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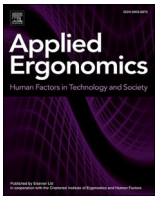

Systematically investigating human and organisational factors in complex socio-technical systems by using the "SAfety FRactal ANalysis" method

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ABSTRACT

In order to manage the performance of socio-technical systems in a safe and sustainable way, the importance of looking at human and organisational factors (HOF) and their contribution to adverse events is widely recognised. In reality, however, the scope of accident and incident investigations stays usually limited to investigating the immediate causes and decision-making processes related to the accident sequence (e.g. Antonsen, 2009). Important factors, including design and planning decisions, contributing to accidents are hereby often overlooked and the weaknesses in the Safety Management System are hardly ever analysed. The SAfety FRactal ANalysis (SAFRAN) method (Accou and Reniers, 2019) can guide investigators in an intuitive and logic way, to ask questions that help to gain deeper understanding of the capability of organisations to monitor and manage safety critical variability. The essence of using the SAFRAN method for evaluating the performance of the different processes in a socio-technical system, is to approach them in a similar way, building on the generic elements that compose a SMS and systematically looking at the HOF that influenced actions and decision making, regardless of the hierarchical level they are situated at. This paper presents the SAFRAN method, specifying its HOF taxonomy and sharing examples of supporting HOF questions. The approach enables non-experts in HOF to systematically identify the different elements that introduce critical variability in performance and to recognise what additional expertise can be called upon when needed.

1. Introduction

Commissioned by the International Ergonomics Association (IEA), Dul et al. (2012) have published a position paper for the human factors/ergonomics (HFE) community in 2012, in which they provide an up-to-date picture of where HFE stands as a professional discipline and which strategies should be used to strengthen this position for the future. They conclude that, despite more than 50 years of history, HFE knowledge has not yet found wide-spread recognition nor implementation and the potential of HFE remains under-exploited. The main reasons for this, still according to Dul et al. (2012), can be found in: (1) no strong stakeholder demand by lack of awareness, (2) no readily available HFE knowledge in design projects, resulting in sub-optimal solutions, (3) no explicit reference to HFE as a discipline, when incorporated in wider design projects and (4) confusion and ambiguity on what HFE is, due to its multi-disciplinary base.

The main strategy direction Dul et al. (2012) propose towards the world-wide application of HFE excellence is to strengthen the demand and application of high-quality HFE through improved communication, the building of partnership with all identified stakeholders (i.e. system actors, system experts, system decision makers and system influencers) and the promotion of high-quality standards for HFE knowledge.

While fully supporting the starting point that HFE has great potential to optimise human performance and well-being, based on their own professional experience with implementing safety management in the railway system in Europe, the authors of this article can only confirm that almost a decade after the publication of this position paper, the need for a better integration and application of HFE knowledge is not only still very recognisable but also urgent. To achieve this, more than better marketing for HFE by the HFE community will be required. HFE should be accepted as an essential prerequisite for safe and sustainable performance and not as an expendable add-on, as it is still too often perceived (Hollnagel, 2014). In that context, Dul and Neumann (2009) argue that HFE can add value to a company's business strategy to create organisational effectiveness. Grote (2014), elaborates on this idea and suggest to embed system design in the management of uncertainty (and

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the management of risk more general) that should be part of the overall objectives in individual and organisational decision-making in order to gain and maintain control of activities to achieve desired goals. Within the European railway legislative framework (European Commission, 2018, 2020), a first step in this direction has been taken by introducing explicit requirements to take a systematic approach to supporting human performance and managing human and organisational factors within the safety management system (SMS).

In line with what Dul and Neumann (2009) suggest, the authors of this article agree that every opportunity to link variability in safety (and wider business) performance with (lack of proper implementation of) HFE should be exploited in order to convince stakeholders, and in particular decision-makers, of the importance of taking HFE into account as a strategic element in controlling activities. An important success factor here is that not only HFE experts are able to do this, but everyone who is involved in the analysis of an operational context, such as auditors and accident investigators. Furthermore, it is important to recognise that the nature of work in the railway sector and therefore also the work environment has changed dramatically over the last decades, with the centralisation of traffic control centers and the still increasing automation of train control and traffic management as only a few examples. As argued by Hollnagel (2014), for HFE to be able to anticipate and properly support these new types of work, the scope of possible interventions should aim beyond the pure design of artefacts and focus on the broad organisation of activities. This also requires the capability to deal with the organisational dimension of socio-technical systems. To put a focus on this need to envisage a broader scope for HFE activities, the authors prefer to refer to "human and organisational factors" and to use the acronym "HOF" (rather than HFE) in the remaining part of this article.

