

# Asset Management and Cost Saving Maintenance Strategy based on Risk-Informed Decision Making

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**Abstract** – “Globalization”, “increased competition”, and “international business” are keywords to characterize the present development on a world wide market. A company’s ability to realize innovative concepts, while meeting national and international standards will be decisive to satisfy the progressive demands on competitiveness. Process-specific control and operation concepts in combination with a sufficient maintenance strategy significantly influence the economic efficiency of a plant in the same way as the quality of its output. Present-day plant management requires an integral approach to enable decision making, considering the interaction between different systems and all significant influencing variables with respect to cost-effectiveness. To actively drive the plant’s assets and to keep the operation of the plant within an acceptable risk adapted probabilistic reliability and risk assessment methods will be presented to provide a solid foundation for decision making in a wide range of usage for asset management and maintenance optimization tasks. Examples demonstrate the benefit.

**Index Terms** — Risk Management, Risk Based Inspection, and Maintenance, Risk Assessment, RIMAP.

## I. INTRODUCTION

Process-specific control and operation concepts in combination with a sufficient maintenance strategy significantly influence the economic efficiency of a plant in the same way as the quality of its output. Present-day plant management requires an integral approach to enable decision making, considering the interaction of different systems as well as different phases during the life cycle of a plant with respect to cost-effectiveness.

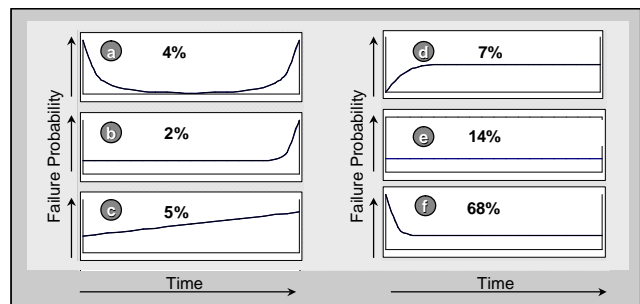
Today, efficient procedures are available for an integral optimization of maintenance, which not only include in-service inspection and maintenance aspects but also measures affecting organizational and operational matters as well as considerable interfaces [1]. The latter is an important issue for the assessment of hazardous equipment, when it becomes necessary to determine the performance of safety and operational control systems.

Here, special emphasis must be given to the overall risk, which shall now be the foundation for decision making. It is important to emphasize that in this context the term “risk” is not limited to a risk concerning safety but also shall be related to a

risk concerning availability, reliability and ultimately money. Therefore the basic question may be: How and with which costs is it possible to keep the operation of a system within an acceptable risk, considering safety as well as business issues?

As risk is defined as the combination of the probability of a failure (PoF) and the consequence of the failure (CoF) it enables a wide range of applications to improve the effectiveness of measures.

On both sides, PoF and CoF, some remarks shall be made. Regarding the failure probability it is often assumed that systems and components follow the well known failure behavior of the bath tube curve as shown in Fig. 1a.



**Fig. 1** Typical failure behavior with respect to time, Source: Aviation, compare [2]

Problems, both at the beginning (teething problems) and at the end of the life cycle (ageing problems) are characteristic for this model. Combined with the typical time related trendable failure mechanisms (Fig. 1c) these models are the basis for performing periodical measure like interval based in-service inspections or the substitution of equipment.

That this is not necessarily the optimal method, is outlined by an investigation conducted by the aviation industry. As the airlines realized that shorter intervals and the increase of measures did not result in better reliability, a detailed investigation was performed. One big conclusion was that the group installed identified six different failure characteristics (see Fig. 1). Beside the already discussed characteristics there is also a behavior, which is purely stochastic (Fig. 1e) or stochastic with teething problems (Fig. 1f). When looking at the percentage numbers, it becomes clear why e. g. shorter

intervals are not suitable in this case. In 89% of all systems in an aircraft no specific end of life can be identified. Therefore, only time based methodologies will bring no positive effect. On the other side, due to the fact that 72% of the systems show a behavior with teething problems, it becomes clear that maintenance measures can create a lot of problems, which may compensate the estimated positive effects. This is also known as the "burn-in" effect and is caused not only by problems with the new component itself but also by failures during dismantling or reassembling. Here, e. g. the optimization of the spare part concept is more suitable to reduce the consequences of those random failures than a classic in-service inspection methodology.

