An Integrated Framework to Optimize the Safety Management for Process Industry: The Gas Station as a Case Study

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Abstract. The safety management is considered to be an effective way to eliminate accident potentials and help managers adopt proper measures to improve the whole system safety level. In this regard, an integrated framework centered maintenance (SRCM) method has been proposed as a crossing strategy to improve the gas station safety performance with resort to Risk Based Inspection (RBI), Reliability Centered Maintenance (RCM) and Safety Instrument Level (SIL). It benefits from the fusion analysis of equipment risk and instrument grade. That is, we address global-scale concerns that may cause combination effect to the system performance and establish a fusion matrix to estimate the optimal maintenance strategy. An innovative logical judgment has been introduced to model the process of selecting proper maintenance measures. Meanwhile, determine the obvious failure impacts or high-risk factors. Also, Hazard and operability analysis (HAZOP) and layer of protection analysis (LOPA) have been developed to validate the SIL. The integrated framework can be also used to explain the issue of unknowns and uncertainties in reliability analysis and how these issues can be addressed in system components by optimizing component breakdown maintenance.

Introduction

Accidents investigation shows that the current safety management technology faced challenges such as coupling risk factors and multiple features analysis. Various factors deriving from components are related to assessment results of the system safety performance. To improve the system reliability and reduce potential hazards, uncertain factors having the possibility of leading to unexpected events should be carefully identified, assessed and monitored. The current research focuses on synthesis risk area involving in static equipment, dynamic machines and instrument system. To ensure the system process a proper safety and reliability state during a long running period, it requires extensive maintenance strategies, renewal risk control measures based inspection or even special safety protection.

Typical production facilities in gas stations usually include: 1) Static equipment, such as process pipelines, pressure vessels, boilers, etc. 2) Dynamic machine, which can be basically divided into three categories: reciprocating, centrifugal and screw type. 3) Instrument system, contains interlock protection, overpressure alarm, interconnected control loop, etc.

Among a number of techniques available to describe the occurrence probability of accident
scenarios or to estimate the failure probability of systems in the context of risk assessment, safety analysis and reliability engineering, RBI, RCM and SIL are the most recognized and widely used. Currently RBI is widely used for equipment inspection (especially for the static devices)[1]. The optimal inspection frequency is determined according to its risk exposure, which can be used to avoid unacceptable risks from under-inspection of some items or from over-inspection of the majority of items, the main objective of which is basically to exploit the limited resources in coping with the really meaningful risks. Shuai et al. [2] proposed a methodology for determine reasonable internal inspection interval (INTII) to balance the safe operation requirement and inspection cost for crude oil tanks. RBI methodology was introduced as a basis to control risk below an acceptable level. This type of inspections is planning to analyze the likelihood and the consequences of the failure in order to develop safety plans [3], predominantly in the oil and gas industries. Chien et al. [4] performed a risk-based maintenance method which was an example of pressure safety valves with considering the combination of conditional value at risk for transportation infrastructure networks [5]. By analyzing system functions and failures, RCM identifies the failure modes and consequences to carry out preventive measures based on utilizing standardized logical resolution procedures [6]. Following the demand of establishing logical/fact-based framework to determine which equipment should be included in critical devices category, since 90s decade, RBI and other maintenance methods have been mixed gradually, and become common by the end of year 2000. This new generation of maintenance strategies has appeared with risk based management (RBM), RCM and condition based maintenance (CBM) characteristics [7]. SIF called safety instrumented function is a complicated and important type of protection layer. It is a combination of logic controllers, sensors and actuators, which is designed for keeping a process in a safe state when predetermined set point is exceeded or safe operating condition is violated. With the purpose of loss prevention, SIL is assigned to describe the SIF’s reliability [8]. The industry standard for safety instrumented systems (SIS), IEC 61511 illustrates their determination by comparing the risk of hazardous events that SIF protect against with risk tolerance criteria to determine if there is a risk gap. Due to the growing complexity of installations and operations, risk-based inspection and maintenance (RBIM) framework was proposed with the aim of risk analysis and multi-attribute decision-making. It has superiority in developing inspection and maintenance programs as well as identifying key facilities where inspections will provide more benefit in reducing the overall risk [9].

