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CoCo TYPE NATIONAL LOCOMOTIVE
RAMS GUIDELINES

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Turkish Railway Vehicles Industry Inc.

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INDEX

I. LIST OF FIGURES

N/A

II. LIST OF TABLES

1. SUBJECT

The purpose of this document is to provide preliminary information about the RAMS guidelines to be followed in the National CoCo Loco project.

1.1. LIST OF ACRONYMS & ABBREVIATIONS

TCDD	General Directorate of Turkish State Railways
TÜRASAŞ	Turkish Railway Vehicle Industry Inc.
LOCO	Locomotive
PHA	Preliminary Hazard Analysis
SHA	System Hazard Analysis
LCMS	Locomotive Control Management/Monitoring System
SIL	Safety Integrity Levels

2. APPLICABLE TECHNICAL DOCUMENTS AND STANDARDS

DOCUMENTS AND STANDARDS

Reference	Standard number	Description
[1]	EN 50126:2017	Railway applications. The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)
[2]	IEC 61508:2010	Functional safety of electrical/electronic/programmable electronic safety-related systems
[3]	EN 50128:2011	Railway applications – Software for railway control and protection system
[4]	EN 50129:2018	Railway applications. Communication, signalling and processing systems. Safety related electronic systems for signalling

ASSOCIATED DOCUMENTS

Reference	Document number	Description
[5]	TB50165	NATIONAL LOCO CoCo TYPE: RAMS targets allocation
[5]	TB50170	NATIONAL LOCO CoCo TYPE: SIL Definitions

3. LOCO MAIN DATA

The National CoCo Type Mainline Locomotive project, which will be produced by TÜRASAŞ, is intended for freight service and has an operating speed of 120 km/h.

The loco has 2 different propulsion systems:

1. Electric Locomotive
2. Diesel Electric Locomotive

4. MISSION PROFILE

Following the mission profile for the CoCo locomotive

Table 1 – Mission profile

Data	Value	Unit
Yearly distance run	300.000	km
Operative days for year	300	
Hours for day	18	
Operative average speed	55	km/h
Max speed	120	Km/h

5. GENERAL DOCUMENTATION

The documents that must be filled for the complete RAMS analysis are the following:

- ✓ Functional breakdown + inherent failure analysis
- ✓ Mission critical failures Analysis
- ✓ FMECA
- ✓ System/Sub-Systems Hazard Analysis
- ✓ Hazard Log + SIL data (if applicable)
- ✓ List of critical components (to be carried out by supplier)
- ✓ Preventive Maintenance Analysis
- ✓ Corrective Maintenance Analysis

In the next paragraphs there are instructions for documents improving and a description of the related templates.

6. RELIABILITY ANALYSIS

6.1. INTRODUCTION

The following sections detail the requirements for the implementation of Reliability activities to be undertaken by the Supplier for the scope of supply specified in this Technical Specification.

6.2. TREE BREAKDOWN STRUCTURE

The Tree Breakdown Structure is a simple but complete tool to describe the composition of a rolling stock, suitable to be easily modified, updated and expanded for other Reliability and Maintainability analysis.

It can be used:

- To calculate the global MTBF (Mean Time Between failure) of the rolling stock by adding columns with relevant components FR (Failure Rate)
- To calculate the LCC (Life Cycle Cost) by exporting section by section of the breakdown in the LCC calculation sheet

6.3. RELIABILITY ANALYSIS

Inherent Reliability

Inherent Reliability is linked to the likelihood of any failure occurring and describes the basic reliability values of each sub-system.

It is evidently a parameter linked to the overall quality of the product and to the number of repairs that it will require during its working life, but it is of little significance precisely because it is not very selective.

It can help to give an approximate idea of the repair costs and the unavailability of the vehicle for downtime, although it is not an accurate measure of these factors.

Service Reliability

Service (or Mission) Reliability is linked to the probability that a fault will occur with heavy consequences on an important functionality of the vehicle. Unlike inherent reliability, it is very significant because it describes the ability of the rolling stock to carry out its main mission and is therefore linked to "service disruption", just as perceived by users.

For this reason, the Service Reliability (together with the Availability) is a parameter directly related to the ability of the rolling stock to create profit for the Buyer or the Locomotive Operator.

6.4. FAILURE CLASSIFICATION

The proposed classification of failure rates reported hereafter helps to identify the type of failure, and to define relevant Reliability targets to be allocated to Suppliers systems/equipment/components.

Class A Failures: The locomotive cannot move; the locomotive must be towed with another locomotive.

Class B Failures: These are the failures that require stopping at the first station, but where the vehicle can go to the parking area with its own power.

Class C Failures: Specific failures seen by the customer as an obstacle to service [causing a delay of more than 10 minutes at the destination (last station)] The delay will be calculated only once for each delay at the last station, not for each intermediate stop.

Class D Failures: It will be defined as the failures in which the locomotive can continue service until the end of the day.

The inherent reliability failure rates are the basis for the evaluation of Corrective Maintenance, including for each sub-system all the level of failure.

Classes A to D affect Inherent reliability, classes A to C affect Service reliability.

6.5. RELIABILITY TARGET

Reliability targets are allocated in cascade to all equipment/systems/components and reported in the Technical Specifications to be passed to the different Suppliers.

6.6. FAILURE RATE ATTRIBUTION

The calculation of the "Failure Rate" does not include failures which are not directly caused by Rolling Stock systems/equipment faults as:

- Repeated same failure due to the same cause and maintenance intervention failing to change the related parts will only be calculated once.
- Consequential failure due to another failure (secondary failure)
- Failure due do accident or vandalism; by proven infrastructure defects and by other 3rd parties, e.g. suicide damaging a vehicle are excluded
- Failure due to improper action of driver or operator.
- Failure due to not respecting maintenance manual
- Failure due to public action or careless omission like forgetting to oil.
- Failure due to the equipment out of the contract.

