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The Functional Resonance Analysis Method for a systemic risk based environmental auditing in a sinter plant: A semi-quantitative approach

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ABSTRACT

Environmental auditing is a main issue for any production plant and assessing environmental performance is crucial to identify risks factors. The complexity of current plants arises from interactions among technological, human and organizational system components, which are often transient and not easily detectable. The auditing thus requires a systemic perspective, rather than focusing on individual behaviors, as emerged in recent research in the safety domain for socio-technical systems. We explore the significance of modeling the interactions of system components in everyday work, by the application of a recent systemic method, i.e. the Functional Resonance Analysis Method (FRAM), in order to define dynamically the system structure. We present also an innovative evolution of traditional FRAM following a semi-quantitative approach based on Monte Carlo simulation. This paper represents the first contribution related to the application of FRAM in the environmental context, moreover considering a consistent evolution based on Monte Carlo simulation. The case study of an environmental risk auditing in a sinter plant validates the research, showing the benefits in terms of identifying potential critical activities, related mitigating actions and comprehensive environmental monitoring indicators.

1. Introduction

Any organization that aims to control its activities generally performs environmental monitoring and auditing, to limit or prevent environmental harms. Respectively, the environmental monitoring and environmental auditing are related to the operational and the managerial status of the organization. However, in practice as well as in literature, these expressions are often used interchangeably or overlapped (Viegas et al., 2013). Monitoring focuses on stringent procedural aspects such as sampling, extraction and calibration (Rubio and Pérez-Bandito, 2009) and it consists basically on capturing, controlling and reporting a specific event while it occurs. On the other hand, auditing consists of periodically reviewing (Ruiz-Padillo et al., 2016) how policy, practices, and operations in a specific process, affect the environment, then suggesting possible mitigating actions (Thompson and Wilson, 1994). Environmental auditing acquires a risk-oriented structure (Boiral and Gendron, 2011; Knechel, 2007; Power, 2003) and thus the risk investigation aimed at risk reduction becomes one of its cornerstones (Oliveira et al., 2011). On this path, the Environmental Audit (EA) acquires a crucial role in auditing. EA is a management tool, which evaluates the environmental performance of a process plant. EA should answer several company managers' questions related to compliance with regulations, quality of practices, operational and economic level of environmental impact (Noble and Nwanekezie, 2016), also assessing potential improvement for the plant itself (UNEP, 1990)

EA has a strong risk-oriented perspective (risk-based audit – RBA) and mostly focuses on the plant's operational aspects and their impact on environmental products, especially when evaluating potential corrections of the Environmental Management System (EMS). Identifying hazards and risks is of utmost importance, in order to minimize the accidents' likelihood. RBA should focus on the environmental contribution rather than on the economic performance, differently from the existing environmental performance auditing studies (He et al., 2015). RBA analyzes agents and processes that may have an environmental impact: rather than focusing only on technical aspects of the plant, it should consider the interactions among different factors, considering the plant as a whole. This conception is particularly relevant in case of plants or processes characterized by not-negligible interactions among human, technological and organizational aspects.

For a more reliable RBA, Harris et al. (2009) argued the need to include multiple causal factors, mapping more properly their causal path, especially in case of a large analysis, or in real case scenarios, with a not-negligible uncertainty (Cardenas and Halman, 2016). Evolving this idea, this paper models the interactions among system agents, adopting the Functional Resonance Analysis Method (FRAM) in order to evaluate those factors contributing to generate a potentially relevant environmental impact. In its traditional structure, FRAM defines a model showing the interactions among agents, and defining variability based on linguistic evaluations of performance. Starting from a recent explorative research in the domain of safety (Patriarca et al., 2017),

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this paper suggests a semi-quantitative evolution of FRAM related to a detailed process. This evolution, based on Monte Carlo simulation, systematically describes how to translate the traditional linguistic characterization of performance variability into distributions of variability. Monte Carlo simulation then allows combining different aspects of variability in terms of probability distribution and subsequently, isolating critical relationships among functions. This approach would be semi-quantitative since the distributions of variability are generally based on qualitative evaluations of performance, rather than quantitative data. To the best of our knowledge, this paper constitutes the first discussion of FRAM for assessing environmental risk, both in its traditional structure, and in the innovative semi-quantitative structure recently proposed in the domain of safety (Patriarca et al., 2017).

The contribution of the paper are as follows. In the first section, the paper briefly summarizes the aspect of current RBA, then focusing on the benefits of developing a systemic method in line with the safety management evolution in other industrial contexts. In the second section, the paper exploits how a systemic perspective may generate benefits for traditional EA. The third section discusses the principles and the building steps of a FRAM model, detailing jointly the proposed semi-quantitative structure. The fourth section details an explorative case study of a sinter plant, then discussed in terms of environmental risks by FRAM in the fifth section. Finally, the conclusions envisage the importance of this approach and pave the way to further research.

