TŞ400133

Technical Specifications for E5000 RAMS Requirements

ANNEX-1

E5000 RAMS Plan

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0	First issue	11/12/2024
1	Risk matrix update	31/01/2025

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ABBREVIATIONS

A	Availability
CM	Corrective Maintenance
EN	European Standard
FMECA	Failure Mode and Effect Criticality Analysis
FTA	Fault Tree Analysis
HAS	Hazard Analysis Sub-System
ISO	International Standardization Organization
LCC	Life Cycle Cost
LRU	Line Replaceable Unit
MTBF	Mean Time Between Failure
MKBF	Mean Kilometres Between Faults
MKBSF	Mean Kilometres Between Service Faults
N/A	Not applicable
PBS	Product Breakdown Structure
PHIA	Preliminary Hazard Identification Analysis
PM	Preventive Maintenance
RAMS	Reliability, Availability, Maintainability and Safety

1. INTRODUCTION

1.1. Assumption

This document describes the RAMS activities planned for the E5000 Locomotive which will be designed and developed by TÜRASAŞ Eskişehir Regional Directorate.

1.2. Scope

The purpose of this document is to detail all the techniques and formats to be used in order to perform all Reliability, Availability, Maintainability and Safety (RAMS) activities.
In accordance with the provisions of EN 50126 - 1 (Rif. [1]), the management arrangements for achieving RAMS requirements are defined here, including details of the adopted policy and strategy, the purpose and planning of RAMS activities.

These activities aim to:

- make a prediction of the RAMS performance of the vehicle developed by TÜRASAŞ Eskişehir Regional Directorate (RAMS Analysis) according to the schedule reported in and (Rif. [18]);
- verify that the results obtained satisfy the relevant RAMS requirements, which will be defined in the Specification document (Rif. [18]), which in turn will incorporate the TÜRASAŞ reference specifications (validation of the RAMS Requirements)

The collection and analysis of data from the field during use of the vehicle will be the element that will subsequently allow to accept the values relating to RAMS performance, which will be provided in the RAMS Analysis.

1.3. Scope of application

This document applies to the vehicle and should be used as a reference for RAMS activities throughout the project life cycle.

The planned RAM activities and milestones for the entire system lifecycle are in compliance with the requirements of EN 50126 (Rif. [1], Rif. [2], Rif. [3]).

2. REFERENCE DOCUMENTS, REGULATIONS AND STANDARD

Rif. [1] *EN 50126-1, "Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)" - Part 1: Generic RAMS process.*

Rif. [2] *EN 50126-2, "Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)" - Part 2: Systems Approach to Safety.*

Rif. [3] *CLC/TR 50126-3, "Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)" - Part 3: Guide to the application of EN50126-1 for rolling stock RAM*

Rif. [4] *EN 50129: 2004, "Railway applications - Communication, signalling and processing systems - Safety related electronic systems for signalling".*

Rif. [5] *IEC 61508, "Functional Safety of Electrical / Electronica / Programmable Electronic Safety Related Systems".*

Rif. [6] *EN 61025, "Fault Tree Analysis".*

Rif. [7] *Directive EU/402/2013, "Common safety method for risk evaluation and assessment".*

Rif. [8] *FMD, "Failure mode/Mechanism Distribution".*

Rif. [9] *MIL–HDBK–217 F, "Reliability prediction of electronic equipment".*

Rif. [10] *MIL-HDBK-338 B, "Electronic reliability design handbook".*

Rif. [11] *MIL-HDBK-470 A, "Designing and developing maintainable products and systems".*

Rif. [12] *MIL-HDBK-472 NOTICE 1, "Maintainability Prediction".*

Rif. [13] *MIL-STD-756 B, "Reliability Modelling Prediction".*

Rif. [14] *MIL-STD-882, "System Safety".*

Rif. [15] *MIL-STD-1472 F, "Human Engineering".*

Rif. [16] *MIL-STD-1629 A, "Procedures for performing a failure mode, effects and criticality analysis".*

Rif. [17] *NPRD, "Non electronic part reliability data".*

Rif. [18] *Technical specification for the procurement of testing and analysis services for the certification and verification processes of E5000 locomotives – Rev.0.*

Rif. [19] *EU/1302/2014, "Technical Specification for interoperability Relating to the "Rolling Stock – "Locomotives and Passenger Rolling Stock" Subsystem of the Rail System in the European Union".*

Rif. [20] *EU/2023/1695, "Technical Specification for the interoperability Relating to the Control Command and Signalling Subsystems of the Rail System in the European Union".*

Rif. [21] *E5000 BAKIM PLANI VER00 – Maintenance Plan*

3. RAMS GUARANTEE POLICY

This section provides information on the organization and management of RAMS activities for the E5000 Locomotive project.

The main purpose of the RAM guarantee policy is to achieve a system that reaches a high level of availability such as to ensure continuity of service. Achieving a high level of availability involves the adoption of elementary approaches:

- Designing for the RAMS;
- Apply a formal RAMS guarantee program throughout the project life cycle

3.1. Formal RAMS Life Cycle Warranty Program

The regulation EN 50126 (Rif. [1], Rif. [2], Rif. [3]), is used as a general guideline for the implementation of the RAMS programme activities.
The guidelines propose a "V" approach to life cycle representation, as illustrated below:

