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RAMS of HVAC for Rolling Stock Application

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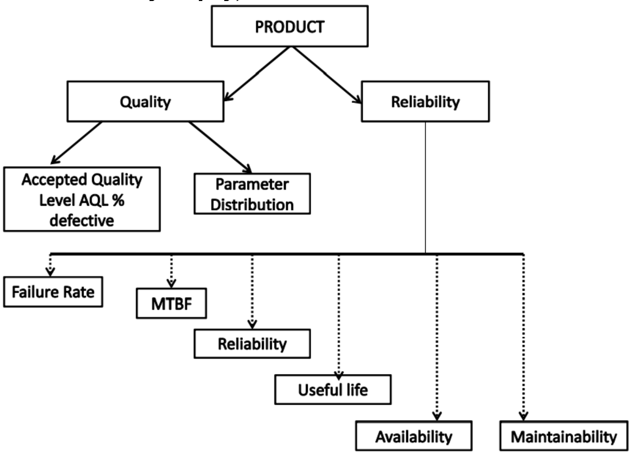
1 Abstract

Purpose -The purpose of this paper is to provide the detailed calculation of reliability, availability, maintainability, safety of HVAC for a desired mission time (time frame).
Methodology & approach - The complete calculation and detailed methodology is based on the systematic approach followed by the standards ROME LABORATORY RELIABILITY ENGINEER'S TOOL KIT, EN-50126 & the practically used techniques in rolling stock industry.
Findings – The paper provides information about the reliability critical items in a HVAC, how the series & parallel method of calculation is performed, how they are used in calculation of RAMS.
Research limitations – This paper is there to provide the RAMS calculation at HVAC level only but this can also be performed at the train level. The author has taken only the methodology which was there in the standards & practically followed by him. There can be some other approach also for this calculation.
Practical Implications - This paper provide the overview of approach & methodology which can be used for the calculation of RAMS of HVAC (Heating Ventilation Air Conditioning) system and can directly use in the rolling stock application.

Key Words- Life Cycle cost, Reliability, Availability, Maintainability and Safety.

2 INTRODUCTION

2.1 RAMS (Reliability Availability Maintainability Safety)

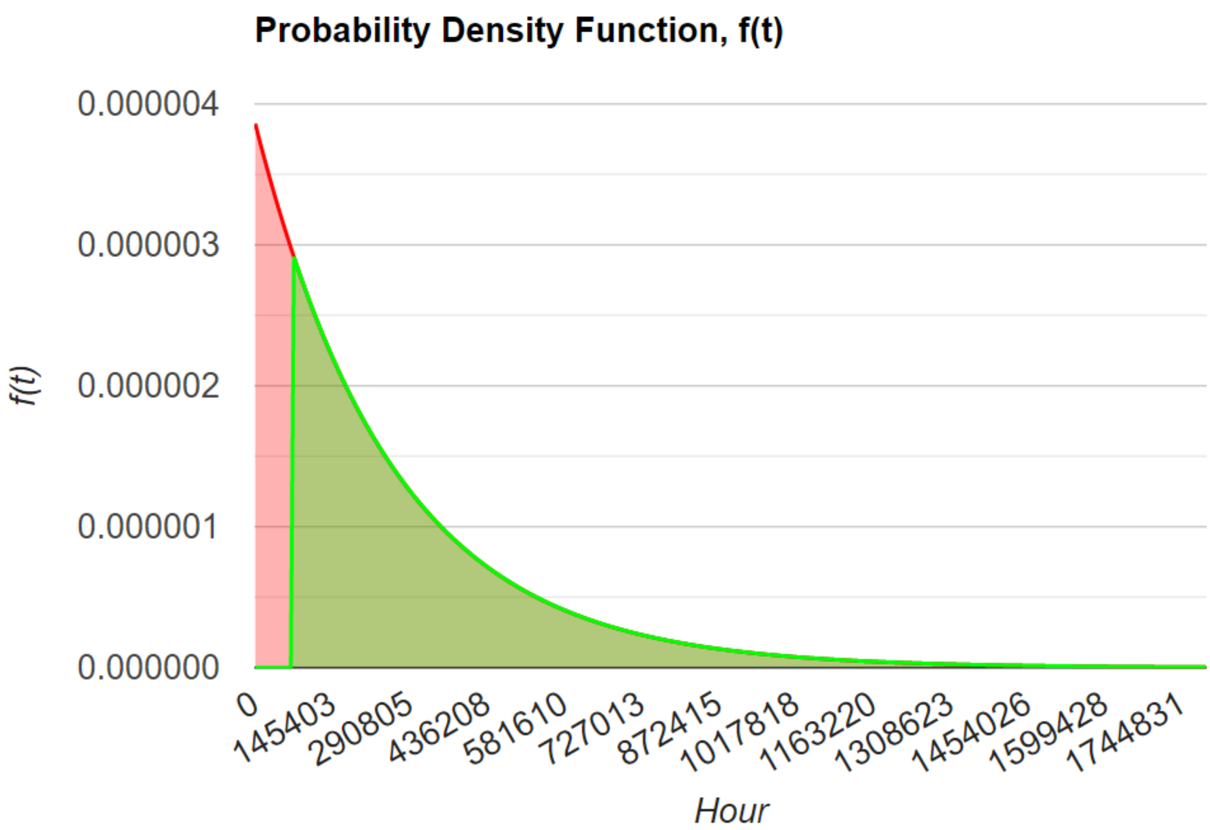


2.2 Reliability

Reliability can be described as a discipline related to the design, development, test, and manufacture of an item, so that it successfully performs a certain task under specified conditions for a certain length of time or number of cycles with a specified probability.

2.2.1 Probability density function $f(t) = \lambda e^{-\lambda * t}$

Where;
f (t)= probability density function
λ = Failure rate
t = mission time
MTBF = 1/ λ
e.g. $\lambda = 3.86 * 10^{-6}$
MTBF = 1/ λ = 259067
Mission time (t) = Time for which the component has to perform its intended function.
t = 69000 hours



The reliability at 69,000 hours is 0.77, as represented by the green shaded area to the right of the 69,000 hour point in the probability density function (pdf) plot shown above. The unreliability or probability of failure is 0.23, as represented by the pink shaded area to the left of the 69,000 hour point in the pdf plot.

2.2.2 Reliability Function R (t) = $\int_t^\infty f(t)dt$ **= e**$^{-\lambda * t}$

Where;

R = Reliability

λ = Failure rate

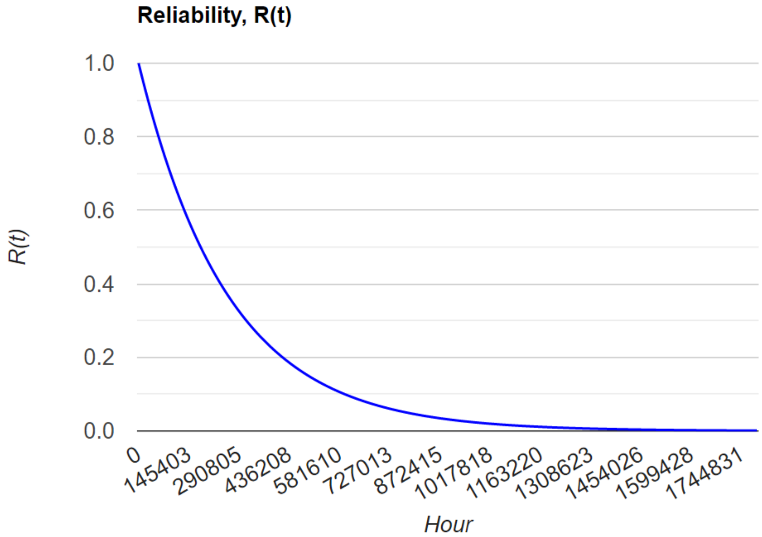
t = mission time

e.g. $\lambda = 3.86 * 10^{-6}$

MTBF = 1/ λ = 259067

Mission time (t) = Time for which the component has to perform its intended function.

For mission time t = 69000 hours



The reliability at 69,000 hours is 0.77. The unreliability or probability of failure is 0.23

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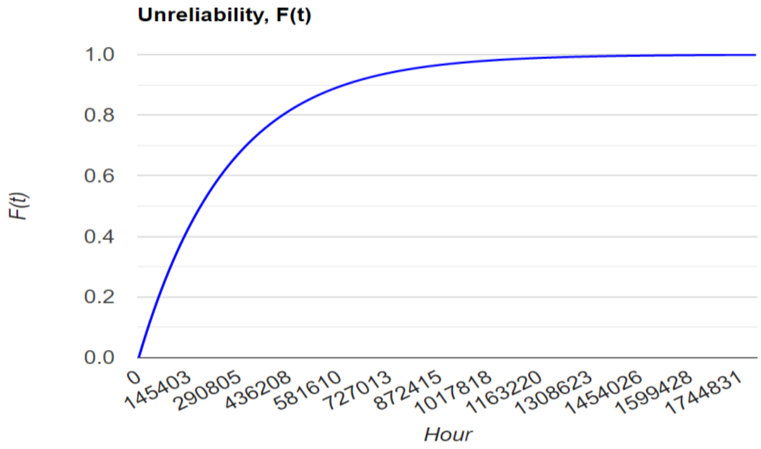
2.2.3 Un-reliability F (t) = 1- R (t)



2.3 Availability

It is defined as the time for which of train is available for revenue service. Availability is defined as the **percentage of time a system is considered ready to use when asked**. It depends on the availability of all the subsystems of the train including HVAC.

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

$$\mathbf{A} = \frac{\mathbf{1/\lambda}}{\mathbf{1/\lambda+1/\mu}}$$

$$\mathbf{A} = \frac{\mu}{\boldsymbol{\lambda+\mu}}$$

Where;
MTBF = Mean time between failure = **1/ λ**
MTTR = Mean time to repair

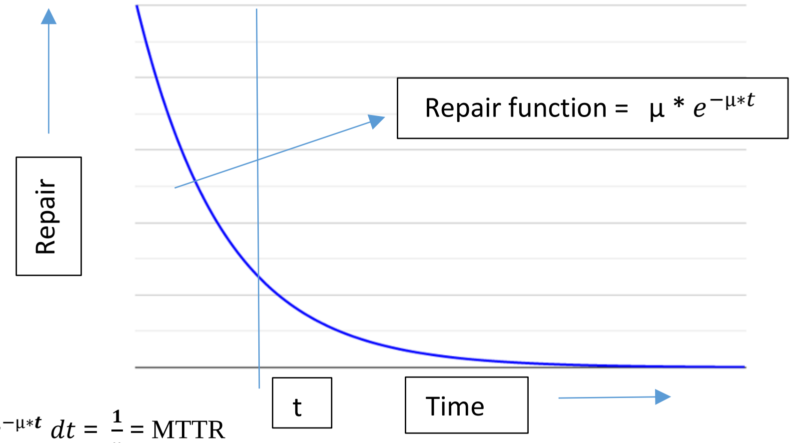
$$\text{MTTR} = \frac{\sum_{i=1}^{n}(\boldsymbol{\lambda i * Qi * MTTRi})}{\sum_{i=1}^{n}(\boldsymbol{\lambda i * Qi})}$$

Where;
$MTTR_i$ is the repair time for each Line Replacement Unit (LRU) with a total quantity **Q_i** and **λ_i** is the failure rate for each LRU.
Where
λ_i = the failure rate of the *i* th repairable unit
$MTTR_i$ = the repair time of the *i* th repairable unit
Q = the number of units in the system

2.4 Maintainability

The probability that a given maintenance action can be carried out within a stated time interval under stated conditions and using stated procedures and resources.

