Crowd sensitive indicators for proactive safety management: a theoretical framework

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The Functional Resonance Analysis Method (FRAM) is a method to develop work domain models able of capturing the nitty-gritty of work. The analysis of different model instantiations supports the identification of possible misalignments between Work-As-Imagined (WAI) and Work-As-Done (WAD). Knowledge elicitation is currently a tricky stage for the modelling process, often being significantly time-consuming. A variety of knowledge elicitation techniques is thus used to compensate such information gap, including document analysis (procedures, standards, manuals), interviews (often open-ended or semi-structured), focus groups, workshops, and observations. Especially for the WAD, data gathering through interviews or mainly naturalistic observations becomes particularly time-consuming and labour-intensive since it has to reconcile multiple data sources (multiple operators performing tasks). For such purpose, we propose an IT framework designed to facilitate sharp-end operators' WAD data gathering through a user-friendly app. Based on a FRAM-based ontology and knowledge elicited, a semantic reasoner named Creativity Machine will complement the data collection. The purpose of the framework consists of defining context-specific potential functional patterns (taking advantage of the FRAM structure). Such patterns will then be proposed to operators in order to receive confirmation about their significance in actual operating contexts. From these informative chunks, the framework will allow inferring multiple WAD instances, and associated context-specific leading indicators, i.e. $H(CS)^2Is$ (Human-Centred Safety Crowd-Sensitive Indicators).

Keywords: FRAM, Leading indicators, Socio-technical systems, Ontologies, Semantical models, Knowledge Elicitation.

1. Introduction

The so-called Safety-II is a recent paradigm for safety management focusing on behavioural complexity in socio-technical systems (Hollnagel, 2017a). Safety-II discerns in the daily variations of working performances the way to reach adaptive and proactive success, even in response to internal and external operating conditions (Woods and Hollnagel 2007). System's resilient performance is clearly achieved through behaviours, habits, and trade-offs that result in a Work-As-Done (WAD) that could be far from the work thought under ideal conditions, i.e. Work-As-Imagined (WAI) (Hollnagel 2017b). The comparison between the imagined situation (WAI) and the one actually done (WAD) is a usual step in the analysis typical of resilience engineering – the discipline that encompasses Safety-II vision (Patterson and Deutsch 2015). It is therefore often necessary to identify and analyze system states corresponding – at least, cf. (Moppett and Shorrock 2018) – to WAD and WAI. Within resilience engineering, the functional resonance analysis method (FRAM) allows functional descriptions of socio-technical systems through the so-called instantiations. These latter are function configurations corresponding to the virtually possible states of the system under examination (Hollnagel, 2012). The WAI represents a state of the system corresponding to a configuration of activities, latent and environmental conditions to which a precise instantiation can be associated and the same can be done for the WAD. Through FRAM, the comparison between WAI and WAD corresponds to a comparison between two instantiations. From this comparison, it is possible to develop subsequent analyses for the identification of leading indicators, proactive indicators of the safety status of the system (Patriarca, Falegnami, et al. 2018). However, typically the process of construction of WAD instantiation is much more difficult than construction of WAI instantiation. This latter is

Proceedings of the 30th European Safety and Reliability Conference and the 15th Probabilistic Safety Assessment and Management Conference
Edited by Piero Baraldi, Francesco Di Maio and Enrico Zio
Published by Research Publishing, Singapore.
ISBN: 978-981-14-8593-0; doi:10.3850/978-981-14-8593-0

similar to the body of rules and prescriptions (i.e. Work-As-Prescribed, WAP) expressed in documentary form, therefore almost entirely directly accessible (Moppett and Shorrock 2018). The construction of WAD instantiation goes through a process of elicitation that generally includes qualitative research tools such as interviews (either semi-structured or unstructured), questionnaires and in situ naturalistic observations, which are often time consuming, expensive and complicated (Son et al. 2020).

Mobile Participatory Crowd-Sensing (MPCS) refers to the opportunity to recruit a group of users to collect data through their handheld devices (Capponi et al. 2019). Nowadays diffusion and progress reached by mobile technology make possible individual data collection concurrently from a large pool of users. On this path, distributed knowledge across multiple operators acting in a complex socio-technical system can be reconstructed in a more efficient way.
The present work introduces a theoretical framework called H(CS)^{2}I (i.e. "Human-Centred Safety Crowd-Sensitive Indicators") encompassing different methods and technologies to facilitate WAD vs WAI comparison. H(CS)^{2}I is based on participatory collection of sharp-end data through a mobile application based on FRAM and ontologies. It inherently brings the potential to leverage the process of building leading indicators in a Safety-II perspective. The remainder of the document is structured as follows: section 2 introduces background information and related work; section 3 details the framework; and section 4 outlines conclusions and anticipates further potential developments.