The number of failures of each sub-system will be collected by the Locomotive Operator and reliability ratios will be calculated following a procedure to be defined and agreed as already mentioned.

The targets are referred to locomotive fleet according to the established mission profile with the relevant “conversion speed” for converting time “failures affected by run km” into “failures affected by time (hours) utilization” and vice versa.

In the apportionment of targets for the different systems/equipment the cascade of requirements will respect the requested global target at locomotive level.

Systematic failures are considered the identical failure on a part/component which occurs on at least 10% of total identical parts/components of the fleet with the same function. In case of systematic failures, proper investigations will be done in order to define a technical solution or modification including Spare Parts modification or replacement.

The requirement is defined for the single Line Replaceable Unit. The LRU represents the sub-system having the lowest hierarchy level in the tree structure breakdown of the vehicle and its devices; it is entirely replaceable during vehicle maintenance.

6.7. FUNCTIONAL BREAKDOWN AND INHERENT FAILURE RELIABILITY TEMPLATE

In this section is described the template to be used for the system breakdown and inherent reliability analysis

Table 2 – Template headers

COLUMN IDENTIFICATION	COLUMN DESCRIPTION
Project	Insert the Project Name.
Document No/Rev:	Insert the document number and the revision number
System:	Insert the description of the system
System Supplier:	Insert the supplier’s name (if applicable)
Issue date	Insert the document release date
Sub-System:	Insert the description of the sub-system
Sub-System Supplier:	Insert the sub-system supplier name (if applicable)
Edited by	Insert the Name of the Compiler.
Drawing nr:	Insert applicable drawing number
Filename	Name of file containing the analysis forms

Table 3 – Template columns

COLUMN IDENTIFICATION	COLUMN DESCRIPTION
RAMS Code	RAMS code number
Name of project	Name of system – sub-system – components corresponding to the code
Part number	Supplier identification number
Data input	Data coming from Supplier or from database
Quantity	Quantity of assembly for each coach
Locomotive Quantity	Total quantity on locomotive
λ unit. BASIC (FPMH)	Basic failure rate per object(failure per Million hours)
Duty Cycle %	Percentage of use of components during vehicle operation
λ Effect. BASIC (FPMH)	Effective failure rate (Basic failure rate multiplied per duty cycle)
λ Train Level (FPMH)	Failure rate at locomotive/train level (Effective failure per quantity)
Train Level LEVEL 1 (FPMH)	Failure rate at system level
Train Level LEVEL 2 (FPMH)	Failure rate at sub-system level
λ (Total Failure rate)	Total failure rate at locomotive level
Total MTBF (h)	Mean time between failure at locomotive level (1 / failure rate)
Total FPMK	Total failure rate at locomotive level per Million km

6.8. CRITICAL FAILURES TEMPLATE DESCRIPTION

The worksheet helps to give support for the identification of “Mission Faults” and corresponding MTBSF:

- MTBSF1 = Mean Time Between Service Failures (mission reliability including A, B and C failure classes)
- MTBSF2 = Mean Time Between Service Failures (mission reliability including only A and B failure classes)

.
This information allow the locomotive Designer to make a FTA analysis (Fault Tree) of the complete locomotive.
Instead of this template, Suppliers could provide an FTA analysis (Fault Tree) of their sub-system.

Table 4 – Critical failures template headers

COLUMN IDENTIFICATION	COLUMN DESCRIPTION
Project	Insert the Project Name
Document No/Rev:	Insert the document number and the revision number
System:	Insert the description of the system
System Supplier:	Insert the supplier's name (if applicable)
Issue date	Insert the document release date
Sub-System:	Insert the description of the sub-system
Sub-System Supplier:	Insert the sub-system supplier name (if applicable)
Edited by:	Insert the Name of the Compiler
Drawing no:	Insert applicable drawing number
Filename	Name of file containing the analysis forms
TOP EVENT description:	Description of the Top Event
TOP EVENT id No.:	Identification Number of the Top Event

Table 5 – Critical failures template columns

COLUMN IDENTIFICATION	COLUMN DESCRIPTION
Pos. No:	Row identity code
Event Id. Number:	Insert the event number corresponding to the Top Event description.
Part/LRU Code:	It shows the code of the examined equipment/ sub-assembly/ LRU/ LLRU or element in accordance with the parts list/breakdown.
Description:	It shows the description of the examined equipment/ sub-assembly/ LRU/ LLRU or element
Part Number:	Univocal code used to define the items
Failure mode:	Shows the expected failure mode of the examined equipment/ sub-assembly/ LRU /LLRU or element. It is takes from the FMECA, if present. It corresponds to the primary event in case in which it is not attributable to an LRU.
Failure Rate:	The failure rate fraction is the fraction of the overall failure rate of the examined equipment/ sub-assembly/ LRU /LLRU or element referring to the actual considered failure mode; the failure rate is calculated in Failure Per Million Hours

COLUMN IDENTIFICATION	COLUMN DESCRIPTION
FPMK:	Number of Failure Per Million Km, evaluated considering the conversion velocity
MTTR:	Main time To Repair refer to the failure mode
Failure Rate Source:	Source of the failure rate in code
Ref.to FMECA:	Indicates the reference to the FMECA document in which is reported the failure mode identified and developed
Remarks:	It shows any technical information deemed necessary to improve the comprehension of what is reported in the cells of the FTA row
Action required:	Eventually explicative notes for recommendations, indications and clarifications

7. SAFETY ANALYSIS

7.1. FMEA / FMECA ANALYSIS

The Failure Mode Effects and Criticality Analysis (FMECA) allows to systematically evaluate and document, through the failure modes analysis, the potential impact of each functional or hardware failure on mission, system performance, maintainability, and maintenance requirements. Each potential failure is ranked by severity of its effects in order that appropriate corrective actions may be taken to eliminate or control the high-risk items.