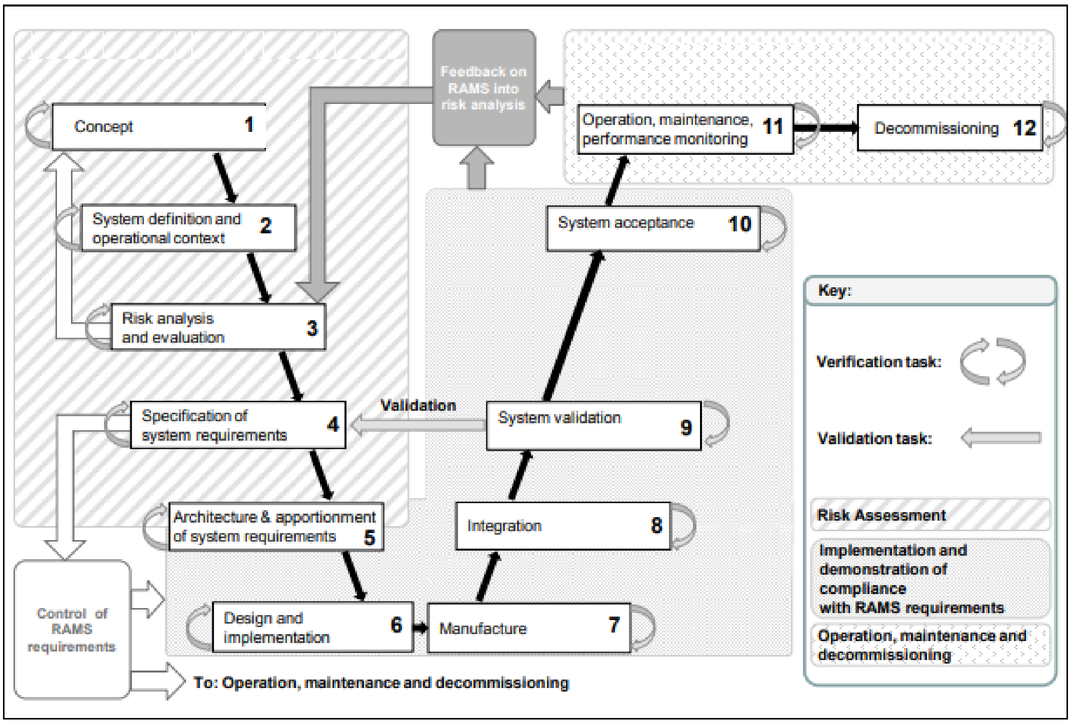

Figure 1 – V-cycle representation EN 50126-1 (Rif. [1])

The top-down branch (left side Figure 1) is generally called "development" and is a refining process ending with the manufacturing of system components. The bottom-up branch (right side Figure 1) is related to the assembly, the installation, the hand-over and then the operation and maintenance of the whole system. The RAMS program for E5000 locomotive is based on same process, in accordance with EN 50126-1 (Rif. [1]).

3.2. Factors that influence RAMS

The RAMS elements (Reliability, Availability, Maintainability, Safety) are interlinked in the sense that a weakness in any of them or mismanagement of conflicts between their requirements can prevent achievement of dependability. Achievement of in-service availability targets will be achieved by optimising reliability & maintainability whilst considering the influence of maintaining safety. The following figure summarizes the concept of interdependence referred to here.

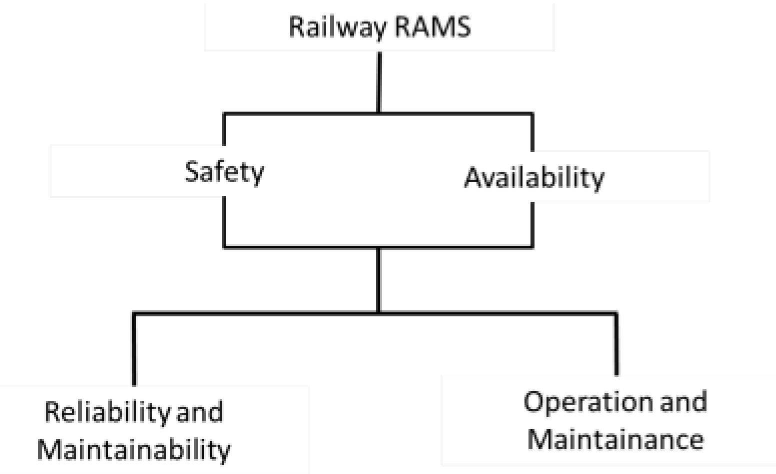

Figure 2 – Interrelation of railway RAMS elements, EN 50126-1 (Rif. [2])

Faults in a system have an impact on its reliability, availability and safety and can be distinguished into:

- Random failures: due to causes that can be described by statistical distributions;
- Systematic failures: due to errors in life cycle activities, which cause deterministic failure of the system in particular combinations of input elements or under particular conditions and are mainly caused by human errors.

Thus, random failures are generally related to events that can be monitored statistically so that their probability of occurrence can be estimated; systematic failures are related to events for which no statistical data are available, so in general their probability of occurrence cannot be estimated.

To create a Reliable System, it is necessary to identify all the factors that influence the RAMS of the system, evaluate their effects and manage their causes, throughout the entire life cycle, so as to optimize its RAMS performance.

The main factors that influence the RAMS of a System can be summarized graphically as in the following diagram, taken from EN 50126-1 (Rif. [1]):

