# “*RAMS high performance achievement starts from concept phase*”.


To achieve the RAMS high performance requirement, that are verified and validated by implementing all RAMS methods throughout the asset life cycle, it’ s necessary to implement the RAMS program in different Railway O&M, Designer and contractor considering all organizations levels.

The Railway Organizations (O&M, Designer and Vendors) need to demonstrate how to implementation of RAMS Program that encompasses the success factors such as:

- RAMS culture;
- RAMS leadership;
- RAMS organizational structure;
- RAMS resources;
- RAMS management process.

The effectiveness of the RAMS Management process depends on the effectiveness of the other RAMS program success factor listed above. The

RAMS Management Process encompasses basically the steps such as RAMS planning, RAMS implementation, RAMS control and RAMS improvement applied to RAMS activities. This PDCA process is implemented throughout the Railway Asset life cycle phase is far more complex and need RAMS guidelines and procedures to support the implementation.

The Railway Organizations (O&M, Designer and Vendors) need to demonstrate that, their RAMS Process based on RAMS guidelines such as RAMS Concept, RAMS System Definition, RAMS requirement definition and apportion, RAM Plan and Safety plan.

The Railway Organizations Designer, and Suppliers need also to demonstrate how they will achieve the RAMS qualitative and quantitative requirement based on RAMS methods, and the obligatoriness Directives, Regulations and Standards are the following:

- The Directives (EU) 2016/797 and Regulation (EU) 2013/402.
- The Standards EN50126-1, EN 50128 and EN 50129.

Indeed, the RAMS high performance is achieved since concept phase based on RAMS Implementation Through the entire lifecycle.

Despite of the very well organized and clear information in standard EN 50126, EN 50128 and EN 50129, the specific RAMS methods must be implemented such as such as ALT, HALT, RGA, LDA, DFMEA, PFMEA, RCM, OPT, FRACAS and Asset Management, are not described in detail in these standards.

In addition, there are many misunderstanding concerning RAMS concepts described in EN50126, EN 50128 and En 50129, which in some cases lead to a wrong interpretation or lack of knowledge about RAMS subjects.

Therefore, in order to have a more effective RAMS Implementation program result, and to demonstrate the qualitative and quantitative RAMS requirement achievement, the RAMS guideline and procedures considering all RAMS

Methods must be implemented. Therefore, RAMS Guidelines and RAMS methods procedures are essential in this process.

The RAMS guidelines implementation such as RAMS concept, RAMS System Definition, RAMS Requirement definition and allocation, RAM Plan and Safety Plan will enable the following:

- Clear understand about the RAMS concepts on different Railways Organisations (O&M, Designers, and Suppliers) in different organizational levels.
- Unification of understanding the RAMS concepts and methods and deliverables among the different Railway organization (O&M, Designers, and Suppliers).
- Effective quantitative methods step by step RAMS requirement implementation to support during BID process.
- Clear system definition considering Product Breakdown Structure, system functions and environmental conditions.
- Clear understanding of O&M, Suppliers, Designer responsibilities, and the RAMS Methods application for RAMS demonstration and deliverables.
- Reduced time on RAMS implementation.
- Safe time and money during lifecycle with RAMS implementation.

The RAMS Methods procedures such as RAM Management, Safety Risk Management, FMEA, RCM, LDA, RAM, PHA, FHA and Sil, FTA and ETA, FRACAS and HRA will enable the following:

- RAM Management process steps by step clearly defined for O&M, Suppliers and Designer.
- Safety Risk Management process steps by step clearly defined for O&M, Suppliers and Designer.
- Clear understand about the deliverable’ s templates, reports and methods.

- Unification of understanding the RAMS methods and deliverables among the different Railway organization such as O&M, Designers, Manufacturers and vendors.
- Effective quantitative methods step by step description to be applied in different phase, organization levels, and also different organization.
- Single and unique way to perform the analysis and avoid different methods, result.
- Reduced time for review RAMS methods analysis and reports.
- Safe time and money during lifecycle with RAMS implementation.

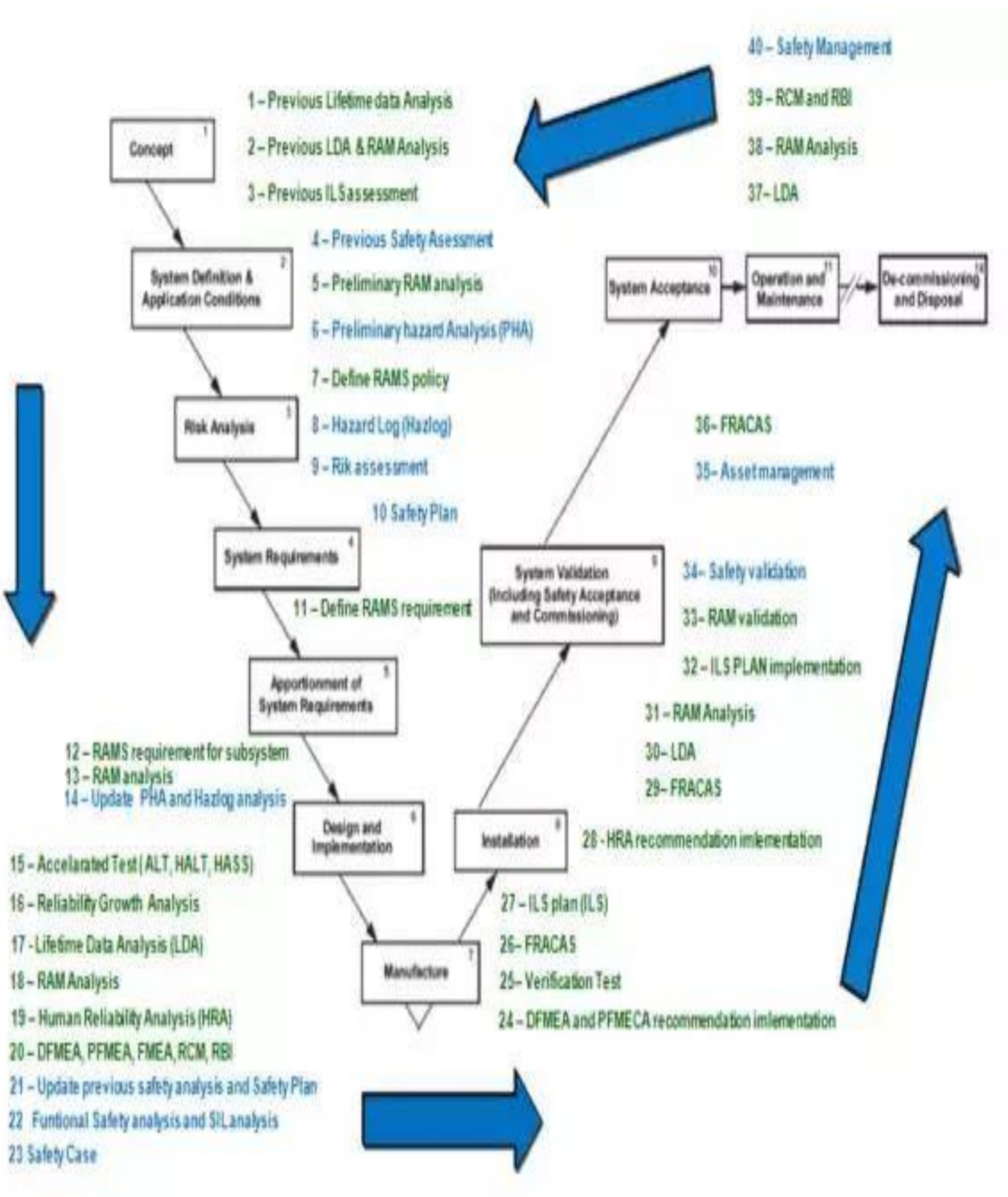



***Figure 1 – RAMS Implementation along Life cycle phase. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

The first phase in RAM & LCC process as described previously, is "**the Concept**" and it is necessarily having a previous RAMS assessment and data to provide a baseline to discuss the preliminary RAMS & LCC performance requirement, in other words, reliability, availability, maintainability and safety targets.

