Safety, Reliability and Risk Analysis: Beyond the Horizon – Steenbergen et al. (Eds)
© 2014 Taylor & Francis Group, London, ISBN 978-1-138-00123-7

Integrated RAMS analysis methodology: The railway case study

E. Calixto
Bombardier Transportation, Germany

ABSTRACT: Nowadays the RAMS process is very well described in EN50126 by "V Diagram" regarding which activities is necessary in railways life cycle phases. Nevertheless, it is not clear which are the specific reliability engineer and risk analysis methods must be applied in order to achieve high performance a long railways life cycle. The methodology described on EN50126 does not consider explicitly for example reliability engineer methods like accelerated test, growth analysis, Life cycle analysis, RAM analysis by Monte Carlo Simulation a long enterprises life cycle.

In many cases, the train industry carry on RAMS and life Cycle Cost to manage their asset but do not optimize the reliability engineer methods to get better results. The equipment life cycle analysis, RAM analysis, Accelerated test, Reliability Growth Analysis, DFMEA, FMECA, RCM and Human reliability analyze are not applied intensively and correctly a long train life cycles to obtain better results. The main objective of this paper is to show advantages on such methods application and how such application can be applied to improve the supplier reliability requirements, the warranty requirement for customer and life cycle cost results.

In order to improve RAM process in Railways industry this paper will discuss the RAMS process gaps and propose improvement based on a train project RAMS analysis case example in order to have more efficient Asset Management by RAMs process to achieve better results.

Thus, regarding different lifecycle phases will be discussed which the best practices to cover such gap. That means which are the gaps on design phase and which are the proposals to improve that using Accelerated Test, Reliability Growth Analysis and DFMEA as well as risk analysis methods. On Basic project phase there are also some gaps that can be improved by life cycle analysis, FMEA, RCM, RAM Analysis, and on construction phase how human reliability can be applied to avoid human error. In addition such methods can be carried on in also in operational phases in order to keep system high performance.

1 INTRODUCTION

The Asset Management assures systematic implementation of processes, practices and technical improvements to ascertain sustained compliance with performance targets by integration of company strategy with different assets performance level at lowest possible cost under consideration of current and future operating and business requirements.

In order to achieve high performance in Asset Management is necessary to establish a process that regards the best methods a long different enterprises phases.

The best approach to carry out Asset management is particular for each industry due to different characteristic of projects and operational phases as well as different systems requirement.

The railway industry has different systems with different reliability and safety requirement that demands different targets as well as methods applications.

System like bogie and brake for example has the reliability related to safety because many of such equipment failures are unsafe failure that trigger accident with catastrophic consequences.

By the other way round, other Systems like windows, toilet, and baggage support for example have no impact on train operational availability or safety in case of failure. Even though, such system requires KPI performance index based on warranty.

The Integration of all such system based on Asset management is always a big challenge regarding different systems with different technology and that requires a very well defined process.

The Railway industry has established the RAMS process to support Asset management and the standard EN 50126 is the main guideline, despite not so specific in some point like to define the best reliability methods practices to achieve high performance in asset management.

This paper will define the best Reliability Engineer and Risk Analysis approaches and methods to achieve the best performance in railway systems asset management in different enterprises phases based on “V Diagram” (EN 50126).

2 RELIABILITY ENGINEER METHODS

In order to understand well how to apply reliability engineer tool is essential to understand the concept of enterprise that basically means the whole product or service lifecycle. The enterprise can be split in phases that are identification and assess of opportunities, conceptual project (concept), basic project (design and implementation), Executive project (manufactory, installation, verification and validation), operation and deactivation.

Depends on Company some reliability engineer methods are more applicable than others. Thus, for equipment suppliers companies, on design phase, accelerated test, DFMEA, Reliability Growth analysis are more applicable in order to certify that their product will achieve the reliability and availability target required for their costumer. The life cycle analysis (Weilbull analysis) is applied whenever similar equipment can be used as reference for the new project or to analyze equipment performance (reliability). The RAM analysis is applied to check system operational availability and define critical equipment. In addition, RAM analysis is a good opportunity to reduce cost, check redundancies, test different configurations. On Basic Engineer phase, it is possible to apply FMEA, RBI, RGBI, RCM and Human Reliability analysis. The FMEA analysis is applied to discuss failure mode and is also can have a safety focus. The RCM analysis can be implemented by FMEA analysis, and such tool allows predicting preventive maintenance and inspections and in this case is possible to estimate maintenance budget to first operational years. The RBI and RGBI can also be applied on project or operational phase in order to define inspections policies. The Human reliability analysis can support risk analysis or even critical operation which take influence on safety or system operational availability as shows Figure 1.

