AN OVERVIEW OF RELIABILITY ANALYSIS TOOLS AND TECHNIQUES

Reliability analysis is often used as a broad term for a range of analyses used to evaluate and improve the quality of products, processes, and systems. While the term "reliability" can apply in a general sense to the overall performance of a product or system, in engineering disciplines, reliability is a specific metric that can be quantitatively assessed. Engineers sometimes use the term RAMS analysis as a more encompassing term for all the techniques used to analyze and improve products and processes.

RAMS is an acronym that highlights four foundational areas that are critical to the design, production, and maintenance of reliable and safe systems and processes: reliability, availability, maintainability, and safety. In this paper, we will provide an overview of a variety of RAMS analysis tools and techniques for a better understanding of how you can use and apply these principles for your own reliability analysis assessments and continuous improvement efforts.

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What is RAMS Analysis?

RAMS analysis is a well-established approach for evaluating four critical factors related to system performance: ***reliability***, ***availability***, ***maintainability***, and ***safety***. Widely used in engineering disciplines, RAMS analysis ensures that systems meet operational requirements throughout their lifecycle. The objectives of RAMS analysis are to assess reliability, availability, maintainability, and safety in an organized way, identify areas of concern, and facilitate improvements to ensure that program goals are met.

Organizations may not focus on all four elements but may instead focus on a specific combination crucial for their particular situation. Additionally, these four elements may be prioritized in different ways depending on the unique requirements for varying market sectors. For example, in some industries risk levels may be a compliance factor, while in others, reliability or MTBF (Mean Time Between Failures) analysis is a contractual requirement. The use of the term RAMS allows for encompassing all these related activities under one umbrella.

What is Reliability?

Reliability is defined as the probability, or likelihood, that an item will perform a desired function without failure under stated conditions for a stated period of time. In general, reliability is an indicator of the likelihood a product will operate without failure.

Consider, for example, a common reference for automobile reliability: Consumer Reports. In their Guide to Car Reliability, Consumer Reports states “A vehicle’s reliability can seriously affect how satisfied you’ll be with a car over the years, and it can significantly influence resale value when you’re ready to replace the vehicle.”

Understandably, this same principle applies to a wealth of products, not just vehicles.

Reliability has a direct impact on business success. As a general overview of reliability indicates, reliability is important not only to manufacturers, but to consumers.

For this reason, reliability is one of the most critical aspects of product design and development. It is why reliability engineering plays a key role in the engineering field and why there are a wealth of tools and techniques available to assess and evaluate product reliability throughout the lifecycle.

What is Availability?

Availability is defined as the probability that a repairable system is in a working state when it is required to be operational. You can see there is a noticeable and important distinction between reliability and availability.

Availability analysis is most applicable to systems which are required to be up and running consistently to support critical missions. In general, availability indicates if an item will be working when it is needed.

For this reason, availability measures factor in the ability to repair failed items. For example, consider a system which is required to be operating at 3:00 pm, but fails at 9:00 am. As long as the system can be repaired prior to 3:00 pm, operation can proceed as needed. Another example to consider is an assembly line. If the assembly line goes down, but can be repaired quickly, output decline is minimal. This indicates how important high availability is in manufacturing production environments.

Availability is a key measure in network systems, such as your internet, cable system, or cloud platform. Availability measures are often considered in terms of "9s", so when a system states that its availability is "five 9s" it means that the availability (a value between 0 and 1) is 0.99999. This indicates that the system is up and running 99.999% of the time. This is a very high bar and is crucial in mission critical systems.

An easier way to think about availability is how important it is to you that your cable does not go out at the last minute of a tied Super Bowl game, but it's ok if it goes out during the halftime show. You are considering the availability of your cable provider in your evaluation!

What is Maintainability?

Maintainability is defined in MIL-STD-721 as "the measure of the ability of an item to be retained in or restored to a specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair." More succinctly, maintainability is the probability that an item can be repaired in a defined environment within a specified period of time. Maintainability analysis is an evaluation of the procedures used in order to maintain a system at peak capacity.

