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RISK BASED METHODOLOGY FOR INDUSTRIAL STEAM SYSTEMS

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INTRODUCTION

Based on US Department of Energy figures [1], steam systems account for about 30% of the total energy used in industrial applications for product output. These systems can be indispensable in delivering the energy needed for operating an industrial plant; including process heating (e.g., heat exchangers) and steam tracing systems, as well as mechanical drives (e.g., steam turbines).

With the continued need for increased competitiveness, steam system specialists regularly work with plants to identify opportunities to reduce the amount of energy consumed by their steam systems. At the same time, steam system maintenance costs must be optimized and most importantly, health and safety issues and unplanned downtime avoided.

It is clear from **Table 1** that steam systems are essential to the refining process. Thus, the integrity and efficiency of steam-using equipment is often critical to refinery productivity. The same goes for steam distribution systems which deliver the steam, and also for steam tracing systems which provide the heat necessary to maintain flow rates in product distribution lines, vessels and reactors. **Figure 1** shows a catastrophic failure of refinery and petrochemical complex steam distribution piping reported by the UK Health & Safety Executive (HSE) [2]. That particular incident resulted in the shutdown of a process unit and associated production losses.

RISK-BASED APPROACH

In the process industry, more and more decisions are risk-based, such as maintenance actions, inspection frequencies, and management of change. Risk-based approaches covering hydrocarbon and chemical process equipment are now generally accepted by refinery and process plant operators, regulators, and insurers worldwide. Uptake is based mainly on guidelines developed by the American Petroleum Institute, API RP 580 [3] and API RP 581 [4] which employs quantitative evaluations of failure risk:

$$Risk = PoF \times CoF$$

PoF is the probability of failure, which is time dependent and incorporates generic failure frequencies, local adjustment factors to account for prevailing component damage mechanisms and a management factor to account for quality issues associated with the plant's management systems. Generic failure frequencies are obtained from industry failure data and represent the average failure frequencies of given equipment types. CoF is the consequence of failure and often expressed as a monetary value and/or square feet or meters of affected area.

A key message of this article is that the risk-based approach is equally applicable to the optimization of steam-using and steam

Table 1. Steam Equipment in Petroleum Refining.

Steam-using Equipment Examples	Process Application Examples
Steam Turbine	Power generation, compressor mechanical drive, hydrocracking, naphtha reforming, pumps mechanical drive
Process Heat Exchanger	Alkylation, distillation, gas recovery, isomerization, visbreaking, coking, storage tank heating
Distillation Tower	Distillation, fractionation
Stripper	Crude & vacuum distillation, catalytic cracking, catalytic reforming, asphalt processing, lube oil processing, hydrogen treatment



Figure 1. Failure of a steam distribution line at a combined refinery and petrochemical complex. [2]

distribution systems. The main driver for this centers on the failure consequences. The sudden release of steam or scalding water can occur due to failures such as water hammer. Water hammer has been cited by Paffel [5] as the 'number one' problem in steam systems. The failure depicted in **Figure 1** was one such case where water hammer led to pipe rupture. Fortunately, in this case there were no major injuries. However, accident investigations conducted by the U.S. Occupational Safety & Health Administration (OSHA) and Kirshner Consulting Engineering [6,7] have reported serious injuries and several fatalities caused by water hammer, as well as associated production losses and corporate penalties.