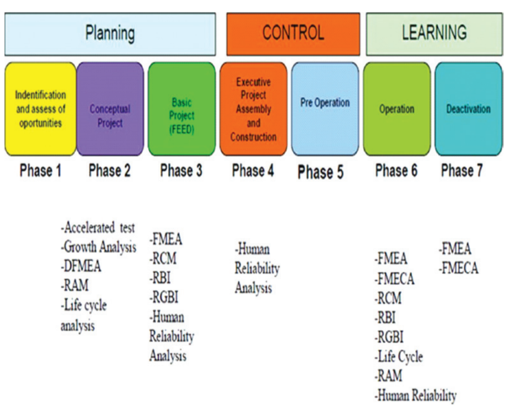

Figure 1. Reliability engineer in enterprise phases. Source: Calixto, 2013.

3 RAMS PROCESS

The RAMS process is a recognized management and engineering discipline for the purpose of guarantee the specified functionality of a product or service over its complete life cycle and to keep the operation, maintenance and disposal costs around a predefined accepted level, by establishing the relevant performance characteristics at the beginning of the procurement cycle, and by monitoring and control of their implementation throughout all project phases (Vozella, 2006).

The general definition of reliability, availability, maintainability, risk and safety used throughout industry and quoted in many engineering books published on this subject follows the example as taken from MIL-STD-785.

Reliability: the ability of an item to perform a required function under given conditions for a given time interval.

Availability (Instantaneous): ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided.

Maintainability: a state in which it can perform a required function, when maintenance is performed under given conditions and using stated procedures and resources.

Risk: undesirable situation or circumstance that has both a likelihood of occurring and a potential negative consequence on a project.

Safety: system state where an acceptable level of risk with respect to:

- fatality;
- injury or occupational illness;
- damage to launcher hardware or launch site facilities;
- pollution of the environment, atmosphere or outer space; and
- damage to public or private property.

Mostly safety and reliability issues are assessed separately for different approaches. In order to access safety, Risk Analysis methods like FMEA and PHA for example are the first step to assess system hazards. By the other way round, to access reliability, availability and maintainability is carried out RAM analysis. Despite effective methodologies, whenever is necessary safety and RAM must be integrated in order to achieve better results.

On Railway industry the standard EN 50126 supplies a guide line of each step to carry on RAMS analysis in each enterprise phase like shows Figure 2.

In all V diagram phases RAM and Risk analysis are carry out in order to achieve high system performance. The next two items will specify each method that must be carrying out by RAM and Risk Analysis.

3.1 *RAM process*

The first step in RAM process is "Concept" and it is necessary to define the impact of RAM tasks in enterprise as well as define reliability, availability and maintainability targets. Such definition will take high influence on whole enterprise phases as well as KPI targets. Is advisable to take into account similar project as reference but is also necessary to consider the new enterprise environments and customer requirement. The reliability concept is the ability of an item to perform a required function under given conditions for a given time interval. In many cases reliability is miscalculated or misunderstood. It is important to understand the reliability concept that is one of the most important index to compare different equipment performance as well as to set up warranty requirement. Many companies in Railway Industry do not understand the reliability concept and define constant failure rate or MTBF as target for systems and equipment. Such targets are applied only for some electronics or electric component that fits well to exponential probability density function. That is not the repairable equipment cases which have wear out requiring preventive maintenance on most of cases to avoid failures. Even though, for electronics component reliability is a better target.

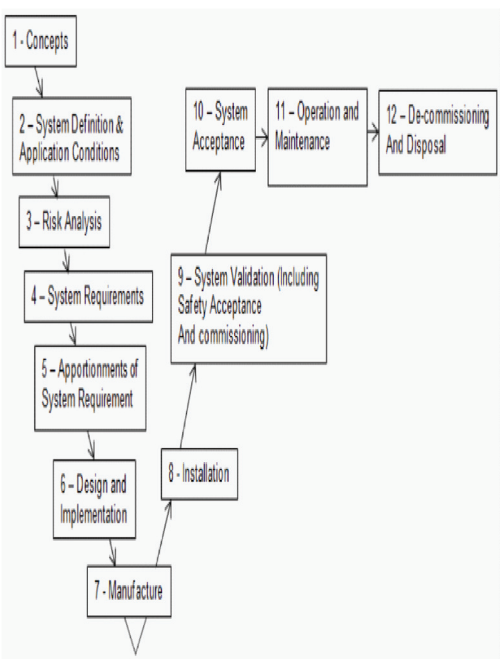

Figure 2. V diagram.
Source: EN 50126.