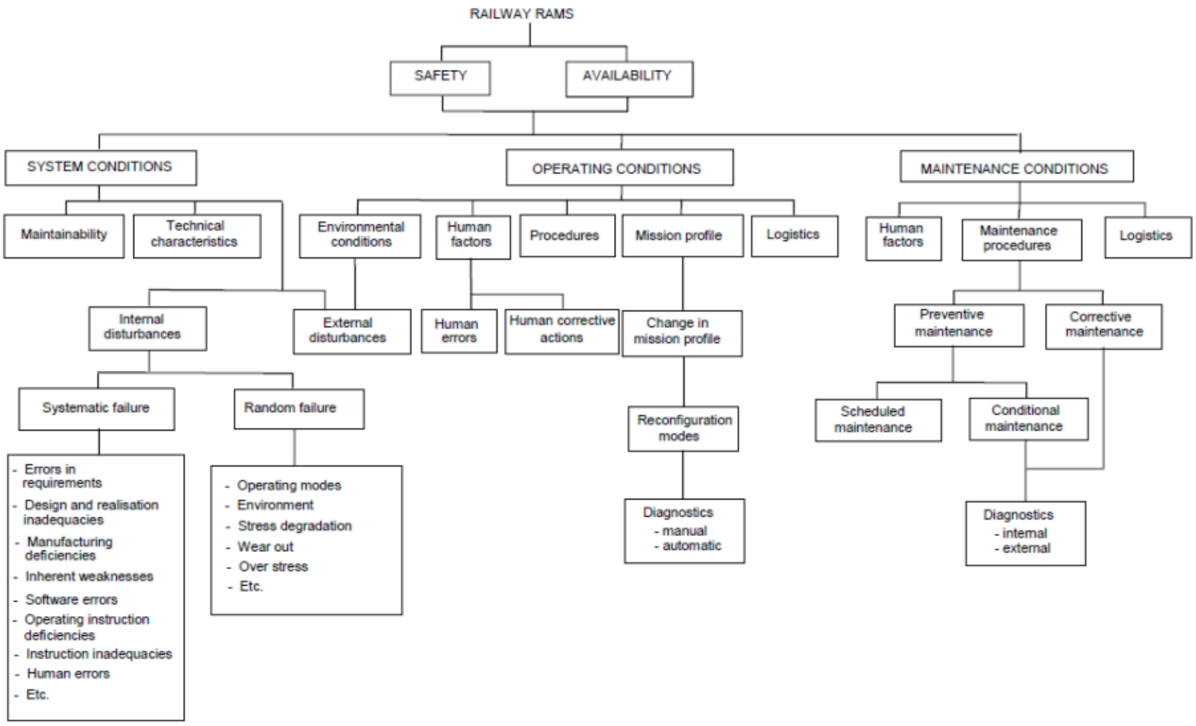

Figure 3 – Factors Influencing Railway RAMS EN 50126-1 (Rif. [1])

For the calculation of the Reliability of the components due to random failures, the application environment of the System, the stress to which the components are subjected and the duty cycle will be considered. Instead, for systematic failures, all the possible influencing factors will be evaluated at a qualitative level.

Therefore, to achieve the RAMS targets of the E5000 Locomotive, all factors that can influence the performance of the system throughout its life cycle will be identified and controlled.

3.3. Reduction of risks related to RAM

The reduction of RAM risk is concerned with reducing loss to the value of the service. Here, in accordance with the requirements of EN 50126-1 (Rif. [1]), the ways in which the activities in each phase of the system life cycle can contribute to reducing risks relating to RAM are defined:

1. improvement in reliability, so that fewer failures occur with consequently fewer occasions for loss;
2. improvement in availability, so that when a failure does occur the resulting loss is smaller.

Measures to improve reliability with regard to random failures include for example:

- Designing system tolerances so that small deviations of parameters from their nominal values do not result in incorrect operation (Phase of Design and Implementation);
- Designing so that components are not expected to operate close to their limits (Phase of Design and Implementation);
- Application of good quality management practices to the procurement of materials and to the control of manufacturing and installation processes (Phase of Manufacture);

- Condition monitoring and preventive maintenance (Phase of Operation, Maintenance and Performance Monitoring).

Measures to improve availability include:

- Provision of duplicate or back-up systems so that a single failure does not result in any loss of function (Phase of Architecture and apportionment of system requirements);
- Provision of facilities for operation in a degraded mode in the event of a failure (Phase of System definition and operational context and Phase of Architecture and apportionment of system requirements);
- Improving the maintainability of the system, so that the time required for repair and restoration of normal operation following a failure is reduced (Phase of Design and Implementation);
- Provision of sufficient resources (such as competent staff, test equipment, spares) so that the time required for repair and restoration of normal operation following a failure is reduced (Phase of Operation, Maintenance and Performance Monitoring).

The strategies listed above are not exhaustive and can be adopted in combination with each other. Systematic failures are also a source of risks for RAM: activities at each stage of the life cycle aim to prevent systematic failure.

4. MISSION PROFILE

The data relating to the mission profile are reported below, as reported in § 5.1 of Technical Specification Rif. [18].

- Annual Mileage 200000[km];
- Vehicle Life 30 years;
- Operating time 18[h/days];
- Operating period 355 [day];
- Labor cost 45 [€/h].

From the above parameters and service-related considerations, the following hours/kilometres conversion factor has been deduced, as shown below:

- Conversion Factor 31,3 [km/h]

5. RAM REQUIREMENTS

The RAM indexes to be respected are:

- RELIABILITY, understood as Basic Reliability and Service Reliability of the vehicle;
- AVAILABILITY, understood as Availability of the fleet for operation (the fleet consists of 10 vehicles);
- MAINTAINABILITY, understood as Maintainability of the vehicle.

The above-mentioned RAM indices will be detected according to the methods indicated in Technical Specification Rif. [18].

The time period for the detection of RAM indices is 12 months as reported in Technical Specification Rif. [18].

5.1. Reliability

5.1.1. Basic Reliability

The basic reliability requirement is defined within the technical specification Rif. [18] in terms of MKBF (sum of type a, b ,c, d failures) for a single E5000 locomotive and is equal to 25.000 km.

The calculation of basic reliability will not take into account the following types of failure:

- Malfunctions that occur due to reasons not caused by the vehicle;
- Malfunctions caused by vandalism;
- Malfunctions caused by driver or locomotive personnel error;
- Infrastructure-related malfunctions;
- Malfunctions caused by use under inappropriate conditions;
- Malfunctions resulting from the use of inappropriate materials/equipment;
- Failures caused by incorrect or untimely maintenance.

5.1.2. Mission Reliability

For the purpose of calculating the mission reliability of the E5000 locomotive, the following failure classes are defined:

- **Class A Faults:** The locomotive cannot move; these are malfunctions that require pulling the locomotive with another locomotive.
- **Class B Faults**: These are malfunctions that require stopping at the first station, but the vehicle can go to the parking area under its own power.
- **Class C Faults:** Specific faults that causing a delay of more than 10 minutes at the destination (final station). The delay will only be calculated once for each delay at the final station and not for each intermediate stop.
- **Class D Faults:** It will be defined as malfunctions in which the locomotive can continue service until the end of the day.

The following table describes the main malfunctions divided into the different subsystems that make up the E5000 locomotive. Additional fault types can be added if necessary.