In addition to consequence issues, steam system reliability data is being collected. In particular, the importance of steam traps in optimizing steam-using systems has been emphasized by Risko [8] and the value of steam trap failure databases has been demonstrated by Nippon Petroleum Refining Company and TLV [9]. Verifiable and representative steam trap failure databases are key in this regard. This required deployment of certified inspection personnel and qualified inspection methods (e.g., ISO 7841 [10]) over several hundred thousand steam traps in a range of types

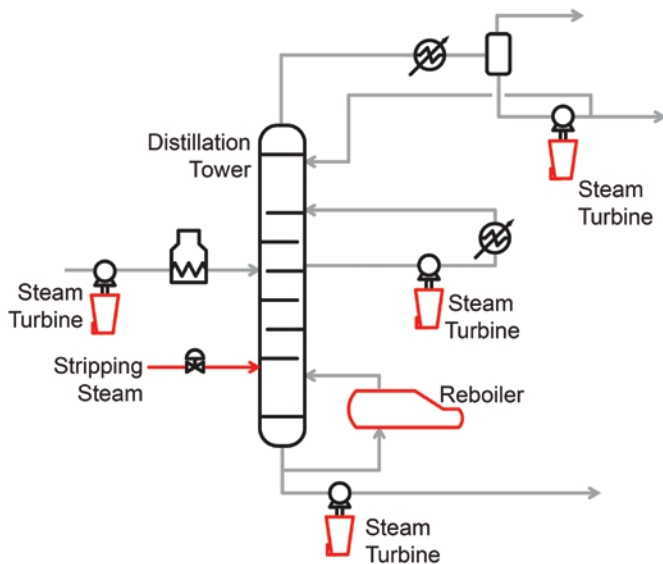


Figure 2. Example of steam system asset.

and applications. When accumulated over many years, these databases form the basis of the PoF assessment. This is coupled with the CoF for safety, environmental and financial impact to provide an evaluation of failure risk for steam system applications.

Having calculated the risk, it is possible to make important decisions on risk mitigation enabling risk-optimized maintenance or monitoring solutions. A steam system risk-based assessment methodology has been developed for this purpose. The requirements and technical features of the methodology are described below.

RISK-BASED METHODOLOGY FOR STEAM SYSTEMS

A systematic and efficient risk-management process, which enables evaluation of optimum maintenance measures or risk mitigation actions, can support a steam system optimization program. The initial focus is on steam-using applications, namely steam turbines, heat exchangers and steam tracing systems in oil refinery, petrochemical and chemical plants. The risk assessment and risk mitigation processes are based on API risk-based concepts and methodologies (API RP 581 [4]).

Povey [11] has pointed out that steam-using equipment, when grouped together, can be considered a steam system 'asset'. Such assets are made up of a series of 'Applications' which individually comprise the steam-using equipment (e.g., steam turbine, heat exchanger) and the associated condensate discharge locations (CDLs). The latter incorporate steam traps and connecting piping. Each Application can be critical to the reliable operation of the process area and often to the plant as a whole. In this regard, one of the most significant factors is to adhere to the requirements of steam utilization principles, such as:

- Supply of dry steam at optimal pressure and flow rate
- Discharge of condensate quickly and effectively
- Minimize steam leakages

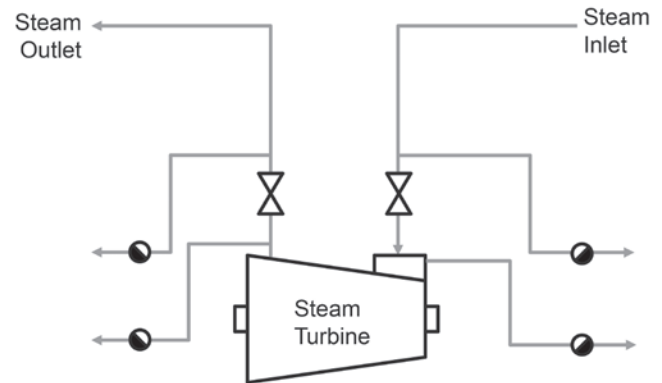


Figure 3. Example of steam application.

It is generally known that steam traps at CDLs can fail either by leakage (including blowing) or due to blockage, often referred to as 'cold' failures. Leakage failures represent considerable energy loss value since the leakage of steam has to be compensated by consumption of additional energy at the steam generation stage [8]. More critically however, cold failures have a direct impact on the reliability of the downstream equipment (e.g., turbines, heat exchangers) and personnel safety. Cold failures can result in back-up of condensate which can lead to, for example, flooding or 'stall' of heat exchangers, excessive erosion in steam turbines, and water hammer failures in associated piping systems.

