The value of RAM

Reliability, availability and maintainability analyses are set to become standard tools in all industries

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RAM analyses – already well established in safety-critical industries such as aerospace or nuclear power – are entering other industries with high pace. While process industries (eg, petrochemical, power plants, oil and gas, and refineries) deploy phased capital project execution methodology with gated transitions from one phase into the next, RAM modeling studies are gradually becoming a standard requirement for the front-end engineering design (FEED) phase deliverables. Based on international standards for RAM studies (IEEE 497, ISO 14224 and others), ABB's FEED delivery model is providing robust reliability and plant availability models in the design stages to mitigate operational headaches later on.

Historically, the design phase – FEED – of a capital project mainly focused on the engineering and design specifications of the equipment, eg, process capacity, design duty, heat and mechanical stresses. Reliability life-cycle studies were seldom performed. Designing for reliability is increasingly becoming mandatory and the results of reliability, availability and maintainability (RAM) modeling studies are critically evaluated in the "gate transition reviews" by the capital project management team.

There are various industry-accepted reliability tools and methods for a reliability professional to deploy. Each method has its applications and limitations. 1 shows the ABB recommendations for a typical capital project. The ideal time for a RAM study is just after the front-end conceptual design is complete, but prior to commencement of the detailed engineering phase. In the later phases, attempts to address the reliability issues are usually cost prohibitive and unfeasible. In short, RAM studies allow project teams to address the potential reliability design issues, bottlenecks, sparing and redundancy requirements before the detailed engineering and construction phase begins Factbox 1.

RAM studies start by developing a pictorial representation of functional interdependencies of the various assets and failure frameworks (commonly referred to as a reliability block diagram, or RBD). With the probability distribution of all states of these interdependencies, Monte Carlo simulations of the whole system provide the modeler with quantitative system-level reliability and availability estimates. The RAM study provides a statistical foundation for each asset's contributions to the overall system availability and reliability.

ABB Reliability Services offers a complete set of reliability tools and modeling services across the entire capital project management life cycle.

"Criticality analysis" is a ranking and categorization method for prioritizing assets based on consequence and probabilities of failures. The results are used to determine in broad terms the overall maintenance philosophy for the asset, such as run-to-failure, condition monitoring, time-based preventive strategies and continuous monitoring.

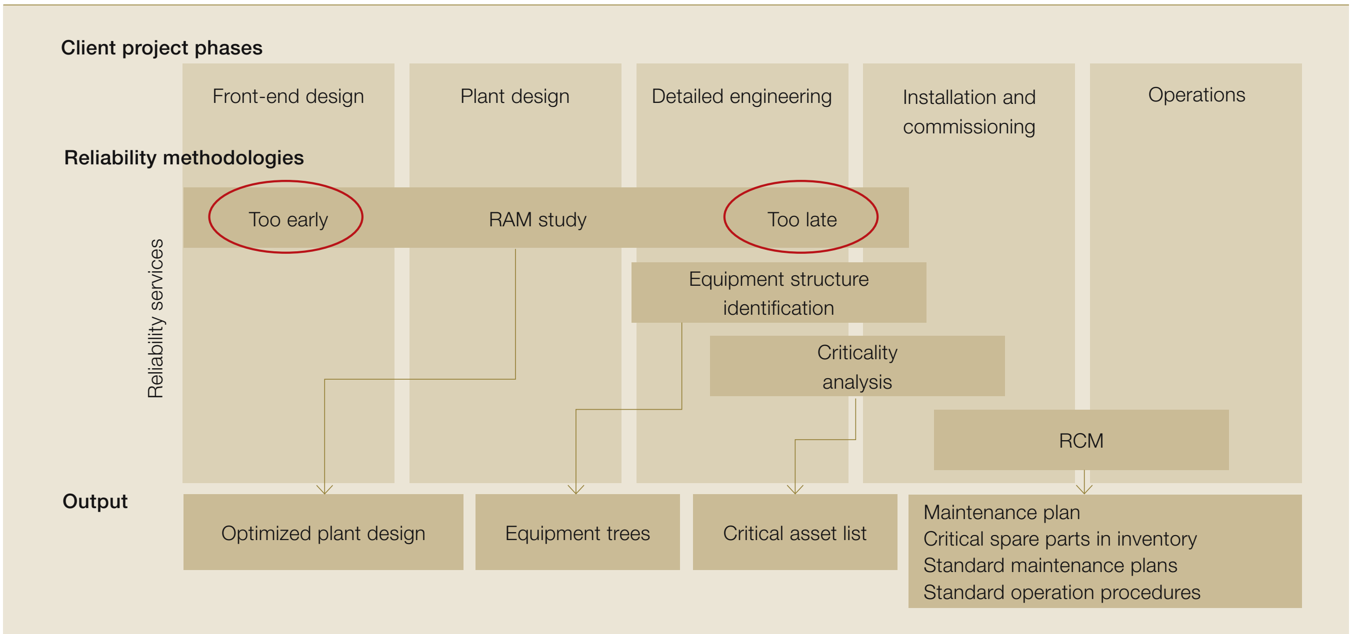
"Equipment trees" refers to the asset hierarchy structure in which all the operating assets are placed in a maintenance management system. The asset hierarchy is a graphical view that shows the relative placement of each asset in the overall system and site based on equipment functions, geography, location and importance. Hierarchical views are very good tools to perform detailed analyses for assets such as costs, reliability and downtime.