With the above in the background, this article describes how the SAfety FRactal ANalysis (SAFRAN) method can be used by non–HOF–experts to identify the different HOF elements that introduce (critical, either positive or negative) variability in all relevant processes and to recognise what additional HOF expertise can be called upon when needed.

2. Using the SAFRAN logic to systematically identify HOF

The SAFRAN method was developed by Accou and Reniers (2019) to guide accident investigators in exploring the composing elements of an SMS in a natural and logic way, starting from the findings close to operations that explain the occurrence. Initially, it was introduced as a combination of a generic model of process management, an investigation flow, and a matching graphical representation. The most appealing element of the method lies in the identification of five recognisable investigation steps that, when iterated, provide a structured way to guide investigators to evaluate any relevant process of the socio-technical system. The logic of this repetition provides an ideal pattern to examine the concerned HOF in a systematic way throughout the socio-technical system.

2.1. The Safety Fractal as an instrument to manage sustainable performance

The Safety Fractal forms the basis of the SAFRAN method (Accou and Reniers, 2020). It describes, in a generic and self-similar way, a five-step safety management delivery system that can assure the design of adequate resources and controls for the proper functioning of processes and safety related activities, at all levels in an organisation:

- (1) **Specify**: The scope and desired outcome of an activity is specified, roles and responsibilities identified, disrupting events are anticipated and risk control measures (rules, barriers) are designed (i.e. work as imagined).
- (2) **Implement** – train, equip, organise: All is done to have activities performed by enough competent people, adequate technical resources are put available and maintained, work products and resources to be used are identified and work is planned in detail.
- (3) **Perform**: The activity is executed, responding to real life constraints and disturbances (i.e. work as done).
- (4) **Verify**: The system's performance is monitored, i.e. verifying the match between work as designed and work as actually performed, as well as the elements that could affect this performance in the near term.
- (5) **Adapt**: It is known what has happened and lessons are learned from experience and the adequate changes to control, or implementation elements, are introduced.

When grouping these steps according to the nature of their goal, three distinct levels to observe the functioning of a process can be identified. A level of **process performance** in step (3) that is representing the direct functioning of the components that interact during process execution ("doing things") and that is also the level where variation against process specifications and/or expectations can be observed. A level of **process implementation** through step (2), providing the resources and means to ensure the correct functioning ("doing things right") of the process components during process execution. And finally a level of **process control**, composed of the steps (1), (4) and (5), ensuring the sustainable control of risks related to all activities of the organisation in possibly and most probably a changing context ("doing the right things"). Provided that resilience is chosen as safety strategy with a clear focus on managing performance variability rather than eliminating threats, Accou and Reniers (2020) argue that the Safety Fractal is the perfect vehicle to improve safe and sustainable performance in complex systems, still making optimal use of the experience gained with safety management systems (SMS) over the past decades.

This Safety Fractal represents a repeatable unit of analysis in which HOF elements can be identified as those factors that could create critical variability in the human or wider system performance. These sources of performance variability (SPV) are always part of a process, function or activity. The main idea behind the proposed approach is that performance variability and the SPV that influence it (i.e. step 3 in the Safety Fractal), once identified in a concrete situation, can be linked to respectively the control and implementing processes, to form the basis for managing safe and sustainable performance.