Using the assembly line example once again, if robotic arms are in use, the need to perform maintenance procedures on the equipment is important. You may need to lube components or recalibrate items in order to keep the production line operating. Ignoring these tasks leads to failures and ultimately to assembly line shutdown, possibly for a long period of time. By employing proper preventive maintenance procedures, assembly line operation can be kept at optimal capacity without failure.

While preventative maintenance procedures are used to prevent failures, corrective maintenance procedures are used when a failure does occur. Clearly, it is important that both are kept to a minimum time by using the most efficient procedures possible.

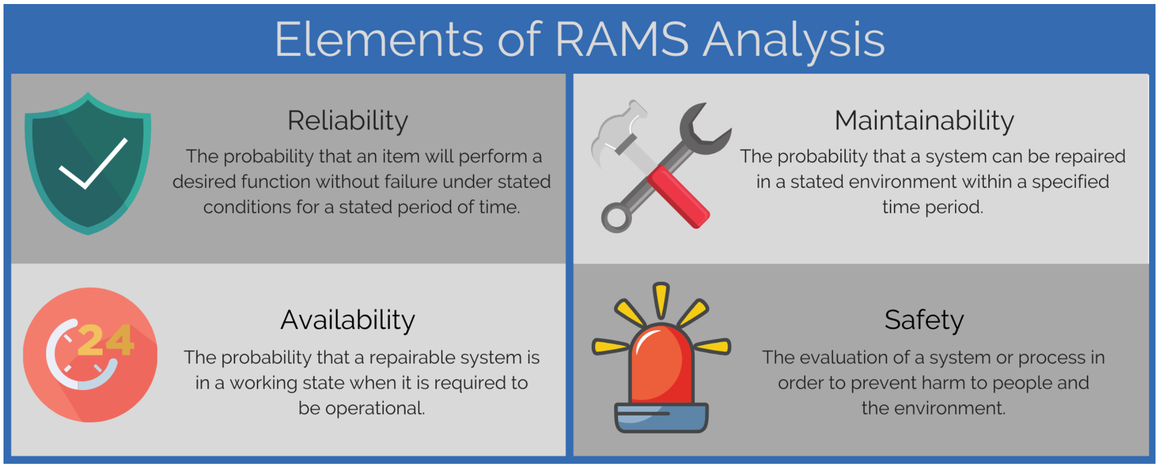
Maintainability analyses are utilized to optimize all types of maintenance procedures.

What is Safety?

Safety is a term with a much clearer definition! When used in reference to RAMS analysis, safety analysis is performed in order evaluate ways to prevent harm to people and the environment by a product, system or process.

Safety analysis is a broad term and may encompass methodologies such as risk analysis, hazard analysis, and probabilistic safety or risk assessment (PSA or PRA). Risk analysis is done by identifying and analyzing potential catastrophic or critical events. Hazard analysis is done to assess the risk associated with identified hazards. PRA is a very comprehensive methodology to quantify risk and is typically used in complex and highly critical systems such as nuclear power plants and airplanes.

Safety analysis is performed in order to eliminate or mitigate system risk. The overall goal is to ensure that the probability of occurrence of risk events is kept at an acceptable level.



How is RAMS Analysis Done?

Depending on your unique needs, RAMS analysis may comprise any combination of reliability, availability, maintainability, and safety analyses. It is up to you to determine which elements of RAMS analysis are important to ensure your product, process, or system goals are achieved. In some cases, you may have compliance requirements that dictate which analyses must be done. In other cases, you may be a subcontractor required to provide results of these analyses to your system integrator. Or, you may have internally-driven objectives to meet.

The tools associated with RAMS analysis are varied, and in most cases fall into one of the four categories. However, it is very important to note that several RAMS tools fall into more than one category. For example RBD (Reliability Block Diagram) analysis is both a reliability and an availability tool.

The breakdown below will introduce some of the most commonly used tools for the given RAMS category. The tools that cross over into multiple categories will also be noted. This is not intended to be an all-encompassing list of reliability and quality methodologies, but presents a solid starting point for consideration.