Concerning previous RAMS & LCC data, it´s important to take into account the new operational environment and application, which might lead to lower or higher RAMS performance indexes.

After the concept phase is the "**Preliminary RAMS & LCC phase**" , which system definition and risk analysis take places. In such phase, more details about the system is defined and the previous RAM and safety assessment are updated. In addition, based on such information it´s possible to define the RAMS policy, high level performance index, which depends on system preliminary configuration.

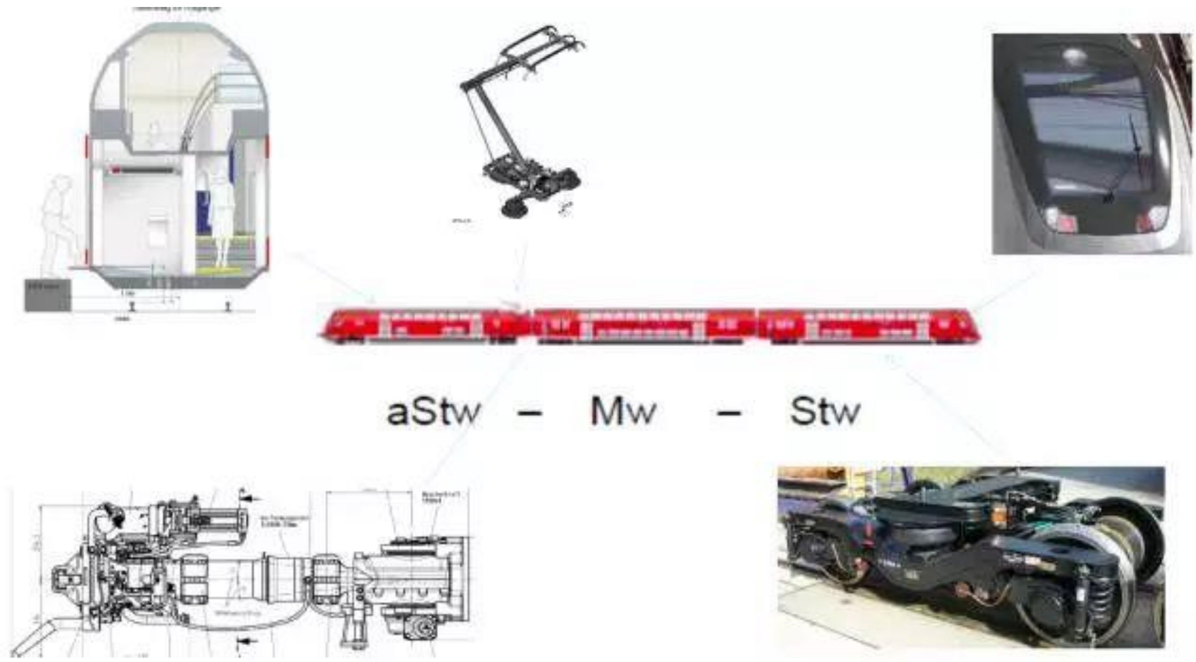



***Figure 2 – Railway Asset Configuration. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

During concept phase, it is important to have a RAMS concept procedure, that will be the guideline for all organization levels and departments involved directly or indirectly with RAMS performance achievement. By understanding the RAMS concept, the different CCEO, Directors and high level managers will understand the importance of the RAMS topic for the organization successful business and will support the RAMS implementation program. Concerning safety, after to get preliminary information about the system, the Preliminary hazard analysis, Hazard log and risk assessment take place. The preliminary hazard analysis encompasses the system hazards, cause and consequences.

In addition, the risk assessment for each hazard is carried out in order to evaluate the risk and propose mitigation when necessary based on risk acceptance criteria. The hazard log is the summarized PHA information which shows the hazards, the risk assessed and the risk mitigation. Based on risk mitigation recommendation the safety plan is defined concerning the actions, the responsibility and when each action must be implemented.

The next phase in RAMS & LCC process is "**System Requirement**" that is the result of preliminary LDA, RAM analysis, RCM, RBI and LCC assessment based on customer requirement. Based on such requirements, the equipment supplier will be selected to supply equipment to the whole system.

The safety requirement must also be established based on the Preliminary hazard analysis, Hazard Log and risk assessment. In this phase the risk criteria are verified and validate in the system level.

The next phase is "**Apportion of system requirement**" and in this phase is necessary to define the RAMS & LCC requirements in subsystem and equipment level. The similar analysis performed in the previous phase such as LDA, RAM analysis, RCM, and RBI are carried out concerning subsystem and equipment level based on updated preliminary information.

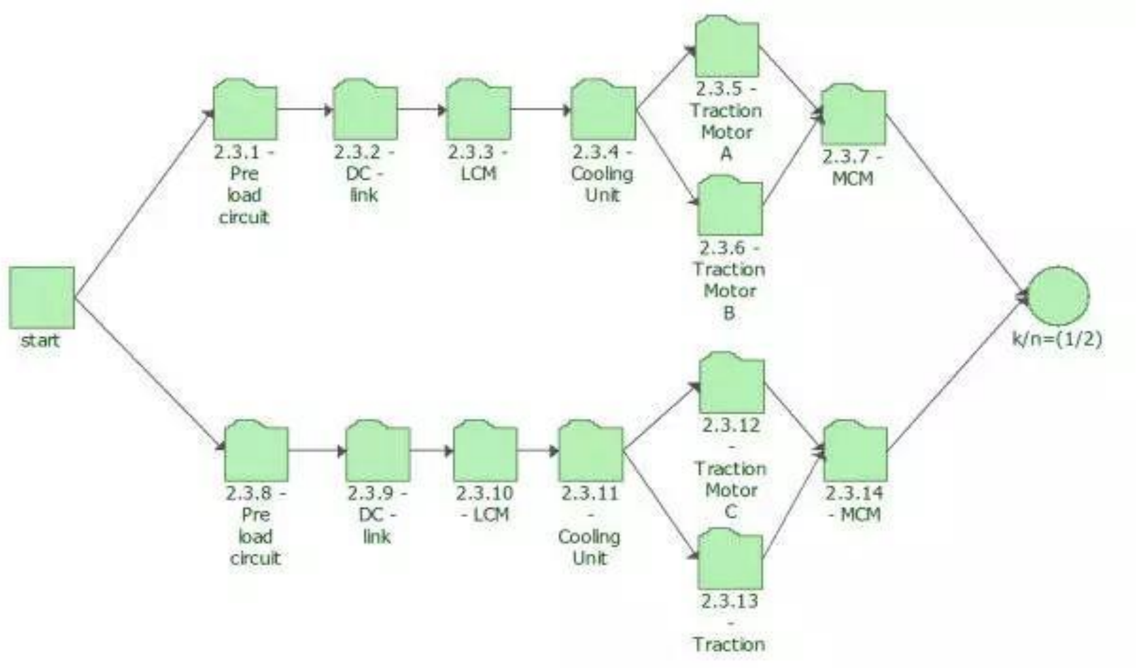
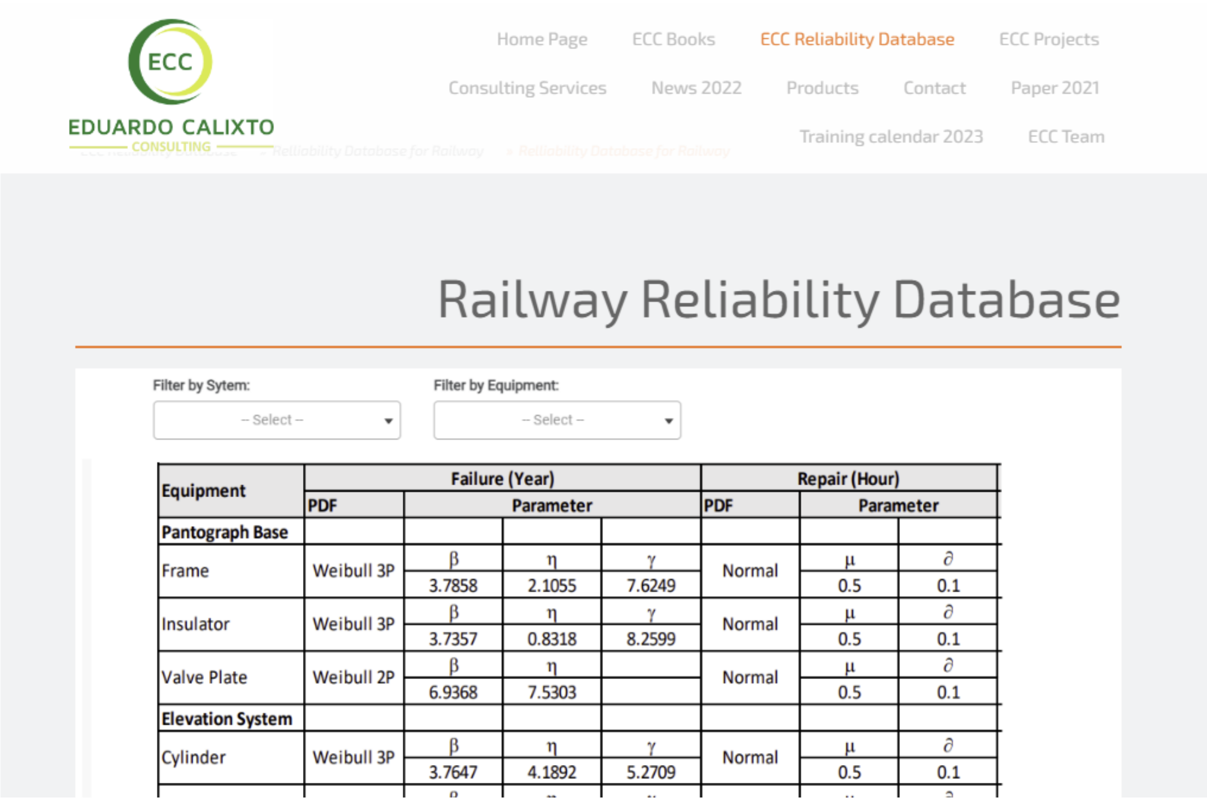