Key features of the risk-based methodology include:

- Risk analysis applied at steam 'application' level (steam-using equipment and associated CDLs)
- Quantitative assessment of risk involving probability of failure and failure consequence costs
- Incorporates generic failure frequencies derived from reliability databases for steam traps and steam-using equipment
- Probability of failure (PoF) is displayed with consequence of failure (CoF) values on risk matrices
- A formal and systematic basis for adopting risk mitigation measures.
- Cost-benefit analysis for selection and scheduling of optimum risk mitigation actions

Implementation is based on breaking down each steam system asset into its constituent steam-using applications. A typical refinery steam system asset is depicted in Figure 2 while an example of an individual application is shown in Figure 3.

Probability of Failure: The probability of failure (PoF) is obtained as a function of time for a range of steam trap types and properties using Weibull fitting to steam trap generic failure frequencies. The PoF of the associated lines is then derived and combined

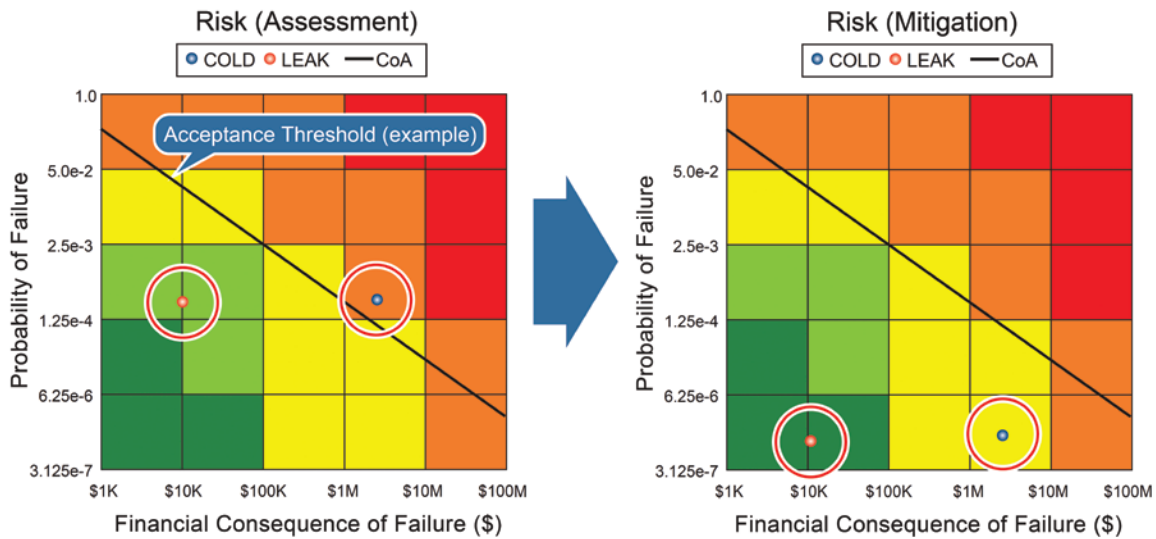


Figure 4. Example of risk mitigation by steam trap replacement: shows risk reduced below threshold for cold.

with the steam-using equipment generic failure frequencies to compute the Application PoF. Final PoF values are obtained by tailoring the PoF for steam traps and equipment to local conditions by customized probability factors. In each case, the PoFs are computed for leak and cold failure modes.

Consequence of Failure: Examples of consequence of failure (CoF) are:

- Lost process production, due to failure event, e.g., due to water hammer
- Lost production due to product sub-cooling (tracing failure)
- Component damage and repair time/cost (pipe cut-off or rupture)
- Cost of loss of steam or condensate
- Injury to personnel and environmental impact (consequence area considerations are employed)

CoF values are summed and expressed as a monetary (\$) value using the approach adopted in API RP 581 [4].

