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IFAC PapersOnLine 50-1 (2017) 13704–13709

# INDUSTRIAL SYSTEM FUNCTIONING/DYSFUNCTIONING-BASED APPROACH FOR INDICATOR IDENTIFICATION TO SUPPORT PROACTIVE MAINTENANCE

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Abstract: Failure Mode, Effects and Criticality Analysis (FMECA) is a well-known method used in safety analysis, reliability analysis, risk assessment and maintenance objectives. Moreover, in the manufacturing domain and particularly in the context of the deployment of the factory of the future, its usage is not entirely satisfactory in relation to the indicator to be observed. Thus, the paper presents a new methodology based on a coupled approach of FMECA and Hazard Operability analysis (HAZOP) which aim is to contribute to the deployment of proactive maintenance strategies by clearly identify pertinent indicator. This approach is based on the formalization of concepts of knowledge which permit to constitute the first pillars of proactive maintenance approach. Applicability of this methodology is illustrated on a machining center sub-system.



*Keywords: functional analysis, dysfunctional analysis, indicator monitoring, maintenance*

## 1. INTRODUCTION

Since early 2000, proactive maintenance, in Europe, and prognostic and health management (PHM) in the US has been developed in order to go beyond classical maintenance strategies. Both rely on the use of monitoring parameters allowing the anticipation of the failure of the system. Health monitoring, and prognostics processes support such anticipation. They require the definition and management of degradation and failure mode set of indicator related to components or (sub-)systems as a whole. On the management side one find some proposal starting mainly from MIMOSA initiative and ISO 13374 standard and further enhanced, for instance, by (Callan et al. 2006). When considering indicator design, monitored parameters are usually given in ad hoc solution. Only few works focus on the design of the parameters to be monitored. Most of them are related to the use of metrics in order to determine if some already define parameters are suitable for monitoring or prognostic purpose (Coble & Hines 2009). When considering root cause analysis, (Medina-Oliva et al. 2012) conclude that no unique tool is able to characterize the knowledge about causal relationship between degradation. They suggest to combine several tools in order to capture the several aspects of the required knowledge. Nevertheless, when considering parameters to be monitored, it requires the definition of sensors. Such sensor cannot always be related to the root causes.

Hence, this paper aims to propose a combined approach to ease the definition of indicators to be monitored. The proposed approach is based on FMECA and HAZOP tools. The combination of both approaches enables the identification of causal relationship between root cause, degradation, failure and flow deviation. Hence, for a single degradation or failure mode, it allows several indicators to be considered for its monitoring. Moreover, by providing a structured approach, it will broaden the use of such strategies in helping engineering to develop monitoring solution on both new system and existing ones. Such indicator structure can be viewed as a health check-up of the system (Abichou et al. 2015). It can be used as *i)* an alarm for the product/system user, *ii)* an appropriate diagnostics tool for failure mechanism, and *iii)* an input for the product models to enhance life time in form of continuous collected data-base (Catelani et al. 2015).

To demonstrate the interest of such combined approach, section 2 will present a state of the art on the combination of FMECA and HAZOP tools and its limits regarding our problematic. Then Section 3 will describe the proposed combined approach to face these limits and section 4 its use on a case study. Finally conclusion and perspective will be sketched.

## 2. PAST WORK COMBINING FMECA and HAZOP

Numerous techniques, and decision support systems based on the integration of FMECA & HAZOP were proposed in different works with the objectives of reliability analysis, safety analysis, risk assessment and maintenance objective.

To support reliability analysis, (Medina-Oliva et al. 2010) proposed a methodology to develop a tool for assessing the dependability and reliability of an industrial system. The idea is to formalize the interactions between an industrial system and the support system (maintenance system) using processing and data models such as SADT (Structured Analysis and Design Technique) and qualitative models such as FMECA, HAZOP. First, they used FMECA to model

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10.1016/j.ifacol.2017.08.2544

failure modes of the functions, failure modes of the components, failure consequences and the criticality of the failure. Second, HAZOP has been used to model flow deviation, causes of flow deviation and failure consequences (impact on the flow). Related to the reliability of robotics, (Maier et al. 1995) described a methodology to identify the derivation of the reliability and make safety analysis by applying methods and technique such as HAZOP, functional analysis, FMECA and FTA (Fault Tree Analysis). HAZOP allow them to focus on specific aspect that can have catastrophic consequences. Then, the identification of particular top events, identified by FMECA, together with the creation of functional system reliability models, enabled to carry out a fault tree analysis and to calculate their probabilities. This proposition is limited to a simple sequential application of methods lacking their combination and do not consider monitoring parameters.

