analysis during the operation phase. In fact, if there´s some equipment modification or missed failure mode, re the task defined in the RCM must be reviewed. However, as long as the equipment operates under the same design concept without modification the maintenance task will not change, but only the task frequency, which depends on the equipment degradation along time.

The current technology solution enables the data collection, data assessment based on an index or trends assessment and automatic alert. Such level of integrated information enables the maintenance specialist to take a decision in time to avoid the undesired failure. Therefore, the Asset Management Concept take place as the main tool to monitor, assess and review the maintenance tasks.

The European commission carried out the Automated and Cost-Effective Maintenance for Railway (ACEM-Rail) collaborative research project funded in order to define the best maintenance practices for maintenance as shows figure 9.

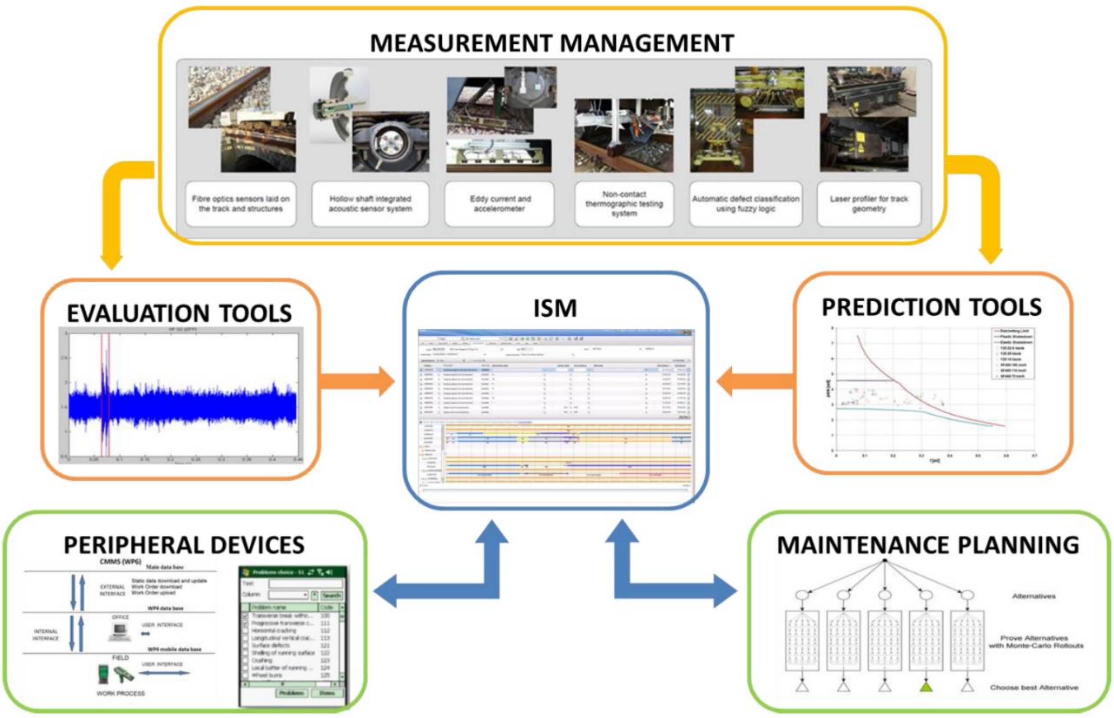


Figure 9: Integration of the ISM with other subsystems
Source: https://perpetuum.com/technology/

In fact, the link between the maintenance plan, predictive maintenance and performance is not completely fulfilled based on the integrated maintenance IT systems, but also by implementing the asset management program, which is not fully discussed and clear for railway industry so far.

The Integration of maintenance information does not mean asset management. The asset management concept defined in the ISO 55000 series, which is also applied in the railway industry define the following element as the basis for the asset management.

