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Improving safety and availability of complex systems using a risk-based failure assessment approach

Qadeer Ahmed, Faisal Khan*, Salim Ahmed

Safety and Risk Engineering Group, Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, NL, Canada A1B 3X5

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ABSTRACT

This paper presents a structured risk-based failure assessment (RBFA) approach, which provides a complete solution to avoid repeated and potential failures to improve overall plant safety and availability. Technological advancements and high product demand have encouraged designers to design mega-capacity systems to enhance system utilization and improve revenues. However, these benefits make the systems more complex and thus prone to unnoticed failure. It is an overwhelming task to address all the failures due to the limited resources and time constraints. This leads to substandard and poor quality failure assessments, which cause repeated failures. To address this common industry concern, a four phase RBFA framework is proposed which is not limited to the identification of root cause(s) but also includes other actions such as failure monitoring. The four phases include the plan phase, the assessment phase, the analysis phase and the implementation-tracking phase. These phases cover identification of failure, failure analysis, root cause(s) analysis, and failure monitoring. In this paper, the applicability and advantages of the proposed approach are examined through two real case studies pertaining to bearing failure and drive coupling failure. By implementing the proposed approach, significant improvements have been experienced in the system availability in both the cases.

1. Introduction

In a processing facility, equipment and systems are anticipated to perform their function safely and reliably to meet the production requirements. Despite the best maintenance and operating strategies, systems and equipment fail. These failures must be analyzed properly to identify the root cause(s) and implement corrective actions to avoid repetition. Repeated failures are very common where the failure assessment is done poorly and corrective actions are implemented without proper validation of the root cause(s). In a study (Bloch et al., 2011), failure history shows that the fuel oil pump experienced 14 failures during an operating life of 10 years. In another study of repeat failures, the authors have mentioned that 18 events of compressor failures occurred during the last 12 years. These examples highlight the fact that failure investigations are either not handled properly or corrective actions are not implemented properly. A thorough and structured investigation process is therefore the need of the hour to avoid the general problem of repeated failures (Bloch and Geitner, 2012).

Failure is defined as, "*inability to perform the intended function*" whereas, fault is "*an abnormal condition or defect at the component, equipment or sub-system level which may lead to a failure*" (ISO 10303, 1994; Define). Risk-based failure analysis in this work is defined as, "*a structured process that discovers the root cause(s)-physical, human or latent of an incident (failure or fault) and addresses these causes with corrective actions to improve the availability and safety of the workplace*". Failure and availability are two sides of a coin; reduction in equipment failures greatly improves the availability of the system and vice versa. Failure can be eliminated or reduced by effective maintenance, adequate operation, proper design and other parameters. However, in case of a failure, proper failure investigation is important to identify and eliminate the root cause(s). Availability improvement is neither one size fits all and nor a piece of technology or software solution; it is a strategic objective to be met. Therefore, all the factors affecting availability are essentially considered with their importance. An appropriate combination of assessment approach, tools and technologies is vital to reduce failures but the list also contains skills and good planning to achieve this goal. Availability suggests the readiness of the system when required. Many factors affect the readiness of the system, including planned downtime for preventive maintenance, unplanned breakdowns, and spares availability. Availability can be

* Corresponding author.
E-mail address: fikhan@mun.ca (F. Khan).

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significantly improved by reducing the equipment downtime by either addressing reliability or maintainability (Ebeling, 2001). A major factor of poor availability is repeat failure or recurrence of a failure which can be reduced by a structured and smarter root cause analysis approach, with the assurance that the corrective actions have been implemented. Analyzing failures correctly improves the failure rate which means minimization of downtime and repair time, hence, ensuring better mean time between failures (MTBF) and mean time to repair (MTTR) as represented in Equations (1) and (2).

$$\text{Availability}(A) = \frac{\text{Up Time}}{\text{Up Time} + \text{Down Time}} \tag{1}$$

Availability can also be written as;

$$\text{Availability}(A) = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} \tag{2}$$

where, MTBF = Mean time between failures, and MTTR = Mean time to repair

Equation (2) can also be represented in terms of failure and repair rate as:

$$\text{Availability}(A) = \frac{\lambda}{\lambda + \mu} \tag{3}$$

where, λ = Failure rate, and μ = Repair rate.

As an illustration, an improvement in MTBF by 90 days and repair time by 5 days in a year, results in an overall availability improvement of 2.5%. However, highly structured failure analysis approaches are required to achieve such objectives in asset intensive industries like gas processing, nuclear and aerospace.