In safety domain, (Casamirra et al. 2009) presented a safety analysis of a high-pressure storage equipment in hydrogen gas refueling station by integrating FMEA, HAZOP and FTA techniques. The work is intended to assess the refueling station design taken into consideration its safety level, at least from the occurrence frequency point of view. It constitutes a basis for further refined studies which considers the consequences aspects, allowing the assessment of the plant risk. Subsequently, (Daramola et al. 2011) presents a conceptual semantic case-based framework for safety analysis, which facilitates the reuse of HAZOP and FMEA experiences. The aim of the framework is to provide credible tool support for safety analysis processes in order to facilitate early identification of potential system hazards, and enable the interoperable reuse of knowledge for both HAZOP and FMEA activities. Another safety analysis was performed to determine possible accidental events in the storage system used in the liquefied natural gas regasification plant using the integrated application of FMECA and HAZOP methods. The proposed integrating analysis (FHIA) has been designed as a tool for the development of specific criteria for reliability and risk data organization. It aims to provide more recommendations than those typically provided by the application of a single methodology. FHIA provides also an exhaustive list of events or combinations of events that affect the same or different TEs (Top Events). This allows to focus on the critical points of a hazard before making a quantitative assessment of the occurrence probability (Giardina & Morale 2015). These scientific contributions are mainly focused on safety analysis and do not address the topic of indicators definition.

In risk assessment domain, (Mechhoud et al. 2016) examined the implementation of a new automated tool dedicated to risk analysis, and assessment of the consequences of the accident scenarios by combining the HAZOP and FMEA methods. The combination enables to localize the problem and its cause in every component. In this method, the authors involve creating two interlinked evaluation models. The first model is evaluated by a criticality matrix extracted from the HAZOP and FMECA analysis. The second is evaluated using the accident scenarios model extracted from the distance effect. To identify the risk of failure levels, (Reitz et al. 2013) proposes a dysfunctional analysis approach based on the joint application of both methods FMEA and HAZOP. The FMEA method focuses on the failure modes that could affect every function, but does not study the malfunctions caused by possible deviations. To address this shortcoming, the author proposed to complete the FMEA approach by involving the HAZOP method. Motorola developed a hybrid HAZOP and FMEA technique for risk assessment approach. This technique separates the risk factors related to human safety, the environment, facility and product damage and business interruption. It provides a systematic method to thoroughly review failure modes and the effects of failures and deviations on the overall system. As these deviations are identified, the HAZOP nodes and the deviation are logged on the FMEA's worksheet. HAZOP deviations are noted on the FMEA worksheet as potential failure modes. Each of these deviations are reviewed to determine the consequences and logged onto the worksheet as potential Effects failure. The HAZOP causes are logged also as potential cause mechanisms (Trammell & Davis 2001). Hence it constitutes a combined FMECA/HAZOP approach. While some coupled approach of risk domain consider causal relationship, they do not define monitoring parameters.

Finally, and related to maintenance objective, (Gabbar et al. 2003) present a system design and mechanism of improved RCM (reliability-centered maintenance) process that is integrated with a CMMS (computerized maintenance management system). In this work, the failure model is developed using HAZOP and FMECA techniques. HAZOP was used to report the possible deviations, causes, and consequences for equipment, while FMECA defines the different failures with the different levels of details along with the criticality of each failure. The combination of these failure and deviation assessment techniques facilitates the analysis of the root cause. Similarly, for the production of large motors, and in particular to identify predominant failure modes, (Edwin & Syam 2010) proposed to apply simultaneously some methods such as FPD (Failure Progression Diagrams), FMEA and HAZOP to the motor sub-systems. He focuses on advantages of simultaneous failure analysis using these three methods. These proposals focused on classical maintenance needs but do not consider the monitoring needs. (Cocheteux et al. 2009) proposed a coupled FMECA-HAZOP approach for proactive maintenance in order to integrate information for prognostic purpose within an extended FMECA worksheet. The parameters to be prognosticated are described as well as the behavior and the influence factors. However, these parameters are prescribed while we are looking for a way to define them. Finally, this review of combined FMECA and HAZOP approach used in reliability analysis, safety analysis, risk assessment and maintenance domain, highlights some lacks in regard to proactive maintenance strategy. Indeed, these works do not consider the definition of monitoring parameters with causal relationship consideration. To face these limits, this paper proposes a functioning/dysfunctioning-based approach for indicator identification.