In this section is described the template to be used for FMECA analysis.

Table 6 – FMECA template header

COLUMN IDENTIFICATION	CORRECTIVE MAINTENANCE COLUMN DESCRIPTION
Project	Insert the Project Name.
Document No/Rev:	Insert the document number and the revision number
System:	Insert the description of the system.
System Supplier:	Insert the supplier’s name (if applicable)
Issue date	Insert the document release date
Sub-System:	Insert the description of the sub-system
Sub-System Supplier:	Insert the sub-system supplier name (if applicable)
Edited by	Insert the Name of the Compiler.
Drawing no:	Insert applicable drawing number
Filename	Name of file containing the analysis forms

Table 7 – FMECA template columns

COLUMN IDENTIFICATION	COLUMN DESCRIPTION
Position No	Row identity code
Part/ LRU Code	It shows the code of the examined equipment/ sub-assembly/ LRU/ LLRU or element in accordance with the parts list/breakdown
Description	It shows the description of the examined equipment/ sub-assembly/ LRU/ LLRU or element
P/N	Univocal code used to define the items
Function	It shows the function of the examined equipment/ sub-assembly/ LRU /LLRU or element (including numbering of failure mode)
Phase	It shows the operational mode where the failure effects of the examined failure mode can occur
Failure Mode index	The numbering of each different failure mode for the examined equipment/ sub-assembly/ LRU /LLRU or element
Failure Mode	Shows the expected failure mode of the examined equipment/ sub-assembly/ LRU /LLRU or element
Cause of Failure Mode	Shows the cause for the expected failure mode of the examined equipment/ sub-assembly/ LRU /LLRU or element
λ unit.BASIC	Basic failure rate per object(failure per Million hours)
Failure rate (FPMH)	It is the failure rate of the examined equipment/ sub-assembly/ LRU /LLRU or element referring to the actual failure mode(considering quantity and duty cycle); it is calculated in Failure Per Million Hours
Failure effect - Local	It shows the failure effect on the examined item
Failure effect - System	It shows the failure effect on the system to which the examined equipment/ sub-assembly/ LRU /LLRU or element
Failure effect - Locomotive	It shows the failure effect at locomotive level
Hazard Severity	It shows the severity level of the failure in respect of Reliability. Classification is indicated by the table "Hazard Severity Level"
Hazard frequency	It shows the severity level of the failure in respect of Safety. Classification is indicated by the table "Hazard Frequency Level Table"
Safety risk index	Insert total safety index incompliance to worksheet 9-Critical Reliability Classification

Failure Identification - Detection	It shows the methods of detection of the expected failure mode
Preventive and compensating measures	It shows the preventive and mitigation measures identified to prevent or to mitigate the effect of considered failure modes, i.e. to reduce the risk associated to the failure. All the useful Design, Maintenance, Operational safeguards shall be taken and possibly the reference to applicable standards or regulation has to be reported.
Remarks	It shows any technical information deemed necessary to improve the comprehension of what is reported in the cells of the FMECA row

- to identify the potential weak points of the examined system/equipment through a systematic and documented analysis of all the possible ways in which a component can fail i.e. to find the relevant failure modes.
- to investigate the potential causes for each failure mode and their effects affecting performance (which can be different for each phase of the service),
- to evaluate the criticality of each failure,
- to identify the local effect of the component failure on the involved system/equipment and on other external connected system/equipment up the final effect at rolling stock level,
- to identify the “single-point failures” which can lead to serious consequences on service and safety if no barriers or mitigation actions are foreseen,
- to identify preventive/corrective actions that can be implemented to limit, control or eliminate the risks associated with each failure mode, during both the design and service phases of the rolling stock.

7.2. SHA/SSHA AND O&SH ANALYSIS

The System Hazard Analyses (SHA) is the tool to be employed for the Hazard Identification process and to generate the Hazard Log, specify the safety requirements and identify both the top-level hazards and low-level hazards. The Hazard Log provides the basis of the justification that the locomotive design is safe and can be operated and maintained at minimum risk.

The System Hazard Analysis (SHA) shall be performed in the design stages in order:

- to integrate the system hazards already identified during the PHA with new detailed hazards deriving from a better understanding of the system under development.
- to collect the eventual sub-system hazards and identify their interface hazards.
- to evaluate casual factors for each hazard
- to collect and group all hazards.
- to identify supporting analyses and requirements as necessary
- to define document process

The Operating and Support Hazard Analysis is a safety analysis developed to identify and mitigate hazards deriving from the Operational and Maintenance procedures of the locomotive system.

The purpose is to identify in a systematic way the adequacy of the Operational and Maintenance procedures.

7.3. SHA/SSHA TEMPLATE DESCRIPTION

In this section is described the template to be used for the SHA analysis.

Table 8 – SHA template headers

COLUMN IDENTIFICATION	COLUMN DESCRIPTION
Project	Insert the Project Name.
Document No/Rev:	Insert the document number and the revision number
System:	Insert the description of the system
System Supplier:	Insert the supplier's name (if applicable)
Issue date	Insert the document release date
Sub-System:	Insert the description of the sub-system
Sub-System Supplier:	Insert the sub-system supplier name (if applicable)
Edited by	Insert the Name of the Compiler.
Drawing no:	Insert applicable drawing number
Filename	Name of file containing the analysis forms

Table 9 – SHA template columns

COLUMN IDENTIFICATION	COLUMN DESCRIPTION
No	Progressive number
Main system ID	RAMS code number
Hazard Category	Numbering for each hazard of the corresponding "hazard type category"
Hazard description (general)	Hazard category in according with Hazard List
Hazard Identification (detailed)	Numbering for each hazard of the corresponding "hazard type"
Hazard description (detailed)	Specific description of the generic hazard
Sequential Numbering	Progressive number associated to previous column