Repair rate = μ = $\frac{1}{\text{MTTR}}$
t = allowable down time



$$\int_0^\infty \boldsymbol{t} * \mu * \boldsymbol{e}^{-\mu * \boldsymbol{t}}\, dt = \frac{1}{\mu} = \text{MTTR}$$

$$\text{Maintainability} = \text{M (t)} = \int_0^t \mu * \boldsymbol{e}^{-\mu * \boldsymbol{t}}\, dt = 1 - \boldsymbol{e}^{-\mu * \boldsymbol{t}}$$

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2.5 Safety
Safety is the state of being "safe", the state of being secure from harm or other non-desirable consequences. Safety can also refer to the control of documented hazards in order to attain a satisfactory level of risk. Capability not to harm persons, the environment, or any properties during a whole life cycle.

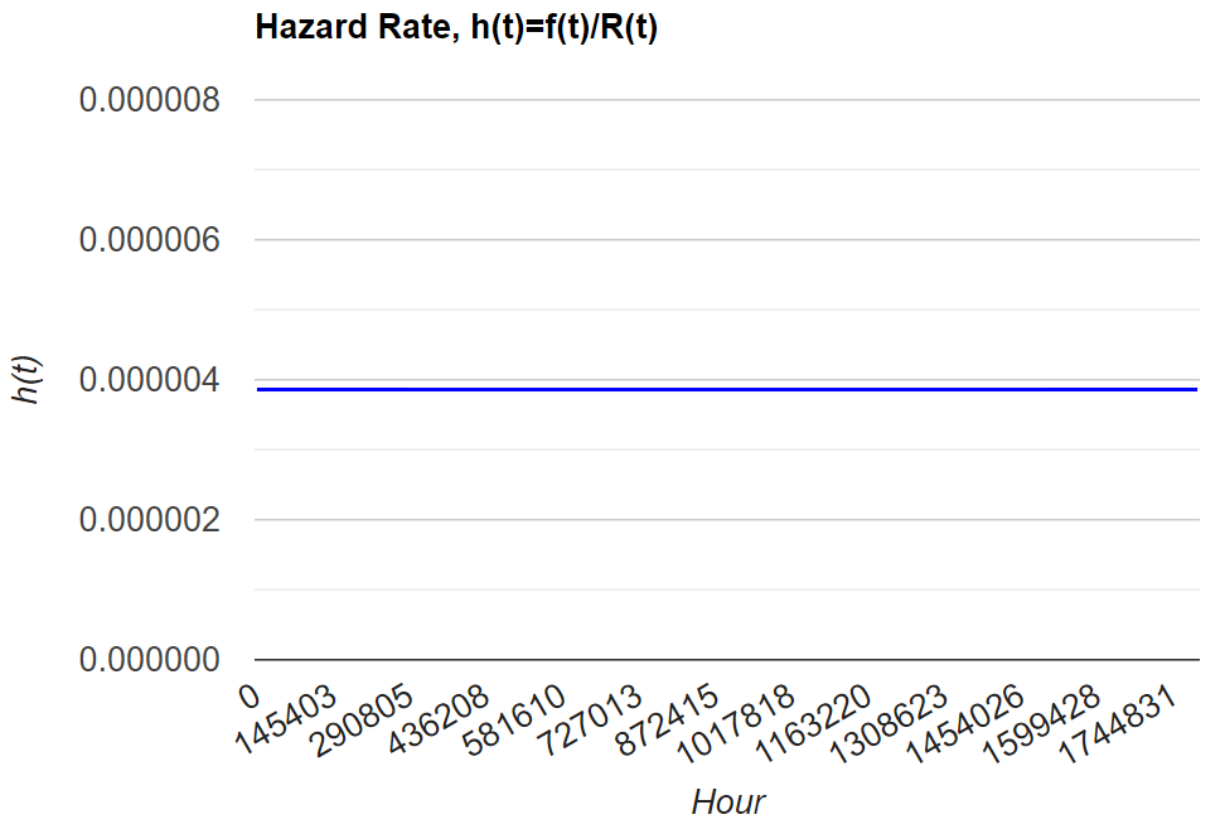
2.5.1 Deliverables of safety plan:-
Risk Analysis.
Hazard log
Interface hazard analysis (IHA)
Operating & support hazard analysis (O&SHA)
Preliminary Hazard Analysis (PHA)
FMECA – Failure mode effect critical analysis
FTA – Fault tree analysis

2.5.2 Failures in HVAC that are considered in Safety Critical Failures

A) Fire start or smoke release from the HVAC.
B) HVAC explosion.
C) HVAC failures leading to electrocution.
D) Features leading to refrigerant leak outside the HVAC unit.

Hazard Function $h(t) = \frac{F(t)}{R(t)} = \lambda$

Where;
R (t) = Reliability Function
f (t) = Probability density function
λ = Failure rate
e.g. $\lambda = 3.86 * 10^{-6}$
MTBF = 1/ λ = 259067
Mission time (t) = Time for which the component has to perform its intended function.
t = 69000 hours



The reliability at 69,000 hours is 0.77**.** The unreliability, or probability of failure, is 0.23.

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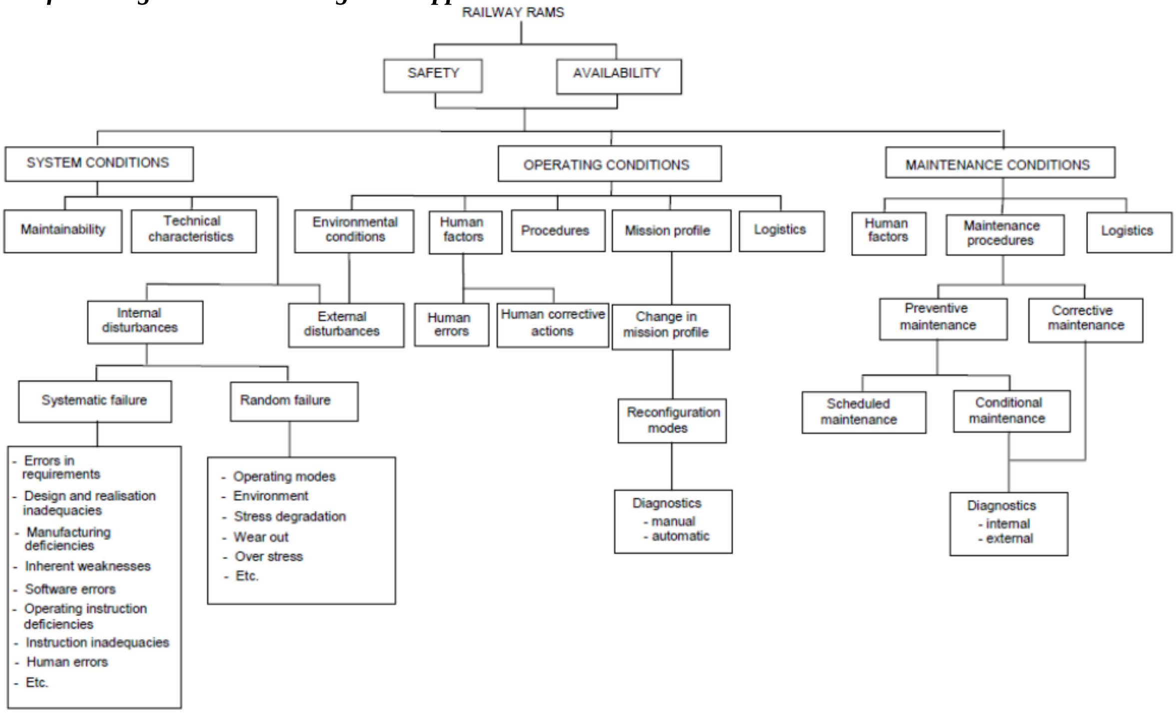
2.6 Factors influencing RAMS in Rolling stock application:-



2.7 RAMS for lifecycle phases

Phase No.	Phase	General Task	RAM Task	Safety Task
1	Conceptual Design	Investigation done on the basis of scope of supply, application of the system & environment in which it has to perform its intended function.	Investigation on the following points to be done – System on which RAM is to be implemented. Previous similar projects on which this RAM was applied also validating its performance by cross checking the failure rates & MTTR values. Predict the failure rates as per respective standards or from the field data of similar projects undergoing in the similar environment & application. Current targets of reliability & how these targets can be achieved i.e. series, parallel combination (redundancy) of the components that are having high failure rates. Describe the possibility of the RAM controlling requirements for successive scheme life cycle RAM tasks. Prepare Reliability Critical item list.	Investigation on the following points to be done – Over-all safety consequences of the system. Previous similar projects on which this safety performance was applied also validating its performance by cross checking the hazard rate. Current targets of safety & how these targets can be achieved i.e. by using EN45545 compliance used for non-metallic materials. Describe the possibility of the safety controlling requirements for successive scheme life cycle safety tasks.
2	System explanation and operative context	Define the following – System Mission period & summary scope of operative requests	Inaugurate – RAM policy RAM plan	Inaugurate – Safety policy Safety plan
3	Risk investigation and calculation		Accomplish – Risk Analysis Modernize – RAM plan	Accomplish – Risk Analysis. Hazard log Interface hazard analysis (IHA) Operating & support hazard analysis (O&SHA) Preliminary Hazard Analysis (PHA)
4	Description of system requests	Specify system necessities	Establish – RAM necessities description RAM plan Validation plan for RAM necessities description	Establish – Safety necessities description Safety-related submission circumstances. Update Hazard log Update Interface hazard analysis (IHA)

