CARE® apmOptimizer™

BQR Reliable Engineering Optimized Maintenance

Asset & Fleet Level Maintenance Planning & Optimization, Empowered by Lifecycle Cost and Reliability Engineering

PLM / SLM – Product / Service Lifecycle Management
Decision Support System for Asset Owners & Integrators

White Paper v5

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Key Words

I-IOT, sensors, Preventive Maintenance, Predictive Maintenance (PdM), Maintenance Plan, Prognostics & Health Management (PHM), Condition Based Maintenance (CBM), Risk Based Inspection (RBI), FRACAS, Root Cause Analysis, Reliability Block Diagram, Fault Tree Analysis (FTA), Failure Mode and Effects Analysis (FMEA), Mean Time Between Failures (MTBF), CMMS, EAM, ERP.

Introduction

Product and Service Lifecycle Management (PLM/SLM) is the new model by which enterprises manage their asset design and service.

PLM

Product Lifecycle Management (PLM) is a flow of complex engineering tasks starting from the definition of the product / asset requirements, and to the point where the asset is operating and the Service Lifecycle Management (SLM) begins.

The final outcome of the PLM process is a complete optimized maintenance plan of the asset, used as input for the SLM.

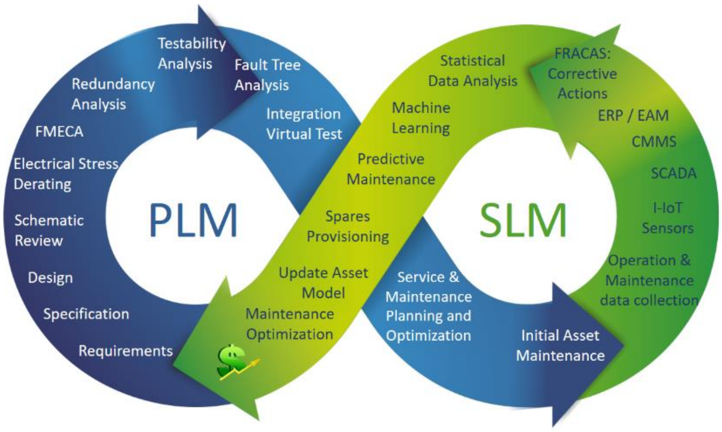
SLM

Service Lifecycle Management is a flow of tasks for servicing an operating asset. This includes inspections, preventive, predictive and corrective maintenance.

SLM and PLM are interconnected, each feeding the other. The asset operation is based on the PLM outcomes. The collection of data from the operating asset (SLM) is an important input for improving the maintenance and design of future facilities.

PLM / SLM flow includes many software tools for detailed electronic and mechanical design along with EAM, ERP and CMMS to manage the operation and maintenance. These tools are moving today from on premise implementations to cloud solutions. In addition, digitalization is used along with BI, AI and Machine Learning algorithms.

One of the hot technologies under the SLM umbrella is Predictive Maintenance (PdM). There are many solutions for PdM, where each is used for a specific type of component and industry, therefore, the results retrieved are also for each individual component. Asset owners are faced with hundreds of solutions, and may already have thousands of installed sensors, generating billions of data records. At the moment, they do not know what to do with the large amounts of data.



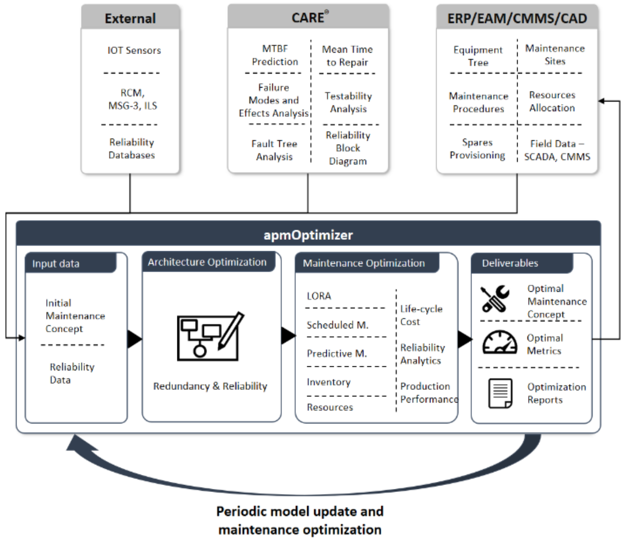
PLM-SLM flow

BQR is trying to position itself to help design a more robust system / product with a more efficient maintenance concept, and furthermore, to integrate in real time all results from sensors for asset level maintenance optimization. In addition to predictive maintenance, BQR's holistic solution also takes into account spare part quantities, spare warehouse locations, repair or replace policy, asset performance, and resources needed to support the maintenance infrastructure.

