ASSET MANAGEMENT SUPPORTED BY RELIABILITY ENGINEERING

ZARZĄDZANIE AKTYWAMI, WSPOMAGANE INŻYNIERIĄ NIEZAWODNOŚCI

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Abstract: Reliability methods are widely applied in design and manufacturing. Techniques such as FMEA, Life Data Analysis (aka Weibull analysis), Reliability Growth, System Analysis and Simulation, and FRACAS amongst others, represent the foundation of a solid reliability program. The collection of these tools and the process of deploying them appropriately is known as DFR in the design and manufacturing sector. Some of these tools and methods have also been applied in the maintenance sector (operators vs. manufacturers), but in many cases not as extensively. In this paper we propose a process for deploying different reliability tools and methodologies and we review their applicability in Asset Management. The proposed Asset Performance Management Process is linked to the DMAIC process and was inspired from the very successful DFR process. The proposed APM process lays down the different APM stages and the corresponding activities within each stage that need to be performed in order to achieve and sustain high asset reliability and availability, as well as reduce the operating costs.

Streszczenie: Metody niezawodnościowe są powszechnie stosowane w projektowaniu i produkcji. Takie techniki jak FMEA, Analiza Danych Życiowych Life Data Analysis (zwana też analizą Weibulla), Wzrost Niezawodności, Analiza i Symulacja Systemu oraz FRACAS reprezentują podstawę solidnego programu niezawodnościowego. Zbiór tych narzędzi oraz proces ich odpowiedniego wdrażania jest w sektorze projektowania i produkcji znany jako DFR. Niektóre z tych narzędzi i metod znalazły zastosowanie również w sektorze konserwacji (między operatorami i producentami), lecz wielokrotnie nie w tak dużym zakresie. W niniejszym artykule proponujemy proces wdrażania różnych narzędzi i metodologii niezawodnościowych, a także omawiamy ich przydatność w Zarządzaniu Aktywami. Proponowany Proces Zarządzania Wydajnością Aktywów (APM) jest powiązany z procesem DMAIC i został zainspirowany bardzo udanym procesem DFR. Proponowany proces APM rozmieszcza poszczególne etapy i czynności powiązane z każdym etapem, które muszą zostać wykonane w celu osiągnięcia i utrzymania wysokiej niezawodności i dostępności aktywów, jak też redukcji kosztów operacyjnych.

1. Introduction

Reliability Engineering is a discipline that combines Practical experience, Maintenance, Safety, Physics and Engineering. In reliability engineering, observational data is combined with experience to create models in order to control the behavior of the equipment, optimize its performance, and minimize the Life Cycle and Operational Costs.

Fig. 1 Reliability Engineering

It is important to note that reliability engineering is not simply statistics, neither always quantitative. Even though the quantitative analysis plays a major role in the reliability discipline, many of the available tools and methods are also process oriented/related. It is therefore useful to separate these methods and tools into Quantitative and Qualitative categories. In the Quantitative category, the typical tools are:

- Life Data Analysis, aka, distribution analysis or Weibull analysis.
- Reliability Growth.
- Accelerated Testing, aka, Life-Stress analysis.
- System modeling (Reliability Block Diagrams).
- Simulation.
- Fault Tree Analysis.
- Design of Experiments (DOE).
- Standards Based Predictions.

In the Qualitative category, the typical tools are:

- FMEA/FMECA
- RCM
- FRACAS
- Root Cause Analysis (RCA).

In this paper we focus on the reliability engineering tools and methods, from the above list, that are most applicable in Asset Performance Management, and how and when each of them should be deployed in order to maximize their effectiveness.

2. The APM Process

Understanding when, what and where to use the wide variety of reliability engineering tools available will help to achieve the reliability mission of an organization. And this is becoming more and more important with the increasing complexity of systems as well as the complexity of the methods available for determining their reliability. With such increasing complexity in all aspects of asset performance management, it becomes a necessity to have a well defined process for incorporating reliability activities. Without such a process, trying to implement all of the different reliability activities involved in asset management can become a chaotic situation, where different reliability tools are deployed too late, randomly, or not at all, resulting in the waste of time and resources as well as constantly operating in a reactive mode.

Managers and engineers have come to this realization and a push for a more structured process has been seen in recent years. The circumstances are very similar to what happened with the "Quality Assurance" discipline back in the 1980s, which spawned successful processes such as *Six Sigma* and *Design for Six Sigma* (DFSS). In most recent years the same realization occurred in "Product Development" with the resulting *Design for Reliability* (DFR) process. It is thus natural that we looked into these successful processes in order to create a process for Asset Performance Management, and it's based on the DMAIC methodology. DMAIC is used for projects aimed at improving an existing business process, and includes five phases:

- **Define** the problem, voice of the customer and the project goals.
- **Measure** key aspects of the current process and collect relevant data.
- **Analyze** the data to investigate and verify cause-and-effect relationships. Seek out root cause of the defect under investigation.
- **Improve** or optimize the current process based upon data analysis and standard work to create a new, future state process. Set up pilot runs to establish process capability.
- **Control** the future state process to ensure that any deviations from target are corrected before they result in defects. Control systems are implemented - such as statistical process control, production boards, and visual workplaces - and the process is continuously monitored.