Reliability Analysis Tools

Reliability tools in general will provide metrics such as reliability, failure rate, and MTBF (Mean Time Between Failures). Reliability tools are useful throughout the product lifecycle. For example, predictive tools enable you to assess likely reliability of a design prior to actual production, thereby enabling you to design-in reliability. Other tools are useful for products in customers' hands by allowing you to track reported issues and work to proactively correct problem areas.

Reliability Prediction

Reliability Prediction analysis is one of the most widely used tools in RAMS analysis. The core function is to evaluate an electro-mechanical system and, based on its parts and their associated operating and rated parameters, estimate or predict its failure rate or MTBF.

Reliability Predictions are performed using a prediction standard, or a document which delineates the methods and equations used to quantify reliability. Some example standards include MIL-HDBK-217, Telcordia, 217Plus, and ANSI/VITA.

Depending upon your particular needs, one standard may be more applicable, or you may even use a combination of standards. Our in-depth guide on reliability prediction standards provides detailed information. These widely accepted prediction standards have been developed over years of research. Using statistical analysis over a huge range of historical device data, the equations defined in the standards represent a solid basis for reliability estimates.

To begin a Reliability Prediction analysis, you describe all the individual components of your system. Depending upon the standard(s) used, you then enter various parameters about the component parts of your system, such as rated stresses, operating stresses, temperature, and environmental conditions. Using this information, calculations are performed using the equations defined in the designated standards. The results of a Reliability Prediction analysis include metrics such as failure rate and MTBF.

An important advantage of Reliability Prediction analysis is the ability to assess system reliability during the design phase in order to design-in reliability. Reliability Predictions allow you to enter as much data as you have at any given point in the design cycle and perform a preliminary assessment. Then, as your design evolves, you can continually return to the prediction analysis to add in further details and more exact data parameters. In this way, your Reliability Prediction analyses become more refined over time.

Reliability Prediction analysis tools are often augmented with an abundance of features that enhance and advance reliability analysis. These include:

- Component part databases for automated retrieval of device parameters
- Derating analysis for evaluating device overstress conditions
- Mission profiling for assessing reliability over a defined mission
- Allocation analysis for determining the optimum allocation of failure rates over a system
- What-If? analyses for performing design trade-off studies

FRACAS

FRACAS, or Failure Reporting, Analysis, and Corrective Action System, is a closed-loop process for handling any type of issue that you want to track and manage. It can be applied to track field failure reports, test failures, customer complaints, compliance concerns, audit report findings, or any type of failure. Once an issue or incident is recorded, a FRACAS defines a controlled workflow path for correction and eventual close-out.

Well-designed FRACAS tools provide trackable statistics and helpful aids such as dashboard overviews. These features allow you to gain a clear understanding of system performance metrics, such as reliability. Importantly, by having a trackable approach, you can proactively address potential issues before they become larger concerns. A FRACAS dashboard may allow you to see that a single issue is being reported across multiple locations. This insight enables you to zero in on this area to track down and correct the underlying cause, thereby maintaining a high level of product reliability.

Some FRACAS tools offer built-in calculations for MTBF and reliability based on recorded incidents. Not only does this offer a metrics-based approach for reliability assessments using FRACAS information, but also enables you to compare predicted reliability (possibly from reliability prediction) to actual field-based reliability metrics.

The steps through a FRACAS, or any Corrective Action (CA) system, are variable and oftentimes unique. There are several commonly accepted process management standards that CAPA (Corrective and Preventive Action) systems, such as FRACAS, follow. Widely known and proven process methodologies include 8D, DMAIC, and PDCA. In some cases, organizations create and adhere to their own defined procedure. Customizable FRACAS tools support all approaches to process management.

For further information, see our post on using FRACAS as a reliability improvement tool which answers all the basic questions about FRACAS.

For a detailed look into ways to maximize the benefits of a FRACAS implementation, download our whitepaper "*Getting the Most Out of Your Closed-Loop Corrective Action Process*."

Weibull Analysis

Weibull analysis, also called life data analysis, is a tool for analyzing various types of life data in order to predict failure and reliability trends. Analysis starts by gathering a sample set of life data, such as the times your product experienced a failure during use. Using statistical analysis based on mathematical distributions, Weibull analysis provides a way to curve fit the gathered data in order to determine trends.