Factbox 1 The merit of RAM studies

The steps involved in RAM studies address a number of issues:

- Identifying potential bottlenecks (mechanical and process)
- Estimating the on-stream availability of the unit
- Outlining the planned and unplanned maintenance demands
- Developing optimum shutdown strategies (interval and duration)
- Analyzing the impact of various maintenance staffing loads
- Predicting the impact of equipment redundancy and sparing
- Developing mitigation strategies for expected failure modes
- Performing a preliminary equipment criticality analysis
- Optimizing reliability at the design stages by analysis of a wide range of scenarios

1 Reliability tools for a capital project timeline



Project design

Reliability-centered maintenance (RCM) is a structured reliability analysis to identify mitigation for each failure mode, cause and effect. It is typically performed toward the later stages of the capital project timeline to develop the detailed maintenance strategies, spare parts stocking and job plans for preventive and predictive maintenance. Usually, RCM is performed after the RAM, criticality analysis and equipment hierarchy studies are completed.

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Design for reliability

Engineers working on a capital project (ie, an electrical power distribution system or a processing unit) typically develop multiple design scenarios or options that meet the client's operational specifications. Each option or scenario is essentially a cost–reliability trade off. A highly robust and redundant system with standby equipment may be capitally expensive but financially attractive with regard to life-cycle costs, cost of operational downtime, lost profit opportunity, etc.

A RAM simulation study is ideal for analyzing and illustrating the business benefits of each design scenario. 2 shows the typical design-for-reliability tradeoff models for an electrical power distribution system for four loads. In this case study, RAM modeling was performed in accordance with the IEEE 497 specification, using the minimal-cut-set technique to determine the unavailability, number of outages and downtime for each point load.

The capital expenditure (CAPEX) for each of the design options is also determined. This allows the CAPEX project management team to perform a decision analysis based on the cost-versus-reliability tradeoff.

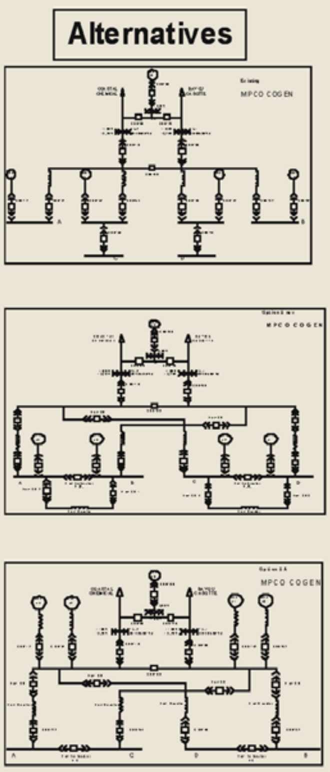
RAM – value drivers

RAM modeling is different from traditional process modeling, simulation modeling, linear program optimization or stochastic modeling. RAM modeling involves analysis of various failure-mode interactions of assets and focuses on identifying operational availability using Monte Carlo simulations. It is highly statistical in nature and requires the analyst to develop distributions for various input parameters. It allows sensitivity modeling – ie, varying the inputs across a range of values that are within the probabilistic range.

