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TŞ400133

Technical Specifications for E5000 RAMS Requirements

ANNEX-11

E5000 High Voltage System RAMS Requirements

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1. INTRODUCTION

Scope of this document is the definition of the requirements for RAMS (Reliability, Maintainability, Availability & Safety) for the Design phase of the HIGH VOLTAGE SYSTEM.

The present document lists and defines the analysis and documentation to be performed to estimate and demonstrate the defined RAMS requirements.

The present document defines the tests that will be performed to verify the SEC performances under the RAMS point of view.

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2. 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] ANSI/VITA 51.1 Reliability Prediction MIL-HDBK-217 Subsidiary Specification

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3. REFERENCE DOCUMENTS

Doc. [1] RAMS PLAN_rev.00

Doc. [2] E5000 BAKIM PLANI VER00 – Maintenance Plan

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4. DEFINITIONS

TERM	
Availability	Characteristic to be evaluated at “Vehicle level”; is usually calculated as the ratio between the operating hours (recorded within an observed period) v/s the sum of maintenance hours (either for preventive and corrective activities) preventing the Vehicle operation – is measured as a “percentage”. N.B.: For the sake of the Availability calculation the 2nd maintenance actions does not affect the Vehicle availability.
CMA	Corrective Maintenance Analysis
EMI	Electro Magnetic Interference
FMECA	Failure Modes, Effects & Criticality Analysis
FPMK	Failure Per Million kilometres
FTA	Fault Tree Analysis
GM	Ground Mobile
HAS	Hazard Analysis System
HR	Human Resources
LCC	Life Cycle Cost
LRU	Line Replaceable Unit
Maintenance Level	For the sake of Vehicle availability and cost efficiency, two different maintenance levels have been defined: 1 st maintenance level = On-Board; 2 nd maintenance level = Off-Board, local workshop; N.B.: For the sake of the Availability calculation the 2nd level maintenance actions do not affect the Vehicle availability.
Manhour	Unit of measurement for the maintenance activity – e.g.: 1 operator working 3.00 hours “produces” 3.00 manhours; 2 operators contemporarily working for 3.00 hours “produce” 6.00 manhours; 2 operators out of 3 contemporarily working for 3.00 hours and the third one involved 1.00 hour only “produce” 7.00 manhours.
MKBF	Mean Kilometers Between Failures – ratio between the run Kilometre v/s the basic failures occurred in the meanwhile.
MTBF	Mean Time Between Failure– ratio between the operation hours v/s the basic failures occurred in the meanwhile
MTTR	Mean Time to Repair. Average time required to bring system from a failed state to an operational state. MTTR shall be calculated considering diagnostic, repair (or replacement), and retest times only. The MTTR shall not include logistics delay time (the MTTR calculation assumes maintenance personnel and spares are available to make repairs).
N/A	Not Applicable
PHIA	Preventive Hazard Identification & Analysis
PMA	Preventive Maintenance Analysis

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TERM	
RAMS	Reliability Availability Maintainability & Safety
SEC	System, Equipment, Component
Train	Vehicles that can be coupled in multiple up to 2 units

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5. 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]

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6. RAMS REQUIREMENTS

This chapter outlines the RAMS requirements (both qualitative and quantitative).

6.1. RELIABILITY

In this paragraph the requirements either for “basic” and “mission” reliability are stated, considering the referenced conversion factor. The SEC shall comply with the following criteria:

- the SEC is to be service proven; the Supplier shall demonstrate that the proposed SEC has been already successfully adopted on railway transportation systems stating where, when and how many SECs are operating and relevant RAMS performances;
- the components/parts are to be commercial standards; avoid, as far as possible, special components/parts;
- the electric and/or electronic components are to be able to normally operate within the range of the min. and max. input voltage and/or current;
- electronic units are to be adequately shielded to prevent EMI;

Exception to what requested above is to be formally agreed with HR.

During the RAMS Test the requirements will be verified; where, during the test, the SEC shows performances not complying with the requirements the Supplier is obliged to promptly act in the way to modify the SEC design, implement modification over the total SEC fleet till the requirements complying.

Failure rates for mechanical components are taken from NPRD (Rif. [17]) and for electrical/electronic components for MIL-HDBK-217F (Rif. [9]) and Rif. [21] in GM environment at 25°C.

Regardless the achievements of the quantitative requirements the Epidemic Failures are not acceptable and are to be solved.