Even though life data analysis is the broader term, Weibull analysis is often used interchangeably with life data analysis. The term Weibull analysis is commonly used because the Weibull distribution is very useful to characterize a wide range of data trends that other distributions cannot. Also, the Weibull distribution can be used to approximate other distributions. Some of the other distributions available typically in Weibull analysis tools include:

- Exponential
- Lognormal
- Normal
- Rayleigh
- Gumbel

Weibull Analysis provides the unique ability to predict reliability performance based on data captured during actual use. This enables you to use field-based data to make forecasts about a product's life, such a system failure rate or reliability, the mean life of a system, and even an optimal warranty period.

To learn more about Weibull analysis, see our guide to using life data analysis.

ALT Analysis

ALT (Accelerated Life Testing) analysis is similar to Weibull analysis in that it is a statistical based tool for reliability and performance evaluation. The defining difference is that while Weibull uses life data as a basis for analysis, ALT uses data gathered from accelerated life tests.

Accelerated life testing subjects a product to high stress conditions in order to induce failures. Such testing is particularly helpful for products which are expected to have long lifespans. Stresses such as temperature, humidity, vibration, or any other type of environmental stress that your product may experience in its lifetime can be considered.

Once a sample set of life data under stress conditions is collected, ALT analysis uses mathematical and statistical techniques to fit the data to a distribution. Based upon the results, failure and reliability trends can be predicted. ALT analysis thereby enables you to gain important insights into your long-term product reliability performance.

For an overview of the basics of ALT analysis, read our introductory blog post.

Additional Tools for Reliability Analysis

These tools, covered in the following sections, can also be used for reliability analysis:

- RBD (Reliability Block Diagram)
- FMEA (Failure Mode and Effects Analysis)
- Fault Tree Analysis (FTA)

Availability Analysis Tools

Availability tools provide the ability to evaluate availability, almost always along with reliability and other commonly used performance metrics.

RBD

RBD, or Reliability Block Diagram, analysis is a tool used to assess system reliability and availability related metrics.

RBD analysis begins with the construction of a block diagram representation of the system to be evaluated. Blocks are used to represent subsystems or parts of the overall system and connector lines are drawn to indicate success paths. Then, characteristics of each of the blocks, or system components, are designated. This data may include information such as the failure rate of the block, the distribution that can be used to model the performance of the specific component, and information about repair characteristics.

Using this information, a wide array of metrics can be calculated. For example, results from RBD analysis may include:

- Reliability
- Failure rate
- Availability

- Mean Availability
- Total Downtime
- Steady-state Availability

A significant advantage of RBD analysis is the ability to evaluate complex systems, such as those that incorporate redundancy in their design. Redundancy means that when a component or path in the reliability block diagram fails, a secondary component or path can take over to keep the system up and running.

Because RBDs can be useful in modeling complex systems, the calculation engines employ both analytical computations and simulation techniques to provide results.

Additional Tools for Availability Analysis

These tools, covered in other sections, can also be used for availability analysis:

- FRACAS (Failure Reporting, Analysis, and Corrective Action System)
- Fault Tree Analysis (FTA)
- Reliability Prediction
- Maintainability Prediction

Maintainability Analysis Tools

Maintainability analysis tools focus more specifically on the repair and maintenance aspects of systems. Because these activities have a direct impact on system performance measures such as availability and uptime, they are vitally important to effectively manage and control.

Maintainability Prediction

Similar to the way Reliability Prediction analysis is used as a way to assess the likely failure rate of a system, Maintainability Prediction analysis is a way to evaluate the maintenance and repair profiles of a system. By defining the tasks required to either repair a failed component (corrective action) or the procedures you employ to keep a system operational and avoid failures (preventive action), you can evaluate your processes and determine upfront the most efficient way to return failed items to an operational state and to perform preventive maintenance tasks.

Maintainability Prediction analysis is based on the MIL-HDBK-472 standard. This standard provides the methodology for describing maintenance procedures, as well as the equations needed to assess maintenance metrics.