Other simulation methods and system process models may contain too many input parameters – failure rates, operational context, restoration times, logistic delays, spare parts availability or stochastic event occurrences – to provide any deterministic results.

RAM processes enable engineers to rank various design options and scenarios; evaluate the impact of future or proposed changes to current operations; allow modeling of spares and maintenance resource constraints; predict system uptime, downtime and slowdowns; and provide a strategic view of the asset's performance over longer time scales.

2 Design-for-reliability study of an electrical distribution system

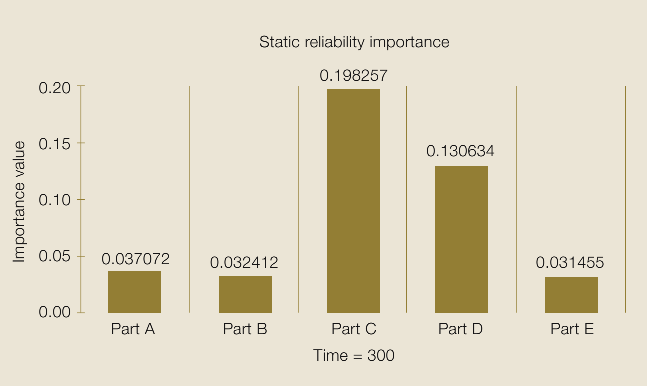


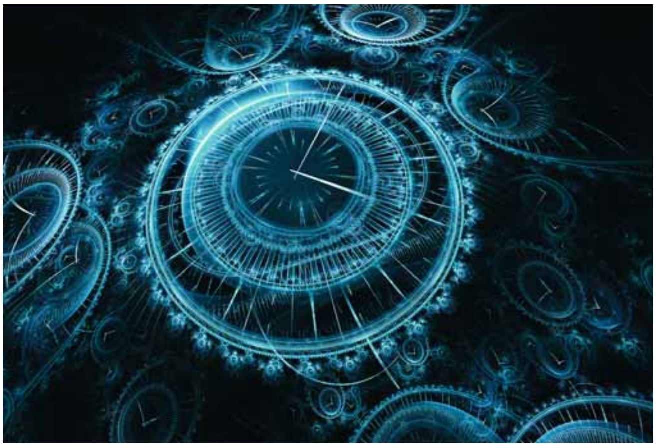
Results

Summary

Name/Location	Average Unavailability	Average Availability	Average Number of Outages 10yr Mission	Outages per Year	Downtime per Year (Hours)	MTBF	
		General Upgrade Cost = $ 650,000					
Sub A Load (Set 1)	0.0022622840	0.9977377160	7.8313	0.78313	19.8	466	Days
Sub B Load (Set 2)	0.0026185500	0.9973814500	8.9096	0.89096	22.9	410	Days
Sub C Load (Set 3)	0.0017560470	0.9982439530	6.3041	0.63041	15.4	579	Days
Sub D Load (Set 4)	0.0017599230	0.9982400770	6.3303	0.63303	15.4	577	Days
Option 8		Project Cost = $ 2,000,000					
Load (Set 1)	0.0002695524	0.9997304476	0.9183	0.09183	2.4	3975	Days
Load (Set 2)	0.0003160500	0.9996839500	1.0577	0.10577	2.8	3451	Days
Load (Set 3)	0.0001755474	0.9998244526	0.6248	0.06248	1.5	5842	Days
Load (Set 4)	0.0001768230	0.9998231770	0.6175	0.06175	1.5	5911	Days
Option 8A		Project Cost = $ 2,700,000					
Load (Set 1)	0.0002192446	0.9997807554	0.7603	0.07603	1.9	4801	Days
Load (Set 2)	0.0002659483	0.9997340517	0.9085	0.09085	2.3	4018	Days
Load (Set3)	0.0001290963	0.9998709037	0.4614	0.04614	1.1	7911	Days
Load (Set 4)	0.0001298799	0.9998701201	0.4676	0.04676	1.1	7806	Days