COLUMN IDENTIFICATION	COLUMN DESCRIPTION
Phase / Operation mode	- Running / Normal operation - Running / Degraded operation - Running / Multiple operation - Running / Emergency operation - Standstill / Parking - Standstill / Stabling - Standstill /Driver cab change - Depot / Maneuver - Depot / Maintenance
System / Sub-System / Component	System/ subsystem /component from which the hazard originates
Causes	Description of the cause that originate the corresponding hazard
Consequence **Potential accident/ damage**	Description of the consequences that could occur in case of the corresponding hazard. The subject of the consequences will be identified.
Severity Level	Severity level category
Probability	Estimated Frequency of Hazard
Risk Category	Risk category and acceptance criteria
Preventive/compensating actions (Design, Maintenance, Operational Safeguards)	The preventive and mitigation measures identified in order to reach the Target risk Objective. All the useful Design, Maintenance, Operational safeguards will be considered, and where available, a reference to applicable standards or regulation will be reported.
Target risk category	Desired risk category and acceptance criteria
Remarks / Documents reference	Reference to drawings or specification or documents
Comments	Any useful comments for a better understanding.

In order to define codes for safety classification, see the table on the sheet “Critical Safety EN-50126.

7.4. HAZARD LOG

The hazard Log (HL) is a record document in which are reported all safety-related hazards identified in the safety analyses already developed (PHA, SHA, SSHA, IHA and O&SHA) with the goal to define and give demonstration of the application of the safety requirements and mitigations needed.
The Hazard Log is a key safety record for the tracking of the hazards and associated actions needed to demonstrate the risk resolution, the acceptability for safety, and provides the basis of the justification that the locomotive design is safe and, can be operated and maintained at minimum risk.

7.5. HAZARD LOG + SIL TEMPLATE DESCRIPTION

In this section is described the template to be used for hazard log analysis.

Table 10 – HL template header

COLUMN IDENTIFICATION	COLUMN DESCRIPTION
Project	Insert the Project Name.
System supplier	Insert the system name
SubSystem supplier	Insert the subsystem name
Document No/Rev:	Insert the document number and the revision number
Issue date	Insert the document release date
Edited by	Insert the Name of the Compiler.
Drawing no:	Insert applicable drawing number
Filename	Name of file containing the analysis forms

The HL analyses will contain the following information:

- **Hazard No. & Main System Identification:** The numbering rule may be: acronym of project name + acronym of system + HL + xxx digits, such as ABC_zxj_HL_001, i.e. item 1 of Hazard Log of zxj system for ABC Project;
- **Hazard Type and Category:** Numbering for each hazard of the corresponding "hazard type category". See the table on the sheet “Critical Safety EN-50126”
- **Hazard Identification (detailed):** Numbering for each hazard of the corresponding "hazard type"
- **Hazard description (detailed):** Specific description of the generic hazard
- **System / Sub-System / Component:** System/ subsystem /component from which the hazard originates.

- **Cause:** Description of the cause that originate the corresponding hazard.

- **Exposed to the hazard:**

    - Driver: To thick the involved type of people
    - Crew: To thick the involved type of people
    - Passenger: To thick the involved type of people
    - Maintainer: To thick the involved type of people

- **Effects:** Description of the consequences that could occurs in case of the corresponding hazard. The subject of the consequences shall be identified.
- **Phase / Operation Mode:** Describe the locomotive operation mode in case of hazards, including

    - - Running / Normal operation
    - - Running / Degraded operation
    - - Running / Multiple operation
    - - Running / Emergency operation
    - - Standstill / Parking
    - - Standstill / Stabling
    - - Standstill /Driver cab change
    - - Depot / Manoeuvre
    - - Depot / Maintenance

If the influences or initial risk levels of hazards occur in various operation modes, the disparate operation modes shall be filled in different lines.

- **Initial Risk Evaluation: Severity Level:** Severity level category. Level of severity of harm caused by the accident associated to the hazard. Fill in with Severity Level with reference to Hazard Severity Category, See table on the sheet “Critical Safety EN-50126”. It Contains the estimated initial level of the severity of the potential consequence (accident caused by a hazard) prior to the implementation of the preventive actions, so previous of the application of the mitigation measures.

- **Initial Risk Evaluation: Frequency**: Estimated Frequency of Hazard. Fill in with Frequency category with reference to Hazard Frequency Level, see table on the sheet “Critical Safety EN-50126”. It contains the estimated initial level of the frequency of the potential consequence (accident caused by a hazard) prior to the implementation of the preventive actions, so previous of the application of the mitigation measures.

- **Initial Risk Evaluation: Risk Category:** Consequent risk category and acceptance criteria. Fill in with risk category with reference to System Safety Acceptance Criteria, see matrix on the sheet “Critical Safety EN-50126”. It contains the estimated initial level of the Risk of the potential consequence (accident caused by a hazard) prior to the implementation of the preventive actions, so previous of the application of the mitigation measures.

- **Safety Function Code [A]:** Code for identification of the Safety Function (derived from function list if produced or from other design document)

- **Description of Safety Function [B]:** Description of the Safety Function

- **SIL [C]:** Report the Safety Integrity Level (SIL) associated to the function if already defined.

- **Software (Safety function) [D]**: YES/NOT. To explain if the software involved in the mentioned function perform safety role.

- **Preventive and Mitigation Measures:** Preventive and mitigative measures should covers the following issues:
    - DESIGN
    - MANIFACTURE/INSTALLATION
    - OPERATION
    - MAINTENANCE

- **Final Risk Evaluation: Severity Level:** Severity level category to be reached after introduction of compensating measures. Fill in with Severity Level with reference to Hazard Severity Category, See table on the sheet “Critical Safety EN-50126”. It contains estimated residual level of the severity of the potential consequence (accident caused by a hazard) after the application of the mitigation measures.