Additionally on the consequence side it is necessary to consider the impact of a failure. Here it is required to clearly identify the operational circumstances a certain component is subjected to. Basic issues of interest may be redundancies or safety related instrumentation, but also secondary measures like fire-extinguishing systems, access control and so on to minimize the safety as well as the business consequences of an undesirable event.

In order to realize an economic maintenance strategy, methods having an integral approach as mentioned before are increasingly applied. Risk-informed decision making also becomes more and more significant due to consequent consideration in national and international codes and standards (see for example [3], [4]). Furthermore, specific requirements for certain components are already identified by using more or less risk-informed procedures (e. g. [5], [6], [7]). "RIMAP" [8] [9], launched in 2001, is a European effort to establish a framework for risk assessment for various industries as well as industry and component specific tools. The final target is to establish a European Guideline, for which the CEN workshop agreement is already on its way.

So the opportunity emerges to question, whether former cost intensive procedures including regulatory issues are still up to date with respect to the real needs of the industry. For this purpose, comprehensive and transparent solutions must be generated especially when dealing with tasks, where regulatory issues are concerned.

## II. THE GENERAL METHODOLOGY

By using risk-informed decision making, not only the number of failures within a considered period (PoF: Probability of Failure) but also the direct and indirect consequences of failures must be considered. The consequences may be measured in terms of damage to the health and safety of employees or public, damage to the environment, and financial damage to the company due to loss of production, repair and replacement of equipment. By defining risk as a product of failure probability multiplied by the consequences the term risk is not restricted to safety related questions but can also be applied to the assessment of principle design or modifications from an economic point of view.

Fig. 2 shows the well known risk matrix, which is still the tool to plot the results of a risk analysis. However, the measures and acceptance levels resulting from the risk assessment must be tailored to the specific task and targets to be achieved [10]. Basically in the area where adapted measures shall be installed,

the optimized mixture between existing strategies, like interval-based, condition-based or corrective procedures can be identified using the information regarding risk-level but also PoF and CoF. Therefore also falling back to corrective measure is part of the discussion especially for components in the "dark green area".

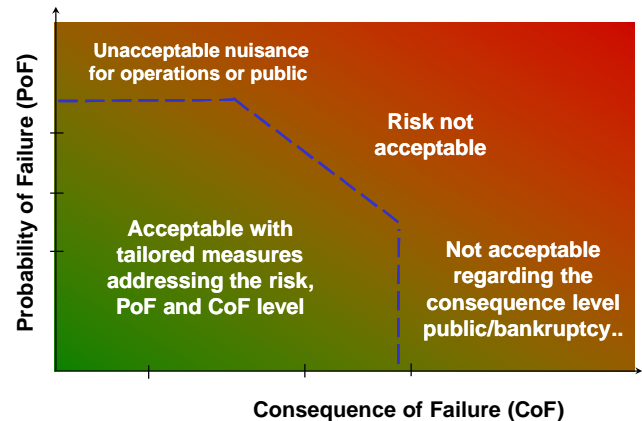


Fig. 2 Risk as deliberate assessment criteria

However, the entire process and the used procedures and techniques should be embedded in a risk management system (compare Fig. 3). In RIMAP [8] this is called the framework.

Herein, the main goals, tasks, and responsibilities should be clearly identified and documented during the preliminary analysis. As risk informed inspection and maintenance planning is a multidisciplinary task, it requires a team where many competencies are represented and expertise are available (e. g. DIN EN ISO/IEC 17020 [11]).