2. Related work

The H(CS)^{2}I framework incorporates several concepts and IT tools. First, it formalizes, semi-automates and makes reproducible the practice now established in Safety-II of comparing WAI vs WAD. One can observe that an efficient socio-technical system, even from a safety viewpoint, is a system in which WAI and WAD tend to be aligned, both because the sharp-ends intimately share the principles on which the system was designed, and because these principles are sufficiently realistic (Blandford, Furniss, and Vincent 2014). When this alignment is lacking it means that the body of normative prescriptions must be adjusted closer to the WAD.

Alternatively, the working environment must be modified in ergonomic and cognitive terms in order to carry out the work as close to the design conditions as possible, trading-off unnecessary deviations and enough margin for adaptation (E. Hollnagel 2017b). There is scarcity of models describing work in line with the front-end operators' perspective (Clay-Williams, Hounsgaard, and Hollnagel 2015). The WAD occurs according to ETTO (Efficiency-Thoroughness Trade-Off) principles – i.e. following local criteria of compromise efficiency-accuracy – with the aim of achieving a well-defined objective, in a particular context, producing consequences that may be unexpected and change context and objective (Hollnagel 2009). The WAI and WAD may be very different in real practices: the latter being more difficult to be adequately modelled. For example, the actual work environment is far from the designed one; workers pursue objectives that are multiple and ever changing, complying variable and unpredictable requirements, by means of degraded resources (Patriarca, Di Gravio, et al. 2018). Data collection is usually also hampered by workers' biases.

From a high-level standpoint, the H(CS)^{2}I framework must encompass the capability of representing and dealing with WAI and WAD system states (e.g. through FRAM); of reducing the difficulties associated with information elicitation for WAD (e.g. through MPCS). This target can be achieved through an information structure able to harmonize the whole (e.g. ontologies).

3. The H (CS)^{2}I framework

3.1 *Background*

3.1.1 *FRAM*

The FRAM is a sine model method, meaning that it does not need an underlying model to describe a sociotechnical system. The FRAM description is carried out in terms of individual activities or processes that are called "functions" and are usually graphically represented by hexagons, because in the FRAM there are six possible different ways of inter-functional interfacing (i.e. "aspects"). The link between two different functions through a couple of their aspects is called a "coupling". The process of modelling through FRAM fulfils the need for a fractal self-similarity description. This latter ensures functions' decomposability into sub-functions or, on the contrary, more functions can be subsumed by other more abstract functions.

FRAM does not possess elements that can be considered atomic. Since its holistically selfsimilar nature, there are functional coupling structures that make sense only in a given context. An ontology is precisely the information structure best suitable to translate and manipulate algorithmically the FRAM. A FRAM-based ontology (as the one presented in (Lališ et al. 2019)) makes it possible to effectively collect data from sharp-end operators for the reconstruction of the WAD instantiation.

3.1.2 *MPCS*

Mobile Participatory Crowd-Sensing (MPCS) is the data collection mechanism that enables context-specific information to be collected directly from sharp-end operators. Previously, we dealt with the bias induced by the organizational structure and the high cost of qualitative data collection methods needed to describe the WAD and its subsequent description as a FRAM instantiation.

The H(CS)^{2}I framework addresses these issues by exploiting the large adoption of personal mobile devices. The individual sharp-end operator is asked via a mobile app to give a description of his/her actual work activity. The app directly builds the FRAM instantiation corresponding to the WAD, without going through the ordinary methods of data collection (interviews/naturalistic observations). The elicitation of knowledge is done aggregating information contribution extracted from all the individual operators involved (Patkar et al. 2019). Considering the expected deviations between WAI and WAD, the mobile app should also support the data collection hypothesizing unusual, still plausible, scenarios (González-Gómez and Richter 2015; Lee, Theng, and Goh 2005).

3.1.3 *Ontologies*

Ontologies are specialized computer data structures able to give formal representation of categories, properties and relations between data concepts and entities related to certain discourse domains. A knowledge graph is a graph representing discourse entities (or concepts) having relationships between them. Knowledge graphs can be extracted from ontologies with respect to a considered set of classes. A built ontology enables the implementation of so-called reasoning algorithms (i.e. capable of gaining more knowledge by inferences and deductions).

A properly designed reasoner can distinguish a correct (syntactically well formed) and a semantically valid FRAM instance. It must rely on a FRAM-based ontology and an application domain-based ontology. The latter is constantly updated and expanded by the information obtained by building the WAI and WAD instantiations. Therefore, the more interactions with the sharp-end through the crowdsensing app, the richer the domain ontology gets.