- **Final Risk Evaluation: Frequency**: Estimated Frequency of Hazard to be reached after introduction of compensating measures. Fill in with Frequency category with reference to Hazard Frequency Level. See table on the sheet “Critical Safety EN-50126”. It contains the estimated residual level of the frequency of the potential consequence (accident caused by a hazard) after the application of the mitigation measures.

- **Final Risk Evaluation: Residual Risk:** Consequent risk category and acceptance criteria. Fill in with risk category with reference to System Safety Acceptance Criteria Matrix. See matrix on the sheet “Critical Safety EN-50126”. It contains the estimated residual level of the Risk of the potential consequence (accident caused by a hazard) after the application of the mitigation measures.

- **Status:** Fill in with the implementation status of mitigation measures.
    - O-Open;
    - C-Closed;

- **Responsibility:**

- Car builder: To thick the involved type of stockholder
- Supplier: To thick the involved type of stockholder
- Maintainer: To thick the involved type of stockholder
- Operator: To thick the involved type of stockholder

- **Remarks / Documents reference**: Any useful comments for a better understanding. Whatever information deemed necessary to help in comprehension and in carrying out the activities relevant to the examined hazard.

8. MAINTAINABILITY

8.1. SCOPE OF PREVENTIVE MAINTENANCE

Preventive maintenance consists in any scheduled operation to maintain an assembly/subassembly or components in its specific operating conditions:

- periodical inspection and diagnostic test for prevention of malfunctioning.
- scheduled replacement operations.
- checks, at specified time intervals, whose outcome determines whether or not replacements will be performed.
- routine operations, such as filling, topping up, change oil, greasing, adjustments, and so on.
- general overhaul of systems and subsystems of the locomotive.

The preventive maintenance can be divided in short term preventive maintenance (carried out at defined interval during a year) and cyclic heavy maintenance (carried out after a certain number of years with a lot of km covered). The different intervals are defined applying the so called “Preventive Maintenance Regime”.

8.2. SCOPE OF CORRECTIVE MAINTENANCE

Corrective maintenance consists in any maintenance operation which is not scheduled (part of preventive maintenance) as a result of a failure happened during service, i.e. any intervention performed following a fault to restore a component/subsystem/system to its specified operating conditions.
Sometimes interventions are necessary after acts of vandalism or malfunctions due to the improper use of the system or external causes as traffic incident; all these interventions are not considered in the costs calculated in the analysis.
To minimize the down time, the corrective maintenance can be performed by replacing some subsystems or LRU which can be subsequently repaired off locomotive. LRU means Line Replacement Unit, i.e. the smallest component that can be replaced in first level maintenance.

8.3. PREVENTIVE MAINTENANCE (PM) INDEX

The figure of PM index has been calculated by mean of following basic formula:

$$PM = \left\{ \left(\sum_i Cmh * Tmh_i + \sum_i Cmat_i \right) / K \right\} * 1.000$$

The figure is expressed in €/1000 km where:

- Cmh = Hourly cost of manpower [€/hours man]
- Tmh_i = Global hours spent for the i-th preventive intervention
- $Cmat_i$ = Global cost of material used for the i-th preventive intervention
- K = km run cumulated by the tram fleet in the considered period

To perform the calculation by mean of electronic sheet the above formula has been re-arranged and some basic parameters have been explicated as for instance the number of interventions done in the considered period.

$$PM = \frac{\left(\sum_i Cmat_i * Q_i \right)}{km_{period}} + \frac{\left(\sum_i Tmh_i * Q_i * Int_i \right) * Cmh}{km_{period}}$$

The figure is expressed in €/1000 km where:

- $Cmat_i$ = global cost of material used for the i-th preventive intervention
- Q_i = quantity of components maintained on the Locomotive
- Tmh_i = global hours spent for the i-th preventive intervention
- Inti = number of interventions done in the considered period
- Cmh = hourly cost of manpower [€/hours man]
- Km_{period} = km run cumulated by the fleet in the considered period

8.4. CORRECTIVE MAINTENANCE (CM) INDEX

The figure of PM index has been calculated by mean of following basic formula:

$$CM = \left\{ \left(\sum_i Cmh * Tmh_i + \sum_i Cmat_i \right) / K \right\} * 1.000$$

The figure is expressed in €/1000 km where:

- Cmh = hourly cost of manpower [€/hours man]
- Tmh_i = global hours spent for the i-th corrective intervention
- $Cmat_i$ = global cost of material used for the i-th corrective intervention
- Km = km run cumulated by the fleet in the considered (defined) period

To perform the calculation by mean of electronic sheet the above formula has been re-arranged and some basic parameters have been explicated as for instance the component failure rate.

$$MC = \frac{\left(\sum_i \lambda_i * Cmat_i * Q_i\right)}{(v_{conv} * 1000)} + \frac{\left(\sum_i \lambda_i * Tmh_i * Q_i\right) * Cmh}{(v_{conv} * 1000)}$$

The figure is expressed in €/1000 km where:

- λi component failure rate [1/106 h]
- $Cmat_i$ global cost of material used for the i-th corrective intervention [€]
- Q_i quantity of components maintained on the locomotive
- v_{conv} conversion speed as per the established mission profile [km/h]
- Tmh_i global hours spent for the i-th corrective intervention [h]

8.5. MTTR

The MTTR (Mean Time To Repair) index is expressed in hours and it is calculated using the following formula:

$$MTTR = \frac{\sum_i \lambda_i * h_i * Q_i}{\sum_i \lambda_i * Q_i}$$

where:

- λ_i = component failure rate [$1/10^6$ h]
- hi = time needed to repair/substitute the component
- Q_i = quantity of components on the locomotive
-

8.6. PREVENTIVE MAINTENANCE REGIME (FREQUENCIES)

The Supplier shall give periodic maintenance intervals on the basis of kilometers.