***Figure 3 – System RBD. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

After defining the RAMS requirements, the tender phase is carried out to enable the companies to choose the best vendors based on the information presented from different vendor. In other words, the railway companies will choose the vendors who have more chance to fulfil the RAMS requirements. The reliability and maintainability historical data about vendor´s asset performance is a key factor in this decision process.

In case of lack of reliability target, the reliability database can be used as reference to set up the RAMS requirement for suppliers.




| Equipment | Failure (Year) | | | | Repair (Hour) | | |
|---|---|---|---|---|---|---|---|
| | PDF | Parameter | | | PDF | Parameter | |
| **Pantograph Base** | | | | | | | |
| Frame | Weibull 3P | β | η | γ | Normal | μ | ∂ |
| | | 3.7858 | 2.1055 | 7.6249 | | 0.5 | 0.1 |
| Insulator | Weibull 3P | β | η | γ | Normal | μ | ∂ |
| | | 3.7357 | 0.8318 | 8.2599 | | 0.5 | 0.1 |
| Valve Plate | Weibull 2P | β | η | | Normal | μ | ∂ |
| | | 6.9368 | 7.5303 | | | 0.5 | 0.1 |
| **Elevation System** | | | | | | | |
| Cylinder | Weibull 3P | β | η | γ | Normal | μ | ∂ |
| | | 3.7647 | 4.1892 | 5.2709 | | 0.5 | 0.1 |

***Figure 4 – ECC Railway Reliability and Maintainability Database, https://www.eduardocalixto.com/ecc-reliability-database/relliability-database-for-railway-1/relliability-database-for-railway/.***

Once the RAMS target and requirement are properly set up, after the vendors (suppliers) selection, the next phase is the "**Design Phase**". Regarding that all previous phases were successful, the design is one of the most important phase, because all performance requirements are achieved or not depending on effectiveness achieved in such a phase.

During the design phase, reliability engineering, qualitative and quantitative methods must be applied. Concerning quantitative approaches, the Accelerated Life Test (ALT) in many cases, must be applied to predict and assure the equipment and component reliability, whenever it´s feasible. The ALT can be applied to predict in a short period of time the equipment and component reliability concerning the stress factors such as temperature, humidity, vibration, etc.

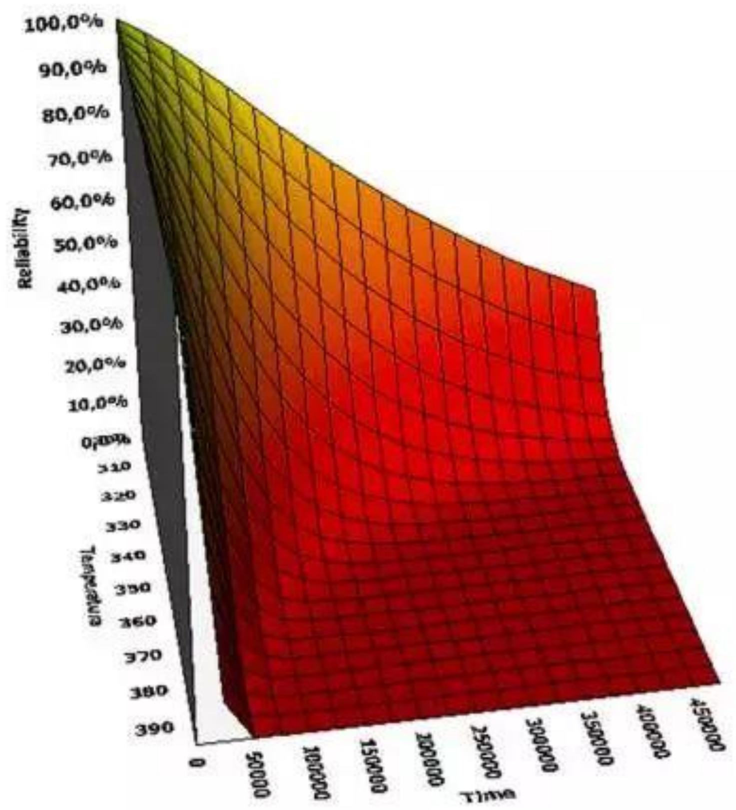



***Figure 5 – ALT reliability prediction. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

In this case, such stress factor is applied under much higher value than operational condition, which force the failure happen earlier.

Whenever the equipment and component achieves lower reliability performance than required, it´s necessary to apply the reliability growth analysis, which enables the increase of reliability based on design modification and improvement actions.