No	Subsystem/Equipment	Fault Type	A	B	C	D
1	AUXILIARY POWER SYSTEM	Auxiliary power system disabled	X			
		Loss of more than 50% of auxiliary power supply		X		
		Loss of 50% of auxiliary power supply			X	
		Loss of 25% of auxiliary power supply				X
		Other auxiliary power system malfunctions				X
2	BOGIE	The wheelset is mechanically blocked	X	X	X	X
		Bogie instability			X	
		Wheelset bearing temperature above alarm level requiring speed limitation			X	
		Line guidance not available		X		
3	TRACTION SYSTEM	A traction motor and/or rectifier and/or inverter is disabled				X
		Two traction motors and/or rectifiers and/or inverters disabled			X	
		Complete loss of Traction Capacity	X			
		Other Traction System malfunctions				X
		Blocked gear unit	X			
		Minor leak in gear unit				X
4	BRAKE SYSTEM	Complete loss of braking capacity.	X			
		Loss of braking capacity leading to a C fault to be determined at the project stage			X	
		Instant emergency brake			X	
		Loss of wheel slip protection			X	

No	**Subsystem/Equipment**	**Fault Type**	**A**	**B**	**C**	**D**
		Brakes cannot be released manually or parking/holding brake does not engage		X		
		A brake unit malfunction, malfunctions requiring brake isolation or bypass, or electrical braking system malfunctions			X	
		It has an applet			X	X
		Other brake system malfunctions				X
5	HVAC SYSTEM (CONTROL CABIN)	Loss of cabin ventilation function			X	
		No heating or cooling possible			X	
		Other air conditioner malfunctions				X
6	CCTV	The inside and outside of the vehicle cannot be monitored from the control centre.			X	
		Other system malfunctions				X
		Recorder not working/recording.			X	
7	PANTOGRAPH	A pantograph does not rise or fall				X
		Two pantographs do not rise or fall	X			
		Other pantograph malfunctions				X
8	EXTERNAL LIGHTING	All or half of the lighting does not come on		X	X	
		One or two lights not working				X
		Locomotive headlights do not work.		X	X	
9	TCMS (Train Control and Monitoring System)	Various malfunctions	X	X	X	X
10	FIRE DETECTION SYSTEM	While there is no fire or smoke, false fire alarms are received in normal operation.		X		
		Other Fire Detection System malfunctions				X
11	ERTMS/ETCS	Interface problems / malfunctions with the ETCS System		X		

No	Subsystem/Equipment	Fault Type	A	B	C	D
12	WINDSHIELD WIPER	Windshield wiper not working				X
		The windshield wiper is working, but it does not throw water even though there is water.				X
		Other malfunctions				X
13	VEHICLE BODY	Various malfunctions	X	X	X	X
14	INTERIOR	Various malfunctions	X	X	X	X
		Water gets into the vehicle				X
15	HORN	Locomotive horn does not work or is constantly activated			X	
		Other horn or whistle malfunctions				X
16	HIGH VOLTAGE SYSTEM	Main circuit breaker does not close	X			
		No line voltage due to vehicle	X			
		Other high voltage faults				X

Table 1 Fault Classification

The mission reliability requirement is expressed in terms of MKBSF and varies depending on the impact of the failure on the mission.
In accordance with Technical Specification Rif. [18]. Class A, B and C failures must satisfy a MKBSF of 100.000 km, while Class A, B failures must satisfy a MKBSF of 400.000 km.

5.2. Maintainability & LCC

The maintainability of the rolling stock is calculated by considering as a reference parameter the "μ" index expressed in €/km Vehicle, obtained from the sum of the cost of corrective and preventive manpower hours (ordinary and cyclical) and the cost of the materials used, per Km of commercial service.

$$\mu = \frac{\sum_i^n [(N\_hours * Hour\_cost) + Mat\_cost]}{\sum_i^n km\ cumulati} * 1000$$

in which:

- n: total number of fleet convoys;
- Hours: number of hours for the i-th convoy;
- Mat. Cost: cost of materials used for the i-th convoy;
- Hour_cost: reference hourly labour cost.

To calculate the maintainability index, the times and materials used (spare parts and consumables) in maintenance operations will be used, keeping in mind that:

- reference hourly labour cost is equal to 45 [€/h];
- the unit costs of spare parts and consumables will refer to the values indicated in the spare parts list.

Maintainability analysis will be done after the definition of Maintenance and Service Plan and Line Replaceable Units (LRUs). This will include details of the interventions to be carried out for each system, the period to be carried out and the indication of the type (Quality or Safety).

Convoy will be managed according to the maintenance schedule in Rif. [21].

Maintenance activities can be divided into the following categories:

- Activities of Corrective maintenance (CM);
- Activities of Preventive Maintenance (PM).

The maintainability index to be respected for the entire life cycle of the train is the following: 2,25 €/km.

5.3. Availability

In accordance with the technical specification Rif. [18], the availability index **A** is calculated on a monthly basis on a fleet of 10 vehicles for 12 consecutive months. The availability index **A** will be expressed in percentage terms and will be calculated according to the following formula:

$$A = \left(\frac{N}{F}\right) * 100$$

in which:

- N: number of days of total locomotives active in a month;
- F: total number of locomotives for days in a month.

The fleet availability requirement reported in the technical specification corresponds to A>90%.

6. METHODOLOGY FOR RAMS ANALYSIS

This chapter describes the approach and methodology that will be followed to perform the RAM Analysis of the E5000 locomotive; the analysis aims to make a prediction of the RAM performance of the System, for which it is necessary to take into account the mission of the system and determine the failure rates of the components that determine the failure of the mission and their configuration. To define and calculate the RAM performance it is therefore necessary to identify the LRUs that make up the system, taking into account the perimeter of the system analysed and associate the relative RAM data to each of them.

6.1. Product Breakdown Structure (PBS)

The first phase of RAM Analysis is represented by the vehicle breakdown, (focused on the physical or functional architecture), in hierarchic levels.
The vehicle breakdown structure must be structured according to the following levels:

0. Vehicle;
1. Main Assembly;
2. Sub-assembly
3. Component/LRU.

Each level is characterized by a breakdown code. For each identified assembly/sub-assembly/component the quantity is shown both at next higher level and at vehicle level. If necessary, more levels could be added following same rules. The breakdown code has a number of ciphers equal to the relevant hierarchic level. The breakdown allows knowing how the system / subsystem is structured down to the last level of analysis: LRUs level.