Maintainability Prediction analysis provides a number of critical system metrics, such as:

- MTTR (Mean Time to Repair)
- MCMT: Mean Corrective Maintenance Time
- MPMT: Mean Preventive Maintenance Time
- MMH/Repair: Mean Maintenance Hours per Repair
- MaxCMT: Maximum Corrective Maintenance Time
- Availability

RCM

RCM, or Reliability Centered Maintenance, involves maintenance planning in a way to ensure that a system remains operational in an optimum way. For any system, there are trade-offs between corrective maintenance (fixing a failed unit), preventive maintenance (performing tasks to keep a system in good working order to prevent failure), system uptime, and resources. RCM is a way to look at all these variables and plan a maintenance program that offers the most optimal approach.

Accepted RCM standards include MSG-3, MIL-STD-3034, MIL-STD-2173, and SAE JA1011. RCM is a process that flows through a series of questions about your system components. The questions considered include:

1. What are the functional requirements of this component?
2. How could this item fail to meet its functional requirements?
3. What is the cause of each failure?
4. What are the effects of each failure?
5. What is the risk level of each failure?
6. What are the tasks that can be performed to prevent, detect, or mitigate each failure?
7. What can be done if a preventive task cannot be determined?

From these questions, it is apparent that RCM is closely tied to FMEA. Indeed, RCM analysis typically uses FMEA data as a starting point. RCM analysis looks at the failure modes identified through FMEA and determines the maintenance tasks required to address them. The result is then an overall maintenance plan to follow. One goal is to make sure your maintenance program is focused on the failures that cause the most disruption to system operation in order to make the most effective use of resources.

Additional Tools for Maintainability Analysis

These tools, covered in other sections, can also be used for maintainability analysis:

- FRACAS (Failure Reporting, Analysis, and Corrective Action System)

Safety and Risk Analysis Tools

The goal of risk and safety analysis is risk reduction. In order to successfully reduce risks due to failures or catastrophic events, typically, a 3-step process is employed:

1. Assess the various failures and events that pose risk
2. Prioritize those risks
3. Determine ways to address risks in order to eliminate or mitigate them so that the system risk profile is acceptable

Note that safety and risk tools don't provide a way to eliminate all risk. The objective is to ensure that a system is designed in a way that controls risk to an acceptable level. That level must be determined on an individual case-by-case basis. In some instances, risk levels may be mandated (as in the nuclear power and medical device industries), are contractual requirements (as in aviation), or are independently established (as in the consumer products sector).

FMEA

FMEA, or Failure Mode and Effects Analysis, is a broadly accepted and proven approach to risk evaluation. In fact, FMEA is one of the most commonly used tools in the reliability engineering field.

FMEA is a structured approach for performing failure analysis of a product, process, or system. First, an item is evaluated for all possible failure modes that may occur. Next, possible causes and resulting effects of those failure modes are determined. Then, the risk level is assessed for each failure mode based on a set of established criteria. Finally, ways for the most critical failures to be detected, mitigated, or prevented are identified.

There are various published standards that can help you establish your FMEA process. These standards can be used as defined but are oftentimes adapted for specific organizational requirements or desires. Or, you can even completely design your own FMEA process if that better suits your needs. Some of the most commonly used FMEA standards include:

- AIAG
- AIAG & VDA
- MIL-STD-1629A
- SAE J1739
- ARP5580

The FMEA standards define the process and also offer a guide for risk assessment. Several common approaches to risk assessment include Risk Priority Number (RPN), Action Priority (AP), or use of criticality numbers.