Failure analysis is a multifaceted and challenging task but with a structured methodology, knowledgeable and skilled team, the real root cause(s) can be efficiently identified. The identification of the root cause(s) does not lead to the conclusion of the objective because the real solution is to develop corrective actions and to implement them to avoid repeat failures. A structured approach is a way to analyze failures because unstructured processes only support opinions and are unable to produce lasting results. Hence, supporting a structured approach in problem solving is highly desirable (Márquez, 2007). Failure consequences drive the classification of the failure investigation. Classification is required so that the investigation can be performed based on the criticality of the failure. Failure investigation can be classified by the importance and criticality of a failure which derives the need of a detailed analysis (Bhote, 1988). Based on the risk consequences, failure analysis is categorized as high, medium or low. Brief investigations are performed on non-critical failures whereas a detailed analysis is required on critical failures along with effective management of the corrective actions. Investigations limited to only identifying the reason of a material failure and restricted to a component analysis are usually classified as component failure analysis and do not address the system issues. For example, a bearing analysis is performed and the result indicates a lack of lubrication but the reasons of the lack of lubrication are not discussed. Root cause(s) investigation covers the other causes i.e., human causes but does not explore the latent causes. Root cause and failure analysis cover all three areas of cause identification as discussed above but still the other parts of the complete process are not included. In this paper, a complete failure analysis process, risk-based failure assessment, is proposed which starts from a failure or fault event, to identification of root cause(s), to implementation of recommendations and extends up to the effectiveness of corrective actions. In this paper, a four phase RBFA framework is proposed which is not limited to the identification of root cause(s) only but also includes all the other actions essential for a successful assessment. The applicability and advantages of the proposed RBFA approach are examined through two case studies pertaining to bearing failure and drive coupling failure.

The remainder of the paper is organized as follows. Section 2 explores the research work done in this area. Section 3 discusses the risk-based failure assessment framework. Section 4 presented two case studies to observe the application of proposed approach and the results. Section 5 discusses the critical success factor of the proposed methodology. At the end, in Section 6, conclusion and contributions are discussed.

2. Background study

Failures and faults are the most undesirable events that adversely affect the availability of an operating facility. To avoid such events, engineers do their best to effectively operate and maintain the system. Many tools such as condition monitoring, process monitoring are available to proactively predict and analyze such unwanted events but failures still exist. Along with other efforts, proper failure analysis is the key to address these unwanted events by identifying the real root cause(s) along with developing and implementing corrective actions.

In industry, many tools are available to carry out root cause analysis of a failure. Some of the common tools employed are 5-Why, Fault Tree Analysis, Ishikawa Diagram (commonly known as Fishbone Diagram), and Failure Mode and Effect Analysis (FMEA). However, their use is questionable as witnessed by many recurrences and repeated failures. In one study, the performances of three popular root-cause analysis tools namely, Cause-and-Effect Diagram, the Interrelationship Diagram, and the Current Reality Tree were analyzed (Doggett, 2005). It was found that these tools have the capacity to find root causes with varying degrees of accuracy and quality due to their individual unique characteristics and application constraints. In literature, different methodologies have been used to estimate the availability ranging from fault detection, Reliability Block Diagrams, FMEA, Fault Tree Analysis and so forth (Bloch and Geitner, 2012; Latino and Latino, 1999; Adamyan and He, 2002, 2004). However, a great opportunity exists in addressing system availability using a risk-based systematic approach which is proposed in this work. Production pressure and operating constraints necessitate that investigations must be completed quickly. Quick complex failure analysis contributes to repeated failures and wrong root cause(s) due to limited focus on identification of the real root cause(s), accepting or rejecting all failure possibilities, and bypassing a structured failure investigation. The other common problem is the lack of focus on the implementation of corrective actions which is one of the major contributors to repeated failures. In this work, more focus is there on the “operate and maintain phase” which is truly the longest phase in the lifecycle of equipment as shown in Fig. 1. However, the proposed model can be used effectively to assess potential failures or conditions in design and construction.

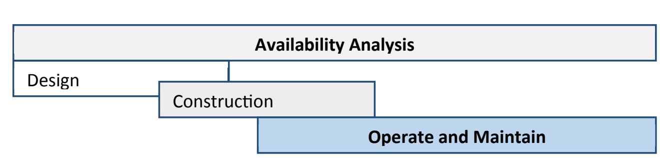

Fig. 1. Availability – operate & maintain.