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				Update Operating & support hazard analysis (O&SHA) Update Preliminary Hazard Analysis
5	Design and allotment of system necessities	Define the system design. Identify the necessities for incorporation of pre-existing subsystems/mechanisms. Define acceptance standards and developments for subsystems/mechanisms.	Assign RAM necessities to subsystems/mechanisms. Provide component level failure rates as per respective standard and calculate the system reliability by Reliability Block Diagram. Modernize the RAM plan. Modernize validation plan for RAM requirements.	Accomplish hazard analysis. Assign safety requirements to subsystems/mechanisms. Update safety-related application situations. Update Hazard log Update Interface hazard analysis (IHA) Update Operating & support hazard analysis (O&SHA)
6	Design and execution	Design subsystems/mechanisms. Prepare O&M module. Define and create engineering process for manufacturing subsystems and mechanisms. Define and create system amalgamation process. Prepare installation and contracting processes.	Strategy of RAM tasks of further phases. Accomplish RAM investigation. Modernize the RAM plan. Modernize authentication plan for RAM necessities. Update Reliability Block diagram. Update Fault tree analysis. Predict the MTTR i.e. time to repair the particular component when the respective failure is arrived. Check the accessibility of all the components to ensure the minimum MTTR so that maximum availability of the system can be ensured.	Strategy of Safety tasks of further phases. Accomplish hazard analysis. Update safety-related submission circumstances. Update safety-related application situations. Update Hazard log Update Interface hazard analysis (IHA) Update Operating & support hazard analysis (O&SHA). Prepare FMECA (Failure Mode Effect Critical Analysis).
7	Manufacturing	Implement and activate industrialized procedure	Inaugurate RAM declaration arrangements. Modernize the RAM plan. Modernize authentication plan for RAM requirements. Check accessibility of all the components to ensure the minimum MTTR so that maximum availability of the system can be ensured. If there is any change in component assembly as per manufacturing constraints update the MTTR and system availability report.	Strategy of Safety tasks of further phases. Accomplish hazard analysis. Update safety-related submission circumstances. Update safety-related application situations. Update Hazard log Update Interface hazard analysis (IHA) Update Operating & support hazard analysis (O&SHA). Update FMECA (Failure Mode Effect Critical Analysis).
8	Integration	Incorporate subsystems and mechanisms. Determine system functionality. Test and examine scheme. Arrange system provision measures.	Inaugurate RAM declaration arrangements. Modernize the RAM plan. Modernize authentication plan for RAM requirements. Check accessibility of all the components to ensure the minimum MTTR so that maximum availability of the system can be ensured. If there is any change in component assembly as per manufacturing constraints update the MTTR and system availability report.	Strategy of Safety tasks of further phases. Accomplish hazard analysis. Update safety-related submission circumstances. Update safety-related application situations. Update Hazard log Update Interface hazard analysis (IHA) Update Operating & support hazard analysis (O&SHA). Update FMECA (Failure Mode Effect Critical Analysis).
9	System Authentication	Establish-Authentication report. Procedure for the achievement and estimate of operational and maintenance data.	Inaugurate RAM declaration arrangements. Modernize the RAM plan. Modernize authentication plan for RAM requirements.	Strategy of Safety tasks of further phases. Accomplish hazard analysis. Update safety-related submission circumstances. Update safety-related application situations. Update Hazard log Update Interface hazard analysis (IHA) Update Operating & support hazard analysis (O&SHA). Update FMECA (Failure Mode Effect Critical Analysis).
10	System approval	Record and recognition by signing off all the documents related to RAMS for Safety. Verify the approval record.	Evaluate RAM authentication. Signoff all targets related to failure rates & reliability.	Inaugurate Self-regulating Safety Assessment Report. Declare validation of safety related documents.
11	Operation, maintenance and performance checking	Provide all statistics essential to express plans/actions for O&M. Implement O&M procedures.	Implement and retain FRACAS procedure for the acquisition and recording of RAM presentation data. Sustain FRACAS and intermittently	Implement and preserve procedure for the acquirement and recording of safety performance data.

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		Record modifications in the scheme configuration.	evaluate FRACAS records. Inaugurate records to trace the RAM tasks commenced. Reports of RAM performance investigation and calculation. Check all the reliability parameters as per plan and implement all of them in the new project.	Accomplish hazard analysis. Validate safety-related submission circumstances. Validate safety-related application situations. Validate Hazard log Validate Interface hazard analysis (IHA) Validate Operating & support hazard analysis (O&SHA). Validate FMECA (Failure Mode Effect Critical Analysis). Inaugurate reports of safety performance analysis and assessment.
12	Decommissioning	Inaugurate decommissioning plan and linked report.	Recognize the RAM impact of decommissioning and dumping.	Recognize the Safety impact of decommissioning and dumping.

2.8 Failure categories and classification of failures according to failures

2.8.1 Relevant failures –

A relevant failure of an item is an independent failure which results in a loss of function of that item caused by any of the following:

• A fault in an equipment or sub-system while operating within its design and environmental specification limits;

• Improper operation, maintenance, or testing of the item as a result of the Contractor supplied documentation.

• Failures of transient nature including those with post investigation status as 'No fault found', shall be considered as relevant failure if in the opinion of the Engineer these are attributable to rolling stock. The decision of the Engineer shall be final.

2.8.2 Service failure –

Any relevant failure or combination of relevant failures during revenue service operations, simulated revenue operations or during pre-departure equipment status checkouts to determine availability for revenue service, which results in one of the following:

• Unavailability of the train to start revenue service after successful completion of pre-departure checkout.

• Withdrawal of the train from revenue services.

• A delay equivalent to or exceeding 3 minutes from the Schedule / Time table as noted at the destination station for the one-way trip.

S. no.	Top level failure events Train Level Effect	Effect on operation (passengers, other sub systems,)	1st line maintenance actions	Failure classification	
				Service Failure	Relevant Failure
1	Loss of ventilation in one car.	No sufficient air flow for emergency situations more than one cars	Withdrawal from operation	X	
2	Loss of overheating protection 3rd level(Thermal fuse)	Passenger Safety	Withdrawal from operation	X	
3	Fire inside the Evaporator section of HVAC	Passenger Safety	Withdrawal from operation	X	
4	Total loss of cooling in one car or more cars	Passenger discomfort	Withdrawal from operation	X	
5	Failure of Cab Booster	Driver discomfort	Withdrawal from operation	X	
6	All Service Failure resulting in delay/detention for more than 60 (sixty) minutes or passenger deboard-ment in mid-section	Train withdrawal / Passenger Deboarding	Withdrawal from operation	X	
7	Loss of ventilation in one HVAC	No sufficient air flow for emergency situations in one car	Withdrawal at the end of trip		X
8	Loss of overheating protection 1st level (bimetal thermostat)	Passenger Safety	Withdrawal from operation at the end of the trip		X
9	Loss of overheating protection 2nd level (SA sensor)	Passenger Safety	Withdrawal from operation at the end of the trip		X
10	Any leakage in piping connections between condenser / evaporator coils	No passenger discomfort	Withdrawal from operation at the end of the trip		X
11	Failure of any one HVAC in any car leading to increase in	Degrade in the temperature control in passenger area	Withdrawal from operation at the end of the trip		X

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S. no.	Top level failure events Train Level Effect	Effect on operation (passengers, other sub systems,)	1st line maintenance actions	Failure classification	
				Service Failure	Relevant Failure
	inside saloon/cab temperature ≥ 28 degree Celsius at the design ambient temperature.				
12	Water dripping problem	No effect on the operation but passenger discomfort	Corrective actions		X
13	Noisy air conditioner due to compressor and condenser fans	Passenger discomfort	Withdrawal from operation at the end of the trip		X

2.9 Reliability prediction

Use recognized standards

- Model failure of machineries
- Examine system
- Compute the system predicted failure of MTBF

Evaluate prediction vs. target or required MTBF

- Evaluate stress or temperature reduction design changes
- Evaluate practically of design change specially when MTBF is self-inflicted

2.9.1 Methodologies

Rank	Method	Early defects	Random effects	Wear out	Description
1	Field Data	✓	✓	✓	This statistics is provided by service team it is being calculated by RAMS team.
2	System reliability assessment	✓	✓	✓	Combine the calculation method that combines prediction, procedure grading, operative profiles, and software and test data using Bayesian procedures.
3	Similar item Data	✓	✓		Based on investigational reliability field failure data on analogous products functioning in similar atmosphere. Uses generic data from association.
4	Translation	✓	✓		Interprets a reliability prediction based on an experimental value. Indirectly accounts for some factors affecting field reliability that is not unambiguously amounted for in the experimental model.
5	Empirical	✓	✓		Typically relies on experiential failure data to enumerate part-level experimental model variables. Applied is that valid failure rate is appropriate.
6	Physics- of- failure			✓	Representations each failure mechanism for each module life separately. Component reliability is determined by merging the probability density function related with respective failure mechanism.

2.9.2 Common standards

- MIL-HDBK 217
  Generally associated with military system
  Provides for many environments
  Provides multiple quantity levels
- Bell core (Telcordia)
  Telecommunication industries standard
  Models patterned after MIL-HDBK 217
  Provides multiple quality level
- HRD 5
  Telecommunication industries standard
  Provides multiple quality level
- NPRD-95
  Non electric parts
  Provides multiple quality level
- NSWC-07 “NAVAL SURFACE WARFARE CENTRE”
  Hand book Reliability Prediction Procedures for Mechanical

2.9.3 Assumptions

- The components are continuous failure rates.
- The mechanisms are in their suitable life period.
- Infant mortalities are detached by element screening.
- Wear out has not been reached.

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- The mechanisms are considerably standardized with those under which failure rates are dignified.
- The prediction model uses a simple reliability series system of all mechanisms, in other words, a failure of any module is expected to lead a system failure.

2.9.4 Environments

- **Ground Benign G_B =** Non mobile temperature & humidity controlled environment**.**
- **Ground Benign G_F =** moderately controlled environment such as installation in permanent racks.
- **Space flight S_F =** Earth orbital. Approaches benign ground condition.
- **Missile, Flight S_F =** Condition related to powered flight of air breathing missiles, cruise missiles.
- **Missile, Launch M_L** =Serve condition related to missile launch, space vehicle re-entre and landing by parachute.
- **Cannon, Launch C_L =** Extreme severe conditions related to cannon launching of 155 mm and 5 inch.

2.10 LCC (Life Cycle Cost)

It is the overall cost which is bared by a stakeholder so that the system can perform its intended function for a particular mission time (time for which the system has to perform its intended function). It Comprise of Labor cost, material cost to perform Corrective, Preventive and overhauling maintenance for the complete life cycle of system.

2.10.1 Three pillars of LCC

Corrective Maintenance – The maintenance activity performed when the failure is happened. Whenever any system or subsystem is produced it cannot be so robust that it will perform its intended function without any failure. Thus when the subsystem fails we replace it or repair it and record the failure rate for the input to RAMS.

Preventive maintenance- To minimize the failures we have to perform some kind of maintenance so that availability & reliability of our system is increased and the system can perform its intended function for more time.

Actions that can be performed as preventive task in HVAC-

- Filter Cleaning (Fresh air)
- Filter Cleaning (Mixed / Return air)
- HVAC Inspection & Cleaning (Evaporator & Condenser Coil, Emergency inverter, transformer, FA RA SA & Humidity sensor)
- HVAC Inspection & Cleaning (Supply fan & condenser fan motor, Compressor, Pressure Transducers, Heater bank, Contactors & circuit breakers, Controller, Fresh air & return air damper, Doors sealing gaskets, Thermal insulation, Sight glass)

Overhauling- Some of the sub-systems are having less life than the system. So we have to replace the subsystem at the particular interval. So that our system can perform its intended function without any failure**.** E.g. If the system is having 15 years of life & subsystem is having 7 years of life, we have to replace that subsystem twice during life of the system.