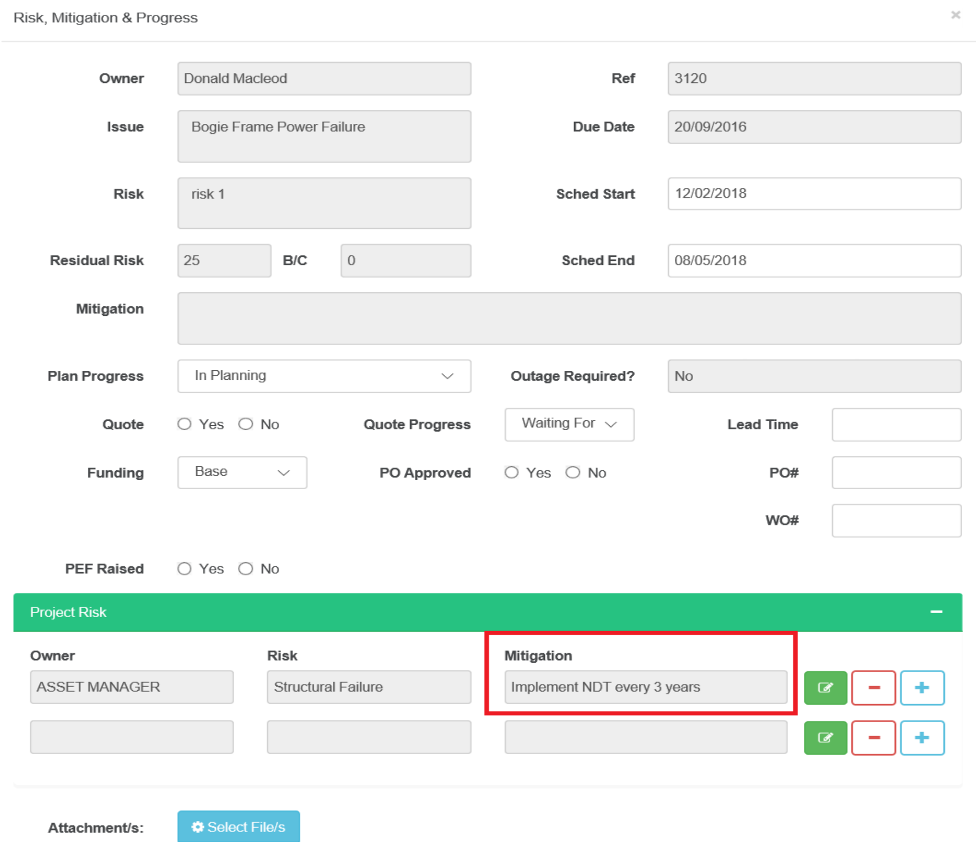
- Context of the organization;
- Leadership:
- Planning:
- Support:
- Operation:
- Performance evaluation.

The ***context of the organization*** includes internal and external context. The external context includes the social, cultural, economic and physical environments, as well as regulatory, financial and other constraints. The internal context includes organizational culture and environment, as well as the mission, vision and values of the organization.
The ***leadership*** includes the Top management is responsible for developing the asset management policy and asset management objectives and for aligning them with the organizational objectives. Leaders at all levels are involved in the planning, implementation and operation of the asset management system.
The ***planning*** context and direction of the organization's activities, including its asset management activities. The organizational objectives are generally produced from the organization's strategic level planning activities and are documented in an organizational plan.
The ***support*** will require collaboration among many parts of the organization. This collaboration often involves the sharing of resources. Coordinating these resources and applying, verifying and improving their use should be the objectives of the asset management system. It should also promote awareness of the asset management objectives across the whole organization.
The ***operation*** enables the directing, implementation and control of its asset management activities, including those that have been outsourced. Functional policies, technical standards, plans and processes for the implementation of the asset management plans should be fed back into the design and operation of the asset management system.
The ***performance evaluation*** can be direct or indirect, financial or non-financial Effective asset data management and the transformation of data to information is a key to measuring asset performance. Monitoring, analysis and evaluation of this information should be a continuous process. Asset performance evaluations should be conducted on assets managed directly by the organization and on assets which are outsourced.

In general terms, the asset management encompasses three key factors such as equipment, process, people as the basis for the risk evaluation as shows the figure 10. Therefore, in addition to online equipment information and integrated database about equipment performance and maintenance, it´s also necessary to have a step by step asset management process, which consider all elements defined by ISO 55000, including people, the constrains and the existing and future risks. A balanced asset management program enables the managers to take a proper decision in time, to balance the risk they are facing with the resource they have available to achieve high performance.

Figure 10: Asset management key success factor
Source: www.enkelt.co.uk

Nevertheless, the equipment performance monitoring, inspection and maintenance are still one of the most important success factor. Therefore, it´s very important to have a good transition from design phase to the operation phase by input all information defined during the RCM analysis in the asset assurance plan. The figure 11 shows an example of input task form RCM to assurance plan.


Risk, Mitigation & Progress

Owner: Donald Macleod
Ref: 3120
Issue: Bogie Frame Power Failure
Due Date: 20/09/2016
Risk: risk 1
Sched Start: 12/02/2018
Residual Risk: 25
B/C: 0
Sched End: 08/05/2018
Mitigation:
Plan Progress: In Planning
Outage Required?: No
Quote: Yes No
Quote Progress: Waiting For
Lead Time:
Funding: Base
PO Approved: Yes No
PO#:
WO#:
PEF Raised: Yes No

Project Risk

Owner	Risk	Mitigation
ASSET MANAGER	Structural Failure	Implement NDT every 3 years

Attachment/s: Select File/s

Figure 11: RCM input for asset management. Source: www.enkelt.co.uk

5 – Conclusion

The RCM still plays an important hole in RAMS & LCC railway program during design and operation phase. The maintenance management process and implemented during the operation phase need to be part of the asset management program considering all aspects defined in ISO 55000 as well as the three key success factors such as equipment data, people and process.

The RCM information during the design are inputting information for other important analysis during the design phase such as RAM analysis, LCC analysis and LORA. In addition, the RCM information is input to the assurance plan during the operation phase as part of an asset management program, which is facilitated with some integrated data system. Such system enables to implement the asset management as a process include performance monitoring, maintenance information (maintenance plan and work orders), FRACAS, time and task management, LCC management. The coming paper will demonstrate all aspects of the asset management for the railway industry.