The other important concept is "Maintainability" the chance of performance maintenance in an expected period of time under given conditions and using stated procedures and resources. The remarkable point in repair time is that some companies do not consider the complete downtime time that equipment under repair cause in system operational availability. Actually, the repair time is the effective time to carry on maintenance or even take place the defected equipment for a new one. On both cases is required a time before start repair to access and check out equipment. Such task requires that system is not in operation state as well as additional time is required to start up equipment after repair. Such total time must be taking into account in order to predict the correct downtime caused by maintenance on system operational availability whenever specific equipment is under maintenance.

The third and most important concept is availability. There are different types of availability index and the most common used as target are Operational Availability, Average Availability, Instantaneous availability and Inherent Availability.

The "Operational Availability" means the percentage of total time that equipment, subsystem or system is available. That's represented by equation

$$A_o = \frac{\text{Uptime}}{\text{Total operating cycle time}}$$

or

$$D(t) = \frac{\sum_{i=1}^{n} t_i}{\sum_{i=1}^{n} T_i}$$

where:
t_i = real time in period i when system is working.
T_i = Nominal time in period i.

The operational availability comprises both reliability and maintainability concept that influence on operational availability targets.

The "Punctual Availability" means the probability of equipment, subsystem or system to be available in specific time t. That's represented by equation:

$$A(t) = R(t) + \int_{0}^{u} R(t-u)m(u)du$$

where,
$R(t)$ = reliability,
$R(t-u)$ = the probability of corrective action be performed since failure occur.

Such Punctual availability is important to support decisions as probabilistic results. Due to be hard to calculate such values can be defined by software applications.

The "Inherent Availability" means the operational availability which considers only corrective maintenance as downtime. That's represented by equation.

$$A_i = \frac{MTTF}{MTTF + MTTR}$$

The remarkable point to be discussed on Inherent Availability concept is that the main assumption to apply such concept is that equipment is identical and independent distributed. Independent means that repairs carried out when failure occurs will not influence on following failure, in other words, equipment is always as good as new. Such assumption can be taken into account for equipment that is replaced whenever fails happen and no corrective maintenance is carried out. Such conditions are assumed for electronic devices for example. Even if in this case, is necessary to assume that environment condition where equipment operates is constant along time that is also not true for many cases.

To be identical, is necessary that equipment belongs to the same population and that means similar production line, under same production conditions, transport and stock. By this way, equipment that replaces the failed one will have similar probability density function. Case of electronics component we regard exponential PDF.

No matter environment conditions and similarity on product population such assumption can be tested. The Laplace test for example is a good test to show if failures along time increase decrease or have no tendency (stationary). Performing such test is possible to prove that equipment have improvement or degradations after repair, that happen on most of cases on repairable equipment. By this way "Inherent Availability" is not a good target for repairable equipment, repairable system or even system with repairable and no repairable equipment.

The operational Availability is indicated to be the main Key Performance Index (KPI) target as well as reliability and cumulative number of failures. Regarding that such target are dependent on time and **"Train System"** is a complex system to model with many parallel configurations is recommended to model such system and subsystem by reliability block diagram and run direct simulation by using software.

The cumulative number of failures is also an important index and regarding repairable system, is possible to consider degradation when the renewal process model or Power law models are applied.

The next step on V diagram is **"System Definition and Application condition"** and in such phase is necessary to carry on RAM analysis based on past experience and available data of similar equipment as well as regarding operational and maintenance condition and additional constrains.

Depends on available data to carry on life cycle analysis (Weibull analysis), in some cases the RBD will regards equipment level due lack of data about component. That is not a limitation because in this phase the main objective is defined operational availability, reliability, maintainability and cumulative number of failure for the whole system and subsystems. Whenever no failures are available is necessary to consult specialist to estimate equipment PDF type and parameters.

When carry on RAM analysis by software is also possible to use the FTA models. The main difference between RBD and FTA is that RBD enable to model complex configuration that is not possible by FTA. Figure 3 shows RAM analysis methodology.

The first step on RAM analysis is to define scope of analysis and in Train system case means to define type of train as well as subsystems. All subsystems which impact on system (Train) operational availability in case of failure must be taken into account on System RBD. There are systems which impact on Train operational availability as well as safety like brakes and bogie. Other systems have particular failure modes which impact on safety like "failure open" in doors case and such event can be modeled by FTA and be taken into account on risk analysis.