Note*- If we are not able to meet LCC targets of our customer we can decrease the frequency of overhauling and increase the failure rate.

2.11 Reliability Critical Item list of HVAC

Condenser Coil, Compressor, Liquid level indicator , Condenser Fan Assembly, HP Switch, LP Switch, Liquid line solenoid valve , Solenoid Valve Coil, Hand shut-off valves, Filter Drier, Supply air Fan Assembly, Evaporator Coil, Expansion Valve, Heater Assembly, Fresh air damper, Emergency Inverter, Emergency Transformer, Temperature probe 1, Temperature probe 2, Temperature probe 3, Humidity sensor, Connector 1, Connector 2, Compressor contactor, Supply Fan Contactor, Condenser Fan Contactor, Heater contactor, Circuit breakers Compressor, Circuit breaker Supply Fan, Circuit Breaker Condenser fan, Circuit Breaker heater, Rotary switch , Controller, Relay, DC-DC Converter, Thermal overheat protector , Bimetal thermostat.

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3 METHODOLOGY & CALCULATION

<table>
<tr><th>Description</th><th>Formula</th><th>Associated RBD</th></tr>
<tr><td>Resultant Failure rate (Series connected)</td><td>

$$\lambda_{system} = \lambda_1 + \lambda_2 + \ldots\ldots\ldots + \lambda_n$$

Where
λ_{system} = Resultant failure rate of the system.
λ_1 = failure rate of component 1
λ_2 = failure rate of component 2
λ_n = failure rate till n no. of components
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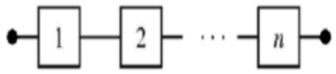

</td></tr>
<tr><td rowspan="2">Resultant Failure rate (Parallel connected)</td><td>

$$\lambda_{(n-q)/n} = \frac{\lambda}{\sum_{i=n-q}^{n} \frac{1}{i}}$$

Where
$\lambda_{x/y}$ is the effective failure rate of the redundant configuration where x of y units are required for success
n = number of active on-line units. n! is n factorial (e.g., 5!=5x4x3x2x1=120, 1!=1,0!=1)
λ = failure rate of an individual on-line unit (failures/hour)
q = number of on-line active units which are allowed to fail without system failure
μ = repair rate (μ=1/M_{ct}, where M_{ct} is the mean corrective maintenance time in hours)
P = probability switching mechanism will operate properly when needed (P=1 with perfect switching)
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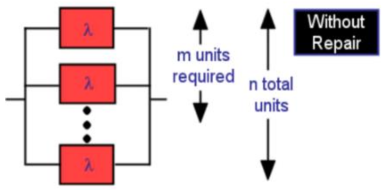

</td></tr>
<tr><td>

$$\lambda_{(n-q)/n} = \frac{n!\,(\lambda)^{q+1}}{(n-q-1)!(\mu)^{q}}$$

Where
$\lambda_{x/y}$ is the effective failure rate of the redundant configuration where x of y units are required for success
n = number of active on-line units. n! is n factorial (e.g., 5!=5x4x3x2x1=120, 1!=1,0!=1)
λ = failure rate of an individual on-line unit (failures/hour)
q = number of on-line active units which are allowed to fail without system failure
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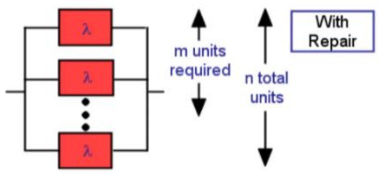
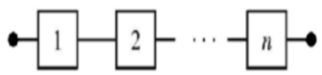


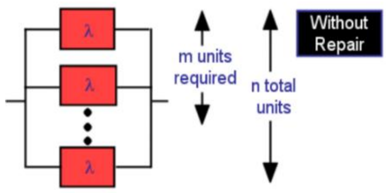
</td></tr>
<tr><td>Resultant Reliability (Series connected)</td><td>

$$R_{system} = R_1 + R_2 + \ldots\ldots\ldots + R_n$$

Where
R_{system} = Resultant reliability of the system.
R_1 = reliability of component 1
R_2 = reliability of component 2
R_n = reliability till n no. of components
</td><td>


</td></tr>
<tr><td>Resultant Reliability (Parallel connected)</td><td>

$$R_{system} = 1\text{-}((1\text{-}\ R_1) - (1\text{-}\ R_2) - \ldots\ldots\text{-}\ (1\text{-}\ R_n))$$

Where
R_{system} = Resultant reliability of the system.
R_1 = reliability of component 1
R_2 = reliability of component 2
R_n = reliability till n no. of components
</td><td>


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3.1 Reliability

3.1.1 Failure Rate prediction at subsystem level and calculation of failure rate at system level:

Table provided below defines the operational parameters of train during a mission time.

Train Mission Profile		
Project: HVAC with 4 refrigeration circuits		Unit
No. of trains	1	nos.
No. of cars per train	6	nos.
Train working hours per day	21	hours
HVAC system working hours per day	21	hours
Annual distance	320000	Km
No. of days in year	365	days
Annual hours of operation	7665	hours
Average speed	46.14	Km/h
Mission time (in years)	2	years
Mission time (in hours)	15330	hours

There are two HVAC system installed in one saloon car of a train. So for 6 car train configuration, there are total 12 HVAC system installed on one train.

Scope of supply		
Equipment	**Qty per car**	**Qty per train**
Saloon HVAC unit	2	12

The failure rate for the items (sub system) mentioned in below tables are taken from standard references. The calculation & conversion of failure rate are elaborated in more details below this table:

Failure Rate Data						
S.No.	**Item Description**	**MTBF (hours)**	**Failure rate (hour-1)**	**MDBF (km)**	**FPMH (10^-6 hours)**	**FPMK (10^-6 km)**
1	HVAC					
2	Condenser Coil	123791	8.08E-06	5711717	8.078	0.175
3	Compressor	62152	1.61E-05	2867693	16.090	0.349
4	Liquid level indicator	545791	1.83E-06	25182797	1.832	0.040
5	Condenser Fan Assembly	83584	1.20E-05	3856566	11.964	0.259
6	HP Switch	167752	5.96E-06	7740077	5.961	0.129
7	LP Switch	167752	5.96E-06	7740077	5.961	0.129
8	Liquid line solenoid valve	167752	5.96E-06	7740077	5.961	0.129
9	Solenoid Valve Coil	1438021	6.95E-07	66350289	0.695	0.015
10	Hand shut-off valves	167752	5.96E-06	7740077	5.961	0.129
11	Filter Drier	3448275	2.90E-07	159103409	0.290	0.006
12	Supply air Fan Assembly	83584	1.20E-05	3856566	11.964	0.259
13	Evaporator Coil	123791	8.08E-06	5711717	8.078	0.175
14	TX Valve	161168	6.20E-06	7436292	6.205	0.134
15	Heater Assembly	12165450	8.22E-08	561313869	0.082	0.002
16	Fresh air damper	99006	1.01E-05	4568137	10.100	0.219
17	Emergency Inverter	9999999	1.00E-07	461399954	0.100	0.002
18	Emergency Transformer	1669449	5.99E-07	77028381	0.599	0.013
19	Temperature probe 1	276816	3.61E-06	12772290	3.613	0.078
20	Temperature probe 2	276816	3.61E-06	12772290	3.613	0.078
21	Temperature probe 3	276816	3.61E-06	12772290	3.613	0.078
22	Humidity sensor	276816	3.61E-06	12772290	3.613	0.078
23	Connector 1	280614108	3.56E-09	12947534943	0.004	0.000
24	Connector 2	280614108	3.56E-09	12947534943	0.004	0.000
25	Compressor contactor	4697065	2.13E-07	216722579	0.213	0.005
26	Supply Fan Contactor	4697065	2.13E-07	216722579	0.213	0.005
27	condenser Fan Contactor	4697065	2.13E-07	216722579	0.213	0.005
28	Heater contactor	4697065	2.13E-07	216722579	0.213	0.005
29	Circuit breakers Compressor	1176470	8.50E-07	54282326	0.850	0.018
30	Circuit breaker Supply Fan	1176470	8.50E-07	54282326	0.850	0.018
31	Circuit Breaker condenser fan	1176470	8.50E-07	54282326	0.850	0.018
32	Circuit Breaker heater	1176470	8.50E-07	54282326	0.850	0.018
33	Rotary switch	12165450	8.22E-08	561313863	0.082	0.002
34	Controller	9999999	1.00E-07	461399954	0.100	0.002
35	Relay	9999999	1.00E-07	461399954	0.100	0.002
36	DC-DC Converter	498845016	2.00E-09	23016709038	0.002	0.000
37	Thermal Overheat fuse	15151823	6.60E-08	699105113	0.066	0.001
38	Bimetal thermostat	15151823	6.60E-08	699105113	0.066	0.001

Calculation of the above table –

1) **Condenser Coil –**

MTBF – 123791 (from NPRD 95 Standard)

Failure Rate (λ) = $\frac{1}{MTBF} = \frac{1}{123791}$

= 8.08E-06 hour^{-1}

MDBF (Mean Distance between failure) = MTBF * Average speed of train = 123791 * 46.14

= 5711717 km

FPMH (Failure per million hour) = Failure Rate (λ) * 10^6 = 8.08E-06 * 10^6

= 8.08

FPMK (Failure per million kilometer) = $\frac{FPMH}{Average\ speed\ of\ train} = \frac{8.08}{46.14}$

= 0.175

Note* - Same calculation is followed for the complete table.