6.1.1. BASIC RELIABILITY

The following reliability performances must be achieved:

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BASIC RELIABILITY		
SEC	MTBF	OPERAT. LIFE
SYSTEM HIGH VOLTAGE SYSTEM	≥ 30.300 [h]	30 years
Surge Arrestor	≥ 743.090 [h]	30 years
Main Circuit Breaker	≥ 313.590 [h]	30 years
Current Transformer	≥ 94.080 [h]	30 years
Voltage Transformer	≥ 94.080 [h]	30 years
High Voltage Cable	$\geq 26.131.900$ [h]	30 years
Roof Insulator	$\geq 2.406.630$ [h]	30 years
Bus Bar	$\geq 6.439.080$ [h]	30 years

6.1.2. 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 for HIGH VOLTAGE SYSTEM. Additional fault types can be added if necessary.

Subsystem/Equipment	Fault Type	A	B	C	D
HIGH VOLTAGE SYSTEM	Main circuit breaker does not close	X			
	No line voltage due to vehicle	X			
	Other high voltage faults				X

The mission reliability requirement is expressed in terms of MKBSF and varies depending on the impact of the failure on the mission.

The following mission reliability performances must be achieved.

MISSION RELIABILITY		
SEC	MTBSF A+B Category	MTBSF A+B+C Category
HIGH VOLTAGE SYSTEM	≥ 484.940 [h]	≥ 121.240 [h]
Surge Arrestor	≥ 11.893.200 [h]	≥ 2.973.280 [h]
Main Circuit Breaker	≥ 5.018.930 [h]	≥ 1.254.740 [h]
Current Transformer	≥ 1.505.680 [h]	≥ 376.420 [h]
Voltage Transformer	≥ 1.505.680 [h]	≥ 376.420 [h]
High Voltage Cable	≥ 418.243.870 [h]	≥ 104.560.970 [h]
Roof Insulator	≥ 38.518.240 [h]	≥ 9.629.560 [h]
Bus Bar	≥ 103.058.040 [h]	≥ 25.764.510 [h]

6.2. MAINTAINABILITY

In this paragraph are stated the maintenance requirements either for preventive and corrective maintenance operations.

Maintenance levels for preventive and corrective are divided as following:

- 1st maintenance level = On-Board;
- 2nd maintenance level = Off-Board, local workshop.

6.2.1. PREVENTIVE MAINTENANCE

The following table defines the maintenance intervals that the main vehicle subsystems must comply with:

MAINTENANCE “GRID INTERVALS”		
Maintenance Code	MIN kilometers INTERVAL [km]	PERIODICITY INTERVAL
SB	1.000	2 days
K	7.500	2 weeks
KB1	50.000	3 months
KB2	100.000	6 months
KB3	200.000	1 year
GB	400.000	2 years
SR	800.000	4 years
GR	1.600.000	8 years
BGR	3.200.000	16 years
TB	N/A	N/A

The SEC has to comply with:

- “Manhour” (translated in cost upon the cost of 45.00 [€/h])
- “Material Cost”

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PREV. MAINT. REQUIREMENT		
SEC	Manhours Cost [h/km]	Material Cost [€/km]
HIGH VOLTAGE SYSTEM	≤ 0,04337	≤ 0,00685
Surge Arrestor	≤ 0,00177	≤ 0,00028
Main Circuit Breaker	≤ 0,00419	≤ 0,00066
Current Transformer	≤ 0,01397	≤ 0,00221
Voltage Transformer	≤ 0,01397	≤ 0,00221
High Voltage Cable	≤ 0,00005	≤ 0,00001
Roof Insulator	≤ 0,00055	≤ 0,00009
Bus Bar	≤ 0,00020	≤ 0,00003

All consumables are to be included in the calculation; where a maintenance task is divided into several ‘maintenance levels’, all labour hours and materials used in each level are to be considered.

6.2.2. CORRECTIVE MAINTENANCE

The SEC has to comply with:

- “Manhour” (translated in cost upon the cost of 45.00 [(€/h)])
- “Material Cost”

CORRECTIVE MAINT. REQUIREMENT		
SEC	Manhours [h/km]	Material Cost [€/km]
HIGH VOLTAGE SYSTEM	≤ 0,00163	≤ 0,00744
Surge Arrestor	≤ 0,00007	≤ 0,00030
Main Circuit Breaker	≤ 0,00016	≤ 0,00072
Current Transformer	≤ 0,00053	≤ 0,00239
Voltage Transformer	≤ 0,00053	≤ 0,00239
High Voltage Cable	≤ 0,00000	≤ 0,00001
Roof Insulator	≤ 0,00002	≤ 0,00009
Bus Bar	≤ 0,00001	≤ 0,00003

When a maintenance operation is divided into several ‘maintenance levels’, all labour hours and materials spent on each level must be considered.