In addition, there are systems which their failures cause no impact on system operational availability as well as insignificant impact on safety like toilet, windows, passenger system communication, radio, etc. Even though, is important to have key performance factors like operational availability, reliability, maintainability and cumulative number of failure for such equipment in order to check performance established on warranty. In such cases, is

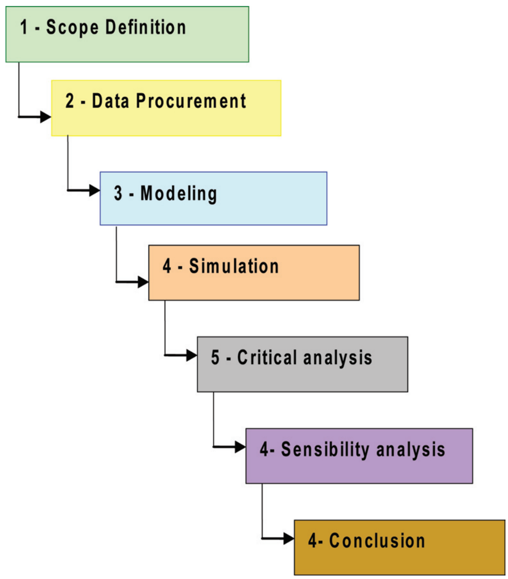

Figure 3. RAM analysis methodology.
Source: Calixto, 2013.

not necessary to break down such system in subsystem and a simple solution is to model RBD in equipment level.

The next step after scope definition is life cycle analysis and is required to access historical failures data to carry on statistical analysis in order to define equipment PDF parameters as well as consult specialist opinion when such data are not available.

The follow step is Model system and two main models came out that are RBD and FTA. Actually for similar system where most of configurations are in series or in parallel is possible to uses both models but in case of complex configuration that looks like a complex net configuration, is advisable to model by RBD. The additional point is that many FTA software models do not enable the possibility of regards maintenance policies and that is a limitation for repairable systems.

The following step is simulation and direct simulation gives important results like operational availability, reliability, cumulative number of failure, number of preventive maintenance, number of inspections, cost of preventive maintenance, cost of corrective maintenance and total cost. It is necessary to take into account all maintenance policies defined by RCM analysis.

The critical analysis is care out as result of simulation where is possible to detect which subsystem and equipment have more impact on system operational availability and system reliability.

The sensitivity analysis has the main objective to highlight the system weakness and vulnerability. Thus is possible to test the stock policies, redundancy configuration as well as impact of other system.

The last and no longer less important step is conclusion and the main objective is to show the main opportunities of improvement to managers in order to improve system performance.

The next phase in RAM process is **“System Requirement”** that is result of RAM analysis, customer requirement and a combination of both. Is important here that the RAM process is clear as well as key performance index stated as target in warranty contracts. Based in such requirements the equipment supplier will be selected to supply equipment to whole system. Thus, the RAM process must be well established in order to keep track all following steps.

The next phase is **“Apportion of system requirement”** and in this phase is necessary to define system components key Performance Index.

On both phases is necessary that suppliers prove their key performance Index data based on historic data or even by accelerated test pediction.

Once selected the suppliers for deliver all train subsystems, the next phase is **“Design Phase”**. Regarding that all previous phase were successful, design is one of the most important phases because all KPI are achieved or not depending on performance achieved in such phase. The KPI are the main target to system design and whenever is necessary to achieve such index, quantitative accelerated test, HALT, HASS and Reliability Growth Program must be applied to do so. One of the most important methods applied on design phase is the “DFMEA” because focus on failures caused by bad material quality, bad design, bad configuration. Thus is possible to drive improvement in design phase based on specialist experience of past product that is stated on DFMEA.

The logistic factors must be also regarded by Integrated Logistic Support (ILS) in design phase and that means regards stock cost, deliver time, and impact of such factors on system operational availability.

Other important issue is to define the critical failure of equipment that impact system. Thus, is necessary to carry out process FMECA and based on FMECA failure mode is enable to add the maintenances policies tasks and update RCM analysis. As mentioned before all maintenance policies will be taking into account in RAM analysis and will be in put on RBD model.

The next phase is **“Implementation”** and once designs of systems are approved and achieve the KPI target, all system, subsystem and components configurations can be defined and established to be manufactured.