Intrinsic Reliability Calculation – Cooling function					
S.no.	**Item Description**	**MTBF (hours)**	**Component Failure rate (/hour)**	**Quantity per HVAC**	**Total failure Rate (/hour) (HVAC Level)**
1	Hand shut-off valves	167752	5.96E-06	8	4.77E-05
2	Solenoid coil	1438021	6.95E-07	4	2.78E-06
3	LP SWITCH	167752	5.96E-06	4	2.38E-05
4	Liquid level indicator	545791	1.83E-06	4	7.33E-06
5	Compressor Circuit breaker	1176470	8.50E-07	4	3.40E-06
6	Compressor Contactor	4697065	2.13E-07	4	8.52E-07
7	Expansion valve	161168	6.20E-06	4	2.48E-05
8	Filter Drier	3448275	2.90E-07	4	1.16E-06
9	HP Switch	167752	5.96E-06	4	2.38E-05
10	Liquid line solenoid Valve	167752	5.96E-06	4	2.38E-05
11	Compressor	62152	1.61E-05	4	6.44E-05
12	Evaporator coil	123791	8.08E-06	2	1.62E-05
13	Condenser coil	123791	8.08E-06	2	1.62E-05
14	Condenser fan circuit breaker	1176470	8.50E-07	2	1.70E-06
15	Condenser fan contactor	4697065	2.13E-07	2	4.26E-07
16	Condenser fan	83584	1.20E-05	2	2.39E-05
17	Supply fan circuit breaker	1176470	8.50E-07	2	1.70E-06
18	Supply Fan	83584	1.20E-05	2	2.39E-05
19	Supply fan contactor	4697065	2.13E-07	2	4.26E-07
Total failure rate HVAC level (/hour)					**3.08E-04**
Intrinsic failure rate FPMH HVAC level (/Million hour)					308.34
Intrinsic failure rate FPMK HVAC level (/Million km)					6.68
Intrinsic failure rate FPMK Train level (/Million km)					**80.19**

Total failure rate HVAC level (/hour) = Summation of all failure rates = 3.08E-04

Total MTTF HVAC level (hour) = $\frac{1}{\textbf{Total failure rate HVAC level}} = \frac{1}{\textbf{3.08E−04}}$

= 3246 hours

Intrinsic failure rate FPMH HVAC level (/Million hour) = Total failure rate HVAC level (/hour) * 10^6

= 308.34

Intrinsic failure rate FPMK HVAC level (/Million km) = $\frac{\text{Intrinsic failure rate FPMH HVAC level (/Million hour)}}{\text{Average Speed}}$

= $\frac{308.34}{\textbf{46.14}}$

= 6.68

Intrinsic failure rate FPMK Train level (/Million km) = Intrinsic failure rate FPMK HVAC level * No. Of HVAC in 1 Train

= 6.68 * 12

= **80.19**

Relevant Failure - Reliability Calculation for Cooling function							
S.no.	**Item Description**	**Quantity per HVAC**	**MTBF (hours)**	**Failure rate (/hour)**	**Duty cycle**	**Component MTBF with duty cycle**	**Total failure rate (HVAC level) with duty cycle**
1	Connector 2	1	280614108	3.56E-09	1	280614108	3.56E-09
2	DC-DC convertor	2	498845016	2.00E-09	1	498845016	2.00E-09
3	Rotary switch	1	12165450	8.22E-08	1	12165450	8.22E-08
4	Controller	1	9999999	1.00E-07	1	9999999	1.00E-07
5	Connector 1	1	280614108	3.56E-09	1	280614108	3.56E-09

Failure rate of electrical components							**1.91E-07**
6	Temperature probe 1	1	276816	3.61E-06	1	276816	3.61E-06
7	Temperature probe 2	1	276816	3.61E-06	1	276816	3.61E-06
Failure rate of sensors							**2.00E-07**
8	Hand shutoff valve	8	167752	5.96E-06	0.6	279587	3.57671E-06
9	Solenoid coil	4	1438021	6.95E-07	0.6	2396702	4.17E-07
10	LP	4	167752	5.96E-06	0.6	279587	3.58E-06
11	Liquid level indicator	4	545791	1.83E-06	0.6	909652	1.10E-06
12	Compressor circuit breaker	4	1176470	8.50E-07	0.6	1960783	5.10E-07
13	Compressor Contactor	4	4697065	2.13E-07	0.6	7828442	1.28E-07
14	Compressor	4	62152	1.61E-05	0.6	103587	9.65E-06
15	Liquid line solenoid valve	4	167752	5.96E-06	0.6	279587	3.58E-06
16	HP	4	167752	5.96E-06	0.6	279587	3.58E-06
17	Filter drier	4	3448275	2.90E-07	0.6	5747125	1.74E-07
18	Expansion valve	4	161168	6.20E-06	0.6	268613	3.72E-06
19	Evaporator coil	2	123791	8.08E-06	0.6	206318	4.85E-06
20	Condenser coil	2	123791	8.08E-06	0.6	206318	4.85E-06
Failure rate of one cooling branch							3.97E-05
MTBF of one cooling branch							25185
Failure rate of two parallel cooling branch							2.42E-05
21	Condenser fan circuit breaker	2	1176470	8.50E-07	1	1176470	8.50E-07
22	Condenser fan contactor	2	4697065	2.13E-07	1	4697065	2.13E-07
23	Condenser fan	2	83584	1.20E-05	1	83584	1.20E-05
Failure rate of one condenser fan branch							1.30E-05
Failure rate of one complete cooling circuits							3.72E-05
MTBF of one complete cooling circuits							26885
Failure rate of all cooling circuits							**2.12E-05**
24	Supply fan circuit breaker	2	1176470	8.50E-07	1	1176470	8.50E-07
25	Supply fan contactor	2	4697065	2.13E-07	1	4697065	2.13E-07
26	Supply fan	2	83584	1.20E-05	1	83584	1.20E-05
Failure rate of one supply fan branch							1.30E-05
MTBF of one supply fan branch							76764
Failure rate of two supply fan branches							**2.60E-06**
Total failure rate HVAC level (/hour)							**2.42.E-05**
Total failure rate FPMH HVAC level (/Million hour)							24.20
Total failure rate FPMK HVAC level (/Million km)							0.52
Total failure rate FPMK Train level (/Million km)							**6.29**

Resultant Failure rate (Series connected) = $\lambda_{system} = \lambda_1 + \lambda_2 + \ldots\ldots\ldots + \lambda_n$

Resultant Failure rate (Parallel connected) = $\lambda_{(n-q)/n} = \dfrac{\lambda}{\sum_{i=n-q}^{n} \frac{1}{i}}$

$$= \frac{1}{((\mathbf{MTBF})^2)/\mathbf{MissionTime})}$$

Failure rate of electrical components (all are in Series)

$= \lambda_{Connector\ 2} + \lambda_{DC\text{-}DC\ convertor} + \lambda_{Rotary\ switch} + \lambda_{Controller} + \lambda_{Connector\ 1}$

= 3.56E-09 + 2.00E-09 + 8.22E-08 + 1.00E-07 + 3.56E-09

= 1.91E**-07 Failures/ hour**

Failure rate of sensors (all are in Parallel) = $\frac{1}{((\mathbf{MTBF})^2)/\mathbf{MissionTime})}$

$\lambda_{Temperature\ Probe\ 1}$ = 3.61E-06

$\lambda_{Temperature\ Probe\ 2}$ = 3.61E-06

MTBF = 276816 hours

Mission Time = 15330 Hours

$= \frac{1}{((276816)^2)/15330)}$

= **2.00E-07** Failures / **hour**

Failure rate of one cooling branch

$= \lambda_{\text{Hand shutoff valve}} + \lambda_{\text{Solenoid coil}} + \lambda_{\text{LP}} + \lambda_{\text{Liquid level indicator}} + \lambda_{\text{Compressor circuit breaker}} + \lambda_{\text{Compressor Contactor}} + \lambda_{\text{Compressor}} + \lambda_{\text{Liquid line solenoid valve}} + \lambda_{\text{HP}} + \lambda_{\text{Filter drier}} + \lambda_{\text{Expansion valve}} + \lambda_{\text{Evaporator coil}} + \lambda_{\text{Condenser coil}}$

= 3.97E-05 Failures/ **hour**

$\text{MTBF}_{\text{one cooling branch}}$ = 25185 hours

Failure rate of two parallel cooling branch = $\frac{1}{((\text{MTBF})^2)/\text{MissionTime})}$

$\text{MTBF}_{\text{one cooling branch}}$ = 25185 hours

Mission Time = 15330 hours

$= \frac{1}{((\text{MTBF})^2)/\text{MissionTime})}$

$= \frac{1}{((25185)^2)/15330)}$ = 2.42E-05 Failures/ hour

Failure rate of one condenser fan branch =

$\lambda_{\text{Condenser fan circuit breaker}} + \lambda_{\text{Condenser fan contactor}} + \lambda_{\text{Condenser fan}}$

= 8.50E-07 + 2.13E-07 + 1.20E-05

= 1.30E-05 Failures/ hour

Failure rate of one complete cooling circuits =

Failure rate of two parallel cooling branch + Failure rate of one condenser fan branch

= 2.42E-05 + 1.30E-05

= 3.72E-05 Failures/ hour

Failure rate of all 4 cooling circuits (Parallel)= $\frac{1}{((\text{MTBF})^2)/\text{MissionTime})}$

$\text{MTBF}_{\text{One complete cooling circuit along with condenser fan}}$ = 26885 hours

Mission Time = 15330 hours

$$\frac{1}{((26885)^2)/15330)}$$

Failure rate of all 4 cooling circuits = **2.12E-05** Failures/hour

Failure rate of one supply fan branch (all in series)

$= \lambda_{\text{Supply fan circuit breaker}} + \lambda_{\text{Supply fan contactor}} + \lambda_{\text{Supply fan}}$

= 8.50E-07 + 2.13E-07 + 1.20E-05

= 1.30E-05 Failures/ Hour

Failure rate of two supply fan branches (Parallel) = $\frac{1}{((\text{MTBF})^2)/\text{MissionTime})}$

MTBF $_{\text{one supply fan branch}}$ = 76764

$$\frac{1}{((76764)^2)/15330)}$$

Failure rate of two supply fan branches = 2.60E-06 Failures/ hour

Total failure rate HVAC level (Series) = Failure rate of electrical components + Failure rate of sensors + Failure rate of all cooling circuits + Failure rate of two supply fan branches

= 1.91E-07 + 2.00E-07+ 2.12E-05+ 2.60E-06

= **2.42.E-05 Failure/Hour**

Total failure rate FPMH HVAC level (/Million hour) = Total failure rate HVAC level * 10^6

= 24.20

Total failure rate FPMK HVAC level (/Million km) = $\frac{\text{Total failure rate FPMH HVAC level}}{\textit{Average speed}}$

$= \frac{24.20}{46.14}$

= 0.52

Total failure rate FPMK Train level (/Million km) = Total failure rate FPMK HVAC level * No. Of HVAC per train

= 0.52* 12

= **6.29**

Relevant Failure - Reliability Calculation for Heating function							
S.no.	**Item Description**	**Quantity per HVAC**	**MTBF (hours)**	**Failure rate (hour-1)**	**Duty cycle**	**Component MTBF with duty cycle**	**Total failure rate on HVAC level with duty cycle**
1	Connector 2	1	280614108	3.56E-09	1	280614108	3.56E-09
2	DC-DC convertor	2	498845016	2.00E-09	1	498845016	2.00E-09
3	Rotary switch	1	12165450	8.22E-08	1	12165450	8.22E-08
4	Controller	1	9999999	1.00E-07	1	9999999	1.00E-07
5	Connector 1	1	280614108	3.56E-09	1	280614108	3.56E-09
Failure rate of electrical components							**1.91E-07**
6	Temperature probe 1	1	276816	3.61E-06	1	276816	3.61E-06
7	Temperature probe 2	1	276816	3.61E-06	1	276816	3.61E-06
Failure rate of sensors							**2.00E-07**
8	Heater circuit breaker	2	1176470	8.50E-07	1	1176470	8.50E-07
9	Heater contactor	2	4697065	2.13E-07	1	4697065	2.13E-07
10	Bimetal thermostat	4	15151823	6.60E-08	1	15151823	1.32E-07
11	Thermal overheat fuse	2	15151823	6.60E-08	1	15151823	6.60E-08
12	Heater	2	12165450	8.22E-08	1	12165450	8.22E-08
Failure rate of SF2 category components							1.34E-06
MTBF of one heating branch							744549
Failure rate of two heating branches							**2.77E-08**
13	Supply fan circuit breaker	2	1176470	8.50E-07	1	1176470	8.50E-07
14	Supply fan contactor	2	1176470	8.50E-07	1	1176470	8.50E-07
15	Supply fan	2	83584	1.20E-05	1	83584	1.20E-05
Failure rate of one supply fan branch							1.37E-05
MTBF of one supply fan branch							73185
Failure rate of two supply fan branches							**2.86E-06**
Total failure rate HVAC level (/hour)							**3.28.E-06**
Total failure rate FPMH HVAC level (/Million hour)							3.28
Total failure rate FPMK HVAC level (/Million km)							0.07
Total failure rate FPMK Train level (/Million km)							**0.85**