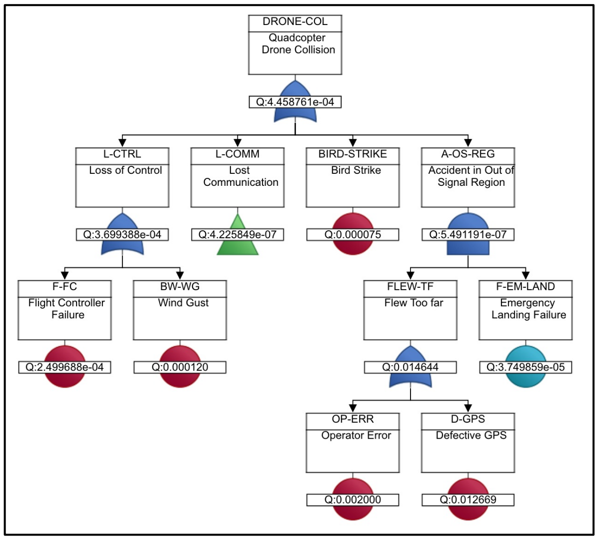
Our in-depth blog post provides a detailed review of the FMEA process and all the various types of FMEAs.

Fault Tree Analysis

Fault Tree Analysis (FTA) is another tool used for risk assessment that offers a highly analytical, quantitative approach for analysis. Developed in 1962 for the United States Air Force by Bell Laboratories for use with the Minuteman system, FTA is now widely used by RAMS analysts.

FTA is used to evaluate the probability of an undesirable, or catastrophic, event. Sometimes FTA is employed to target the analysis of highly critical events discovered during the FMEA process.

Fault Tree Analysis employs a graphical approach: starting with the topmost undesirable event, a fault tree diagram is constructed to model all the contributing events which can lead to the top-level event. The fault tree diagram is created using Boolean logic, which uses logic gates, such as AND gates and OR gates. For detailed information about logic gates, events, their associated properties, and their usage in FTA, see our definitive article on this topic.



Once the diagram is complete, fault tree analysis tools use analytical techniques to determine various risk-based metrics. Some examples of the results from FTA include:

- Unavailability
- Failure Frequency
- Mean Unavailability
- Number of Failures

Fault Tree Analysis can also evaluate Minimal Cut Sets (MCS). MCS analysis identifies all the individual event paths that will ultimately lead to the occurrence of the top-level event. The probability of each cut set is also determined. This qualitative approach to FTA provides valuable insights into your most at-risk events. You can then target your improvement and mitigation efforts in your most critical areas.

You can find a wide variety of publications online and in print that offer guidance on fault tree methodology. One of our most popular blog posts answers several key questions about Fault Tree Analysis.

Additional Tools for Safety Analysis

These tools, covered in other sections, can also be used for safety analysis:

- FRACAS (Failure Reporting, Analysis, and Corrective Action System)

The Benefits of Using Multiple Analysis Tools

All of the above-mentioned RAMS analysis tools can be used in a stand-alone fashion. However, using a combination of tools offers a well-rounded approach that enables you to deliver products with optimal reliability, availability, maintainability, and safety.

One reason to use multiple tools is to analyze your product throughout its lifecycle. For example, Reliability Prediction analyses and FMEAs can be done during the design process, in order to help make improvements before production even begins. During development and testing, Weibull and ALT analyses may be useful to assess product failure trends. Then once your product is in customers' hands, FRACAS can be used to capture, track, and manage failures that arise during use.

Overall, RAMS tools and techniques enable you to deliver high quality products. "High quality" is a general, sometimes nebulous, term, but is a good way to describe the overall goal of manufacturers and product designers. Whether reaching that goal means ensuring your MTBF is high, your system uptime is maximized, your product has a low risk of failure, or any combination of these, RAMS tools provide a way for you to achieve your objectives. Determine your particular quality objectives and select a set of RAMS tools that helps you meet them.

Conclusion

Delivering and supporting reliable, highly available, easily maintainable, and safe products and services is crucial to meeting or exceeding customer expectations and attaining high levels of customer satisfaction. By employing some of the most commonly used RAMS tools during design, development, and deployment, you can be sure you are achieving the reliability and quality your customers expect.

There are many organizations and materials available to aid you in establishing a reliability program or maximizing your existing processes. There is an annual RAMS Symposium which offers tutorial sessions, as well as technical papers on topics related to reliability and maintainability. You can also find a wealth of information at the IEEE Reliability Society and from ASQ (American Society for Quality). Of course, please feel free to contact us at Relyence. We more than welcome your questions and can help provide guidance as needed.