The following table describes the sheet “BD” reported in the template used for the analysis attached to this document (**ANNEX I-ANALYSES WORKSHEET**):

Level		*Item level inside Breakdown (0=Vehicle, 1= Assembly, 2= Subassembly, 3= LRU*
RAM Code		*RAM Code inside BD. Code is linked to the item level. Items of level 1 have code of 1 cipher, items of level 2 have code of 2 ciphers, etc...*
Description		*Description of the item*
Part Number (P.N.)		*Part number of the item*
Q.ty	***[unit]***	*Quantity of the item per assembly*
Q.ty tot x Ve		*Total quantity of component per vehicle*

6.2. Basic Reliability

The breakdown is the base to perform the reliability predictions. In the sub system reliability evaluation, the reference to the inherent reliability of the subsystem/component, intended as the inclination to failure of the subsystem/component in the foreseen operating condition (functional, use, maintenance, environmental), is to be used.
To determine reliability values of the assembly and of its constituting components, service data base should be used. In lack of field data reference to provisional evaluation, according to MIL-HDBK-217 F, Rif. [9] and NPRD Rif. [17] should be made.

The following table describes the sheet "PRED" reported in the template used for the analysis attached to this document (**ANNEX I-ANALYSES WORKSHEET**):

Level		*Item level inside Breakdown (0=Vehicle, 1= Assembly, 2= Subassembly, 3= LRU)* ***(Automatic field, not to be compiled by hand)***
RAM Code		*RAM Code inside BD. Code is linked to the item level. Items of level 1 have code of 1 cipher, items of level 2 have code of 2 ciphers, etc..*
Description		*Description of the item*
Qty x as	***[pcs]***	*Quantity of the item per assembly*
Q.ty car	***[pcs]***	*Quantity of the component to be maintained for each car constituting the vehicle (the number of columns to be filled depends on the number of cars constituting the vehicle;*
Total Qty per vehicle	***[pcs]***	*Total quantity of component per vehicle (***Automatic field, not to be compiled by hand***)*
Single basic failure rate	***[1/h]***	*Basic Failure rate per component*
Single basic MTBF	***[h]***	*MTBF of single Assembly/Component. It is the inverse of the failure rate. To be compiled for items of level 1 and 2.* ***Automatic field, not to be compiled by hand for item of level 3)***
Failure rate (train level)	***[1/h]***	*It is the total failure rate for the LRU examined, basing on the quantity at train level* ***(Automatic field, not to be compiled by hand)***
Failure Rate (train level)	***[Fpkm] or [1/km]***	*It is the total failure rate (1/km or 1/miles) for the LRU examined, basing on the quantity at train level* ***(Automatic field, not to be compiled by hand)***
Identification Code / Part Number		*Part number of the item*
Data Source		*Reference to the source of the data*

6.3. FMECA Analysis

Failure Modes and Effects Analysis is a reliability analysis procedure that documents all possible failures in a system.
This analysis, through an examination of all possible failure modes of components, determines the effect of each failure on the vehicle and (through failure classification) on the system operations, identifying, if applicable, any single-point failures, i.e. those failures critical to the success of the mission or to the safety of passengers and personnel.
FMECA uses an inductive logic based on a "bottom up" approach. For each LRU that composes the system and from the knowledge of the failure modes of the individual part, the analyst traces upwards in the hierarchy to determine the effect that each failure mode will have on the performance of the system.

Per each failure mode the following shall be stated:

- possible causes (several can be identified);
- percentage of failure probability for the considered failure mode (all the failure modes identified for an item must totalize 100%);
- possible effects (consequences) over the considered Item (several can be identified);
- possible effects (consequences) over the next higher assembly or function (several can be identified);
- possible effects (consequences) at Vehicle level, either physical and the revenue service (several can be identified);
- possibility to identify/detect the occurred failure
- possible preventive and/or compensating measures.

The table describes the sheet "FMECA" reported in the template used for the analysis attached to this document (**ANNEX I-ANALYSES WORKSHEET**):

The "FMECA" sheet also reports the effect of the single failure modes on the mission according to the failure category defined in the paragraph 5.1.2 and the impact on safety according to the risk matrix defined in EN-50126 Rif. [1].

RAM Code	RAM Code inside BD. Code is linked to the item level. Items of level 1 have code of 1 cipher, items of level 2 have code of 2 ciphers, etc..
Description	Description of the item
Part Number	Part number of the item
ID. Failure Mode	Failure mode identification number of the component. Must be in the format "FMxxx" where xxx is a sequential number starting from 1 to 999
Function	Description of the function performed by the LRU.
Working Phase	Operational phase in which the failure mode can be verified
Failure Mode	LRU failure mode. One failure mode for row. Each failure mode corresponds to only one ID.

Failure Cause		Description of the cause of the failure
Effects	**Local**	Description of the effect of the failure at local, system (assembly), vehicle level
	System	
	Vehicle	
Failure Category (mission)		Failure Criticality Category. Assessment of the impact of the failure on mission success (A,B,C,D)
FR Ratio		% of failure rate associated with failure mode
LRU Failure Rate	**[1/h]**	Failure Rate of single LRU
FM Failure Rate	**[1/h]**	Failure rate relative to failure mode **(Automatic field with formulas, not to be filled in manually**)
Severity		Severity of the final effect of the failure mode (vehicle level), considering the implementation of the recommended corrective actions (see Table 2.)
Frequency		Frequency of occurrence of the final effect at vehicle level, considering the implementation of mitigation measures (see Table 3).
Risk		Risk category according to the risk matrix (see Table 4)
Hazard Corde Ref.		Hazard identification code where the failure mode has impact. (If applicable). For hazard details refer to the vehicle hazard list
Detection / Diagnosis		Detection method, fault detection / diagnostics associated with failure mode / Symptoms
Corrective Action Code		Recommended corrective action identification code. Each corrective action has its own code. The code must be in the form "Caxxx" where xxx is a sequential number starting from 1 to 999
Corrective Actions / Countermeasures		Corrective action description
Corrective Action Category		Corrective action category (Project, Safety device, warning device, procedures).
Maintenance Code Ref.		Recommended maintenance procedure code for the failure mode. The code must be of the type PMxxx or CMxxx where PM and CM indicate that the maintenance procedure is Preventive or Corrective and xxx is a sequential number from 1 to 999.
Down Time [h]		train stoppage required to repair the fault (includes time for fault finding, repair maintenance intervention, testing and release of the vehicle)
Comments		Comments