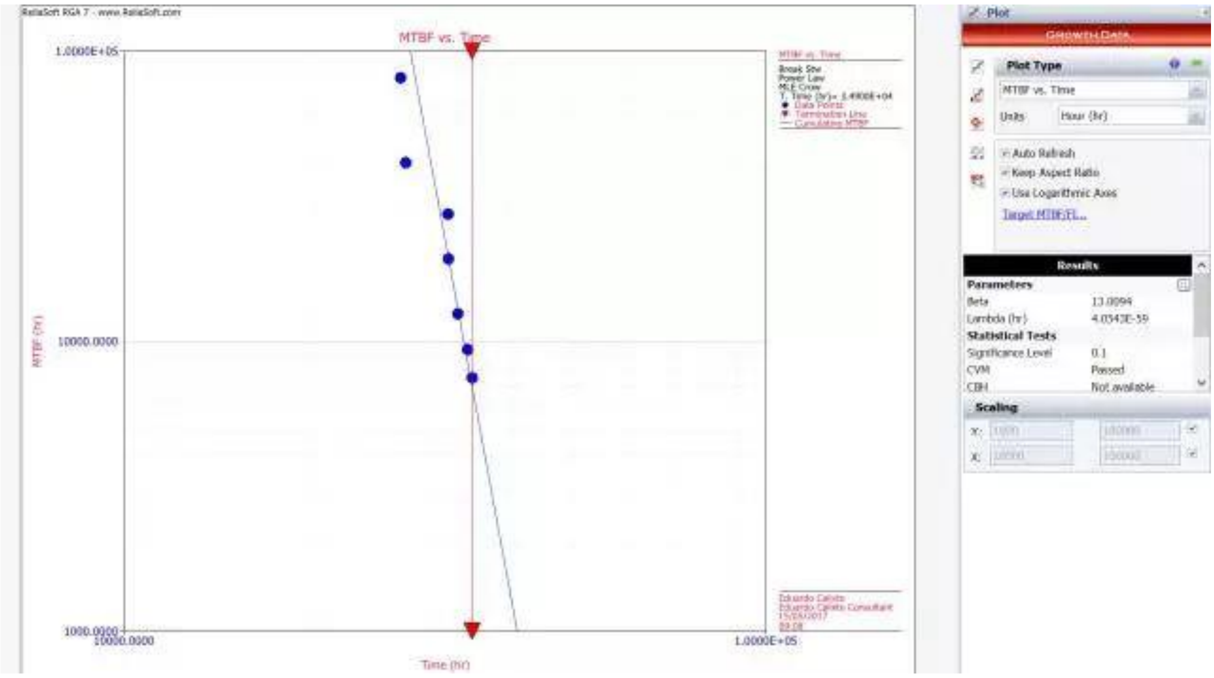



***Figure 6 – RGA reliability prediction. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

On contrary to what is understood in many cases in the railway industry, the reliability growth analysis must be carried out during the design phase and not during the early life phase. The early life failures must be eliminated during the design phase as much as possible, but even though in some cases, the manufacturing, transportation and installation may cause equipment and component degradation which will trigger early life failures.

In these cases, such effect can be eliminated by proper manufacturing, transportation and installation. Therefore, the item with early life failure will be replaced for another similar one which has no effect of wrong manufacturing, transportation or installation. In fact, this item has the same reliability´s performance as previous defined and there´s no reliability improvement. By the other hands, there will be cases that the root cause of early life failures is the poor design and it will be necessary reliability improvement. These are the cases that reliability growth is required, but it´s supposed to be done during the design phase and not during early life phases in order to avoid the increasing effect on LCC.

Additionally, the qualitative test such as HALT and HASS are applied to improve the product robustness and also to learn about the equipment failures under hard operational conditions. Such conditions are verified based on high stress factor levels during the test.

***Figure 7 – ALT, HALT and HASS reliability test. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

The additional qualitative reliability engineering methods applied during the design phase is the "DFMEA" which focus on failures caused during design such as bad material quality, bad design, bad configuration. Therefore, it is possible to drive improvement in design phase based on DFMEA recommendations. The DFMEA may also have the criticality index, which will enable to prioritize the most critical failures concerning criticality index.

The additional type of FMEA such as PFMEA (Process FMEA) and FMEA (During operational houses) is also carried out in order to mitigate the causes of failure mode during the manufacturing, the first case, and the operational phase of the second case.

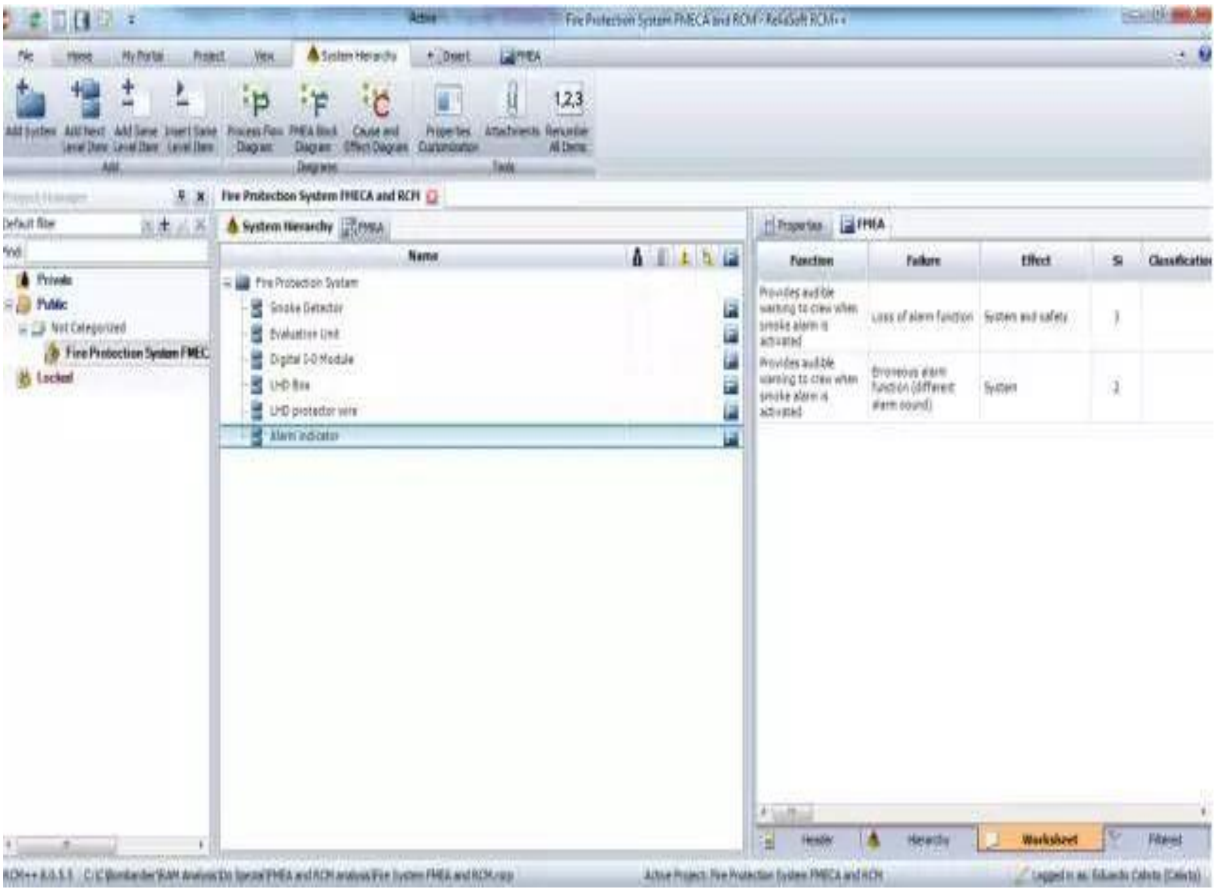



***Figure 8 – FMEA Software example. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

The FMEA process used to take a considerable time and investment to produce the FMEA analysis and report. In case of lack of knowledge on the system or to accelerate the process it is recommended to have access to a FMEA data base.