These intervals shall be optimized on vehicle basis and must be compliant to these requirements:

- ✓ No scheduled maintenance in locomotive depot shall be required before one month or 40,000 km
- ✓ Overhauls shall not be required before 3 years (intermediate overhaul) and 6 years (general overhaul)

The Supplier shall agree with CoCo Loco upon possible different frequency keeping into account particular needs of its scope of supply.
The overhauls interval can be proposed by Supplier, as a multiple of previous intervals

8.7. MANTENANCE LEVEL

8.7.1. Preventive maintenance level

1) Preventive maintenance intervention during service

The locomotive is recovered generally in the depot and the return to revenue service is foreseen within short time.
Intervention on involved LRUs are simple substitution or operations that do not require any dismantling work of other locomotive parts or specialized workshop [these operations are generally classified as “first preventive maintenance level”].

The code used in the analysis is: On-T.

2) Preventive maintenance intervention/overhaul out of service

The locomotive may be recovered either in the depot or in a specialized workshop/heavy maintenance depot. These interventions/overhaul performed on LRUs require more complex maintenance operations that cannot be done on locomotive.
Removed LRUs are dismantled up to elementary sub-component and can be either overhauled in loco (if specialized maintainers and tools are available) or in specialized workshop or by the original supplier.

The code used in the analysis is: Off-T.

8.7.2. Corrective maintenance level

1) Corrective maintenance intervention during service without LRU substitution

The locomotive is recovered generally in the depot and the return to revenue service is foreseen within short time.
Intervention on involved LRUs are simple operations that do not require any particular Sub-Assembly A work or specialized workshop. Of course, the LRU must be reparable.
What has been stated above for the LRU must be referred to the Superior Assembly/Sub-assembly if the preventive maintenance operation concerns the whole superior assembly/sub-assembly.

As example, the code used in the analysis is: 1R.

2) Corrective maintenance intervention during service with not reparable LRU substitution

The locomotive is recovered generally in the depot and the return to revenue service is foreseen within short time.
Intervention on involved LRUs which are not reparable, is limited to a substitution with a spare. The costs of consumable materials used, and the amount of time spent for all the envisaged operations (search and access to the LRU, dismantling, mounting and functional verifications) are reported by the analyses. The global cost includes the cost of the spare.

As example, the code used in the analysis is: 1NR.

3) Corrective maintenance intervention out of service with reparable LRU substitution

The locomotive is recovered generally in the depot and the return to revenue service is foreseen within short time. In case of complex systems or particular heavy intervention the locomotive is sent to specialized workshop or heavy maintenance depot.
LRUs are removed from the locomotive and substituted by a spare LRU. The removed LRU is sent to supplier plant/specialized center for the repair operation.
The costs of consumable materials used, and the amount of time spent for all the envisaged operations (access of the LRU, dismantling, cost of repair, mounting and functional verifications) are reported by the analyses. The global cost includes the cost of reparation and delivery to the supplier factory/specialized center.

As example, the code used in the analysis is: 2R.

8.8. PREVENTIVE MAINTENANCE TEMPLATE

Here following are listed and described the contents of the template (Excel file) used to calculate the figures relevant to the Preventive Maintenance.
Each data sheet filled with requested data gives as final result the maintenance indexes and costs for a defined system.
The further tables collect together all the results about all systems/equipment of the locomotive giving the results at locomotive/fleet level.

Table 11 – MP template headers

COLUMN IDENTIFICATION	INPUT	OUTPUT	PREVENTIVE MAINTENANCE COLUMN DESCRIPTION
Document number	X		Insert document number
Revision number	X		Insert revision number
Date:	X		Insert the Date of the document.
Project	X		Insert the Project Name.
Equipment:	X		Insert the Description of the equipment supplied by the Supplier.
Supplier:	X		Insert the Supplier name.
Compiled by:	X		Insert the Name of the Compiler.

Table 12 – General input data of the Project (table General Parameter of calculation sheet)

COLUMN IDENTIFICATION	INPUT	OUTPUT	PREVENTIVE MAINTENANCE COLUMN DESCRIPTION
Conversion speed	**X**		Insert the speed value reported by the Mission Profile and used to convert failure rate in the calculation sheet.
Manpower cost	**X**		Insert the Manpower cost per hour.
Yearly distance run	**X**		Insert the Yearly distance covered in Km (from Mission Profile).
Running days per year	**X**		Insert the number locomotive services days per year (from Mission Profile).
LCC considered period	**x**		Insert the period (in years) for that the calculation of LCC parameters is done. For instance: • Warranty period: 2-3 or 5 years. • locomotive life: 25 -30 years.
Basic maintenance frequency	**x**		Insert this frequency, generally expressed in km (or month). It's the basic reference maintenance interval given in the contract or locomotive main technical specification. In the calculation table it is used to determine the number of intervention the above "Considered Period".
Distance covered in the considered period [km]		**x**	*Is the distance covered by* locomotive *in the considered period, this value calculated automatically.* *(Do not insert data).*
locomotive number in the fleet	**x**		Insert the number of locomotive composing the fleet.