The starting point of modeling the product / asset is to build a model, which reflects the system characteristics, with its availability, reliability of the various components, the maintenance tasks needed to keep the asset running, turnaround-times and cost. The model name is Life Cycle Cost (LCC), and it is the main model that PLM / SLM tool providers should propose to their customers for asset level robustness, data driven decision making, and optimization.

Solution

The lack of LCC modelling tools, and the need for LCC optimization guided BQR to develop CARE, apmOptimizer and the BQR-Digital cloud. These tools assist in designing the best system / product, and the best maintenance policy to keep the asset constantly running, where all maintenance tasks are planned without any unexpected failures and stops.



BQR Solution for PLM / SLM

fiXtress:

fiXtress detects hidden design errors during the schematic phase of electronic circuits. It works as a plug-in with all popular CAD and EDA tools. fiXtress includes the following modules:

- ✓ Automated Schematic Review
- ✓ Automated electrical stress analysis and Derating
- ✓ Thermal analysis

CARE® (Computer Aided Reliability Engineering):

CARE is an integrated suite of software tools and a database that helps engineers carry out PLM tasks related to Reliability, Availability, Maintainability, and Safety (RAMS). The tools follow standard methodologies such as Failure Mode and Effects Analysis (FMEA) and Fault Tree Analysis (FTA). CARE includes the following modules:

- ✓ Mean Time Between Failures (MTBF) prediction
- ✓ FMEA
- ✓ FTA
- ✓ Testability Analysis
- ✓ Mean Time To Restore / Replace (MTTR)
- ✓ Reliability / Redundancy Block Diagram (RBD)
- ✓ Markov chain models

apmOptimizer:

apmOptimizer is an integrated solution for asset maintenance and logistics optimization, as well as for strategic decision making during asset design or overhaul.

Using the models produced by the CARE suite, together with maintenance, logistic and cost data, a complete asset behavior model is constructed. The model is then used to analyze LCC, and to optimize the maintenance plan.

apmOptimizer calculation types:

- ✓ Life-Cycle Cost calculation
- ✓ Performance (production)
- ✓ Sensitivity analysis for down-time drivers

apmOptimizer optimization modules:

- ✓ Repair or replace policy
- ✓ Spare parts (quantities, locations, shared / local)
- ✓ Scheduled Maintenance (optimal, task grouping)
- ✓ Predictive Maintenance (inspections, task grouping)
- ✓ Resources (manpower, tools, ATE and materials)

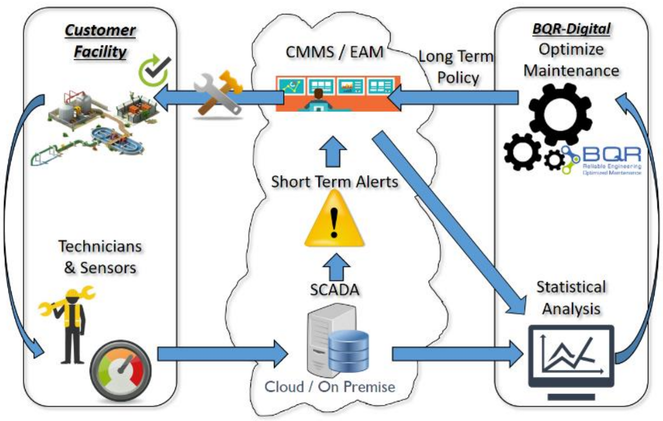
Result: Average saving of 35% on annual logistics and maintenance cost!
Asset expenses are divided to Capital Expenses (CAPEX), most of which are spent during the project stage, and Operational Expenses (OPEX) which are spent during operation and maintenance. A truly optimized design must account for the tradeoff between CAPEX and OPEX. This is achieved by optimizing for minimal LCC.

BQR-Digital FRACAS

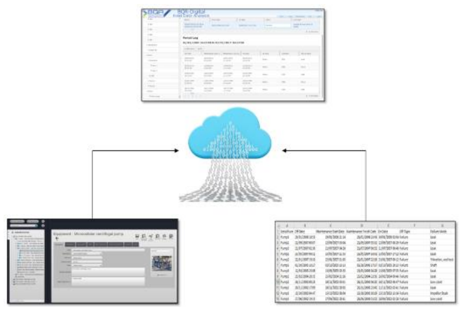
BQR-Digital servers host several applications, among them are the field data analysis and FRACAS tools.
BQR FRACAS collects failures and maintenance events (corrective and preventive). The data is then analyzed to produce failure and repair time distributions.

The output has two main uses:

- ✓ Predict Remaining Useful Life (RUL)
- ✓ Update apmOptimizer asset model and generate the Corrective Actions for improving the maintenance concept



BQR Cloud Based Maintenance Optimization



Data flow to BQR-Digital from many sources

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BQR products used in the PLM process:

During products development and design, several analyses should be done in order to verify that the final product is the most reliable and robust, and is ready to be manufactured:

Schematic Review- This analysis spots design errors which affect the Asset / Product safety and robustness. It consists of predefined rules based on experience and a wizard to define new rules.