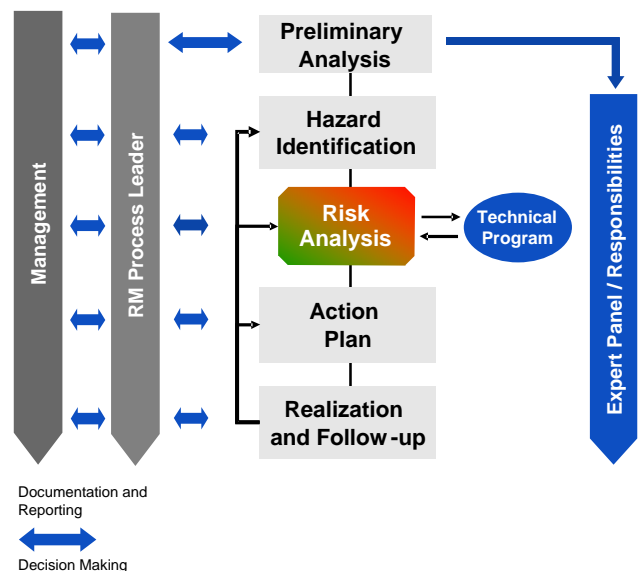


Fig. 3 The Management Process

Regarding the specific technical program, it is necessary to provide industry specific as well as component specific knowledge and tools how to handle the problems to be considered in a risk informed environment to come up with a detailed action plan. Due to the fact that the procedure presented is valid for long term as well as short term planning, it must be clear that the follow up due to the assessment of new information resulting from these measures is an important prerequisite as well as to monitor the important parameters with respect to the boundary conditions originally chosen for the analysis. Therefore recurrent work is necessary to make sure that the entire process runs into a closed loop.

Coming back to the specific technical program to be chosen, Fig. 4 demonstrates that there are various tools available for each step to be performed. Depending on the targets identified in the preliminary analysis, the most suitable methodologies and measures shall be applied.

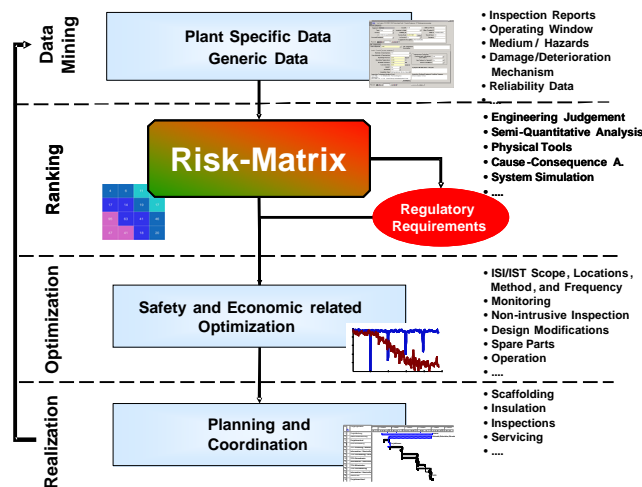


Fig. 4 The technical program

In the following chapter some examples will demonstrate the various possibilities and benefits using the approach described above.

### III. APPLICATION EXAMPLES

#### A. Example for the prolongation of the time between two time consuming shut-downs

##### 1) The situation

For pressurized technical equipment in Germany falling under the scope of the German in-service inspection code (BetrSichV, [12]) usually a 5 year interval for internal inspections is required.

- §15 (1) *Der Betreiber hat die Prüffristen der Gesamtanlage und der Anlagenteile auf der Grundlage einer sicherheitstechnischen Bewertung zu ermitteln.* (The operator of a plant has to determine inspection intervals for the entire plant and its components on the basis of a safety related assessment).

- §15 (9) *Bei Druckbehältern müssen Prüfungen von ZÜSen durchgeführt werden; innere Prüfung spätestens nach fünf Jahren und Festigkeitsprüfung spätestens nach zehn Jahren.* (For pressure vessels inspections have to be performed by ZÜS organisations)
  - internal inspections latest after 5 years
  - strength tests latest after 10 years

These requirements also influence the entire operation period for plants in continuous operation, where generally a big shut down not later than every 5 years is the consequence. However it is sometimes necessary to have either more flexibility in doing these inspections or simply to try to avoid or reduce the interruption of the production due to these shut downs in total.

##### 2) The task

So for a specific chemical plant in continuous operation the task was to create an inspection philosophy and a detailed inspection plan to avoid the big shut-down after 5 years and run into a 10-year period without any shut-down due to inspection requirements.