The next phase is **"Manufacture"** is very important to take into account the production line effects on equipment reliability. Thus, is also important to consider which are the best production condition for equipment based on it characteristics in order to avoid bad production effects on equipment reliability. The equipment must be tested after production 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 in assembly systems that may have bad influence in systems reliability. Some of probable human error can be identified by DFMEA as well as process FMEA. Is advisable to take into account such human factors and in some cases human reliability analysis are recommended to access probable human error in assembly system by define human error probability as well as human performance factors which have more influence on such human error.

The next phase is **"System Validation"** and the main objective is update RAM analysis with real data from systems and their equipment. Therefore is essential to carry out life cycle analysis with real failures.

After validation the next phase is **"System Acceptance"** and the main objective is to accept or reject system performance based on warranty index (Operational Availability, Reliability, maintainability and cumulative number of failures).

A remarkable method to support such decision in System validation and acceptance phases is "FRACAS" analysis which will detail the failures and their root causes.

The systems that are not approved must be take place or improved. On first case, low performance system cause is explained by some mistake on project, process or transportation that affected systems reliability and if take place for usual similar system that is expected to achieve the index established on warranty. On second case, the system do not achieve index established on warranty even when a new one is take place. In such cases is necessary to carry on Reliability Growth Program to certify that reliability as well as other index like operational availability, maintainability cumulative number of failures will be achieved.

After successful acceptance the project can be considered finished and **"The Operational and maintenance"** phase starts. In his phase is necessary update the RAM analysis whenever the life cycle analysis (Weibull analysis) is updated. Furthermore is also necessary to update the RCM analysis in order to have best maintenance policies which lead to best system availability performance.

Is very important to update RAM analysis whenever system and a long operational phase and whenever system is modified. The **"Reliability Data Bank"** must be build up to support futures RAM analysis or similar projects in future. The final and one of the most important analyses is the **"The Optimum replacement time"** and such analysis must take into account reliability as well as operational cost. Whenever is detected increased operational cost the equipment must be take place.

3.2 *Safety process*

By Safety point of view the concept of safety, risk assessment process as well as the risk target must be well defined in order to lead system to high performance.

Based on EN-50126 2 (2007), Risk assessment mainly addresses the identification of hazards, evaluation of risks and a judgment on the tolerability of the risks where risk management involves identification and implementation of cost effective risk control measures and assurance that resources are diligently applied to control and maintain risk at acceptable levels.

Thus, the first step is to define risk target that means qualitative and quantitative risk. The qualitative risk is based on risk matrix that comprises values of severity and frequency and depends on system features and life time.

The quantitative risk is based on **"The Individual Risk"** that means number of expected deaths in years caused by catastrophic accidents.

Regarding qualitative risk approach, is important to understand that different equipment on Train system have different life cycle time and such systems requires different values of severity as well as frequency in risk matrix. Even though, the standard EN 50126 establishes an example of risk matrix six per five as well as quantitative risk requirement that must be followed by Railway industry.

Once identified the qualitative and quantitative risk target the second step is to carry on risk identification that means identify system hazards as well as accident scenarios. The risk identification is defined as third step on V Diagram. The best approaches to hazard identification are PHA (Preliminary Hazard Analysis) and FMEA (Failure Mode Analysis). On both cases is possible to apply risk matrix and by this way the third Risk management step is carry on risk analysis.

It is important to realize that the criticality index applied on FMECA is necessary only for system which has impact on operational availability or safety. In case of impact on safety, whenever occult failures are possible the criticality index (Risk priority number = Frequency × Severity × Detection) must be implemented. On safety cases, the severity will consider safety consequence and on this case we have FMECA analysis with safety focus. When occult failure does not have significant impact but unsafe failures are possible the risk matrix must be implemented and we have a FMEA with safety focus. When Risk analysis is carried out is necessary to be clear that risk is combination of frequency and severity and if risk matrix is used the risk will be number or a combination of number and letter that came from frequency and severity classification.

Figure 4 shows an example of risk matrix with risk index.

The next step is risk evaluation, that means compare risk with risk target and if risk is not tolerable the mitigation actions are necessary. On Figure 4 above is possible to identify different risk levels by different colors.

The red regions means intolerable level and all risk in such region must be mitigated. The orange and yellow region means Tolerable and moderate and theoretically is necessary to mitigate such risk as much as practicable and on green region that is not necessary.

The ALARP concept is applied to evaluate risk and compare with tolerable risk region and in case of intolerable risk, such risk must be mitigate as well as tolerable and moderate risk must be mitigated as much as practicable in terms of return of investment.

The MEM (Minimum Endogenous Mortality) concept incorporates the lowest natural death rate and uses this to assure that the total additional technical risk will not be greater than such natural death risk. The tolerable individual risk is defined by number of deaths per year as shows Figure 5.