Starting from these process phases, we determined the asset performance stages within each of these phases, and we subsequently derived the reliability activities (methods and tools) as they pertain to asset management.

The proposed process can be used as guide to the sequence of deploying the different tools and methods involved in an asset reliability program in order to maximize their effectiveness and to ensure high reliability. This process can be adapted and customized based on the specific industry, corporate culture and other existing processes within a company. In addition, the sequence of the activities within the APM process will vary based on the nature of the asset and the amount

of information available. It is important to note that even though this process is presented in a linear sequence, in reality some activities would be performed in parallel and/or in a loop based on the knowledge gained as a project moves forward. The different phases of this proposed process and the activities within each phase are reviewed next.

Fig. 2 The proposed APM Process

3. Define Phase

The first step of any project is to define its objectives. It is a very key activity since in this step the requirements and goals will be defined. The activities performed in this phase will provide a direction for all future phases and activities to be performed. All too often projects are initiated without a clear direction and without a clear definition of the objectives. This leads to poor project execution. Therefore, it is essential that we:

- Define the Asset Performance/Reliability objectives.
- Define requirements and goals.
- Define the scope of the analysis.
- Determine budgetary and time constraints.
- Determine the recourses and their responsibilities.
- Plan activities and set criteria for success.
- Define the appropriate Key Performance Indicators (KPIs) for the organization.
- Define the KPI targets.

Define KPIs

A **performance indicator** or **key performance indicator (KPI)** is a measure of performance. Such measures are commonly used to help an organization define and evaluate how successful it is, typically in terms of making progress towards its long-term organizational goals.

It is very important that time is spent at the start of a project to define the KPIs that are important to the organization, as well as review existing performance indicators to determine their usefulness and/or how they are obtained. Reviewing and understanding the current indicators can also provide a benchmark for judging the success of a project.

KPIs can be specified by answering the question, "What is really important to different stakeholders?" As such, different levels of performance indicators can be specified, and aligned to the organization's business objectives.

Fig. 3 KPI Categories

Another aspect of the criticality of defining the KPIs at this stage, is the impact on the required data for obtaining these KPIs. In other words, the chosen KPIs will also determine which data and information needs to be reviewed or captured in the future.

Finally, it is also important to note that KPIs should be monitored, in order to assess the present state of the business and to assist in prescribing a course of action

4. Measure Phase

Prior to conducting any type of reliability analysis, it is important to collect all the required data and information. In addition, it is crucial to also determine what kind of data is available, and where they reside. The type of data and their availability will determine which analyses can be performed, as well as identify future steps for gathering the right type of data necessary. Therefore, the typical first step in this

phase is to perform a “Gap Analysis,” then we seek the Data, and based on the results of these two steps, we select the Appropriate Analysis techniques.

Gap Analysis

The purpose of a Reliability “Gap” Assessment is to identify the shortcomings in achieving the Asset Performance Management objectives so that a Reliability Program Plan can be properly developed. Many companies implement APM tasks without first understanding what drives reliability task selection. The “gaps” are those issues or shortcomings that, if closed or resolved, would move the company in the direction of achieving its APM targets. In addition, during this activity, the available data sources can be identified, and if inadequate, resort to other sources of information. During the gap assessment, answers to the following questions are sought:

- Identifying reliability activities currently in place. For example, is there an existing RCM available? Has it been successfully executed?
- What personnel are currently supporting reliability activity?
- What procedures document current reliability and APM practices?
- How is reliability data currently collected (e.g. CMMS, FRACAS, Production Losses, etc.)?
- How is asset reliability and performance currently computed (i.e. methods and tools)?
- Can we compute all the KPIs we defined?

Data

Data, and specifically Failure Data, worth gold to a reliability engineer. On the flip side, the more failures the worst the condition of the asset is. In any case, data represent the most important aspect in performing Quantitative analyses. It is thus crucial that data is collected and categorized appropriately. This data will be used in computing the different KPIs, as well as in performing a variety of reliability calculations.

In addition to Failure data, the Repair duration is also a very important input in the R&M model, since the availability of the equipment is dependent on it. By having this information, the availability of the system can be computed. In fact, the different types of data/information typically necessary for a thorough reliability analysis of assets are:

- Failure times/intervals.
- Repair durations.
- Failure codes/IDs (cause of failure).
- Current maintenance task types and intervals.