The "specify" element (1) of the Safety Fractal will cover the ability to anticipate and prepare for normal operations and foreseeable hazards. Several authors (e.g. Le Coze, 2020) also argue that part of the response to sudden disruptions should be included at this stage, in the design of the system, which will require a reflection on possible SPV. This is in line with the view of pioneers such as Chapanis (in Fitts, 1951) or Norman (2002), who indicated the importance of considering the users of each part of the system in their interactions with it, right from the design stages. The origin of performance variability and the potential room for improvement should therefore not only be sought in the process that failed (or in which operational users err), but also in the whole system. Furthermore, in line with Norman (1983) who pointed that "people will make errors, so make the system insensitive to them", questioning HOF influences should go beyond the process taken at the start of the analysis and cover most of the possible interactions within the socio-technical system.

Continuous monitoring of the system to ensure that performance boundaries are not crossed is represented by the "verify" element (4) of the Safety Fractal. To cope with the fact that in complex system, with non-linear interactions, it is more difficult to understand the "latent condition pathways" (Reason, 1997) or the "mechanisms" that lead to risks (Hollnagel, 2008), this monitoring will have to shift from looking at past performance (i.e. the more traditional lagging indicators) towards looking at actual performance and resources (i.e. the leading indicators).

Knowing what to measure then requires an understanding of the (effect of) SPV (on performance), which in turn requires regular input from the people taking real-time decisions.

Finally, dampening the critical variability, i.e. the solution to create "resilient performance" according to Hollnagel (2008), could be achieved by the implementing processes, in step (2) of the Safety Fractal, that impact the SPV and that should create those HOF-conditions that make work succeed. By choosing resilience, and more specifically managing critical variability in performance, as the main goal for each Safety Fractal, the need to integrate HOF in SMS is explicitly recognised.

Repeating this logic for all relevant processes in the different hierarchical levels of the socio-technical system will help investigators to overcome the downfall that, according to Salmon et al. (2013), characterises the already existing systems-oriented analysis methods, namely losing the fine-grained analysis provided by methods that focus more on the individual behaviour. They suggest using both system and individual oriented approaches in a complimentary manner as the solution, and further claim that a better understanding of the complexities of human behaviour and the impact of the system on behaviour will support the development of more exhaustive countermeasures.

The proposed SAFRAN method nurtures and structures the repetition of a set of basic questions, guiding investigators both through the socio-technical system processes and through the potential influences of/on HOF. In other words, it offers the combination of both human (i.e. the identification of SPV) and system analysis (i.e. iteration logic) approaches together. By doing so, the method also offers the potential to find the right balance between looking for latent conditions and accounting for the active errors Young et al. (2004) are looking for.

2.2. Illustration of the SAFRAN analysis

Analysing the performance of processes through the identification of HOF elements (i.e. SPV) and repeating this logic for the processes that should manage the related performance variability, was first tested in the context of accident and incident investigations.

To develop this illustration, the information contained in the RAIB report (2017) on the overturning of a tram at Sandilands junction, at Croydon on 9 November 2016, has been identified and restructured.

In the early morning of that day, a tram did not slow down to the required 20 km/h (as trams normally do) and was still travelling at 78 km/h when approaching a sharp curve in the tracks. The driver applied the brakes, but the tram was still travelling at 73 km/h when it entered the sharp curve and began to turn over onto its right-hand side. The accident resulted in seven fatalities, nineteen people seriously injured, and 43 passengers with minor physical injuries (including the tram driver). This accident was chosen because of the comprehensiveness of the final investigation report (RAIB, 2017), identifying HOF throughout a complex socio-technical system. It has also to be noted that elements not related to the over-speeding (e.g. evacuation of passengers) were not included in the analysis.

Starting close to the sequence of events, the first function that is reported showing critical variability, is to maintain appropriate speed. For this function, the RAIB report lists the following SPV: situational awareness, fatigue, low workload and the infrastructure design element related the tight left hand curve and the elements approaching the curve (i.e. three closely spaced tunnels and the visibility of lineside signs). In application of the SAFRAN analysis logic, the next functions to be analysed would then either represents the management of these identified sources of performance variability or the delivery of monitoring and/or learning capability related to over-speeding. For each of these functions, the same logic (i.e. identifying critical variability, SPV and the next functions to analyse) can then be repeated, resulting in yet further iterations. The result of the full analysis can be seen in the following Table 1. The notion "NFI" indicates that "no further information" on the item was available in the investigation report.