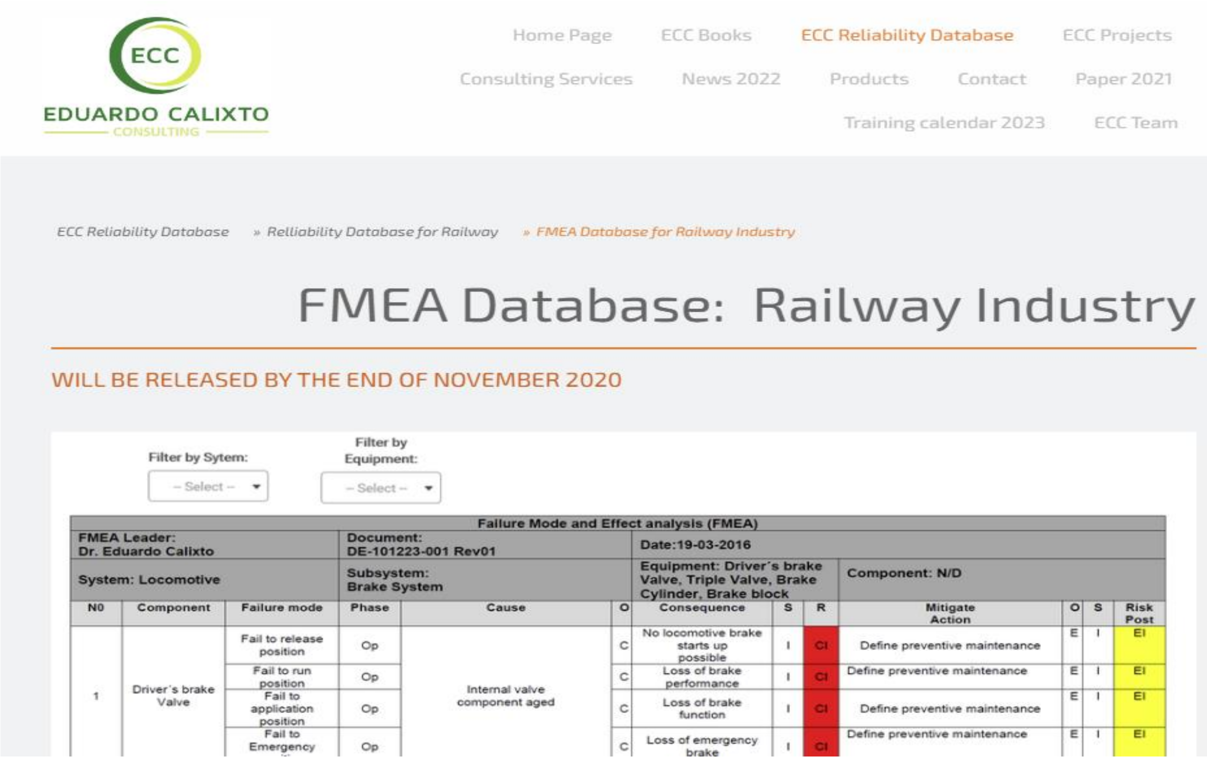



***Figure 9 – ECC Railway FMEA Database, https://www.eduardocalixto.com/ecc-reliability-database/relliability-database-for-railway-1/relliability-database-for-railway/.***

The FMEA concerning operational phase failures is the input for the RCM (Reliability centred Maintenance) and RBI (Risk based Inspection). The RCM procedure is an important procedure as part of RAMS Management program.

" ***I use to say that the best maintenance strategy is to have a reliable and robust product.*** "

Indeed, maintenance strategy and a clear definition of maintenance task shall be defined since design phase. Therefore, the RCM analysis, get the FMEA information input and during a workshop, the type of maintenance task, the frequency of such task take place is the main objective of RCM. The RCM is also the main input for the Maintenance manual and LCC.

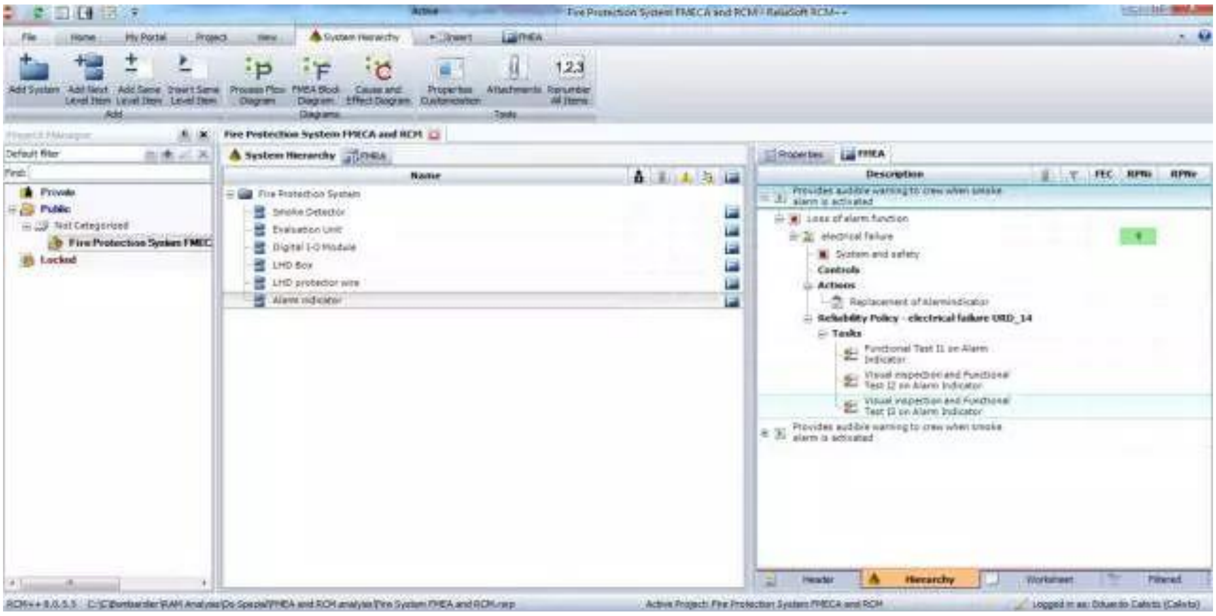


***Figure 10 – RCM Software example. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

The RCM analysis defines all preventive maintenance tasks based on equipment and component failure modes which include scheduled maintenance, predictive maintenance, online monitoring and corrective maintenance.

The RBI analysis includes all inspections concerning the risk of the equipment and component failures. Usually, the RCM are applied to rotating equipment and an RBI for static equipment and structures.

Additionally, the other quantitative methods to be applied during the design phase are the lifetime Data analysis and the RAM analysis.

In the first case, because the accelerated test is expensive and in many cases it´s not possible to reproduce operation conditions in laboratory, it´s necessary to carry out the lifetime data analysis, which is based on similar equipment and component failure historical data. The LDA enable to define the probability density functions (PDF), which better fit on historical failure and repair data. Therefore, such parameters will be input on RBD during RAM analysis. In addition, based on PDF parameters, it's possible to predict the reliability and failure rate index.


***Figure 11 – Reliability function CDF example. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

The RAM analysis is based on information defined on LDA, or even based on past experience or available database of similar equipment regarding operation and maintenance condition and additional constrain. Depends on available data, in some cases the RBD (reliability block diagram) will regard different levels such as equipment, component and subcomponent levels.

In order to carry out the RAM analysis, based on RBD model, it´s necessary to perform the Monte Carlo simulation by using commercial software. The Software enables to get a reliable result very fast compared to manual calculations. Additionally, the software considers all types of RBD configuration, such as parallel, k out of the N, stand by as well as the effect of preventive maintenance, inspection and logistics (spare parts, transportation and delays) on system performance prediction. Indeed, complex system configuration is hardly calculated properly during a feasible period of time when it´s manually calculated or by excel sheets. Therefore, many assumptions must to be considered which in the end, will not come out with a reliable result.