3.2 ***The framework stages***

The framework consists of 7 stages (Fig.1):

- Documentary knowledge elicitation
- FRAM WAI modelling
- Ontology engineering
- Creative re-design
- MPCS and validation
- FRAM WAD modelling
- Safety assessment.

3.2.1 *Documentary knowledge elicitation*

This stage acquires data for the definition of the WAI instantiation. An in-depth and detailed documentary analysis is used to reconstruct all the work activities as imagined in regulatory and prescriptive terms. The data collected defines the domain and the limits of the application of the FRAM model, the foreground, and the background functions. The elicited knowledge about WAI is used to clarify which elements are in the focus of the analysis. At this stage, it may be appropriate to check the completeness and accuracy of collected data by interviewing blunt-end operators. Management is generally accustomed to providing guidance on how the work should be done (WAI), which is usually their focus of analysis.

This data can be considered generally reliable even if the blunt-end can ignore (or more rarely omit) the actual working conditions of the sharp-end, since it is an imagined, theoretical work. This phase requires the presence of at least one operator experienced in FRAM development (i.e. FRAM analyst), who knows how to direct interviews and data collection in general towards the acquisition of relevant information (e.g. the couplings and aspects involved, the assessment and aggregation of variability, the agents involved, and the level of resolution required by the model).

3.2.2 FRAM WAI modelling

The FRAM analyst builds the FRAM instantiation corresponding to the WAI through a software application (namely myFRAM[a]). The

[a] myFRAM is an open tool - released freely by Sapienza "Industrial Systems Engineering" research group - to support

tool allows to perform some preliminary analysis and to verify the correctness and closure of the model. Then, it generates the digital translation of the instance to allow further analysis, but above all it represents the entry point for the rest of the proposed framework.

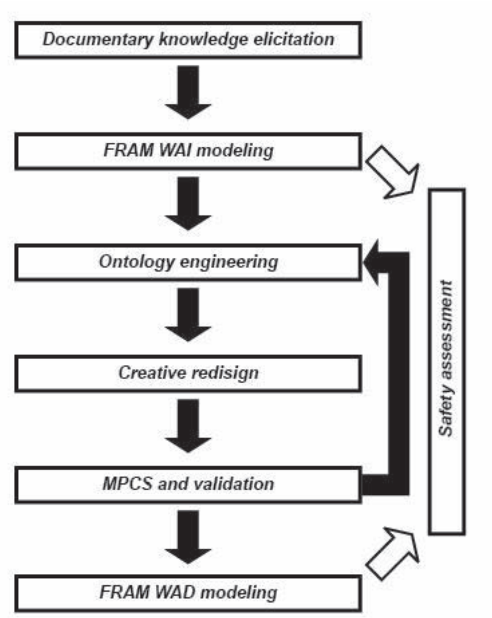

Fig. 1. The H(CS)^{2}I framework's seven stages. The safety assessment (and the subsequent leading indicators construction) is unlocked by the concurrent presence of both the WAD and the WAI instantiations. The ontology can take advantage of feedback on the information elicited during the MPCS stage.

3.2.3 Ontology engineering

This step focuses on data ingestion and feeding an ontology that forms the data structure at the core of the entire H(CS)^{2}I framework. A FRAM-based upper model ontology establishes the syntax, i.e. the rules for which an instance (its functions, coupling) can be considered "well formed" (Lališ et al. 2019). The upper model (Rousseau et al. 2018) describes the concepts of phenotype, variability, function, instantiation, etc. The WAI FRAM instantiation is parsed in a format that allows a further application to feed a FRAM ontology based on the domain and the application of interest. A dedicated analyst is in charge of verifying the internal consistency, solving possible semantic overlaps and integrating, if required, the underlying ontology (De Nicola and Missikoff 2016).

3.2.4 Creative redesign

An application called "Creativity Machine" generates, according to some semantic rule patterns coding the above-mentioned ETTO patterns, a high number of FRAM model variants consistent with the analysed context. These potential variations should then be prioritized depending on their actual reasonableness in the specific context. In this step, at least one ontology master and one FRAM Subject Matter Experts (SME) are necessary to validate the generated model variants (De Nicola, Melchiori, and Villani 2019).

3.2.5 MPCS and validation

In this step, the process of knowledge elicitation related to the WAD instantiation is carried out through a mobile app. This latter is used by the sharp-end operators to perform the crowdsensing tasks by means of the creativity machine. The app allows users to describe their work practices through a user-friendly interface. Starting from the activity the user is describing (i.e. a function), the interface proposes some linguistic choices congruent with the context (see Fig.2), as supplied by the creativity machine.

If the user considers them potentially adequate, he/she can use them to describe his/her activities, otherwise he/she can insert new information that feeds the FRAM domain-based ontology.