From this analysis, we can conclude that the report contains

Table 1
Available information on the Sandiland junction derailment structured according to the SAFRAN logic.

Function and identified critical variability	Identified source(s) of performance variability	Next function: Manage SPV	Next function: monitoring critical variability
Maintain appropriate speed: curve with allowed train speed of 20 km/h entered with 73 km/h	Situational awareness	**Verify driver's situational awareness**	**Monitor over-speeding** (at critical points)
	Fatigue	**Manage driver fatigue**	
	Low workload	NFI	
	Infrastructure design issues	**Design – identify risks**	
Monitor over-speeding: - Reluctance of drivers to report own mistakes - Potential learning from customer complaints not fully exploited - Tram speed checks did not identify drivers travelling above permitted speed	Drivers believing that reporting would result in unnecessary action and/or disciplinary action	**Measure perception/ culture**	**Oversight of tramway system**
	Driver's lack of trust with line controllers and senior management		
	On track data recorders overwrite older data	NFI	
Verify driver's situational awareness: driver's situational awareness not controlled	No device capable of detecting driver's loss of awareness	NFI	NFI
Manage driver fatigue: - Fostering a culture that encourages to report fatigue - Poor review process for checking time sheets for excess hours	No adequate guidance for drivers	NFI	**Measure perception/ culture**
	Rostering and the monitoring of rest day working	NFI	
	Published industry practice not followed	NFI	
Design – identify risks: - Actual level of risk associated with over-speeding on a curve not recognised - Little evidence of use of common risk assessment techniques - Formal recording of route hazard assessment	Rely on driver to mitigate risks of over-speeding	NFI	**Oversight of tramway system**
	Risk not fully understood	NFI	
	Evidence from other transport systems not fully taken into account	NFI	
	Limited bus and coach experience of consultant facilitating risk assessment workshops	NFI	
	Desire among designers, residents and others for the amount of land of acquisition to be minimised	NFI	
Measure perception/ culture: - Biennial staff surveys	Actual response to address identified issues was considered sufficient	NFI	NFI

(*continued on next page*)

Table 1 (*continued*)

Function and identified critical variability	Identified source(s) of performance variability	Next function: Manage SPV	Next function: monitoring critical variability
- Regulator's audit of safety culture and SMS			
Oversight of tramway system: Regulatory strategy provided a lower level of intervention for tramway than for other sectors	Availability of resources	NFI	NFI

information on relevant HOF (i.e. the SPV) for all identified functions throughout the investigated socio-technical system. Except for one SPV identified in the first iteration (i.e. low workload), for all the other SPV that influenced the over-speeding the investigations has looked at the functions that are expected to manage them.

However, we can also conclude that this approach is no longer followed for further iterations. The lack of adequate guidance on fatigue management for drivers, for example, is noted, but the function to develop and manage this guidance appears not to be analysed. On the side of monitoring critical variability, all elements that could have influenced the potential of the concerned organisation to be aware of drivers not respecting speed limits are not analysed. The role of the regulator to provide oversight on the SMS and thus most of the control and implementation processes is not further analysed.

What is considered by the investigation report as ending points, strong enough to recommend mitigations, can also serve as new starting points for further iterating the logic of the analysis through the relevant SPV and (control) processes. These further iterations (corresponding to the NFI in Table 1.), when further explored during an investigation analysis, may lead to more sustainable mitigations and contribute to consider more latent failures within the socio-technical system.

2.3. Identifying sources of performance variability

When investigating incidents or accidents, the aim (and the challenge) of investigating human performance is to find out how peoples' assessments and actions made sense at the time, given the circumstances that surrounded them. When testing the SAFRAN method for use in the aviation sector, Flovenz (2020) highlighted the possibility to have taxonomies to support the analysis as possible area for improvement, in order to guide the investigators "to ask the appropriate question to determine whether such (i.e. human and organisational) factors need to be included or excluded.". Based on similar needs expressed by other investigators that were informally testing the method, it was decided to develop a set of reference SPV that match the SAFRAN investigation logic. This taxonomy could then help investigators to formulate hypothesis on HOF elements that may have influenced a certain decision or action and that can be checked. According to Underwood (2013), having a taxonomy may positively affect the efficiency and effectiveness of a method. Several other authors consider the availability of a taxonomy that allows for classifying the factors that contribute to an event as a critical element when evaluating accident analysis methods (e.g. Speziali and Hollnagel, 2008; Salmon et al., 2013; Waterson et al., 2015).