Table 13 – MP template columns

COLUMN IDENTIFICATION	INPUT	OUTPUT	PREVENTIVE MAINTENANCE COLUMN DESCRIPTION
RAMS Code	**x**		Insert the RAMS Code used in the Breakdown and FMECA (identification number used trough the different RAMS analyses).
Description	**x**		Insert the description (name) of the device/LRU.
Part Number P/N	**x**		Insert the part number of the system.
Locomotive quantity	**x**		Insert the number of components installed in every vehicle into the corresponding column.
Total quantity		**x**	*Total number of components installed on* locomotive *calculated automatically by the sheet.* *(Do not insert data).*
Step Nº	**x**		Insert the relative number to step of action in reference to progressive number of complete action list.
Maintenance level	**x**		Insert the classification of operation as described in the dedicated paragraph: On locomotive (train) → On-T Off locomotive (train)→ Off-T
Maintenance task	**x**		Insert the relative task of maintenance action for example: Inspection / repair / replacement.
Standard tool	**x**		Insert the list the "standard tools" used for this task.
Special tool	**x**		Insert the list the "special tools" used for this task. The special tool is a particular tool expressly designed for the task or hardly available on the market (off the shelf).
Materials	**x**		Insert the list of part necessary for the maintenance task.
Frequency unit	**x**		Insert one of three following options: • Kilometre • Month
No of multiple interval	**x**		Insert the total number of specific interval if it is multiple.
Cancellation per year	**x**		In case the task described in this row is included into another more complex task, insert the number of this occurrence, to do not count two or more times the task.

COLUMN IDENTIFICATION	INPUT	OUTPUT	PREVENTIVE MAINTENANCE COLUMN DESCRIPTION
Cancellation at service life end	**x**		In case the task described in this row happens at the end of the life of the locomotive, insert 1 to not count useless last operation.
Frequency (expressed in km)		**x**	*This information is calculated automatically.* *Whatever is the original period chosen in km or month this frequency is expressed in km calculated automatically by the sheet.* *(Do not insert data).*
Maintainer skill LEVEL	**x**		Insert the skill request at maintainer for specified task i.e. mechanical, electronics, electrical … .
No of maintainer	**x**		Insert the total number of maintainers needed to perform the specific task.
Failure Diagnosis time (express in minutes)	**x**		Insert the time expressly dedicated only diagnosis.
Accessibility time to the LRU (expressed in minutes) of the integrator.	**x**		Insert the time to obtain the accessibility at the specific LRU (time for mounting and dis-mounting of all the components which obstruct the access to the LRU object of the maintenance action). *NOTE: this time is under responsibility of the locomotive integrator/car-builder, not of the supplier.*
Accessibility time to the LRU (expressed in minutes) of the supplier.	**x**		Insert the time to obtain the accessibility at the specific LRU (time for mounting and dis-mounting of all the components which obstruct the access to the LRU object of the maintenance action if they are part of the scope of supply, excluding the components mentioned above row). *NOTE: this period of time is under responsibility of the supplier of the equipment. It is the time requested for dismounting and mounting the LRU as if the equipment were "bare" or not installed on the locomotive.*
Change, Repair, Functional check time (minutes)	**x**		Insert the time requested to Change, Repair, or effectuate Functional check of the failure component or system.
Other activities time (minutes)	**x**		Insert the time needs to carry out other activities not included before (if any).
Off- locomotive - Number of maintainers	**x**		Insert the number of maintainers that work at component off- locomotive
Off- locomotive - Activity time (minutes)	**x**		Insert the total time that needs for the all off-locomotive activities.

COLUMN IDENTIFICATION	INPUT	OUTPUT	PREVENTIVE MAINTENANCE COLUMN DESCRIPTION
Operation time (global expressed in hours)		**x**	*Total operation time calculated by the sheet and expressed in hours calculated automatically by the sheet.* *(Do not insert data).*
Man-hours operation time (hours)		**x**	*Total man-hours time calculated automatically by the sheet.* *(Do not insert data).*
Material cost	**x**		Insert the cost of spare parts or consumable material used to maintenance task.
Remark / Note	**x**		Insert the specific notes concerning the maintenance task to clarify, to explain or to add useful information.
No of interventions (in the period)		**x**	*Total number of interventions in the reference period calculated automatically by the sheet.* *(Do not insert data).*
Material cost in the period (calculated) per type of item		**x**	*Material cost calculated for the defined period calculated automatically by the sheet.* *(Do not insert data).*
Manpower cost in the period (calculated) per type of item		**x**	*Manpower cost calculated for the defined period calculated automatically by the sheet.* *(Do not insert data).*
Total cost in the period (calculated) per type of item		**x**	*Total cost calculated for the defined period calculated automatically by the sheet.* *(Do not insert data).*

8.9. CORRECTIVE MAINTENANCE TEMPLATE

Here following are listed and described the contents of the template used to calculate the figures relevant to the Corrective Maintenance.
Each data sheet filled with requested data give as final result the maintenance indexes and costs for a defined system.
The further tables collect together all the results about all systems/equipment of the locomotive giving the results at locomotive /fleet level.

Table 14 – MC template headers

COLUMN IDENTIFICATION	INPUT	OUTPUT	CORRECTIVE MAINTENANCE COLUMN DESCRIPTION
Date:	**x**		Insert the date of the document**.**
Project	**x**		Insert the Project Name.
Equipment:	**x**		Insert the description of the equipment supplied by the Supplier.
Supplier:	**x**		Insert the supplier name.
Compiled by	**x**		Insert the Name of the Compiler.

Table 15 – General input data of the Project (table General Parameter of calculation sheet)

COLUMN IDENTIFICATION	INPUT	OUTPUT	CORRECTIVE MAINTENANCE COLUMN DESCRIPTION
Conversion speed	**x**		Insert the speed value reported by the Mission Profile and used to convert failure rate in the calculation sheet.
Manpower cost	**x**		Insert the Manpower cost per hour.
Yearly distance run	**x**		Insert the Yearly distance covered in Km (from Mission Profile).
LCC considered period	**x**		Insert the year period for that the calculation of LCC parameters is done. For instance: • Warranty period: 2-3 or 5 years. • Locomotive life: 25 -30 years.
locomotive number in the fleet	**x**		Insert the number of locomotives composing the fleet.