Despite of such limitation, in many cases, the system reliability prediction is based on simple calculation on excel sheet considering MTBF and MTTR for all equipment and components which will not produce a reliable prediction result. In fact, the additional problem is that the excel sheets are not able to model different RBD configuration, and consequently, its consider all equipment and components in the series, which gives a pessimist reliability and LCC prediction. In addition, the effect of inspection and preventive maintenance are not properly considered by excel sheet calculation.

| With Preventive Maintenance | |
|---|---|
| Mean Availability (All Events): | 0.9999 |
| Std Deviation (Mean Availability): | 0.00E+00 |
| Mean Availability (w/o PM, OC & Inspection): | 1 |
| Point Availability (All Events) at 14700: | 1 |
| Reliability(14700): | 1 |
| Expected Number of Failures: | 0 |
| Std Deviation (Number of Failures): | 0 |
| MTTFF (Hr): | 21207617 |
| System Uptime/Downtime | |
| Uptime (Hr): | 14698.15 |
| CM Downtime (Hr): | 0 |
| Inspection Downtime (Hr): | 0.649148 |
| PM Downtime (Hr): | 1.198096 |
| OC Downtime (Hr): | 0 |
| Total Downtime (Hr): | 1.847244 |
| System Downing Events | |
| Number of Failures: | 0 |
| Number of CMs: | 0 |
| Number of Inspections: | 16.269 |
| Number of PMs: | 11.653 |
| Number of OCs: | 0 |
| Number of OFF Events by Trigger: | 0 |
| Total Events: | 27.922 |
| Costs | |
| Total Costs: | 8419.44 |

| Without Preventive Maintenance | |
|---|---|
| Mean Availability (All Events): | 0.9974 |
| Std Deviation (Mean Availability): | 7.00E-06 |
| Mean Availability (w/o PM, OC & Inspection): | 0.997396 |
| Point Availability (All Events) at 14700: | 0.977 |
| Reliability(14700): | 0 |
| Expected Number of Failures: | 18.239 |
| Std Deviation (Number of Failures): | 0.046061 |
| MTTFF (Hr): | 1464.4 |
| System Uptime/Downtime | |
| Uptime (Hr): | 14661.72 |
| CM Downtime (Hr): | 38.28088 |
| Inspection Downtime (Hr): | 0 |
| PM Downtime (Hr): | 0 |
| OC Downtime (Hr): | 0 |
| Total Downtime (Hr): | 38.28088 |
| System Downing Events | |
| Number of Failures: | 18.239 |
| Number of CMs: | 18.239 |
| Number of Inspections: | 0 |
| Number of PMs: | 0 |
| Number of OCs: | 0 |
| Number of OFF Events by Trigger: | 0 |
| Total Events: | 18.239 |
| Costs | |
| Total Costs: | 3118.869 |

***Figure 12 – Sensitivity Analysis comparing PM and CM system Performance. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

The other important issue is the logistic factors that must be also considered by the Integrated Logistic Support program which starts in the design phase concerning spare parts, LCC, deliver time, and impact of such factors on system operational availability.

The ILS integrates all reliability engineering methods results to the operational phase and assure that the best practice and recommendation will be implemented during operational phase. In fact, the Integrated Logistic Support (ILS) plan must be defined before the operation phase in order to define not only the logistic issues such as spare parts but also the maintenance procedures as well as IT technology applied to maintenance, reliability and logistic.

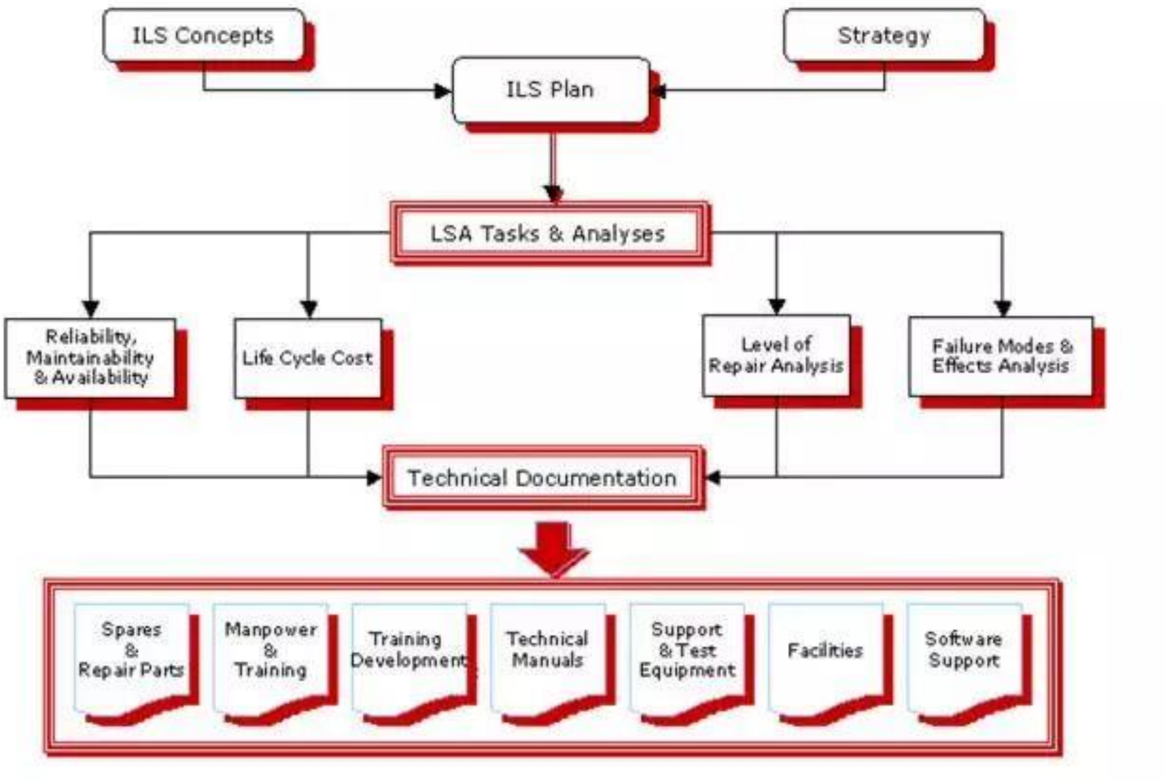



***Figure 13 – RAMS And ILS flow. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

The ILS encompasses all information from RAM carried out in the previous phase. In addition, based on ILS information, the RAM model must be updated. In fact, the ILS must be taken into account since the concept phase because the logistic issues may affect the RAMS & LCC performance.

The Human reliability analysis must be also be part of the design, which enables to anticipate probable human errors which affect the RAM and safety performance during operational phase. Many of such human errors can be defined during DFMEA, PFMEA and FMEA.

Additionally, the human performance factors, which affect such human error must be assessed based on human reliability analysis methods which also enable to predict the human error probability which affect RAMS asset performance.

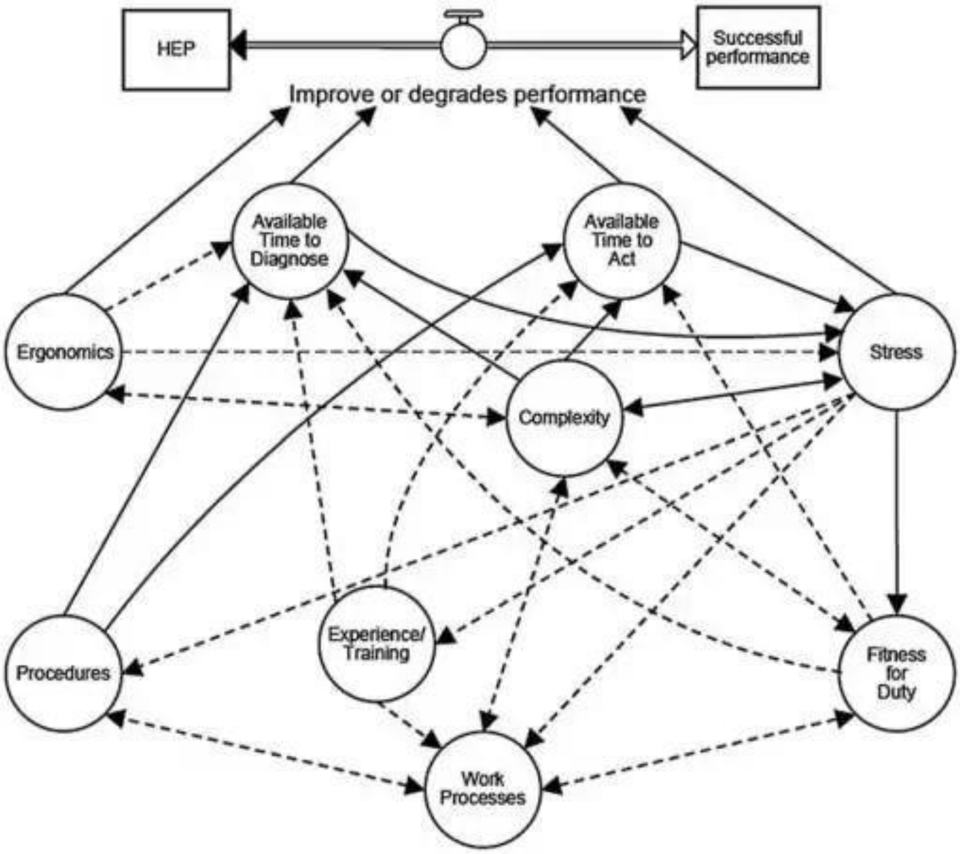



***Figure 14 – Human performance factors. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

Concerning the safety analysis, additionally to update the PHA and Hazard log it´s also necessary to carry out the functional hazard analysis and SIL assessment.