The Integrated Framework to Optimize the Safety Management

In accordance with the integrity evaluation-based approach, this paper aims to extend maintenance support model developed by RCM and SIL such that it could be applied to comprehensively analyze risk and make multi-attribute decision. Therefore, a novel SRCM matrix model is set up by using a semi-quantitative analysis approach for which the optimal maintenance strategy can be estimated. The fusion matrix is developed to illustrate the path of safety reliability management and provide practice guidance as well as theory supporting. Moreover, HAZOP and LOPA are implemented to the multiple analysis layers to deal with numerous outputs (which can be input into the further analysis of the next hierarchy). Fig. 1 illustrates how the proposed method is preformed:

● FMEA is designed to identify cause-consequence relationships between component failures and system hazards. As a failure-oriented, it also provides information for RCM decisions.
The risk range of key components, for which logical inference is adopted to determine optimal maintenance measures.

Validation of SIL based on HAZOP and LOPA is obtained to provide the global-scale performance of the gas station situation.

A two-dimensional decision model is developed with matrix analysis to indicate the proper maintenance policy and operational measures for safety management.

The research shows that the identification of hazardous events to scientifically evaluate the safety performance requires RBI, RCM and SIL to be used effectively. Fundamentally, the risk of a process system is determined by their hazard scenarios, control measures and safety instrument protection. Hazardous events should be defined in multiple aspects depending on how hazard scenarios are aggregated, developed and controlled. However, there is rarely unique way to do so. A combination of the existing techniques in the literature demonstrates that the present study not only replicates the results of the previous work, but it also is in better application with safety integrity management.

The use of SRCM model based on safety and reliability analysis need a set of rules for their fusion and the allocation of each technology. It would be difficult to develop such a quantitative set of rules. However, it will be probably difficult to implement these technologies consistently. The solution to this dilemma is to work on novel matrix that supplies special cross areas of risk rank and SIL level so that the results of RCM and SIL can be used directly for determining qualitative maintenance strategy. HAZOP and LOPA are necessary to construct the whole framework as well as individual scenario risk analysis.

In gas stations, the last two decades have been marked by a significant increase in preliminary hazard analysis, advanced control, maintenance decision-making and protection technologies that have vastly enhanced the ability and sensitivity of the integrated safety
assessments. Nevertheless, the literature mentioned above rarely implemented the safety integrated estimation from the view of global-scale situations with multiple appointments. In other words, traditional methods may ignore the indispensable correlation assessment for complex evaluating factors. As an example, consider a system consisting of two critical objects A and B related to a failure, in which A is planned to operate as a standby to B. It is meaningful to observe that A involved in evaluation procedures usually cannot completely reflect the final state of the system when B is not taken into account. Considering the abovementioned problems encountered, SRCM is proposed to integrate risk analysis, maintenance strategy and safety instrument level. Among which RBI focusing on tanks, boilers and process piping had been applied on the risk assessment of static equipment form the view of fuzzy analytical hierarchy process.

In accordance with the integrity evaluation-based approach, this paper aims to extend maintenance support model developed by RCM and SIL such that it could be applied to comprehensively analyze risk and make multi-attribute decision. In this regard, a novel SRCM matrix model is set up by using a semi-quantitative analysis approach for which the optimal maintenance strategy can be estimated. The fusion matrix is developed to illustrate the path of safety reliability management and provide practice guidance as well as theory supporting. Moreover, HAZOP and LOPA are implemented to the multiple analysis layers to deal with numerous outputs (which can be input into further analysis of next hierarchy). Fig. 2 illustrates how the proposed method is performed as for a gas station.

**Figure 2. Logical inferences for priority maintenance strategy based on FMEA.**

**Discussion and Conclusion**

Generally, multiple hazard scenarios involving a variety of hazardous factors contribute to the risk of a facility. The goal must be to ensure that the summary of their risks is at or below the facility risk tolerance. Such as in a gas compressor station, safety management is to review the operation process and equipment reliability to identify hazardous scenarios and ensure the system is properly safeguarded. Based on accident investigations for the last decade it can be found that accident happening is related more than one failure cause. Therefore, the multi-aspect analysis will help knowledge transfer and strategy adjust through the comparison and structured use of expert knowledge. Motivated by the same thought, further work for safety integrity management is still needed. Through combining RBI, RCM and SIL function as a
basis to evaluate and prioritize the management strategy quantitatively. It is not only assesses the risk of main components and improves safety level by paying attention to high-risk facilities, but also can predict or audit the applicability of management measures.

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