6.4. Maintainability & LCC

6.4.1. Corrective Maintenance (CM)

Corrective Maintenance analysis is performed in order to maximize the train availability, analysing all vehicle maintenance repair tasks due to random faults.
Maintenance is organized in 2 levels, according the following distinction:

- First Level: maintenance operations performed where the equipment has failed, or on-board repair or substitution;
- Second Level: maintenance operations performed on assemblies removed from board and immediately substituted with other correctly functioning. Operation is performed in Depot or Commitment Magazines, or at Supplier.

For this analysis is hypothesized to operate in an organized depot, with full availability of maintenance station, pit, depot tools, special tools, spare parts, personnel, manuals, etc.
In the analysis is only considered the primary failure (fault that occurs independently of other possible associated faults and therefore NOT correlated or correlateable with other faults); induced and systematic failures (faults that are the consequence of failures of other connected groups/subgroups or components and which can be demonstrated as the cause of the failure.) are not considered.
The FMECA (and relevant failure mode identification codes) will be the baseline to perform this analysis; the CM should be made per each single failure modes identified in the FMECA.

The following table describes the sheet "CMA" reported in the template used for the analysis attached to this document (**ANNEX I-ANALYSES WORKSHEET**):

RAM Code		*RAM Code inside BD. Code is linked to the item level. Items of level 1 have code of 1 cipher, items of level 2 have code of 2 ciphers, etc. It is the same RAM code used in reliability analysis*
LRU Description		*Description of LRU, according to what reported in the break down*
FMECA failure mode ref.		*Reference to Failure mode ID which the corrective action is referred to. (FMECA source)*
Failure rate (1/h)		*Basic Failure rate of the LRU in (events/hour)*
Q.ty (Vehicle)		*Quantity of the component to be maintained at vehicle level* ***(Automatic field, not to be compiled by hand; compilation of "Q.ty car" columns needed)***
Maintenance description		*task description*
Comments		*Field free for comments*
First Level maintenance		
Skill specialty		*Personnel qualification (EM= electromechanical, E=Electronic, M=Mechanical). To be chosen from dropdown menu*
Skill level		*Skill level of the personnel (B= Base, I=Intermediate, A=Advanced) To be chosen from dropdown menu*
Troubleshooting (localization) and Fault Isolation (h)	**No. of Persons**	*Number of personnel required to localize/troubleshoot isolate the item under analysis.*
	Time (h)	*Time to localize/troubleshoot isolate the item under analysis (in hours).*

Remove and Replace / Repair (h)	**No. of Persons**	*Number of personnel required to Remove and Replace / Repair the item under analysis*
	Time (h)	*Time to Remove and Replace / Repair the item under analysis (in hours).*
Functional Check out (h)	**No. of Persons**	*Number of personnel required to functional checking out the item under analysis.*
	Time (h)	*Time to functional checking out the item under analysis (in hours).*
Task Maintenance time (h)		*Maintenance activity duration (per component)* ***(Automatic field, not to be compiled by hand)***
Man Hours		*Total man hours required for the task execution* ***(Automatic field, not to be compiled by hand)***
Task Material cost M1 (1)	Indicate in the yellow field the unit of measurement	*Cost of material for single task required for First Level Maintenance operation € or $ or any currency depending upon specific mission profile)*
Special Tools and parts replaced		*List of special tools necessary to perform the task*
Man Hours (MH) per year		*Total man hours required for the task execution per year* ***(Automatic field, not to be compiled by hand; project operating hours a year needed)***
MH per distance unit	Indicate in the yellow field the unit of measurement	*Man hour per km or mile* ***(Automatic field, not to be compiled, project mileage/year ratio needed)***
Mat cost per distance unit	Indicate in the yellow field the unit of measurement	*Cost of material (€ or $ or any specified currency) required for maintenance operation every Km or mile* ***(Automatic field, not to be compiled, project MDBF/MTBF ratio needed)***
Second Level maintenance		
No. of Persons P2		*Number of personnel required to perform the Second Level Maintenance task.*
Time T2 (h)		*Time to perform the Second Level Maintenance task (in hours).*
Man, Hours MH2		*Total man hours required for the task execution* ***(Automatic field, not to be compiled by hand)***
Task Material cost M2	Indicate in the yellow field the unit of measurement	*Cost of material required for Second Level Maintenance operation (€ or $ or any currency depending upon specific mission profile)*
Man Hours (MH) per year		*Total man hours required for the task execution per year* ***(Automatic field, not to be compiled by hand; project operating hours a year needed)***
MH per distance unit	Indicate in the yellow field the unit of measurement	*Man hour per km or mile* ***(Automatic field, not to be compiled, project mileage/year ratio needed)***
Mat cost per distance unit	Indicate in the yellow field the unit of measurement	*Cost of material (€ or $ or any specified currency) required for maintenance operation every Km or mile* ***(Automatic field, not to be compiled, project MDBF/MTBF ratio needed)***

6.4.2. Preventive Maintenance (PM)

By means of the Preventive Maintenance Analysis it is possible to examine all maintenance actions that allow preventing failure verification, through the research and removing of incipient failures, or through the scheduled substitution of components subject to wear and tear, for which the shelf life is known, or for which is difficult to verify the deterioration.
Preventive maintenance analysis highlights tests, verification and actions necessaries to reach set objectives and allows estimating resources (personnel, test equipment, spare parts) necessaries to perform the activities.
The PMA is developed at Assembly, Subassembly or LRU level. For this analysis is hypothesized to operate in a well-organized depot, with full availability of maintenance station, pit, depot tools, special tools, spare parts, personnel, manuals, etc.