The Functional Hazard analysis concerns all system function which is related to some hazards which depends on the risk evaluated which must be mitigated. The functional analysis encompasses hardware and software.

In addition, the Safety integrity level (SIL) is related to the probability of failure on demand of some function related to safety which must be assessed based on SIL methodology and will be integrated to functional analysis.

In some cases, in order to clarify the top hazard events and verify the safe index achievement, the Fault tree analysis, which consider the combination of event which trigger the top event will be carried out.

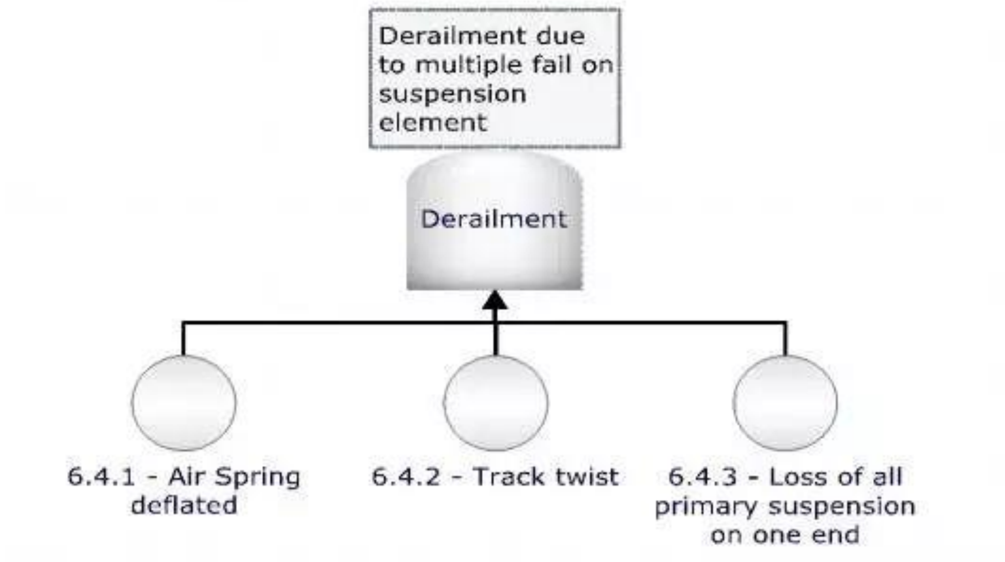



***Figure 15 – FTA example. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

The next phase is "**Manufacturing**" and it´s very important to take into account the production line (manufacturing) effects on equipment reliability. Thus, is also important to consider which are the best operation condition of equipment based on its characteristics in order to avoid bad effects on equipment reliability during operational phase. Such effect must be defined on PFMEA during the design phase which will provide a list of recommendations, which will be a checklist during this phase. Furthermore, the equipment and component must be tested after production or montage and if necessary the production as well as product must be modified.

The next phase is "**Installation**" and it is very important to take care of human error, previous defined during the design phase, when manufacturing, assembling and transporting systems, because human error may have a bad influence in systems reliability. After Installation, the "**Validation**" takes places and the main objective is validate the system requirement defined during the design phase for subsystem and component. Therefore, such validation is based on real data from the field.

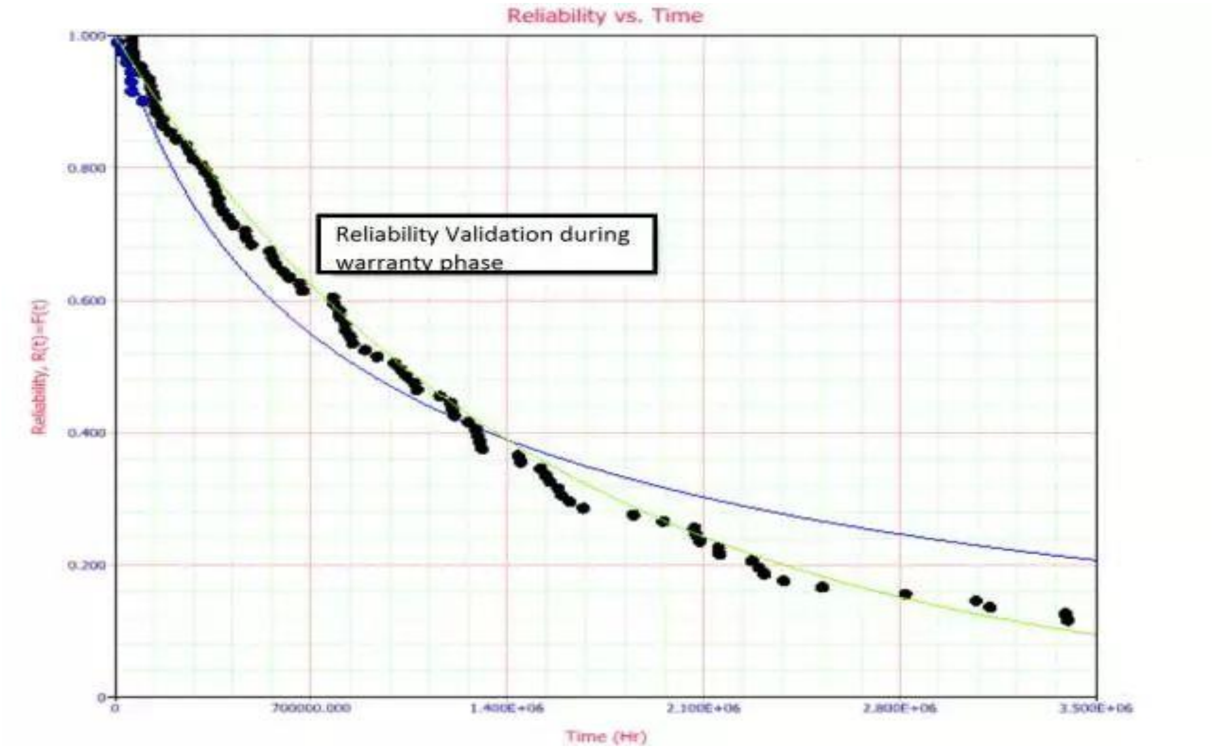



***Figure 16 – Reliability Validation. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

In order to validate the RAMS performance index, it´s necessary to have a reliable database. The FRACAS will enable the collection of the data as well as the corrective actions. Therefore, based on FRACAS information, the LDA and RAM analysis take place and will verify the RAM achievement for the warranty time as well as for the whole life cycle. The failure report and corrective analysis system (FRACAS) must be implemented before the operational phase, based on the FMEA failure mode, cause and consequence definition by creating a specific code in the FRACAS system. The FRACAS will enable to collect the failure historical data.