In addition to calculating the cost of corrective maintenance, the MTTR will also be calculated according to the formula below:

$$MTTR = \frac{\sum_i^n \lambda_i t_i}{\sum_i^n \lambda_i}$$

where:

- -n is the number of components (LRUs) in the system;
- - λ_i is the failure rate of the i-th component;
- - t_i is the repair (replacement) time of the i-th component.

Furthermore, the SEC must comply with the above:

6.3. AVAILABILITY

The system must be designed and managed in such a way that its impact on vehicle availability is reduced as much as possible; i.e.: where possible, ‘Off-Board’ maintenance (removing/replacing an assembly for maintenance) can be chosen to reduce vehicle downtime.

As part of the maintenance analysis, an estimate of vehicle availability must be carried out.

The availability index calculation must be carried out according to the formula below:

$$A = \frac{MTBF}{MTBF + MTTR}$$

The availability index is expressed as a percentage value and refers to the fleet available for operation.

The minimum values that must be guaranteed for the system depending on the rolling stock to be supplied are:

AVAILABILITY REQUIREMENT	
SEC	AVAILABILITY [%]
HIGH VOLTAGE SYSTEM	≥ 99,99313
Surge Arrestor	≥ 99,99999
Main Circuit Breaker	≥ 99,99994
Current Transformer	≥ 99,99929
Voltage Transformer	≥ 99,99929
High Voltage Cable	≥ 99,99999
Roof Insulator	≥ 99,99999
Bus Bar	≥ 99,99999

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6.4. 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.

6.4.1. 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 1 and their probability of occurrence in Table 2:

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 1 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 2 Events levels probability

The risk assessment will be based on the combination of the probability level of the hazard (frequency of occurrence of the hazard) and the severity level of the hazard (the worst credible incident resulting from personnel error, environmental conditions, design inadequacies, procedural deficiencies; or system, subsystem, or component failure or malfunction) to find the risk index.

The system must adhere to the following risk assessment matrix:

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 3 Risk matrix

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6.4.2. PRELIMINARY HAZARD ANALYSIS VEHICLE LEVEL

All hazards that could involve people on board the vehicle, people getting on/off the vehicle, people at stops, people working on or near the line and drivers and maintenance personnel shall be analysed.

The following table describes the main hazard at vehicle level. Additional safety hazards can be added if necessary.

HAZARDS LIST		
N. hazard	Hazard ID	Description
1		Uncontrolled vehicle movement
	1°	Accidental movement of the vehicle due to involuntary engagement of the traction
	1b	Wrong direction of travel due to incorrect command
	1c	Loss of functions at the interface with CCS
	1d	Loss of vehicle traction due to failure of the traction system (motor generator/traction cabinet...)
	1e	Wrong direction of travel due to failure of the traction system (inverter)
2		Vehicle braking absent
	2°	Failure to apply service braking with vehicle in single-drive configuration
	2b	Failure to brake when parking (parking) with vehicle in single configuration
	2c	Failure to apply emergency braking with vehicle in single-drive configuration
	2d	Damage to the braking system components
	2e	After activation of an emergency braking command, no train deceleration due to the traction system failing (tractive effort \geq braking force)
3		Derailment
	3°	Vehicle Structural Failure (Wheel Breakage, Spindle Breakage, Suspension Breakage, Bogie Frame Failure)
	3b	Obstructions on the line
	3c	Falling objects on the tracks (underbody mounted elements, diagnostic systems installed on the bogie and on the roof)
	3d	Vehicle dynamic performance not optimal
	3e	Driver confusion due to inadequate dashboard layout (confusion in the arrangement of buttons, LEDs, displays and enable keys)
4		Danger to personnel entering and exiting the vehicle or on board the vehicle
	4°	Danger of crushing or entrapment for persons in the entry or exit area during shutdown (external door)
	4b	Crushing hazard for persons in the entry or exit area during travel (interconnecting internal doors)
	4c	Danger of falling from access stairs