Other additional Risk concept is "GAME" and principle states that a new system should be globally at least as good as the current system, including an element of continuous improvement.

No matter Risk principles establish per regulator authority, to define individual risk is necessary to identify the risk scenarios that have death consequences like "derailment" for example and estimate

Frequency		Risk			
Frequent	5	5	10	15	20
Probable	4	4	8	12	16
Ocasional	3	3	6	9	12
Remote	2	2	4	6	8
Unprobable	1	1	2	3	4
		1	2	3	4
		Insignificant	Marginal	Critical	Catastrophic
		Severity			

Figure 4. Risk matrix.
Source: Author.

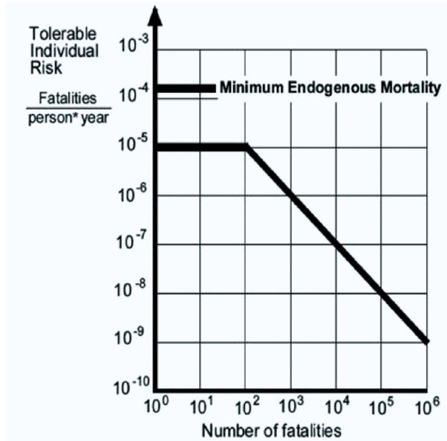

Figure 5. MEM individual risk criterion.
Source: EN 50126-2.

the number of deaths as well as frequency of occurrence. Such index is the individual risk and to calculate for the whole train system is necessary to sum risk for each scenarios as shows equation below.

$$RI = \sum_{i=1}^{n} C_i X f_i$$

where:
f = frequency of accident scenario (year),
C = consequence of accident scenario (deaths in plant area).

Figure 6 summarize the Risk Management Process regarding different phases.

Additional Qualitative Risk analysis approach like Hazard log and C-Hazard as well as quantitative methods like FTA, ETA, Bow tie and SIL analysis must be applied a long enterprise's phases in order to define more precise risk and help to mitigate it.

Once establish risk requirement and selected suppliers for all system the next phase is **"Design Phase"**. As well as in RAM process, design phase is one of the most important to safety. The safety KPI are the main target to system design and it is necessary to demonstrate such index achievement. Whenever is necessary the quantitative accelerated test, HALT, HASS and Reliability Growth Program must be applied to do so. It is also important to understand that, by safety point of view, reliability is associated with unsafe failure for many systems in Train. Thus the safety indexes are risk, reliability and number of failures.

The "DFMEA" is also important because recommendation try to avoid unsafe failures caused due to have bad material quality, bad design, bad configuration that can trigger accidents. Thus is

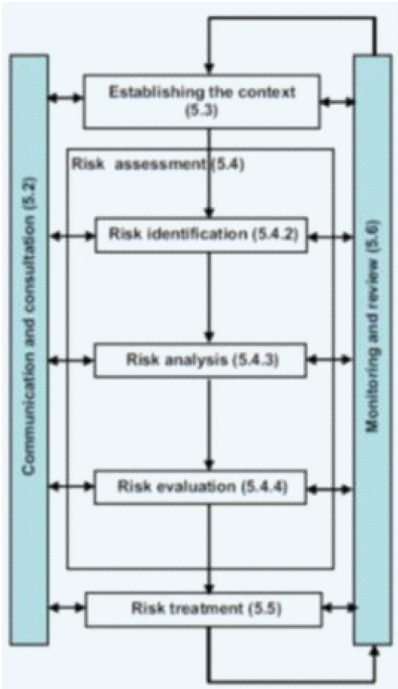

Figure 6. Risk management.
Source: ISO 31.000 (2009).

possible to drive improvement in design phase based on experience of past product described in DFMEA.

The **"Implementation, Manufacture and "Installation"** phases is also necessary to avoid bad influence on equipment reliability that can increase risk.

On **"System Validation phase"** the main objective is update Risk Analysis with real data and new accident scenarios from systems and their equipment. The unsafe failures must be taking into account to update equipment reliability.

After validation the next phase is **"System Acceptance"** and the main objective is to accept or reject system performance based on warranty index (Risk, Operational Availability, Reliability, maintainability and cumulative number of unsafe failures).

The systems that are not approved must be take place or improved similar in RAM case based on safety warranty.

At this stage the project can be considered finished and **"The Operational and maintenance"** phase starts. In his phase is necessary update the Risk analysis whenever the life cycle analysis is updated. Furthermore, is also necessary to update the RCM analysis in order to have best maintenance policies which lead to best system safety performance.