The following table describes the sheet "PMA" reported in the template used for the analysis attached to this document (**ANNEX I-ANALYSES WORKSHEET**):

First Level Maintenance		on vehicle activities (Field maintenance).
Second Level Maintenance		off-vehicle activities (depot /workshop maintenance)
RAM Code		*RAM Code inside BD. Code is linked to the item level. Items of level 1 have code of 1 cipher, items of level 2 have code of 2 ciphers, etc... It is the same RAM code used in reliability analysis*
Description		*Description of LRU, according to what reported in the break down*
Mileage Interval	Indicate in the yellow field the unit of measurement	*Periodicity of the maintenance task in Km or miles. Intervals are project dependant. Mileage Interval and Time Interval shall correspond each other and to the time intervals required in the RAMS/LCC Spec.*
Time Interval [years]		*Periodicity of the maintenance task in years. Intervals are project dependant. Mileage Interval and Time Interval shall correspond each other and to the time intervals required in the RAMS/LCC Spec.*
Time task (T) Distance task (D)		*Where the task is time dependant then the letter "T" is to be here reported; where the task is mileage dependant then the letter "D" is to be here reported*
Task no. /year		*Number of tasks per year (**Automatic field, not to be compiled, project mileage/year ratio needed**)*
Q.ty (Vehicle)		*Quantity of the component to be maintained at vehicle level **(Automatic field, not to be compiled by hand; compilation of "Q.ty car" columns needed)***
Task Code		*This is the identifying code for each maintenance task*
Maintenance task description		*Description of maintenance task.*
Maintenance Category		*Maintenance category can be related to worn (W), Aging (A), Safety (S) or Regulations (R)*
Justification of activities		*Reason(s) for introducing that specific maintenance task*
Reference to technical documentation		*Id code, paragraph, chapter of Hazard Analyses, test reports, technical description justifying that specific maintenance task*
Reference to Maintenance Manual		*Reference (id code, paragraph, chapter) of the maintenance manuals in which the procedure to accomplish the task is described.*
Comments		*Field free for comments*
First Level maintenance		

Skill specialty		*Personnel qualification (EM= electromechanical, E=Electronic, M=Mechanical). To be chosen from dropdown menu*
Skill level		*Skill level of the personnel (B= Base, Intermediate, A=Advanced) To be chosen from dropdown menu*
No.of Persons		*Number of personnel required to perform the task*
Maintenance task time (h)		*Task time duration (per component)*
Man Hours		*Total man hours required for the task execution* ***(Automatic field, not to be compiled by hand)***
Special Tools		*List of special tools necessary to perform the task*
Spare Parts/ Consumables		*Consumables necessary to perform the task*
Material cost M1	Indicate in the yellow field the unit of measurement	*Cost of material required for First Level Maintenance operation (€ or $ or any currency depending upon specific mission profile)*
Man Hours year		Total man hours required for the task execution per year ***(Automatic field, not to be compiled by hand)***
MH per distance unit	Indicate in the yellow field the unit of measurement	*Man hour per km or mile* ***(Automatic field, not to be compiled, project mileage/year ratio needed)***
Mat cost per distance unit	Indicate in the yellow field the unit of measurement	*Cost of material (€ or $ or any specified currency) required for maintenance operation every Km or mile* ***(Automatic field, not to be compiled)***
Second Level maintenance		
No.of Persons P2		*Number of personnel required to perform the Second Level Maintenance task.*
Time T2 (h)		*Time to perform the Second Level Maintenance task (in hours).*
Man Hours MH2		*Total man hours required for the task execution* ***(Automatic field, not to be compiled by hand)***
Material cost M2	Indicate in the yellow field the unit of measurement	*Cost of material required for Second Level Maintenance operation (€ or $ or any currency depending upon specific mission profile)*
Man Hours year		Total man hours required for the task execution per year ***(Automatic field, not to be compiled by hand)***
MH per distance unit	Indicate in the yellow field the unit of measurement	*Man hour per km or mile* ***(Automatic field, not to be compiled, project mileage/year ratio needed)***
Mat cost per distance unit	Indicate in the yellow field the unit of measurement	*Cost of material (€ or $ or any specified currency) required for maintenance operation every Km or mile* ***(Automatic field, not to be compiled)***

6.5. FTA Methodology (Mission Reliability & Safety)

The Fault Tree Analysis (FTA) is a deductive logic model technique, and one of the most common hazard investigation tools (causal analysis). A fault tree is a model that graphically and logically represents the various combinations of possible failures and events occurring in a system that lead to a failure condition at the top. The performed FTA uses a "top-down" approach, in order to identify all potential causes of an undesired top event that lead to the occurrence of the top event itself. The analysis begins with the undesired top-level event and systematically determines all possible causes, both single failure and combination of failures, at the subsequent lower levels until a Basic Event is encountered. The fault trees developed include two types of symbols: event and logic (gate). An event symbol is used to describe an existing condition or a physical event. A logic gate is used to tie together the events of various branches under it and to show the logical relationship among these events. The inputs and outputs of logic symbols are always events.
Definition of symbols used in Fault Tree (according to EN 61015 Rif. [6]) is given in the following figure:

Events			Gates			
Symbol	Name	Symbol	Name	Symbol	Name	Inputs
	Basic	An event that is not developed further for which failure and repair data is available		OR	Output event occurs when any one or more input events occurs.	>=2
	Undeveloped	An event that cannot be developed further for which failure and repair data is available		AND	Output event occurs when all input events occur.	>=2
	Conditional	Similar to a basic event but represents a probability input into an INHIBIT gate.	m	VOTE	Output event occurs when m number of input events occur.	>=3
	House (or Switch)	An event which is definitely occurring or not occurring i.e. has a probability of 1 or 0.		Exclusive OR	Output event occurs when any but not both input events occur.	2
	Dormant	Similar to a basic event but represents a dormant or hidden failure.		INHIBIT	Output event occurs when both input events occur but one input must be a Conditional event.	2
	Transfer	Used to show where trees are developed on other pages or elsewhere in the diagram.		Priority AND	Output event occurs when all input events occur in sequential order from left to right.	>=2
	Describer	Describes further the event or gate attached.		NOT	Output event occurs when the input event does not occurs.	1