2. EA: the need for a systemic and systematic perspective

EA is a tool carried out to check on existing practices, in order to assess the environmental effects of current activities (*ex post*). The International Chamber of Commerce (ICC) defined EA (ICC, 1991) as a "management tool comprising systematic, documented, periodic and objective evaluation of how ell environmental organization, management and equipment are performing with the aim of helping to safeguard the environment". It started as an internal control tool, to help companies verifying their specific position with respect to environmental regulation, but nowadays it is acknowledged as an instrument leading to cost savings and management effectiveness.

Following ISO 14000 family, specifically ISO 14001, EA represents a documented verification process of objectively obtaining and evaluating audit evidence to determine whether specified activities, events, conditions, management systems, or information conform with audit criteria. In this sense, EA differs from Environmental Impact Assessment (EIA), which aims to provide information as a consequence of a specific activity (*ex ante*) (Wathem, 1990). EA should be carried out including a kick-off meeting, detailed inspection, interviews, document review as well as closeout meeting with the plant management (Smith and Hull and Associates, 2003).

Two main forces encourage the development of an EA: direct pressure, i.e. regulation and mandatory audit, and indirect pressure, i.e. the need to move towards public environmental disclosure, see (e.g.) one of the very company report, i.e. Norsk Hydro (UK) report in 1990 (Maltby, 1995). EA should then be conceived as an on-going process developing and acquiring more accurate data for improved evaluations and business performance, rather than a time-consuming process.

According to an operational perspective, general guidelines about EA suggest following specific checklists related to relevant environmental parameters (e.g. emissions to air, ambient air quality, surface water quality, ground water seepage, ground water quality, etc.) (Buckley, 1991). These evaluations relate to the so-called terms of reference (TOR), which are actually confirmed to be site-specific and thus requiring the involvement of auditors with detailed knowledge of the specific industry being addressed (World Bank Group, 1998).

It is possible to highlight this descriptive perspective in several industrial applications. For example, the EA program in a sugar factory of Kolhapur district of Maharashtra (India) confirms EA as a need for the company to survive in today highly regulated scenario, to prove the compliance of the plant, and define measures to reduce the consumption of water and fuel (Rao et al., 2011). Similar results emerge from the EA conducted in Olkaria III, a geothermal power plant in Kenya, by the definition of a hazards list and related causal factors (Tole et al., 2009). EA of municipal solid waste management in Bangalore city shows how the values of system indicators, compared with expected values, might lead to identify process areas requiring further investigation (Ramachandra and Bachamanda, 2007). Two relevant patents have been assigned to two EA-related inventions, proving the industrial relevance of this type of audit. The patents respectively discuss a methodology for performing systematically an EA and summarizing the results in an easily understandable format based on an environmental score (Baum, 2011); and a system for managing EA information based upon a set of established safety protocols, accessible through an internetworked system (Virag and Smith, 2006).

Furthermore, the Leopold matrix (LM) represents a methodology, originally intended for the EIA, but potentially helpful also for the purpose of EA (Leopold et al., 1971). LM is a two-dimensional representation, referencing activities (the rows) and existing conditions (the columns) potentially affected by them, see e.g. Josimovic et al. (2014). The benefits of this analysis are limited in case the activities are strongly linked to each other, and the environmental impact may be affected by their interactions in everyday activities, sometimes hardly to represent and describe, by system decomposition. This static representation might have limitations to highlight properly how the system actually works in normal condition, representing everyday variability and its effects on environmental outcomes.

These descriptive evaluations undoubtedly help characterizing the plant and identifying which ones of a set of pre-defined indicators are critical, with respect to acceptable pre-defined levels. However, they might fall at identifying the factors leading to unacceptable values, emerging due to the complex interactions of specific processes.

To fill this gap, this paper acknowledges the benefits arising from the recent research in the domain of safety for socio-technical systems, relating this innovative perspective to environmental analysis. In the safety domain, safety management is shifting from Safety-I to Safety-II, acknowledging the not-negligible complexity of current systems. Safety-I relies on the *causality credo*: an accident or incident happen because something goes wrong, with the possibility to find and treat its causes. However, although it is obviously reasonable that consequences are preceded by cause, it is not always correct to assume that the causes are easily detectable. This concept is even more important if considering modern industrial plants, where an increasing complexity emerges, in terms of transient interactions and tight couplings among human, technical, procedural and organization agents (EUROCONTROL, 2009; Hollnagel, 2014). We could discuss this point in terms of EA: even if it would be detectable the cause-effect links, there might be some instances where this link would become hardly identifiable, or even impossible to detect. A systemic perspective should thus be more appropriate to address current working conditions, acknowledging that they have significantly changed over the past decades. A reliable EA should thus take into account this new perspective, addressing the features of current procedures, technology, IT software, human tasks and human machine interface (HMI), organizational productivity pressures, workload effects, etc. In a modern plant, only few agents and processes are independent from each other and subsequently isolating and analyzing them in a one-by-one strategy could become ineffective. System description becomes elaborate, requiring many details, and systems may change before their description is completed. Thus, it is possible to know the principles of functioning just partly, underspecifying the whole system. These observations pave to way to the development of Safety-II (Hollnagel, 2014):

- Systems cannot be decomposed in a meaningful way
- System functions are not bimodal but everyday performance is flexible and variable