Additional information that would improve the analysis if available, include:

- Throughput/capability of each equipment.
- Repair Crew availability (e.g. number of crews and corresponding logistic delays).
- Repair Costs (parts, labor, etc.).

- Spare parts availability and costs.
- Inspection policies (e.g. condition monitoring).

There are multiple sources of data. For example, Failure data can be obtained from maintenance records (work orders, downtime logs, etc.), from OEM reliability specs, or from generic equipment data.

For existing equipment historical data can be used. There may be a great deal of historical data that has been generated over many years. It is necessary to find out where these data reside, and which data can assist in meeting our objectives.

Once the sources have been identified, the quality and consistency of the data must be analyzed. One of the most common problems is the quality of the collected data. All too often, even though records are kept, it turns out that the data are not really usable. Most common problems with available data include:

- Not specifying the cause of the failure (e.g. the component, the part, the equipment).
- Not having the appropriate system hierarchy in the CMMS for reliability data purposes. For example, in many CMMSs the asset hierarchy is setup in such way which prevents the “roll-up” of failure frequency information from the component to the subsystem to the equipment. So we can see that a “valve” failed for instance, but we cannot see where this valve belongs (for equipment level analysis). In addition, if there is another valve failure, the data analyst cannot determine if it was the same valve that failed before.
- No data tracking system.
- Poor implementation of work orders workflow. For example, work orders left opened much after the work has been completed, providing a false indication of repair duration if this data was taken as repair duration data.
- CMMS/EAM in place, but not capturing production loss data.
- Inspection data not captured (e.g. inspection intervals and results of each inspection). This data can be very useful in determining Safety Integrity Levels (SIL), and in Risk Based Inspection (RBI) methodology.

To prevent/avoid such problems, it is also imperative to implement actions for ensuring a good data collection process and management.

Assuming all the relevant information and data is available, then the System Availability, Downtime, Production Output (throughput), Maintenance costs, etc. can be estimated using Simulation.

Select Analysis Techniques

Selecting the appropriate analysis technique depends on the available data (determined previously), and on what needs to be optimized (specified in the Define phase).

5. Analyze Phase

Depending on the previous results, the appropriate analysis should be executed in order to optimize the performance of the asset.

In the next sections we will present the objectives, applications and benefits of each analysis that can be used in Asset Performance Management

RCM

Reliability Centered Maintenance (RCM) analysis provides a structured framework for analyzing the functions and potential failures for physical assets in order to develop a scheduled maintenance plan that will provide an acceptable level of operability, with an acceptable level of risk, in an efficient and cost effective manner.

RCM can be:

- Quantitative and based on the reliability analysis (as explained in prior sections).
- Qualitative, following a strict step-by-step methodology as dictated by many RCM probationers.
- A combination of both of the above.

A lot has been written on RCM methodology and its benefits, and it's outside the scope of this paper to get into the details. However, it's worth mentioning some of the widely accepted benefits of RCM, which include:

- Prioritize actions based on equipment criticality (multiple criticality classifications exist).
- Reduce and ultimately eliminate chronic failures and reliability problems.
- Document maintenance program and practices.
- Reduce unscheduled maintenance.
- Reduce risk.
- Document reasons for current activities and for future changes.

Life Data Analysis

Life Data Analysis refers to the application of statistical methods in determining the behavior of the life of equipment based on life data. Life Data Analysis utilizes sound statistical methodologies to build probabilistic models (i.e. distributions) from life data, such as Weibull, Lognormal, etc. The models are then utilized to compute the item's reliability, make predictions, as well as revise or determine maintenance policies and maintenance task intervals. These models should be applied at the Lowest Replaceable Unit (**LRU**) level.

Benefits:

- Understand failure patterns.
- Understand life expectancy of components.
- Understand repair duration patterns.
- Use these models in the RAM analysis.
- In next phases of the APM process (Improve) utilize the results of this analysis for spare part provisions, determine optimum maintenance intervals, make design changes, etc.

Fig. 4 Statistical Distribution fitted to Failure Data

Degradation Analysis

Another way of obtaining reliability metrics involves a type of analysis known as “degradation analysis.” Degradation analysis involves the measurement and extrapolation of degradation or performance data and can be directly related to the presumed failure of the item in question.

Many failure mechanisms can be directly linked to the degradation of part of the product. Assuming that this data is captured (CBM data), degradation analysis allows the analyst to extrapolate to an assumed failure time based on the measurements of degradation or performance over time. This analysis essentially determines the P-F curve, and the results can be used to:

- Understand failure patterns
- Understand life expectancy of components
- Build life distributions, which will be later used in the RAM analysis and optimizations (Improve phase).