Examples of rules:

- ✓ For electronics PCBs: Avoid floating ground
- ✓ For electrical design: Avoid over stress of electrical current in wires, which can cause a fire
- ✓ For mechanical design: Do not connect two metals with galvanic issues

Rules covering regulations and international standards:

- ✓ Reliability: Includes backup and redundancy for safety related systems
- ✓ Safety: Do not include safety functions and non-safety functions in one component
- ✓ Testability (Built-In Test - BIT): Verify that all DC/DC converters are tested in operation
- ✓ Maintainability: Do not combine a cheap component with high failure rate with an expensive component with a low failure rate

Electrical Stress Analysis and Derating- Calculates the actual electrical stress such as power, voltage and current, and checks if the stress is below a safety margin for high robustness.

MTBF Predictions

- ✓ Electronics
  Calculate components and assemblies MTBF and failure-rates based on Hierarchic-BOM, Operational/Non-Operational profile, environment, temperature and electrical stress.
  Predictions are based on various standards such as: Mil-Hdbk-217 F2 / G, Telcordia, IEC-62380, SN-29500, FIDES, HRD, and REL-Tools.
- ✓ Mechanical
  Calculates components and assemblies MTBF and failure-rates based on NSWC standard using exponential distribution, and the estimated failure time distribution for dynamic mechanical components such as: bearing, gear boxes using Finite Elements and Monte Carlo simulation.

Failure Modes Effects and Criticality Analysis (FMECA) - Specifies for each component, function (Hardware or Software) and signal the failure modes, their effects on the system level (bottom up analysis), and their occurrence probability. It also lays the basis for diagnostic and troubleshooting diagrams as well as Fault Tree Analysis (FTA).

- ✓ Identify and mitigate single points of failure
- ✓ Find key failure drivers
- ✓ FMECA method can be applied to safety, environment, and financial risk management

Fault Tree Analysis (FTA)- Is the calculation of safety event occurrence probability due to complex combinations of sub-events and end events (top down analysis).

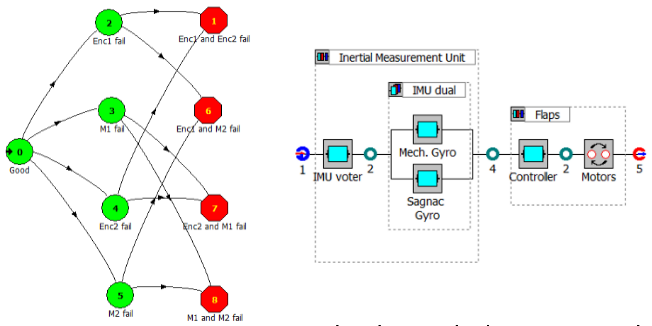
- ✓ Reduce probability of safety events
- ✓ Identify leading combinations of events that cause the top safety event
- ✓ Can be used also for troubleshooting

Testability Analysis- This analysis provides the guideline for designing BITs and verifying their ability to detect and isolate failures for on-line quick diagnostics.

- ✓ Identify failure modes which are not covered
- ✓ Identify failure modes with overlapping tests, that may reduce the possibility for failure isolation

Reliability Block Diagram (RBD)- Provides insight for system architecture to provide high asset Availability. This is achieved by analyzing the effects of backups and redundancies on the asset behavior.

- ✓ Allocates component failure rates during initial system concept design, useful for feasibility analysis and requirement definitions for subcontractors
- ✓ Calculates system availability, reliability, mean time to fail, and mean time to repair or replace during detailed design
- ✓ Identifies leading causes of downtime
- ✓ Optimizes redundancies (hot and cold)



Redundancy Block Diagram and Markov Models

BQR Tools for service planning:

Repair or New (Level Of Repair Analysis)- used for setting up the restoration logistics network including repair shops, spare part OEMs and warehouses. Originally developed for the defense industry, this analysis is useful for asset intensive facilities and fleets.