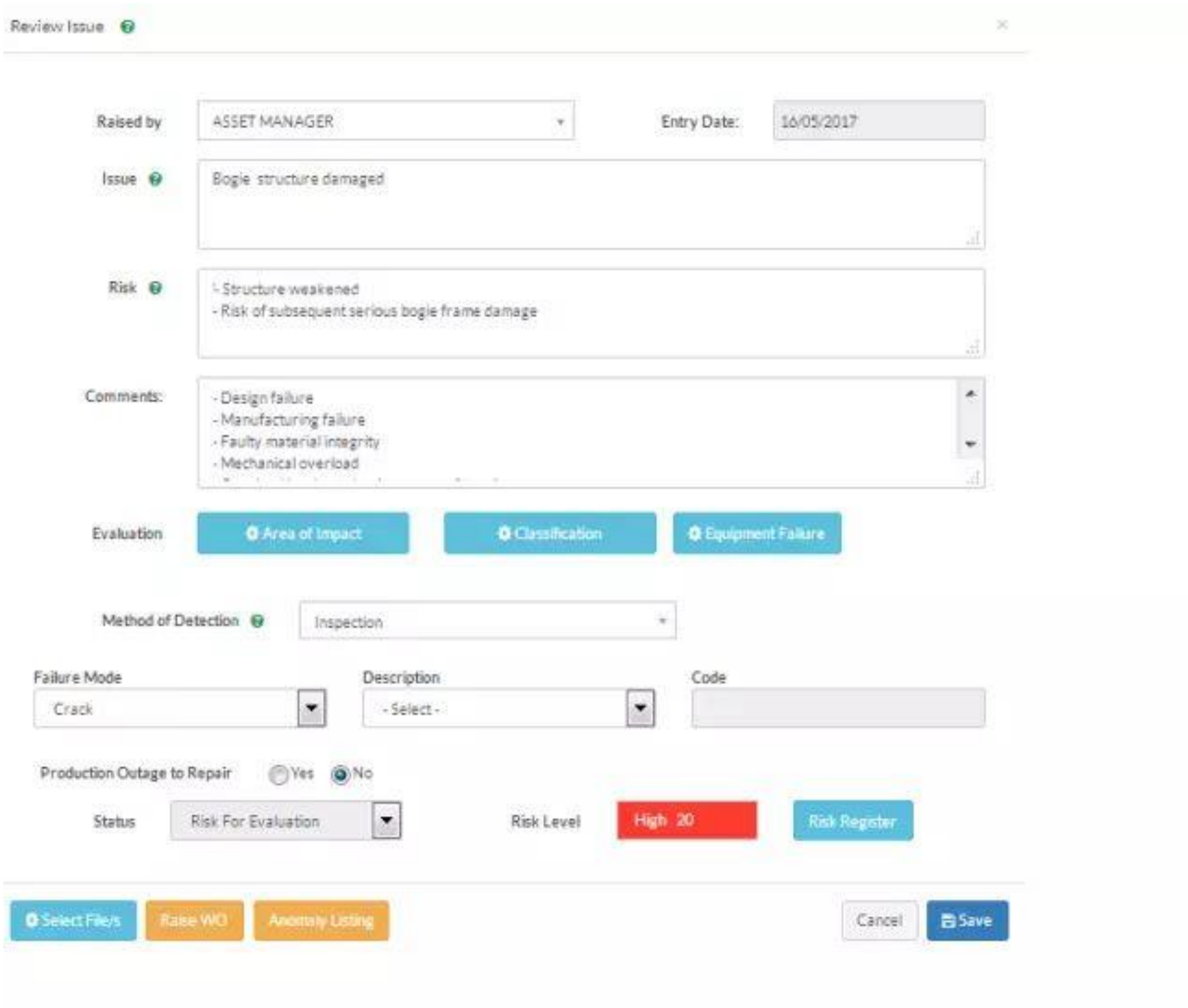



***Figure 17 – FRACAS a spart of Enterprise Asset Management. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

During the validation phase, the systems that don't achieve the RAMS requirement must be replaced or improved. Therefore, the low performance system causes are explained by some mistake during manufacturing, transportation, operation that affected the system reliability and are do not comply with the warranty terms.

After successful performance achievement and acceptance, the project can be considered successful and the operational phase begins. Such phase aims to monitor and maintain the asset operational performance throughout the asset life cycle.

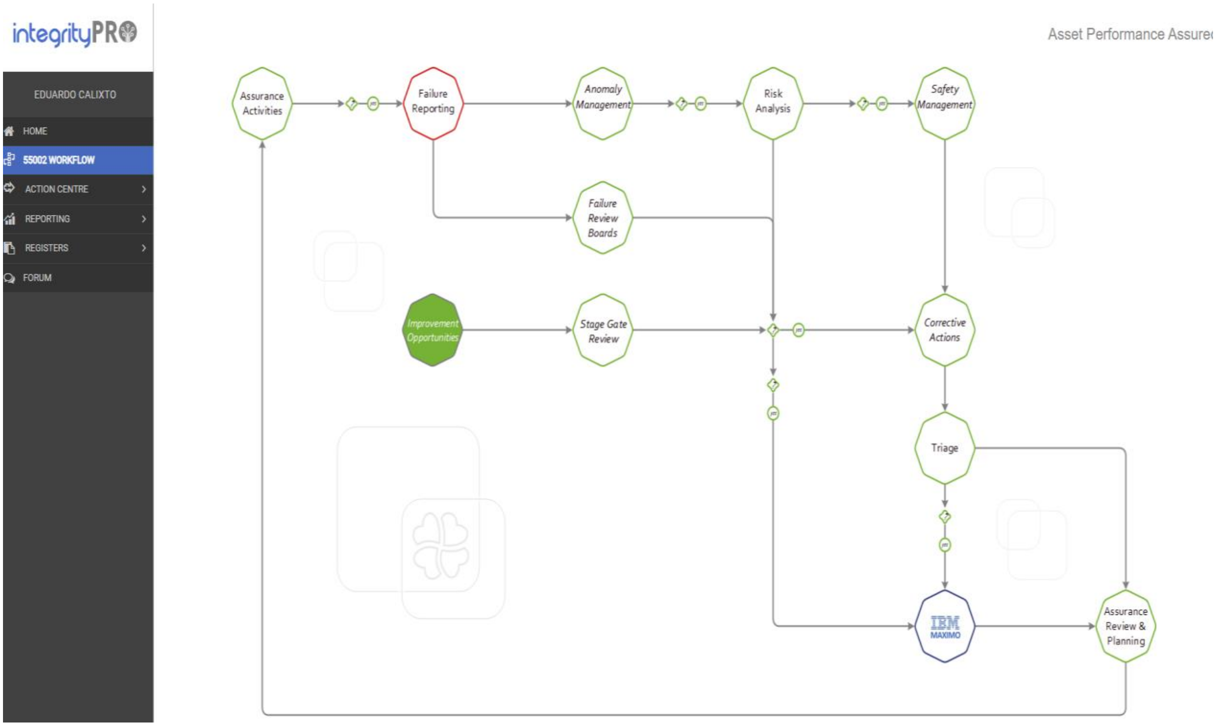



***Figure 18 – Asset Management Flow Integrity Pro software example. Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization.***

Despite of the importance to apply reliability and safety engineering methods during the design phase, such as LDA, RAM, RCM, RBI, FTA, ALT, HALT, SIL and others, it is also important to have the Asset Management program to support the Railways asset performance achievement during the operational phase. The effective asset management system encompasses not only the asset performance monitoring, but also the FRACAS system (failure reporting), Reliability 4.0. Prognostic Health Management, Anomaly Management, Risk analysis, lesson learned, corrective actions, request modification, financial approval management, capital investment plan, project work pack, work order, and assurance plan.

***Bibliography***

Calixto Eduardo, Book RAMS and LCC Engineering for Railway Industry: Analysis, Modelling and Optimization. https://www.amazon.com/-/de/dp/1986524701/ref=sr_1_7?__mk_de_DE=%C3%85M%C3%85%C5%BD%C3%95%C3%91&crid=30GRGMW4AMOIO&keywords=eduardo+calixto&qid=1674895189&sprefix=eduardo+calixto%2Caps%2C284&sr=8-7.