Is also important to update Risk analysis a long operational phase and whenever system is modified.

The **"Reliability Data Bank"** about unsafe failures must be carried out to support futures Risk analysis or similar projects. **"The Optimum replacement time"** is also important for systems which have unsafe failures as well as safety functions. In such cases, the optimum time must consider operational cost, risk and expected number of unsafe failure.

4 RAMS PROCESS PROPOSED

The RAMS process proposed regards the best Reliability Engineer and Risk analysis practices a long enterprise phases.

As mentioned before, once defined system target like Operational Availability, Reliability, Cumulative Number of failures and risk based on life cycle analysis, RAM analysis and Risk analysis the next step is to carry on select supplier and confirm their index based on warranty. In order to anticipate problems in validation phase and additional project cost all effort in design phase must be carry out in order to systems achieve the specified targets. In some cases, in order to predict new product reliability as well as robustness the quantitative accelerated test and HALT must be necessary. In case that such system do not achieve reliability, operational availability, cumulative number of failure, The Reliability Growth program in design phase must be taking place. Figure 7 shows the proposed methods that must be applied a long Train enterprise.

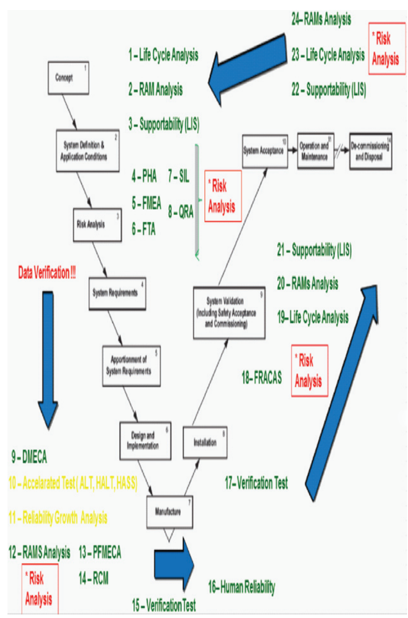

Figure 7. RAMS proposed methodologies.

A long operational phase is necessary update reliability data, RAM and Risk Analysis as well as RCM analysis in order to have the best maintenance policy to guarantee system availability and safety.

The Optimum replacement Time for all equipment must be analyzed in order to reduce operational cost, keep system with high availability and under acceptable risk level.

5 RAMS CASE STUDY APPLICATION

The Train system is encompassed for different subsystems which in case of failure cause Train unavailability, accident or both situations. There are systems which in case of failure do not cause impact on train availability and safety but need to assess to have the minimum of quality expected and achieve operational cost target.

On first case, there are some subsystems which in case failures have direct impact on train availability like bogie, breaks, propulsion and pantograph. Other subsystems, in case of failure cause an unsafe condition that can lead an accident like TCMS, doors (Fail open) and also bogie and break.

Whenever RAMS analysis is carried out in different phases of train life cycle, such systems are analyzed individually to check if KPI (Operational availability, Reliability, number of failure) are achieved as shows Table 1.

Regarding safety we can see in Table 1 that break, bogie, door and TCMS have high reliability that means high safety level. In case of bogie and break such reliability is achieved by preventive maintenance and inspection that restore reliability. By the other way round, operational availability are impacted by such downtime caused by preventive maintenance and inspection.

Moreover than individual analysis is important to integrate all subsystem in train configuration that depends on each subsystem impact in different train wagon as shows Figure 8.

One common mistake is to define KPIs targets for subsystem individually but not for the whole system (train). The RAM analysis must be a top down analysis, but when there are not specific KPIs

Table 1. Train subsystems performance (KPI).

Subsystem	Availability (2 years)	Reliability (2 years)	Failures (2 years)
Bogie	99,96%	100%	0
Break	99,99%	91%	0,2
Pantograph	99,98%	100%	0
TCMS	100%	95%	0,05
Propulsion	99,92%	90%	0,07

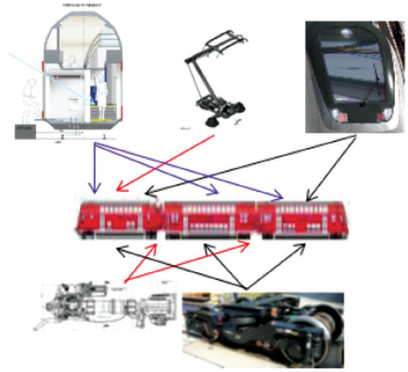

Figure 8. RAMS train configuration.

targets to the whole train system, once RAM analysis is carried out and defined the RBD which comprise all subsystems which cause impact train availability, as well as failures and repair PDF parameters, after run Monte Carlo simulation, is enable to define such KPI to the whole train system.