3 Reliability importance ranking chart for a system of five components





RAM studies can often answer the following questions:

- Which are the potential critical components and process bottlenecks?
- Which equipment has the highest risk of operational failures?
- What is the production and cost impact of adding or removing equipment?
- What are the "What-if" scenarios and their predictions?
- What are the potential single points of failure?
- What is the impact on system reliability and availability of varying duty cycles, service-life limitations, wear-out items, or environments and conditions?

The RAM process

To successfully utilize the RAM model, it is essential that all engineering disciplines have a sense of ownership and that the project team, including the operational and maintenance representatives, is completely engaged in the development of the model. The process outlined below involves a high level of consultancy approach and involves a high level of engagement.

The ABB RAM process involves completion of five basic tasks. The method is very simple, highly repeatable and reproducible. The key feature of this method is the requirement that the developed RAM model is "owned" by all disciplines – eg, process, electrical, mechanical, instrumentation, and project management. The work breakdown structure for each task of the ABB approach is shown in Factbox 2.

A RAM study is often viewed as a comprehensive risk analysis for the capital project that models the operational and reliability risk dimensions. It is a powerful tool for developing Six Sigma strategies, supply chain optimization (process reliability modeling) and world-class pacesetter turnarounds, and an excellent tool for incorporating design-for-reliability concepts in the capital project design.

Quantitative risk understanding

A RAM study is an excellent quantitative tool that provides the project team with numerically ranked indices and importance values for a system of components. 3 shows how the reliability importance of a five-component system has been analyzed for each failure mode. The reliability importance value for each component is a measure of its weight to the overall system's reliability value. In the system shown here, Parts C and D have the highest impact on the overall system's reliability. Hence, the designer may want to ensure that adequate redundancy, sparing and optimization be done on those components with

Factbox 2 ABB's RAM approach

1. Data collection
- Asset registry
- Equipment taxonomy based on structure, failure modes and maintainability
- Historical and estimated failure rates by failure modes
- Estimated restoration and repair times
- Mean logistic delay times (spare parts availability, crewing, resource availability, work planning, etc.)
- Asset-dependency identification (reliability networks) development
- Failure impact on production, throughput, safety, etc.
- Material damage mechanisms and their impact on asset life
- Preliminary preventive maintenance models

2. Review and block model validation
- Validating the block model with multidisciplinary team
- Identifying sensitivity parameters

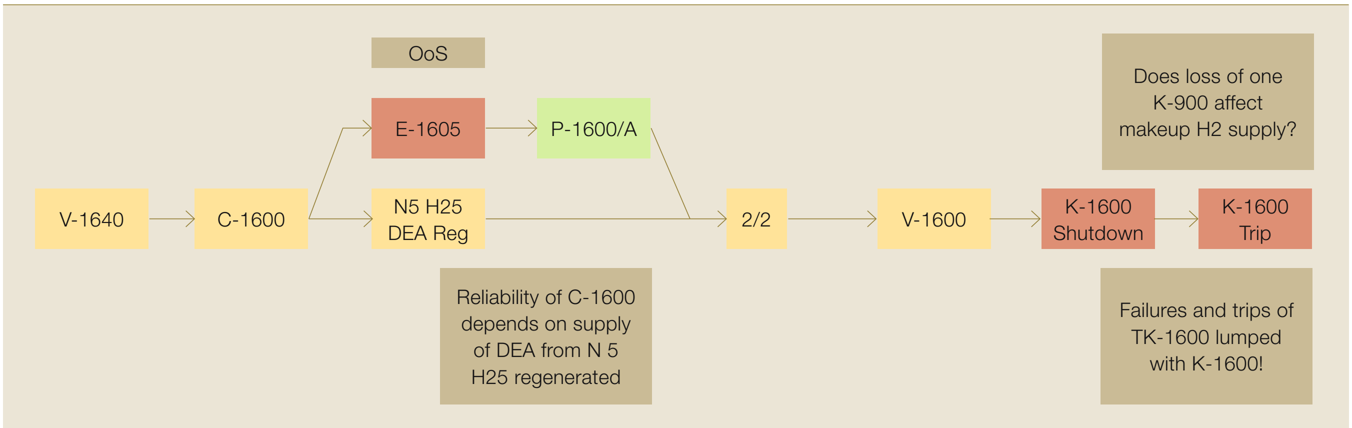
3. Modeling and simulation
- Performing simulations with various parameter input
- Developing scenario portfolios
- Identifying P10, P50 and P90 scenarios (probabilistic values of 10%, 50% and 90% likelihoods)