##### 3) The track

Opening paragraphs in [12] generally provide the flexibility necessary if the procedure is accepted by the "Zugelassene Überwachungsstelle (ZÜS)":

- §15 (10) *Bei äußeren und inneren Prüfungen können Besichtigungen durch andere geeignete gleichwertige Verfahren und bei Festigkeitsprüfungen die statischen Druckproben durch gleichwertige zerstörungsfreie Verfahren ersetzt werden, ....* (External or internal visual inspections can be substituted by other adequate measures and regarding the strength test the hydro-test can be substituted by adequate NDT-methods, ....)
- §15 (17) *Die zuständige Behörde kann die genannten Fristen im Einzelfall verlängern, soweit die Sicherheit auf andere Weise gewährleistet ist, oder verkürzen, soweit es der Schutz der Beschäftigten oder Dritter erfordert.* (The regulator can case by case extend the periods, if the safety can be guaranteed in an adequate manner reduce these periods, if it is required to guarantee the safety for staff and externals)

In general, demands have to be related to the consequences for staff and public as well as to the probability of the corresponding failure. As described above this is exactly the definition for risk and therefore risk-oriented procedures are suitable for the task described. In the specific problem, it was chosen to follow the way described in §15 (10) of BetrSichV and therefore it must be demonstrated that the measures in substitution and in addition to the internal inspection over the ten year period create the same confidence as the regular internal inspection after five years.

To establish the specific tasks and to get a solid acceptance level at all parties involved, it was decided to use a procedure in compliance with the requirements of RIMAP [8]. The principle strategy was to perform several

assessments to compare the original situation with the new situation, while demonstrating that by installing additional measures during the next shut down and during the entire ten year interval, the risk level is comparable to the one for the original situation and within an acceptable range.

Especially for the PoF evaluation, it is very important to start early in advance of the next regular shut down and to have risk plot available to carefully plan the actions during the shut-down. This is necessary to increase the confidence level regarding the assumptions to be made. These are for trendable deterioration mechanism:

- deterioration mechanisms acting
- actual state of degradation
- degradation rate

If non-trendable degradation mechanisms are identified, sufficient monitoring systems have to be identified and/or safety systems and requirements have to be installed in addition.

A basic issue in CoF evaluation is the assessment of the principal hazards of a certain component as well as the assessment of all safety measures installed to realize that something is going wrong and to minimize the results of a undesirable event.

#### 4) The benefit

Fig. 5 shows the risk levels for the component type heat exchanger for the old interval of 5 years as well as for the new interval of 10 years including the additional NDT measures as described above.

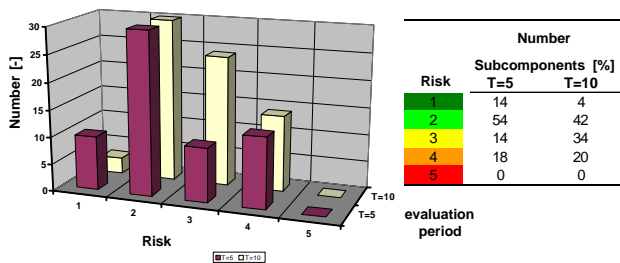


Fig. 5 Comparison of risk level for T=5 and T=10 years

According to the results it was agreed by all parties involved that the 5 year shut-down consuming approx. 4 weeks can be avoided by installing the measures identified (see Fig. 6).

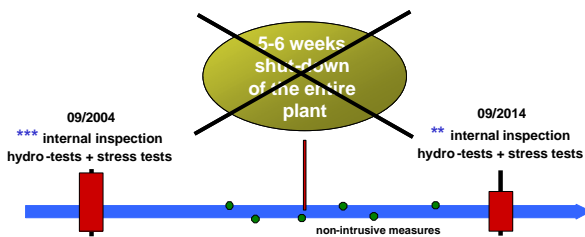


Fig. 6 New principal time schedule

In the meantime the third train of the plant is in the pipeline due to the enormous economic advantage. For more information regarding the methodology and the special application see [13] and 14].