Risk Matrix: The assessed PoF and CoF are displayed for leak and cold for each application as points on a 5x5 Risk Matrix. Since the PoF is time dependent, the risk matrix can be established at the current time of assessment and forecasted for future years.

Risk Mitigation: The methodology enables calculation of the risk reduction achievable as a result of risk mitigation actions. Risk mitigation actions include improvements in steam utilization and condition monitoring. A risk acceptance threshold is employed to evaluate the optimum extent and timing of the mitigation action. The threshold is based on the cost of the risk mitigation action. **Figure 4** gives a demonstration of risk matrix output showing the effect of mitigation, for example by replacement of a steam trap. Risks are shown before mitigation and the risk is forecasted after mitigation. It is seen that the cold risk is reduced below the threshold line (CoA: Cost of Action).

Cost-Benefit Analysis: A cost-benefit analysis is incorporated which enables optimum selection and scheduling of risk mitigation actions. Thus, for example, to decide on the optimum risk mitigation action, the potential cost saving (\$ risk reduction) achieved through the mitigation action is compared with the cost of the action. Both a benefit-cost ratio and time for return on investment are derived.

Risk Mitigation Software: The risk-based methodology has been encoded in a software tool for steam system risk mitigation, SSRM®. **Figure 5** gives a summary overview of the software showing the primary import and outputs.

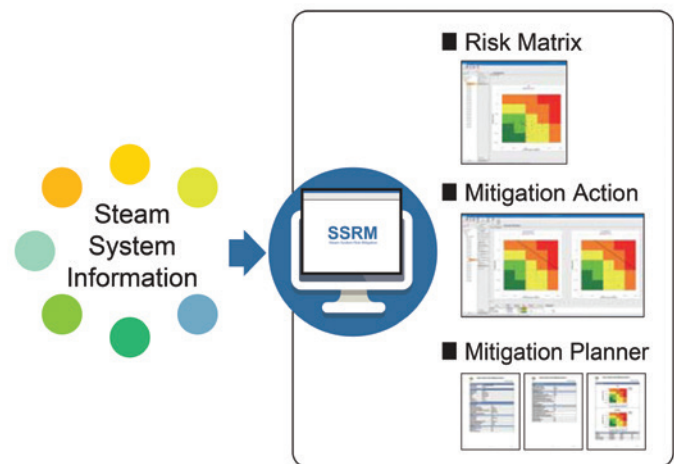


Figure 5. Summary overview of SSRM®

INTEGRATION OF RISK MITIGATION IN A STEAM SYSTEM OPTIMIZATION PROGRAM

The risk mitigation approach should form an integral part of the plant-wide steam system optimization program. Such a program incorporates various plant-based surveys which complement each other. These include:

- Visualization of the entire steam system and surveying all

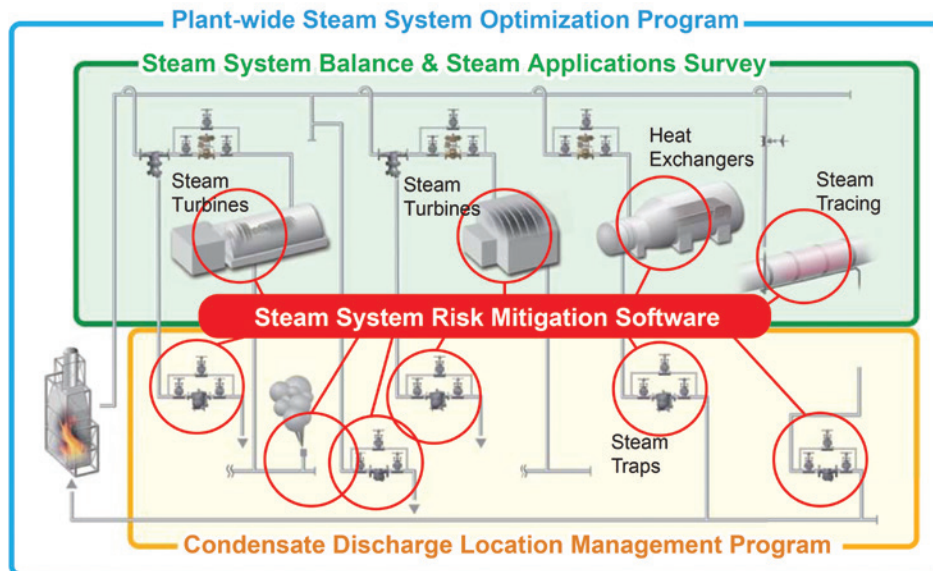


Figure 6. Integrated steam system optimization program (Courtesy of TLV).

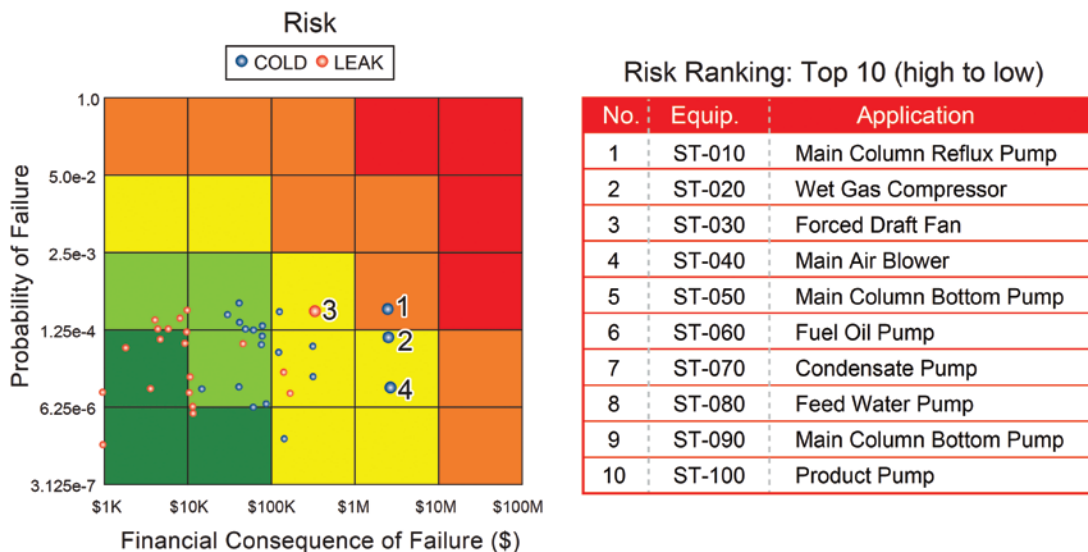


Figure 7. Steam turbine risk matrix display and risk ranking. (Equipment data has been anonymized.)

steam applications to identify key steam-related problem areas requiring priority attention. These areas become the focus for application of the risk mitigation approach.

- A condensate discharge location (CDL) management program which incorporates regular inspection surveys of all CDLs. Reference [9] gives an example of a CDL management program applied to refinery plants. Such programs enable generic failure frequency database development which is essential input to the probability analysis within the risk mitigation process

Figure 6 shows the above elements of a steam system optimization program. The figure illustrates the integration of plant-based steam system balance and steam application surveys with a CDL management program, each of which feed into the risk mitigation software.

FIELD TRIAL

An illustrative case study on the application of the steam system risk mitigation methodology and software on steam turbines in a fluid catalytic cracking (FCC) process unit of a Japanese refinery is given below.

Probability of failure (PoF) and consequence of failure (CoF) values were systematically computed for all steam turbines in current use. The results are shown for cold and leak failures on a risk matrix in Figure 7.