- ✓ Compare alternative logistics policies in terms of cost, turnaround time, and effect on system availability

Maintenance Plan:

Maintenance plan includes optimization of PM Schedule (Preventive Maintenance), inspections intervals, and sensors for monitoring:

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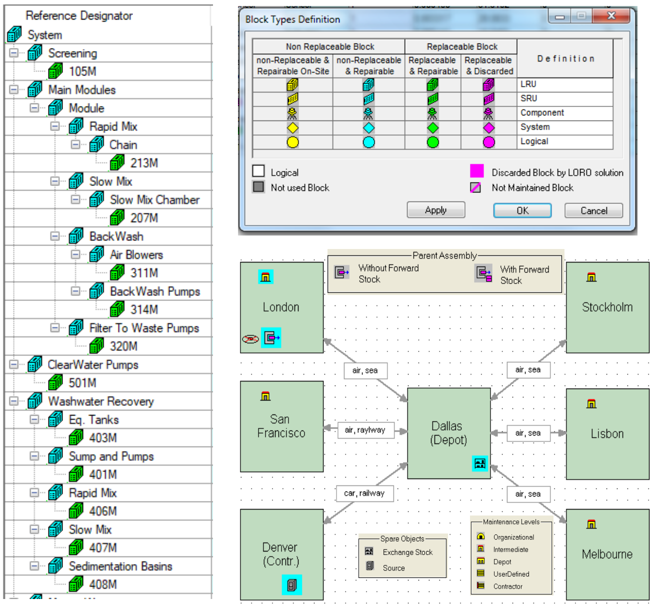
PM Schedule (Preventive Maintenance) - PMs are actions whose goal is to improve equipment state before the equipment fails (restore or replace). The optimal PM schedule should reduce the probability of equipment failures, move the maintenance team to a proactive track rather than reactive, and reduce maintenance cost.

- ✓ PM is only effective for equipment that ages (failure rate increases with the equipment age)
- ✓ Smart grouping of PM and inspection tasks can save a lot of time and money



Maintenance Concept

Predictive Maintenance (PdM)– The goal of predictive maintenance is to detect equipment degradation before unexpected failures occur. This is achieved by following an inspection schedule and / or by placing sensors (I-IoT) for prognostics and monitoring equipment health.

PdM Analysis considers the benefits and costs of various PdM strategies, finding the best one in terms of safety and ROI (Return On Investment).

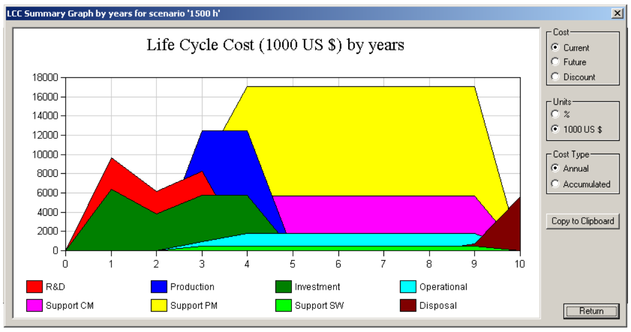
- ✓ Inspections are critical for safety related equipment and systems that may have hidden failures
- ✓ Although sensors provide real-time warning of approaching failure, they are not always the best solution. One must consider the sensors effectiveness, cost of installation, IT, data storage and analytics (often requiring a data scientist), as well as failures of the PdM system.

Spare Parts Inventory Optimization- The quantities of spare parts in each warehouse (central stocks and local warehouses) can have a significant effect on the asset performance. Delays in spare part availability and delivery can increase downtime and production loss. On the other hand, obtaining and storing more spare parts than needed increases costs. The optimization process is aimed at finding the most suitable combination of spare parts that will ensure the Availability of parts for the asset or fleet.

- ✓ While most spare part planners focus on preventing stock-outs, one should optimize for system/Asset availability.

Life-Cycle Cost (LCC)- Provides estimated cost for maintaining the system passed its expected life, including:

- ✓ Spare parts procurement and handling
- ✓ Resources for maintenance and inspections (manpower, consumables, support equipment)
- ✓ Production loss and environmental penalties due to equipment failure
- ✓ Collateral damage
- ✓ Transportation cost



LCC contributions by year

LCC analysis is very useful for:

- ✓ Identifying main OPEX and CAPEX drivers
- ✓ Preparing for expected expenses in advance
- ✓ Updating spare parts, maintenance and logistics policies in order to reduce LCC

BQR products used in the SLM process:

BQR-Digital FRACAS- Used for logging component failures as well as preventive and corrective maintenance actions. This is the basis for statistical analysis (fail and repair time distributions) and maintenance optimization.

Maintenance Optimization- Is obtained by periodically updating the LCC model, and repeating the optimization steps: Repair or Discard, PM schedule, PdM, and Spare Parts. It will assist asset owners with upgrades and renewing aged equipment's.

Root Cause Analysis (RCA)- BQR's FTA software can be used for RCA, helping to identify the drivers of failures and safety events. Results of RCA can be translated to design rules to be implemented in the Automated Schematic Review module and improve design of future systems.

Conclusions

The set of BQR software tools enables asset owners and integrators to design and build the optimal architecture. With BQR tools, any asset up time will be maximal with minimum investment and operational maintenance costs.

The use of BQR software tools reduces the asset design time, saves investment money, reduces the Life-Cycle-Cost and as well keeps the owner's profit high.

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