Relevant Failure - Reliability Calculation for Ventilation function							
S.no.	**Item Description**	**Quantity per HVAC**	**MTBF (hours)**	**Failure rate (hour-1)**	**Duty cycle**	**Component MTBF with duty cycle**	**Total failure rate on HVAC level with duty cycle**
1	Connector 2	1	280614108	3.56E-09	1	280614108	3.56E-09
2	DC-DC converter	2	498845016	2.00E-09	1	498845016	2.00E-09
3	Rotary switch	1	12165450	8.22E-08	1	12165450	8.22E-08
4	Controller	1	9999999	1.00E-07	1	9999999	1.00E-07
5	Connector 1	1	280614108	3.56E-09	1	280614108	3.56E-09
Failure rate of electrical components							**1.91E-07**
6	Temperature probe 1	1	276816	3.61E-06	1	276816	3.61E-06
7	Temperature probe 2	1	276816	3.61E-06	1	276816	3.61E-06
Failure rate of sensors							**2.00E-07**
8	Supply fan circuit breaker	2	280614108	3.56E-09	1	280614108	3.56E-09
9	Supply fan contactor	2	280614108	3.56E-09	1	280614108	3.56E-09
10	Supply fan	2	83584	1.20E-05	1	83584	1.20E-05
Failure rate of one supply fan branch							1.20E-05
MTBF of one supply fan branch							83534
Failure rate of two supply fan branches							**2.20E-06**
Total failure rate HVAC level (/hour)							**2.59.E-06**
Total failure rate FPMH HVAC level (/Million hour)							2.59
Total failure rate FPMK HVAC level (/Million km)							0.06
Total failure rate FPMK Train level (/Million km)							**0.67**

Service Failure - Reliability Calculation for Heating							
S.no.	**Item Description**	**Quantity per HVAC**	**MTBF (hours)**	**Failure rate (hour-1)**	**Duty cycle**	**Component MTBF with duty cycle**	**Total failure rate (HVAC level) with duty cycle**

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1	Thermal Overheat fuse	2	15151823	6.60E-08	0.5	30303646	3.30E-08
	MTBF Fuse						3.03E+07
	Parallel FAILURE RATE Fuse						2.29E-14
2	Supply fan circuit breaker	2	1176470	8.50E-07	1	1176470	8.50E-07
3	Supply fan contactor	2	4697065	2.13E-07	1	4697065	2.13E-07
4	Supply fan	2	83584	1.20E-05	1	83584	1.20E-05
	Failure Rate Series						1.30E-05
	MTBF						7.68E+04
	Parallel FAILURE RATE Of supply fan						2.60E-06
Failure rate of SF2 category components							**2.60E-06**
Total failure rate FPMH HVAC level (/Million hour)							2.60E+00
Total failure rate FPMK HVAC level (/Million km)							0.0564
Total failure rate FPMK Train level (/Million km)							**0.677**

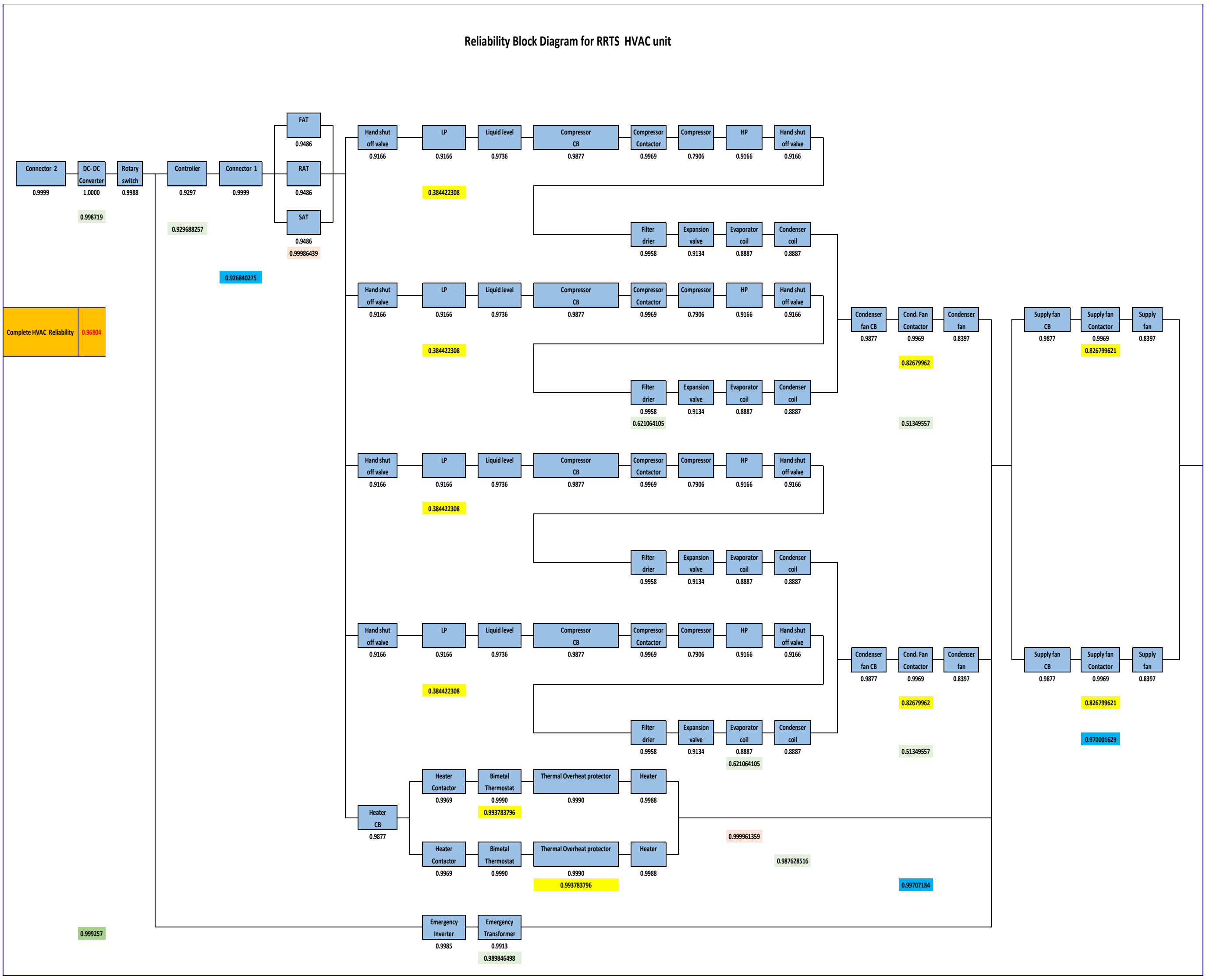
Service Failure - Reliability Calculation for Emergency Ventilation function							
S.no.	**Item Description**	**Quantity per HVAC**	**MTBF (hours)**	**Failure rate (hour-1)**	**Duty cycle**	**Component MTBF with duty cycle**	**Total failure rate on HVAC level with duty cycle**
1	Connector 2	1	280614108	3.56361E-09	1	280614108	3.56E-09
2	DC-DC converter	2	498845016	2.00463E-09	1	498845016	2.00E-09
3	Rotary switch	1	12165450	8.22E-08	1	12165450	8.22E-08
4	Emergency Inverter	1	9999999	1.00E-07	1	9999999	1.00E-07
5	Emergency Transformer	1	1669449	5.99E-07	1	1669449	5.99E-07
Failure rate of electrical components							**7.87E-07**
6	Supply fan circuit breaker	2	1176470	8.5E-07	1	1176470	8.50E-07
7	Supply fan contactor	2	4697065	2.12899E-07	1	4697065	2.13E-07
8	Supply fan	2	83584	1.1964E-05	1	83584	1.20E-05
Failure rate of one supply fan branch							1.30E-05
MTBF of one supply fan branch							76764
Failure rate of two supply fan branches							**2.60E-06**
Total failure rate HVAC level (/hour)							**3.39.E-06**
Total failure rate FPMH HVAC level (/Million hour)							3.39
Total failure rate FPMK HVAC level (/Million km)							0.07
Total failure rate FPMK Train level (/Million km)							**0.88**

Reliability Calculation category wise		
S.no.	**Item Description**	**Total failure rate (Train level) FPMK**
1	Relevant Failure Cooling function	6.294
2	Relevant Failure Heating function	0.853
3	Relevant Failure Ventilation	0.673
4	Service Failure Emergency Ventilation	0.881
5	Service Failure Heating	0.677

3.2 Reliability Block Diagram

Item Description	Per HVAC	MTBF	Life of item in years	Hour Per year	Mission Time (Hours)	Reliability	Reliability %
HVAC	1						96.804%
Condenser Coil	2	123791	2	7300	14600	0.889	88.875
Compressor	4	62152	2	7300	14600	0.791	79.064
Liquid level indicator	4	545791	2	7300	14600	0.974	97.360
Condenser Fan Assembly	2	83584	2	7300	14600	0.840	83.973
HP Switch	4	167752	2	7300	14600	0.917	91.665
LP Switch	4	167752	2	7300	14600	0.917	91.665
Liquid line solenoid valve	4	167752	2	7300	14600	0.917	91.665
Solenoid Valve Coil	4	1438021	2	7300	14600	0.990	98.990
Hand shut-off valves	8	167752	2	7300	14600	0.917	91.665
Filter Drier	4	3448275	2	7300	14600	0.996	99.577
Supply air Fan Assembly	2	83584	2	7300	14600	0.840	83.973
Evaporator Coil	1	123791	2	7300	14600	0.889	88.875
TX Valve	4	161168	2	7300	14600	0.913	91.339
Heater Assembly	1	12165450	2	7300	14600	0.999	99.880