### B. Example regarding a power supply unit in a chemical plant

#### 1) The situation

For an auxiliary steam generating unit in a chemical plant the task was to increase the availability for a long term use as well as per demand by developing an optimized maintenance strategy. Until now the system was only in operation for some days a year. The availability of the system should be optimized with respect to the inspection and test frequency, repair and replacement measures as well as specific testing procedures and the quality of the components to be used.

#### 2) The track

To simulate the behavior of the system, 287 Elements were used. In Fig. 7 the principal block wiring diagram for the entire system is shown together with the detailed modeling of the I&C.

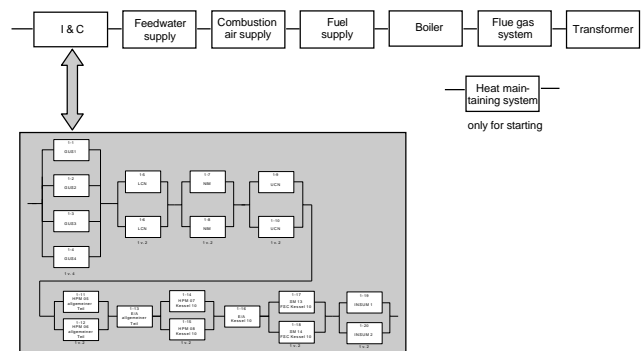


Fig. 7 Block wiring diagram

#### 3) The results

In the following Fig. 8, the influence of the different modifications on the reliability of the entire system is summarized. Starting from the basis – 3 years without inspection, as it was done until now – the most important improvements are given by the increase of test starts. The influence of the quality of the most important components (improved MTBF) and the influence of extended working time (shift at night = MTTR = 50%) are the next in the ranking. Not so satisfactory was the additional redundant design of the I&C.

| Failure Rate      | Basis: 3 years without inspection | 4 x more test-start | 2 year inspection interval | Improved MTBF 10% | Improved MTTR 50% | I & C redundant | annual burner test: inspection 2 year interval |
|-------------------|-----------------------------------|---------------------|----------------------------|-------------------|-------------------|-----------------|--|
| Startsystem       | 13,2 %                            | 5,8 %               | 10,4 %                     | 9,7 %             | 11,2 %            | 12,1 %          | 5,7 %  |
| Production-system | 3,7 %                             | 1,9 %               | 2,7 %                      | 2,1 %             | 2,8 %             | 3,3 %           | 1,2 %  |
| Per Demand        | 1,6 %                             | 1,2 %               | 1,2 %                      | 0,9 %             | 1,0 %             | 1,4 %           | 0,7 %  |

Fig. 8 Results

The operator decided to apply a combination between the increase of test starts for the burner combined with a two

year inspection interval for the other components. This resulted in an accepted improvement of the reliability of the total system.

### C. Example regarding operational management

#### 1) The situation

An in-house energy supplier has to ensure a high availability of electrical energy for certain power consumers. For this purpose use was made of external as well as internal generated electricity. Most of the electricity generated was supplied to a central distribution station and from there distributed to the individual consumers. Due to losses in production caused by power failures, a risk informed assessment should identify the weak points and act as solid basis for the optimization.

#### 2) The track

The simulation was performed for the entire system. Records regarding all events from the past couple of years were evaluated and assessed. The basic input data for the system simulation could be extracted (see Fig. 9).

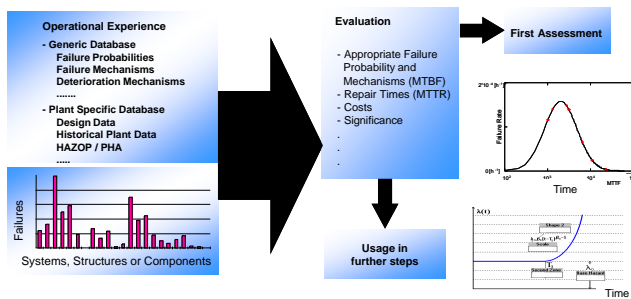


Fig. 9 Data assessment

#### 3) The results

The simulation showed clearly that the failures were primarily caused by the electricity distribution (see Fig. 10), and here mainly by human errors in the required switching operations. It was found that this failure was caused by an unsatisfactory ergonomic design and by failures in the written procedures.