Table 16 – MC template columns

COLUMN IDENTIFICATION	INPUT	OUTPUT	CORRECTIVE MAINTENANCE COLUMN DESCRIPTION
RAMS Code	**x**		Insert the RAMS Code used in the Breakdown and FMECA (identification number used trough the different RAMS analyses).
Description	**x**		Insert the description (name) of the device/LRU.
Part Number P/N	**x**		Insert the part number of the system.
Failure Mode	**x**		Insert the predicted or observed results of a failure cause on a stated item in relation to the operating condition at time of the failure.
Failure rate	**x**		Insert the attributed failure rate (number of failure per million hours [1/(10^6 h)]).
MTBF (express in hours)		**x**	*Means Time Before Failure is the inverse of failure rate and it is calculated automatically by the sheet.* *(Do not insert data).*
Duty Cycle	**x**		Insert the rate of utilization of the considered item; i.e.: • 100% part working: full time • 50% part working: half time
Applicable Failure Rate		**x**	*Result of failure rate multiplied by the duty cycle; calculated automatically by the sheet.* *(Do not insert data).*
Quantity per Locomotive	**x**		Insert the number of components installed in every vehicle into the corresponding column.
Total Quantity		**x**	Total number of components installed on locomotive calculated automatically by the sheet. (Do not insert data).
Maintenance level	**x**		Insert the classification of operation as described in the dedicated paragraph: On locomotive (train)= On-T Off locomotive (train)= Off-T
Maintenance task	**x**		Insert relative task of maintenance action for example: Inspection / repair / replacement.
Standard tool	**x**		Insert the list of “standard tools” used for this task.

COLUMN IDENTIFICATION	INPUT	OUTPUT	CORRECTIVE MAINTENANCE COLUMN DESCRIPTION
Special tool	**x**		Insert the list of "special tools" used for this task. The special tool is a particular tool expressly designed for the task or hardly available on the market (off the shelf).
Maintainer skill LEVEL	**x**		Insert the skill request at maintainer for specified task i.e. mechanical, electronics, electrical …
No of maintainer	**x**		Insert the total number of maintainers needed to perform the specific task.
Failure diagnosis time (express in minutes)	**x**		Insert the time spent for to.
Accessibility time to the LRU (expressed in minutes) of the integrator.	**x**		Insert the time to obtain the accessibility at the specific LRU (time for mounting and dis-mounting of all the components which obstruct the access to the LRU object of the maintenance action). NOTE: this time is under responsibility of the locomotive integrator/car-builder, not of the supplier
Accessibility time to the LRU (expressed in minutes) of the supplier.	**x**		Insert the time to obtain the accessibility at the specific LRU (time for mounting and dis-mounting of all the components which obstruct the access to the LRU object of the maintenance action if they are part of the scope of supply, excluding the components mentioned above row). NOTE: this period of time is under responsibility of the supplier of the equipment. It is the time requested for dismounting and mounting the LRU as if the equipment were "bare" or not installed on the locomotive.
Change, Repair, Functional check time (minutes)	**x**		Insert the time requested to Change, Repair, or effectuate Functional check of the failure component or system
Other activities time (minutes)	**x**		Insert the time needs to carry out other activities not included before (if any).
Off- locomotive - Number of maintainers	**x**		Insert the number of maintainers that work at component off- locomotive
Off- locomotive - Activity time (minutes)	**x**		Insert the total time that needs for the all off-locomotive activities

COLUMN IDENTIFICATION	INPUT	OUTPUT	CORRECTIVE MAINTENANCE COLUMN DESCRIPTION
Global Operation Time (expressed in hours)		x	*Total operation time calculated by the sheet and expressed in hours calculated automatically by the sheet.* *(Do not insert data).*
Global Man Time (expressed in hours)	x		Total man-hours time calculated by the sheet. (Do not insert data).
Percentage of global MTTR		x	*Percentage respect to global MTTR:* $\frac{Global\ Man\ Time_{single\ item}}{MTTR_{Global}} = \frac{\lambda_i\ h_i\ q_i}{\sum \lambda_i\ q_i}$ *(Do not insert data).*
Material cost	x		Insert the cost of spare parts or consumable material used to maintenance task.
Remark / Note	x		Insert the specific notes concerning the maintenance task to clarify, to explain or to add useful information
Single Item Failure rate / locomotive		x	*Value calculated automatically by the sheet.* *(Do not insert data).*
Single Item MTBF [h] / locomotive		x	*Value calculated automatically by the sheet.* *(Do not insert data).*
Single Item Material cost / locomotive		x	*Value calculated automatically by the sheet.* *(Do not insert data).*
Single Item Manpower cost / locomotive		x	*Value calculated automatically by the sheet.* *(Do not insert data).*
Single Item global cost / locomotive		x	*Value calculated automatically by the sheet.*
Single Item failure number / locomotive		x	*Value calculated automatically by the sheet.* *(Do not insert data).*
Single Item % of failure / locomotive		x	*Value calculated automatically by the sheet.* *(Do not insert data).*
Single Item material cost / locomotive		x	*Value calculated automatically by the sheet.* *(Do not insert data).*
SINGLE ITEM manpower cost / locomotive		x	*Value calculated automatically by the sheet.* *(Do not insert data).*
SINGLE ITEM Total Cost / locomotive		x	*Value calculated automatically by the sheet.* *(Do not insert data).*
SINGLE ITEM material cost /fleet		x	*Value calculated automatically by the sheet.* *(Do not insert data).*

COLUMN IDENTIFICATION	INPUT	OUTPUT	CORRECTIVE MAINTENANCE COLUMN DESCRIPTION
SINGLE ITEM manpower cost /fleet		**x**	*Value calculated automatically by the sheet. (Do not insert data).*
SINGLE ITEM Total Cost /fleet		**x**	*Value calculated automatically by the sheet. (Do not insert data).*

9. ANNEXES

In the following annexes the templates have been reported:

- Annex 1: RAMS analysis templates
- Annex 2: Preventive maintenance template
- Annex 3: Corrective maintenance template

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