In addition, performing RAM analysis is possible to define the most critical equipment in terms of operational cost, impact on system availability and reliability as well as to define redundancy policies, stock policies and compare different system performances.

By doing so, is essential to understand train configuration as well as subsystem which impact train availability and also safety.

In some cases when we have different trains configuration we need to define which are the best one regarding KPI (operational availability, reliability, failures) as well as operational cost. Actually the life cycle cost must be also analyzed to support the last decision.

An example of different Trains configuration is represented by Figure 9. In this case one of such configuration must be proposed as final solution.

The final solution by this case is presented on Table 2 and shows that as big as the configuration the reliability reduce and the expected number of failure increase an well as the operational cost. The operational availability has not significant impact because even having more number of inspection and preventive maintenance at biggest train configuration, such preventive maintenance and inspection are carried out simultaneously on similar subsystems to avoid additional impact on downtime.

Thus, based on such results, life cycle cost analysis and project deliver time the best configuration is C2. In this case the required trains can be delivered in required time buy customer with a better NPV (Net Present Value). In order to improve KPI,

Figure 9. RAMS train configuration. (aStw = motor driver wagon, Mw = middle wagon and Stw = driver wagon).

Table 2. Different trains configuration performance (KPI).

System	Availability (2 years)	Reliability (2 years)	Failures (2 years)
C1	99,50%	70%	0,55
C2	99,50%	68%	0,87
C3	99,48%	53%	1,1
C4	99,47%	40%	1,3

maintenance policies must be discussed as well as system reliability must be compared among different system' suppliers.

6 CONCLUSION

Nowadays to apply RAMS process a long Train System enterprises faces a big challenge due different subsystems technologies involved, number of specialist and different knowledge levels about reliability and risk analysis methods.

Because such enterprises require high investment and in case of failure can produce accident with consequence for the whole society such reliability and risk analysis methods are essential to enable profits and provide reliable and safe trains.

Despite most of Reliability and Risk analysis methods are spread out in many industry all over the world, in Railway Industry such methods are not completely understood as well the benefits for their application.

In addition, the correct success of such methods application required a very well RAMS process established as well as Reliability and Risk Analysis Specialist.

Both aspects are nowadays a big challenge in Railways Industry in specific by Train enterprises. The Risk Analysis process is well describe by EN 50126-2 but the RAM process not because EN 50126-3 do not consider all methods and have simple assumptions to make RAM applications easier as mentioned previously. The second point is that Risk analysis as well as Reliability engineers are not easy to hire and due to very specialized activities on most of cases such analysis and methods is not very well carried on for other professional that have not deep knowledge about such issues and consequently produce bad results.

Even though such RAMS process is successfully defined and Reliability and Risk Analysis professional are hired is necessary to consider the RAM and Safety integration as well as RAMS process integration with other Management process like Project Management which has high influence on RAMS process.

REFERENCES

Bayer Technology Services Asset Life Cycle Management. www.bayertechnology.com.
Calixto Eduardo. 2012. Gas and Oil relibility Engineer: Modeling and Analysis. Elsevier ISBN: 9780123919144.
Carson, Carl S. 2006. FMEA mais eficazes a partir das lições aprendidas. SIC 2006.
Harry W. Mclean. 2009. Halt, Hass and Hasa explained. Accelerated Reliability Techniques.American Society for Quality, Quality Press, Milwaukee.
Pallerosi A. Carlos. 2007. Confiabilidade, A quarta dimensão da qualidade. Conceitos básicos e métodos de cálculo. Reliasoft, Brasil.
Patrich D.T O'connor. 2010. Practical Reliability Engineering. Fourth Edition. John Wiley & Sons Ltd.
Paul. A. Tobias, David C. Trindade. 2012. Applied Reliability. Third Edition. CRC Press.
R&M process. NASA-STD-8729-1. www. http://www.hq.nasa.gov.
Standards: PAS 55, EN-50126, Army Regulation 700–127.
Standard CLC/TR EN 50126.
Standard CLC/TR EN 50126-1.
Standard CLC/TR EN 50126-2.
Standard CLC/TR EN 50126-3.
Standard ISO 31.000 (2009).
Standard MIL-STD-785.
Yang, Guangbin. 2007. Life Cycle Reliability Engineering. John Wiley & Sons Ltd.