HAZARDS LIST		
N. hazard	Hazard ID	Description
	4d	Tripping hazard due to unevenness of the floor surface
	4e	Outside door open while train is moving
5		Fire / smoke development
	5°	Fire hazard, smoke development
	5b	Short circuit of on-board electrical systems
	5c	Overheating of mechanical/electrical parts
	5d	Insufficient supply of fire extinguishers
	5e	Danger arising from failure of the fire prevention system
6		Explosion
	6°	Explosion, bursting of devices/components (pressure, flying parts, gases or fluids emitted.)
7		Vehicle damage
	7°	Case damage (structural failure / corrosion / aging)
	7b	Damage to the trolley (structural failure / corrosion / aging)
	7c	Out of shape
	7d	Vandalism inside the vehicle (e.g. theft of on-board equipment)
	7e	Vandalism outside the vehicle (e.g. "surfing", graffiti, fuel theft)
	7f	Damage caused by atmospheric agents
	7g	Damage to the main traction box due to unexpected pantograph lifting and unexpected extra-rapid closing (at 25kV)
8		Malfunctions due to electrical interactions with other systems and vehicles
	8°	The vehicle causes malfunctions in external systems (e.g. signalling systems, safety systems, other vehicles)
9		Involuntary disconnection of the convoy
	9°	Involuntary train disconnection due to hook failure
	9b	Disconnecting the brake system half-couplings
	9c	Disconnecting the 18-pin connection
10		Dangers related to the internal conditions of the vehicle (driver's cabin, diagnostic cabin)
	10°	Danger due to inadequate ventilation/air conditioning
	10b	Hazards due to the design of the interior (e.g. risk of falling, risk of injury on sharp edges and corners, crushing, hot parts)
	10c	Dangers due to excessive noise levels

HAZARDS LIST		
N. hazard	Hazard ID	Description
	10 d	Inadequate resistance of structures fixed to the crate
	10 e	Other hazards (e.g. toxic materials, vapor emissions, harmful substances)
	10 f	Danger due to untimely or inadequate communication
	10 g	Danger due to poor ergonomics (bad posture/excessive effort)
	10 h	Presence of exhaust fumes in the cabin
	10 i	Danger due to excessive vibrations
	10 l	Danger due to confused/distracted driver
1	1	Collision with obstacles
	11 °	Poor or insufficient visibility
1	2	Failure to manage emergency situations
	12 °	Evacuation of persons not possible in case of emergency, escape routes insufficient or inadequately accessible (e.g. driver's escape door, emergency exits)
	12 b	Inadequate life-saving equipment
	12 c	Inadequate installation of emergency devices (e.g. red emergency mushrooms,)
1	3	Electrical Hazards
	13 °	Electrocution
	13 b	Direct/indirect contact with live parts
	13 c	Exposure to electric arcs
	13 d	Inadequate grounding
	13 e	Rodent damage
1	4	Dangers related to vehicle lighting conditions/glare from other vehicles

HAZARDS LIST		
N. hazard	Hazard ID	Description
	14 °	Failure to report the vehicle
	14 b	Insufficient external lighting while driving
	14 c	Insufficient interior lighting (driving desk/interior spaces)
	14 d	Insufficient emergency lighting
	14 e	Glare of oncoming vehicle caused by diagnostic system illuminators installed on the roof
1 5		Dangers associated with the detection of diagnostic systems
	15 °	Emission of electromagnetic waves in the bands of interest of train detection systems
1 6		Other dangers
	16 °	Failure of the remote-control function in convoy via TCN (remote control mode)
	16 b	Failure to give acoustic warning of vehicle
	16 c	Operator damage due to difficult access for maintenance
	16 d	Poor quality process (Inadequate supplier management, Inadequate/absent risk management, Absent/poor configuration management)
	16 e	Non-compliance with Standards

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7. RAMS/LCC MONITORING PERIOD

The RAMS/LCC requirements will be verified over the all the Vehicles during a dedicated test period as per the Technical Specification for Service (ST Service) attached to the contract.

Whereas, during the early period of the RAM test, the quantitative requirements are not complied then the SEC Supplier has to promptly undertake compensating actions (design modification, parts change, etc...) aimed to reach such quantitative requirements.

Regarding Safety requirements, the Supplier shall be fully compliant with and have demonstrated that compliance through the provided documentation.

Possible incidents occurring during revenue service or maintenance activities on these vehicles, causing significant effects on the Safety, due to design or quality defects or poor/wrong documentation, will be under the Supplier's responsibility according to the national laws.

8. CONCLUSIONS

All analyses have to be performed according to Doc. [1]. (RAMS Plan given in Annex-1)