Fresh air damper	2	99006	2	7300	14600	0.863	86.289
Emergency Inverter	1	9999999	2	7300	14600	0.999	99.854
Emergency Transformer	1	1669449	2	7300	14600	0.991	99.129
Temperature probe 1	1	276816	2	7300	14600	0.949	94.862
Temperature probe 2	1	276816	2	7300	14600	0.949	94.862
Temperature probe 3	1	276816	2	7300	14600	0.949	94.862
Humidity sensor	1	276816	2	7300	14600	0.949	94.862
Connector 1	1	280614108	2	7300	14600	1.000	99.995
Connector 2	1	280614108	2	7300	14600	1.000	99.995
Compressor contactor	4	4697065	2	7300	14600	0.997	99.690
Supply Fan Contactor	2	4697065	2	7300	14600	0.997	99.690
Condenser Fan Contactor	2	4697065	2	7300	14600	0.997	99.690
Heater contactor	2	4697065	2	7300	14600	0.997	99.690
Circuit breakers Compressor	4	1176470	2	7300	14600	0.988	98.767
Circuit breaker Supply Fan	2	1176470	2	7300	14600	0.988	98.767
Circuit Breaker Condenser fan	2	1176470	2	7300	14600	0.988	98.767
Circuit Breaker heater	2	1176470	2	7300	14600	0.988	98.767
Rotary switch	1	12165450	2	7300	14600	0.999	99.880
Controller	1	200401	2	7300	14600	0.930	92.974
Relay	25	9999999	2	7300	14600	0.999	99.854
DC-DC Converter	2	498845016	2	7300	14600	1.000	99.997
Thermal Overheat protector	1	15151823	2	7300	14600	0.999	99.904
Bimetal thermostat	1	15151823	2	7300	14600	0.999	99.904



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3.3 Availability

3.3.1 MTTR (Mean Time to repair) of complete HVAC

S.no.	Item Description	Qty per system, Qi	Individual Failure Rate, λ_i [FPMH]	Average Time to Perform Corrective Maintenance Tasks, $MTTR_i$							$MTTR_i$ (h)	$Q_i \times \lambda_i$	$Q_i \times \lambda_i \times MTTR_i$
				Localization	Isolation	Disassembly	Interchange	Reassemble	Alignment	Checkout			
1	Condenser Coil	2	8.078	0.16	0.16	0.25	0.25	0.93	0.25	6	8.00	16.16	1.29E+02
2	Compressor	4	16.090	0.16	0.16	0.25	0.25	0.93	0.25	6	8.00	64.36	5.15E+02
3	Sight glass	4	1.8322	0.0833	0.083	0.25	0.25	0.93	0.25	6	6.00	7.33	4.40E+01
4	Condenser Fan Assembly	2	11.964	0.0833	0.083	0.06	0.06	0.06	0.06	0.06	0.5	23.92	11.96
5	HP Switch	4	5.96118	0.0833	0.083	0.06	0.06	0.06	0.06	0.06	0.5	23.84	11.92
6	LP Switch	4	5.96118	0.0833	0.083	0.06	0.06	0.06	0.06	0.06	0.5	23.84	11.92
7	Liquid line solenoid valve	4	5.961	0.0833	0.083	0.25	0.25	0.93	0.25	6	6	23.84	143.07
8	Solenoid Valve Coil	4	0.695	0.0833	0.083	0.016	0.017	0.017	0.017	0.017	0.25	2.78	0.695
9	Hand shut-off valves	8	5.96118	0.0833	0.083	0.25	0.25	0.93	0.25	6	6	47.69	286.14
10	Filter Drier	4	0.29	0.0833	0.083	0.166	0.167	0.167	0.167	0.167	1	1.160	1.160
11	Supply air Fan Assembly	2	11.964	0.0833	0.083	0.066	0.067	0.067	0.067	0.067	0.5	23.93	11.96
12	Evaporator Coil	1	8.078	0.16	0.16	0.25	0.25	0.93	0.25	6	8	8.078	64.63
13	TX Valve	4	6.205	0.0833	0.083	0.25	0.25	0.93	0.25	6	6	24.82	148.912
14	Heater Assembly	1	0.082	0.0833	0.083	0.06	0.06	0.06	0.06	0.06	0.5	0.0822	0.0411
15	Thermal overload fuse	1	0.066	0.0833	0.083	0.02	0.02	0.02	0.02	0.02	0.25	0.066	0.01649
16	Thermal fuse	1	0.066	0.0833	0.083	0.01	0.01	0.01	0.01	0.01	0.1	0.066	0.00659
17	Bimetal thermostat	3	0.066	0.0833	0.083	0.01	0.01	0.01	0.01	0.01	0.1	0.198	0.01979
18	Fresh air damper	2	10.1004	0.0833	0.083	0.37	0.37	0.37	0.37	0.37	2	20.20	40.402
19	Emergency Inverter	1	0.1	0.16	0.16	0.04	0.04	0.04	0.04	0.04	0.5	0.1	0.0500
20	Emergency Transformer	1	0.599	0.16	0.16	0.04	0.04	0.04	0.04	0.04	0.5	0.599	0.2995
21	Temperature probe 1	1	3.613	0.0833	0.083	0.02	0.02	0.02	0.02	0.02	0.25	3.613	0.903
22	Temperature probe 2	1	3.613	0.0833	0.083	0.17	0.17	0.17	0.17	0.17	1	3.612	3.613
23	Temperature probe 3	1	3.613	0.0833	0.083	0.0167	0.017	0.017	0.017	0.017	0.25	3.612	0.9031
24	Humidity sensor	1	3.613	0.0833	0.083	0.0167	0.017	0.017	0.017	0.017	0.25	3.612	0.90312
25	Connector 1	1	0.00356	0.0833	0.083	0.0667	0.067	0.067	0.067	0.067	0.5	0.003	0.00178
26	Connector 2	1	0.00356	0.0833	0.083	0.1667	0.167	0.167	0.167	0.167	1	0.003	0.0035
27	Compressor contactor	4	0.2129	0.0833	0.083	0.0167	0.017	0.017	0.017	0.017	0.25	0.851	0.2128
28	Supply Fan, Condenser Fan & Heater contactor	6	0.2129	0.0833	0.083	0.0167	0.017	0.017	0.017	0.017	0.25	1.277	0.31934
29	Circuit breakers (all type)	10	0.850	0.0833	0.083	0.0167	0.017	0.017	0.017	0.017	0.25	8.500	2.125001
30	Rotary switch	1	0.0822	0.0833	0.083	0.0167	0.017	0.017	0.017	0.017	0.25	0.082	0.02055
31	Controller	1	0.1	0.05	0.05	0.08	0.08	0.08	0.08	0.08	0.5	0.1	0.050000
32	Relay	25	0.1	0.0833	0.083	0.0667	0.067	0.067	0.067	0.067	0.5	2.500	1.250000
33	DC-DC Converter	2	0.002	0.0833	0.083	0.0167	0.017	0.017	0.017	0.017	0.25	0.004	0.001002

$\sum_{i=1}^{n}(\boldsymbol{\lambda i} * \mathbf{Qi} * \mathbf{MTTRi}) = 1.43E+03$

$\sum_{i=1}^{n}(\boldsymbol{\lambda i} * \mathbf{Qi}) = 3.41E+02$

$\text{MTTR} = \frac{\sum_{i=1}^{n}(\lambda i * Qi * MTTRi)}{\sum_{i=1}^{n}(\lambda i * Qi)} = \frac{1.43E+03}{3.41E+02}$

MTTR of Complete HVAC = 4.20E+00 hours

3.3.2 MTBF (Mean Time between Failures) of complete HVAC

Reliability for 2 years of mission time = 96.80398%

Mission Time (hours) = 2 years = 2* 7665

=15330 hours

R (t) = $\int_{t}^{\infty} f(t)dt$ = $e^{-\lambda * t}$

After applying above equation Failure rate (λ) of complete HVAC = 2.121E-06

MTBF = 1/ Failure rate (λ) =471475

3.3.3 Availability of Complete HVAC –

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

$$= \frac{471475}{471475 + 4.20}$$
$$= 0.99999109$$

Availability of complete HVAC = 99.999109%

3.4 Maintainability

Repair rate = $\mu = \frac{1}{MTTR} = \frac{1}{4.20}$
= 0.23809

t = allowable down time
= 2 hours

$$\text{Maintainability} = M(t) = \int_0^t \mu * e^{-\mu * t}\, dt = 1 - e^{-\mu * t}$$
$$= 0.3788$$