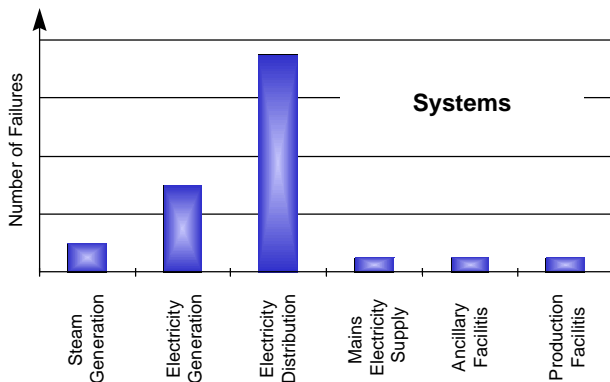


Fig. 10 Significance of the systems considered

### D. Example for the application of IEC 61511

Risk-informed decision making is also an integral part of standards concerning the functional safety of electrical, electronic and programmable electronic (E/E/PES) like IEC 61508 [5] or IEC 61511 [6] (IEC 61511 implements special requirements for the process industry). "Functional safety" is the part of the overall safety relating to the process and the process control system which depends on the E/E/PE safety-related systems, but also on safety-related systems using any other technology or external risk reduction facilities. That is, the IEC requires an overall hazard and risk analysis as starting point for deriving special requirements on E/E/PES.

These special requirements are called "safety integrity requirements", where safety integrity is defined as the probability of a safety-related system satisfactorily performing the required safety functions. To characterize the "level of quality" of a system the safety integrity levels (SIL) are introduced, again in a quantitative way.

From this it becomes clear that the procedure described above fits exactly the requirements of the IEC: In both cases we have to consider hazards and consequences first, i.e. risks. Moreover, we can identify the potential of risk reduction for systems of "other technology" or "external risk reduction facilities", as IEC calls it. Of course, due its nature IEC gives no detailed requirements for these "non-E/E/PE-systems". However, as described above, the integral and overriding view guarantees that all systems are treated on a common basis and means that the necessary "extent of risk reduction" for all these systems can be estimated much more effective now – including E/E/PES. Therefore the hazard and risk analysis required by IEC may not be a "stand-alone" solution just for process control systems but can be integrated within the framework of the overall risk assessment.

For an application example see [15].

## IV. CONCLUSIONS

Availability and safety of plants and the related cost efficiency and quality of the products are influenced by many factors. Without an integral approach, adapted tools and appropriate knowledge in the disciplines required, it is not possible to judge the consequences of singular measures, sufficiently. The presented risk-informed method is able to ensure an integral plant assessment, where all sufficient factors can be considered by applying adopted procedures. So, maintenance strategies can be developed with a focus on safety as well as on economic aspects.

The main objectives can be either one or more of the following aspects:

- high operating reliability
- high availability
- high procedure- and process safety
- estimation of life-cycle expenses
- realistic estimation of technical problems, incidents, ...
- avoiding unnecessary redevelopment and replacement measures

- understanding the actual aging processes
- cost/economic operation
- ....

In order to establish a successful risk-oriented maintenance program, it is strictly necessary to install the required risk management processes and to ensure the acceptance of the methodology on a high level.

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## VI. VITA

Robert Kauer (Dr.-Ing.) received his Dipl.-Ing. degree at the Technical University of Munich in 1991. Since this time he has been working in the field of pressure vessel and piping technology, starting as an R&D engineer at the Institute of PVP Design, Experimental Stress Analysis and Plant Engineering in Munich. Since joining TÜV SÜD he handled various national and international projects concerning all kind of questions related to structural risk and reliability analysis, Fitness for Service, and inspection programs for nuclear and non-nuclear applications. He is member of European Commission projects RIMAP RTD and TN. He holds an US National Board and Texas Commission as ASME Authorized Inspector for Boiler and Pressure Vessels. He is author and co-author of a large list of national and international publications.