Figure 4 – FTA Symbol

The FTA methodology is used to verify both:

- mission reliability targets;
- safety targets

In terms of mission reliability, the FTA is used to the purpose of evaluating the effect of single or multiple failures affecting vehicle service. The resulting probability of occurrence is used for the theoretic verification of the Reliability Targets.
In terms of safety, the FTA is used to the purpose of demonstrate the effectiveness of the mitigation and the acceptability of the residual risk, identifying any single or multiple failures, resulting in a critical condition and calculating the probability of occurrence of each hazard.

6.6. SAFETY

The safety analysis process is based on the principle that for each identified hazard there is an associated risk. The entire safety process is aimed at eliminating or mitigating this risk, that is, establishing that the risk associated with each hazard must be as low as possible. This concept is in accordance with the specifications of EN 50126-1 (Rif. [1]) and Common Safety Method for Risk Assessment (Rif. [7]):

The steps to be followed in PHIA/HAS are summarized below:

I. failures/interruptions that may occur in the system due to a dangerous situation (hazard) will be assumed;

II. for each hazard, the hazard level (starting from severity and frequency) will be determined, and each cause and consequence will be identified.

III. for each hazard with an unacceptable or undesirable level of risk, the countermeasures to be implemented will be analysed and examined so that the risk falls into the "negligible" or "tolerable" category.

IV. finally, after the implementation of countermeasures, the final risk level required to cover each hazard will be determined.

The Preliminary Hazard Analysis (PHIA) will be updated whenever a new hazard is detected for the system. Starting with the PHIA, the hazard analysis will be created and updated

The following table describes the sheet “PHIA” reported in the template used for the analysis attached to this document (**ANNEX I-ANALYSES WORKSHEET**):

Hazard ID	Identification code for the hazard (refer to hazard list)
Hazard type	Typology of the hazard (O&S =maintenance, I=interface, S/SS= system/subsystem).
Hazard Description	Hazard description (refer to hazard list)
Operating phase	Operative phase (Running, Standstill, Maintenance, Sleeping, all modes) Operative modes could differ for each project
Triggering events	Conditional Event that can lead to hazard verification
Causes	Synthetic description of the hazard causes. Where causes derive from FMECA analysis, refer only the Failure mode ID used in FMECA.
System involved / Interface	Description of the system involved in hazard or the interface in case of interface Hazard
Consequences	shows the worst consequences due to the occurrence of the potential hazard
Initial Severity	severity before the implementation of the preventive actions (see Table 2.)
Initial Freq	Initial probability of occurrence of the hazard (without implementation of mitigation measures). (see Table 3.)
Initial Risk	Initial risk of the hazard (according to project risk matrix (see Table 4)

Mitigation	Description of the recommended mitigation measure (One mitigation for each row)
Type of mitigation	Category of the mitigation (Design, Safety Devices, Warning devices, Procedures)
Final Severity	severity after the implementation of the preventive actions (see Table 2.)
Final Freq	Final probability of occurrence of the hazard (after implementation of mitigation measures) .) (see Table 3.).
Initial Risk	Final risk of the hazard (according to project risk matrix (see Table 4)
Implemented measures	Description of the implemented measure (One measure for each row)
Type of implemented measure	Category of the implemented measure (Design, Safety Devices, Warning devices, Procedures)
Note	Notes / Description of the interfaces in case of an interface hazard

6.6.1. Severity level, probability of occurrence and risk matrix

For the assessment of each hazard, in accordance with the technical specifications, the classification of the severity of the hazards is defined in Table 2, their probability of occurrence in Table 3 and safety matrix is defined in Table 4.:

Severity Category	Consequences
1: Catastrophic	Fatalities and/or multiple severe injuries
2: Critical	Single fatality and/or severe injury or Loss of major system
3: Marginal	Minor injury and/or sever system(s) damage
4: Insignificant	Possible minor injury or minor system damage

Table 2 Severity category

Frequency level	Description	Range (Failure/Hour)
A: Frequent	Likely to occur frequently. The hazard will be continually experienced.	$\lambda > 10^{-3}$
B: Probable	Will occur several times. The hazard can be expected to occur often.	$10^{-3} \geq \lambda > 10^{-4}$
C: Occasional	Likely to occur several times. The hazard can be expected to occur several times	$10^{-4} \geq \lambda > 10^{-5}$
D: Remote	Likely to occur sometime in the system life cycle. The hazard can reasonably expect to occur.	$10^{-5} \geq \lambda > 10^{-7}$
E: Improbable	Unlikely to occur but possible. It can be assumed that the hazard may exceptionally occur.	$10^{-7} \geq \lambda > 10^{-9}$
F: Incredible	Extremely unlikely to occur. It can be assumed that the hazard may not occur	$\lambda \leq 10^{-9}$

Table 3 Events levels probability

Frequency of occurrence of a Hazardous event	**Risk Acceptance Categories**			
Frequent	Undesirable	Intolerable	Intolerable	Intolerable
Probable	Tolerable	Undesirable	Intolerable	Intolerable
Occasional	Tolerable	Undesirable	Undesirable	Intolerable
Remote	Negligible	Tolerable	Undesirable	Undesirable
Improbable	Negligible	Negligible	Tolerable	Undesirable
Incredible	Negligible	Negligible	Negligible	Tolerable
	Insignificant	**Marginal**	**Critical**	**Catastrophic**

Table 4 Risk matrix

6.7. RAMS REPORT

At the end of the analyses carried out, a report will be developed which will summarise the main results and the related conclusions.

7. ANNEX I-ANALYSES WORKSHEET

The analyses shall be performed using the embedded EXCEL file.

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