The turbines were ranked in terms of current assessed risk. The top 10 highest risk turbines are tabulated and the top 4 are identified on the risk matrix. The highest assessed failure risk was found to be for the main column reflux pump turbine ST-010. This was borne out by the field interrogation of this turbine which found significantly low steam temperatures causing wet steam at the

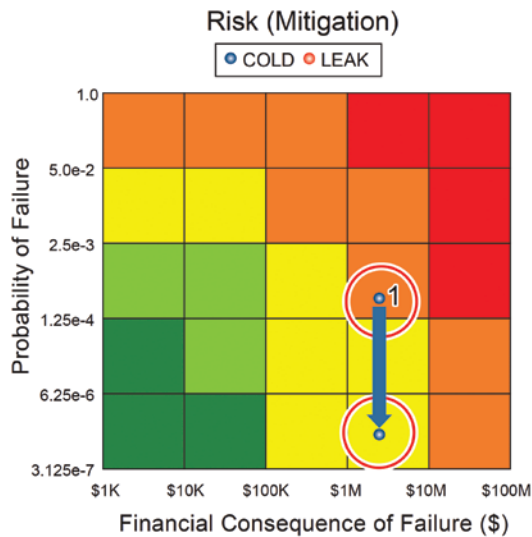


Figure 8. Assessed risk before and after risk mitigation action for steam turbine ST-010.

turbine inlet, condensate back-up in the system due to non-optimal temperature adjusted steam traps, and a history of erosion at the governor valve which was leaking steam. The primary threat is erosion damage to the turbine resulting in potential unplanned downtime for the FCC unit and turbine replacement.

In view of the criticality of the ST-010 turbine, it was considered essential to propose risk mitigation actions. In order to prevent condensate ingress and consequent turbine erosion damage or trip, the following solutions were proposed:

- Ensure dry steam supply to the turbine by installing a separator on the inlet line
- Ensure no condensate accumulation at low points of turbine and surrounding piping by using steam traps capable of continuous discharge

With these risk mitigation actions it was possible to demonstrate a significant reduction in the PoF. This is seen in the risk matrix after mitigation in **Figure 8**.

A cost benefit analysis can be performed on the basis of the reduced financial risk. The risk mitigation actions for ST-010 are projected to produce a reduced risk equivalent to US \$193,000 when considered for a 5-year period, after accounting for the cost of mitigation.

The risk assessment process also enabled the refinery to focus and prioritize maintenance efforts based on a quantitative assessment of failure risk.

CONCLUSIONS

1. This article has presented a risk-based solution to assist engineers in the optimization of industrial steam system assets in refinery, petrochemical, and process plants.
2. The availability of generic failure frequency databases for application in probability of failure assessment combined with the severity of failure consequences relating to safety and business

interruption makes a risk-based approach entirely appropriate for steam systems.

3. The methodology employs a formal, systematic risk management approach involving quantitative assessment of risk of failure for steam-using applications followed by selection and scheduling of risk mitigation recommendations.
4. The approach enables decision support in selecting optimum steam system maintenance or upgrade plans with full visibility on potential cost savings.
5. The methodology is developed to be compliant with risk assessment and risk mitigation schemes used in the latest API guidelines (API RP 581).
6. The methodology has been encoded in a software tool (SSRM[®]) which is an integral part of an overall industrial steam system optimization program.
7. A field trial has been conducted using SSRM[®] for the case of steam turbines in the FCC unit of a petroleum refinery. Current failure risks are quantified in monetary terms together with ranking of turbines in terms of failure risk. Risk mitigation action and forecasted risk reduction is demonstrated for the highest risk turbine. ■

For more information on this subject or the author, please email us at inquiries@inspectioneering.com.

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Brian Cane is an independent consultant engaged by TLV Co., Ltd. He has over 40 years of experience in asset integrity matters for process and power sectors and is author of more than 60 publications on the subject. During his career, he has pioneered the development and application of innovative plant life and risk assessment technologies and has served in director roles at several international research and engineering organizations.