Maintainability of complete HVAC = 37.88 %

3.5 Safety

Hazard Rate h (t) = $\frac{F(t)}{R(t)}$

F (t) = 1- R (t)
= 1 – 0.96
= 0.04

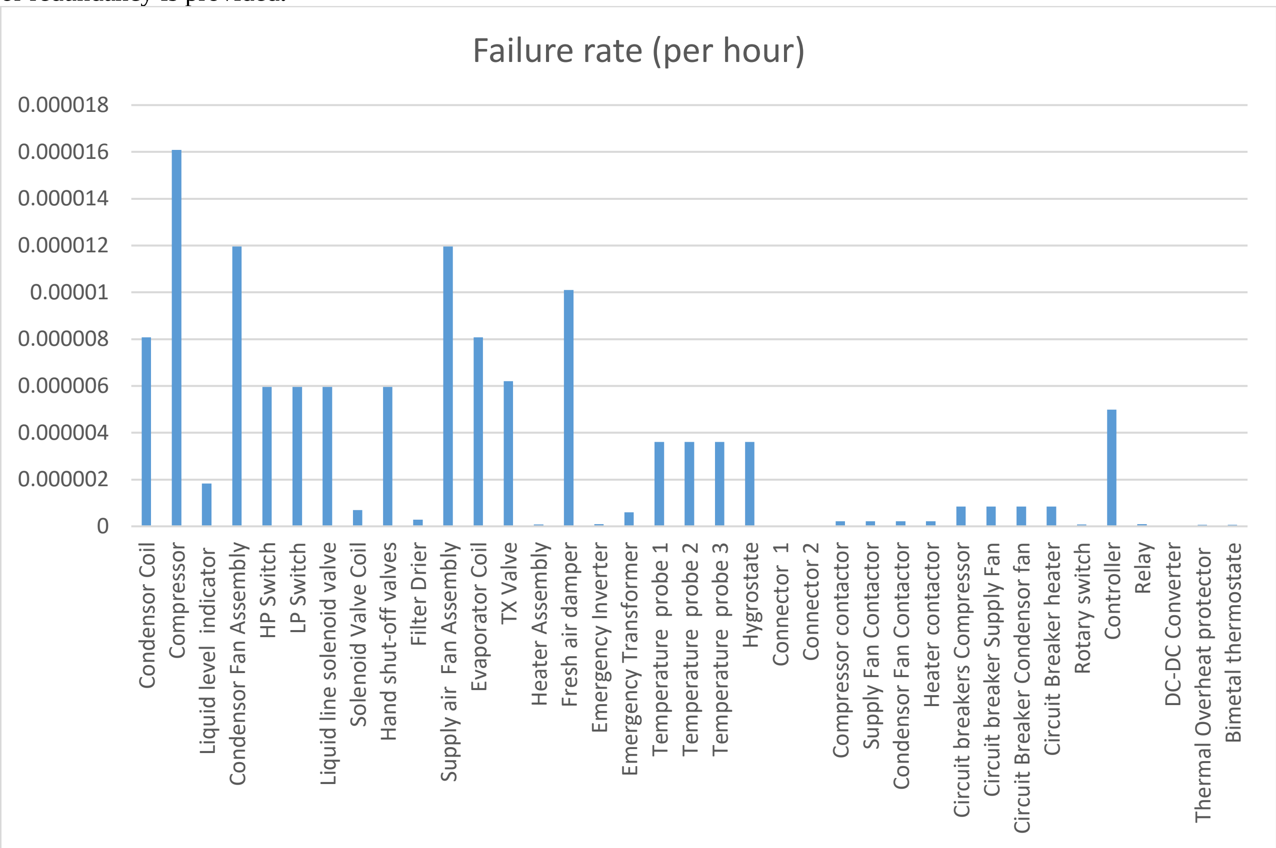
R (t) = 0.96

h (t) = $\frac{0.04}{0.96}$ = 0.04166

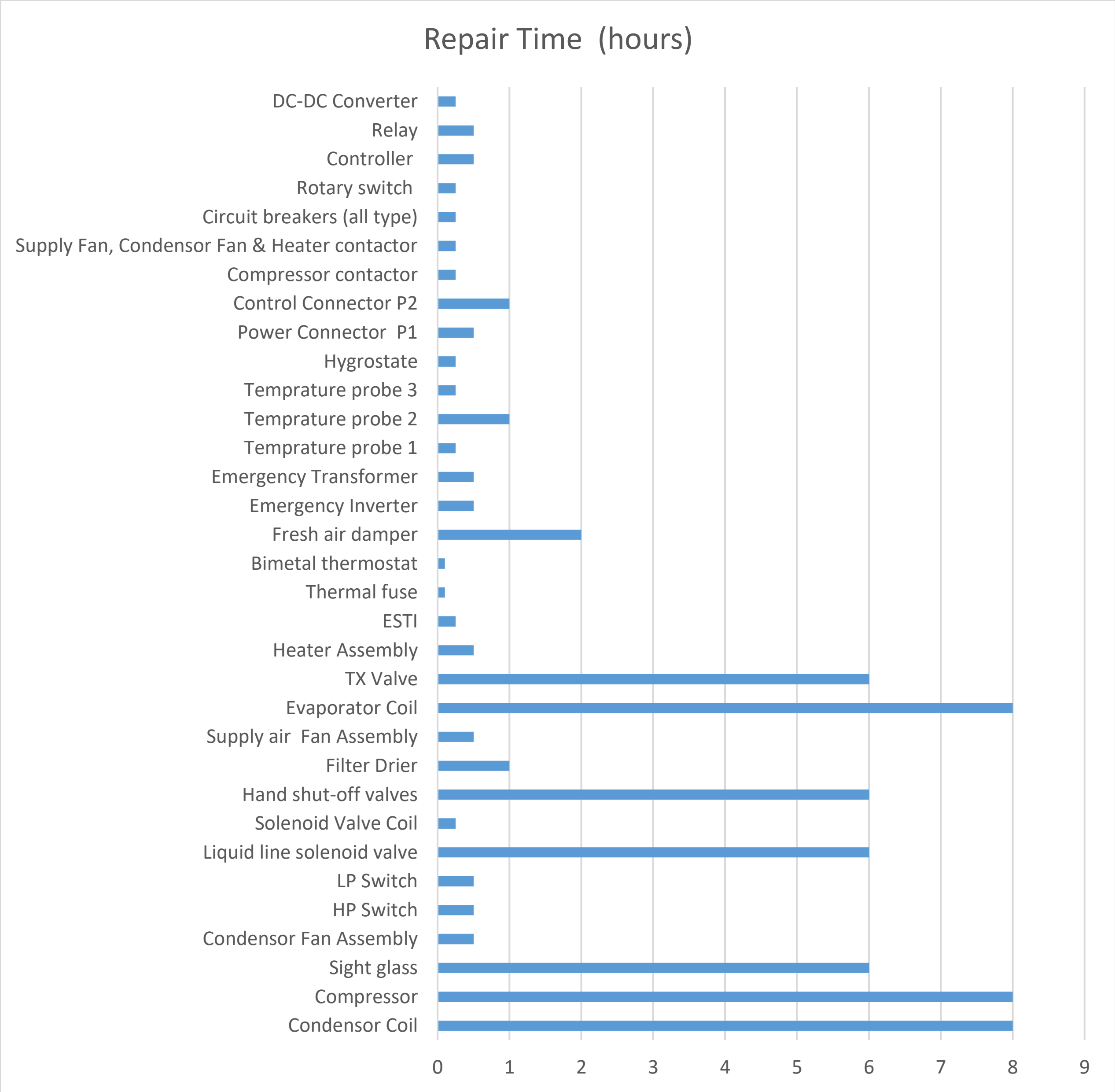
Hazard Rate of complete HVAC = 4.166%

4 RESULTS

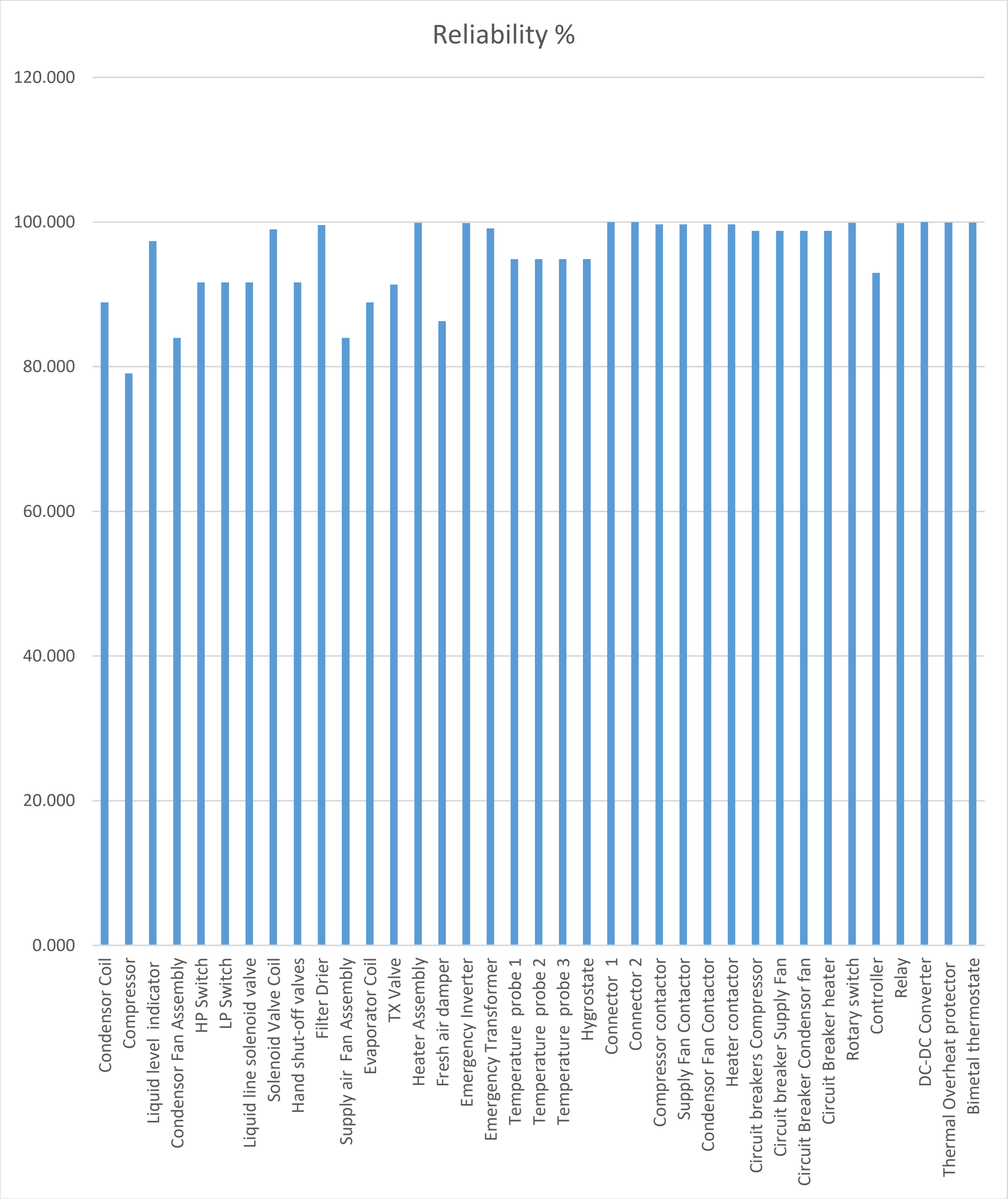
Failure Rate of individual components so that main culprits of failure can be find out and either the components are to be changed or redundancy is provided**.**



Repair of individual components so that main culprits of loss in availability can be find out and either the components are to be changed or redundancy is provided**.**



Reliability of individual components so that main culprits of reliability can be find out and either the components are to be changed or redundancy is provided**.**



Data	Results
Reliability of complete HVAC with 4 Circuits (2 years of mission time)	96.804%
MTTR of complete HVAC with 4 Circuits (2 years of mission time)	4.20E+00 hours
Availability of complete HVAC with 4 Circuits (2 years of mission time)	99.99911%
Maintainability of complete HVAC with 4 Circuits (2 years of mission time)	37.88 %
Safety/ Hazard rate of complete HVAC with 4 Circuits (2 years of mission time)	4.166%

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5 CONCLUSION

This research was accomplished in assistance with mentor in RAMS & service of HVAC with an approach of quality & reliability enhancement at the system level by taking in consideration of service failure & relevant failures.

The research work was carried out to find the reliability at system level by using the sub system level approach. To enhance the reliability of the system we provided redundancy at the subsystem level by analyzing the failure rate (taken from respective standards) of reliability critical sub system along with mission time.

On the basis of reliability & time to restore the system to perform its intended function, we calculated the availability of the system at train level.

Maintainability analysis of the system is carried out by taking in consideration of the repair rate and allowable down time at train level.

For safety analysis, we have taken the HVAC failure which leads to fire, HVAC explosion, toxic refrigerant leak, electrocution. We have calculated the Hazard rate by taking inputs from probability density function and reliability function.

The key objective of the research was to study how the redundancy provided at sub system level will enhance the system level reliability.

The key objective of this research was the calculation of the availability of HVAC at train level. The benchmark value of availability for HVAC in rolling stock is approx. greater than 95% during normal operation as by the calculation of 4 circuit, we get the value of 99.99 %. This shows the series parallel combination of sub system is perfect as per requirement of rolling stock.

6 ABBREVIATIONS

RAMS – Reliability, availability, maintainability & safety
HVAC – Heating ventilation air conditioners
MTBF - Mean time between failure
MDBF – Mean distance between failure
FPMH - Failure per million hour
FPMK - Failure per million kilometers
MTTR – Mean time to repair
LCC – Life cycle cost

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