During the creative redesign stage, despite the action of pruning rules, the pattern-based information chunks are generated in large amount. Therefore, it is not necessary (nor convenient) to present all possible patterns to the user as contextual. An automated pattern filtering action is applied. It relies on object (i.e. patterns) ranking obtained by a prioritization algorithm. AS for the pruning process within the pattern generation, some syntactic and semantic rules rank the pattern according to FRAM (semantical rules) and context (ontology). Finally, the app will present only a limited – but most valuable – number of objects to the user.

3.2.6 FRAM WAD modelling

Concurrently, the information collected by the individual operators is used to build the WAD instantiation. In this step, the instantiation is translated back into a human-readable format to ensure that an analyst can properly evaluate its consistency and closeness.

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the applicability of the FRAM analysis (Patriarca, Di Gravio, and Costantino 2018).

3.2.7 Safety assessment

A focus group including both blunt and sharp-end operators is coordinated by a FRAM analyst to examine the differences between WAD and WAI instantiations. In this step, two types of leading indicators are constructed: the ones based on differences between aspects of functions, and those on systemic semantic differences. The former examines the upstream-downstream functions allocation to define meaningful indicators (Falegnami et al. 2019). The latter exploit the instantiation's graph of knowledge properties (Pomi and Mizraji 2004).

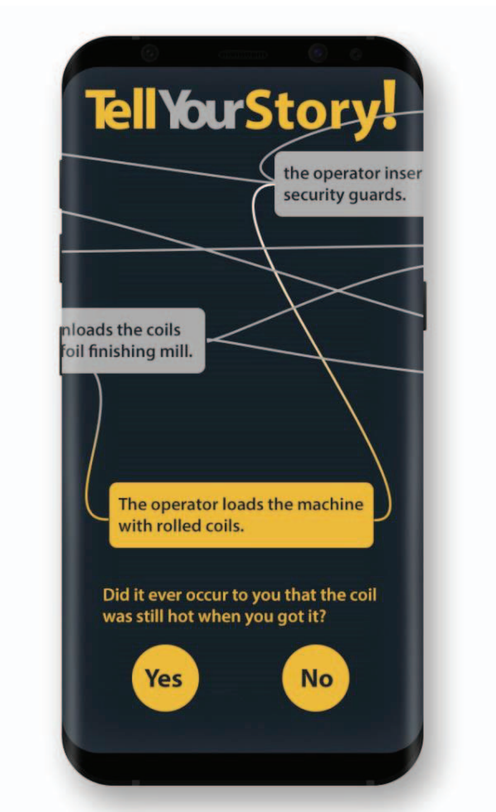

Fig. 2. A mock-up depicting the MPCS app's user-friendly interface.

4. Conclusions

Socio-technical systems are complex organisms which may exhibit elaborate behaviours because the operating work conditions are generally very different from the ideal designed ones. Moreover, information regarding WAD is difficult to obtain since it is normally distributed among multiple sharp-end operators. The H(CS)[2]I framework proposes the adoption and integration of methods, tools, and technologies with the precise aim of overcoming hindrances concerning the WAD detection. The MPCS seems to have the potential for simplifying the practices related to detection and treatment of WAD. The FRAM offers a proven language to describe socio-technical possible states by means of the process of instantiation. Ontologies allow for coexistence and harmonization between MPCS and FRAM.

Using the IT tool myFRAM as a starting point, the H(CS)[2]I framework provides an interface between human (the FRAM analyst) and machine (the IT support tools) interaction, unlocking the chance for building the instantiations at run-time. These latter remain meaningful if built on a two-tiered ontology (i.e. FRAM-based and domain-based). The software module generating WAD-related meaningful chunks of FRAM instantiations is called "Creative machine", and its duty is to offer non-trivial prompts to sharp-end respondent during the crowd-sensing stage.

The proposed conceptual idea aims to unbind the respondents' possibilities in providing their experience about process deviations that may occur during work time. The framework encourages practitioners to suggest, even by unlikely yet plausible examples, deviations that could be considered out-of-the-blue. We believe that the framework can reduce WAD acquisition effort, allowing the safety analyst to focus more on modelling aspects rather than mundane legwork. Moreover, MPCS technologies make H(CS)[2]I easily scalable, even though its efficiency shall be tested, given the large amount of data to be managed.

Besides the target of the current project, we aim to evaluate the possibility of equipping the app's user interface with a text auto-completion system through linguistic patterns congruent with the domain context.

Future research is devoted to test the applicability of this theoretical framework in progressively larger scale real work domains.

Acknowledgement

This paper present early results about H(CS)[2]I framework, a project funded by INAIL under 2018 SAF€RA EU funding scheme.

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