Recurrent Events Data Analysis

The Recurrent Event Data Analysis is different than the “traditional” life data analysis (or distribution analysis), as it’s applied on equipment and system level data. In other words, the data is used to build a model at the Equipment, rather than the component/part level. In Distribution analysis, time-to-failure is used,

where each failure represents an independent event. In the Recurrent Events Data analysis, the cumulative operating time and the cumulative number of events are data utilized. The models in this case are used to track the behavior of the “Number of Events” over time and understand the “Effectiveness” of repairs. The most commonly used models for analyzing Recurrent Event Data are the NHPP and the General Renewal process (GRP).

System Modeling/RAM Analysis

An RAM analysis typically starts from the creation of a System Diagram, which represents the overall process and the corresponding major subsystems. This diagram is known as a Reliability Block Diagram (RBD).

The next step is to expand the major subsystems into subsubsystems, and keep repeating until the level where reliability information is available (ideally at the LRU level) has been reached.

The analysis will be based on the configuration (represented by the diagrams) of these items, and their Failure and Repair duration properties. The Failure properties (i.e. Reliability) determine the frequency of occurrence of failure of each LRU, and the repair duration determines the downtime. Based on the configuration the effect on the overall system is determined. The effect on the overall system could be that the whole system fails, or a percent reduction in the total output of the system (throughput).

To perform a complete RAM analysis, the following data and information is required:

- System Diagrams/Drawings (P&IDs).
- Failure data.
- Repair duration data.
- Process capabilities of individual machines.
- Repair costs.
- Maintenance types and intervals.
- Repair Crew availability (e.g. number of crews and corresponding logistic delays).
- Spare parts availability and costs.

The results of such an analysis include (at different levels, e.g., asset, equipment, etc.):

- Availability
- Downtime
- Number of failures
- Spares usage
- Production output
- Life Cycle Cost

Having this model will allow us in the “Improve” phase to perform “what-if” analyses and investigate the effect on the above results of any proposed changes/improvements.

Root Cause Analysis

RCA is a methodology to logically analyze failure events, identify all the causes (physical, human, and primary) and define corrective actions to prevent their reoccurrence. It is a critical activity in understanding failures and being able to determine corrective actions. Without a formal RCA procedure, the wrong remedies might be frequently implemented.

Improve Phase

The main objective of an APM process is to drive improvements, thus this phase represents the most critical step. During this phase the objective is to identify the improvements that can increase the performance of the asset and optimize it, including:

- Define the most appropriate maintenance policy.
- Determine the optimum maintenance task intervals.
- Determine adequate spare part provisions.
- Apply design changes when it's necessary/feasible.
- Drive new requirements to suppliers.
- Add to the simulation cost information to run a dynamic life cycle cost (LCC) analysis.

In the case of optimizing the interval of performing a Preventive Maintenance action (PM), the following equation is used:

$$CPUT(t) = \frac{C_P \cdot R(t) + C_U \cdot [1 - R(t)]}{\int_0^t R(s) ds}$$

where:

$R(t)$ = reliability at time t . This is determined by performing the Life Data Analysis, using the data described in Section “Data”.

C_P = PM Cost per Incident (planned maintenance)

C_U = CM Cost per Incident (unplanned maintenance)

The equation is solved for time, t , that results in the least possible cost per unit of time.

Fig. 5 Optimum PM Interval

6. Control Phase

Every time the APM process is initiated, it is imperative to execute activities which can Sustain the achieved results. As such, certain activities to monitor and control the performance need to be applied, including:

- Implement the new maintenance tasks and new intervals into the CMMS.
- Seek continuous improvement, i.e., new KPI targets can be defined and monitored
- Monitor the asset's performance. Reliability growth analysis needs to be implemented. For example the Crow-AMSAA model is typically used to model the reliability performance of the asset(s) over time (e.g., month-to-month).

Another critical function in this phase, is sustaining the knowledge acquired by all previous activities, as well as retaining the information that have lead to a particular action/change. Failing to retain this knowledge can lead to “re-inventing the wheel” down the road, as well as repeating past mistakes. Different activities (including analysis, action plans, and decisions) should be registered properly and stored in a location where other professionals involved in the asset's management can access in the future.

7. Summary

In this paper we reviewed the role of Reliability Engineering in Asset Performance Management, and we proposed an APM Process for deploying all the different tools and methods available. The proposed process is based on the DMAIC methodology, and lays down the steps and activities for a more formal and structured deployment of the different reliability tools and methods, where they can be most effective. The process is general enough to be easily adopted by different industries and to use in conjunction with current reliability practices.

8. References

- [1] *Developing Performance Indicators for Managing Maintenance*, Terry Wireman, 1998
- [2] *Life Data Analysis Reference*, ReliaSoft Publishing, 2005
- [3] *System Reliability Reference*, ReliaSoft Publishing, 2007
- [4] Mettas, A., and Zhao, W., "Modeling and Analysis of Repairable Systems with General Repair," RAMS January 24-27, 2005, Alexandria, VA.
- [5] www.weibull.com