4. Validation and documentation
- Validating the final simulation results
- Documenting various scenarios: assumptions and probabilities

5. Report generation
- Developing time-based charts for reliability (probability of event occurring), availability (predicted uptime and downtime) and maintainability (predicted resource demands)
- Documenting bottlenecks: process, reliability and other events
- Developing impact curves on turnaround schedules
- Quantifying benefits for stocking decisions
- Projecting life-cycle costs
- Projecting maintenance staffing requirements

Project design

4a Typical reliability block diagram



the highest reliability importance.

Reliability block model
4a and 4b show a block model and simulation results (respectively) for a small section of a typical refinery unit. The unit has been synthesized into a number of characteristic blocks. RAM analysts use color conventions to depict the significance of each block on the RBD in terms of the block's operational impact, eg, complete shutdown, slowdown, partial shutdown, momentary trip, sustained outage and no impact.

4b Typical simulation results

General	
Mean operational availability (all events)	0.9387
Expected number of failures	23.05
MTTFF (Mean time to first failure)	158.3 days
System uptime / downtime / slowdown	
Uptime	1713 days out of 1825 days
Slowdown	90 days
Shutdown	22 days
System downing / slowdown events	
Shutdown	16.4
Slowdown	17.6

Experienced RAM modelers document the various scenarios and impacts of external factors on each of the blocks and employ various techniques, such as lumped failure blocks, container blocks, mirror blocks, phase diagrams, nodes, event blocks, asset blocks, clustering, shutdown posturing, load shedding, buffering, and resource constraints.

These are just examples of the methods to describe the risks of failures in a system. RAM models involve fairly complex simulations and are increasingly important decision-making tools for capital project execution.

ABB experience
A number of RAM studies carried out with demanding customers revealed several issues that are of critical importance for the success of a risk assessment for failures of complex systems.

A RAM study is not merely an engineering, number-crunching exercise, but a multi-disciplinary engagement activity where the various team members collectively represent the operational risk profiles and events to be modeled. It cannot be developed with a "silo" approach, but requires a high level of collaboration.

A RAM study is an excellent quantitative tool that provides the project team with numerically ranked indices and importance values for a system of components.

RAM analysis is an important FEED-stage gate deliverable in capital projects. The results can be used to make business decisions to select the best-case design scenario, estimate maintenance staffing decisions and properly estimate the long-term system availability and reliability.

RAM analysis is one of several tools and methods available to the reliability analyst. To develop a high reliability system design in the capital project, it should be applied in conjunction with other reliability tools, such as reliability-centered maintenance (RCM), failure mode and effects analysis (FMEA), criticality analysis, asset hierarchies or stress-life estimations.

Finally, to complete a thorough RAM study, it is important to ensure that all data to develop a comprehensive reliability block model are available. All operational modes, maintenance modes and sensitivity parameters must be simulated to provide a complete risk profile for the system. RAM studies for a typical processing unit or electrical- or gas-distribution system last from four to 10 weeks, depending on the level of complexity and assets.

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