To overcome the problem that the majority of existing taxonomies is domain specific, strongly referring to situational, organisational and environmental elements of the purpose or field they were developed for, Kyriakidis et al. (2018) have developed a "Basic Unit of analysis of the human in a socio-technical context" and a related, standardised list of sector-independent performance shaping factors (PSFs). Although an appealing starting point, also because of the similarity between the logic introduced by the Safety Fractal and this Basic Unit, an evaluation of this detailed list shows that various adjustments are needed to use these factors with the SAFRAN method. Firstly, the essence of using the SAFRAN method for evaluating the performance of the different processes in a socio-technical system, is to approach them in a similar way. As explained above, the strength of the method is that its logic can be applied regardless of the hierarchical level at which the analysis is situated. For application with the SAFRAN method, having "SMS" as a source of performance variability, for example, is much too related to a fixed dimension or scale of analysis, therefore preventing it to be used at higher levels of iteration. Furthermore, a SMS is a combination of mutually dependent processes and arrangements for which the composing elements should be covered in much more detail when analysing implementing and control processes of a certain function and eventual further iterations.

Therefore, starting from the set of PSFs that is developed by Kyriakidis et al. (2015, 2018) and taking into account available reviews of existing HOF research (e.g. Teperi et al., 2017) as well as relevant elements from other system analysis methods (e.g. Stringfellow, 2010; Hollnagel, 2012), five categories of SPV are identified, which can be used with the Safety Fractal. Four of these categories are organised in a two by two logic: static and dynamic features of the individuals (and teams), or, of the situation. The last and fifth category focuses on the socio-psychological interactions, resulting in the following five groups: dynamic staff, dynamic situational, static staff, static situational and socio-interactional (see Fig. 1). This choice was mainly driven by the aim of providing non-HOF experts with a quick but well-defined and solid overview of the most critical HOF, forging a "HOF mindset" and allowing a more systemic approach when questioning and documenting variability in system performance. The staff-situational duality refers to the classical distinction in existing taxonomies between internal and external factors, with the latter describing situational characteristics, job and task characteristics or environmental circumstances, whereas the internal factors refer to individual characteristics (Kumamoto and Henley, 1965 – cited in Kyriakidis et al., 2018). The dynamic versus static duality, on the other hand, refers to whether or not the factors are strongly related to the precise moment of performance or the exact moment that the occurrence took place (Kyriakidis et al. 2015, 2018). The socio-interactional category, finally, covers the interactions between people while in a situation and certainly in reference to an organised context, with individuals and teams working and communicating towards the achievement of a common goal.

This new grouping was used as a reference structure to build a more pragmatic taxonomy of which each factor will be presented in detail further on. The taxonomy was first stabilised with the help of several series of works that describe the organisational and human factors as critical in socio-technical systems have been taken into account: e.g. the AcciMap introduced by Rasmussen (1980, 1997); the HFACS introduced by Shappell and Wiegmann (2000). An initial list of categories and factors was then available and within each of the five categories, with the input of non-HOF experts, a "regrouping" of the different listed factors has taken place, to finally result in a "5x5" structure that is easy to memorise and remind (see Fig. 1).

Although we refer to this set of factors as a taxonomy, its main objective is not to traditionally classify the causes of an event, but rather to help non-HOF experts seeing human performance as shaped by the constraints of the environment and to provide them with a structured overview of the HOF universe that needs to be explored when trying to understand the system performance. Furthermore, when using this universe of factors, possible interdependencies between factors cannot be excluded (Kyriakidis et al., 2018). Such interdependencies, which are at the heart of classical HOF definitions, are in fact handled by the iterative application of SAFRAN. As a consequence, the order of exploring the different factors is not important as such. However, according to our first audience, the investigators, it seemed more practical and logical to start with the dynamic factors, since they may require a

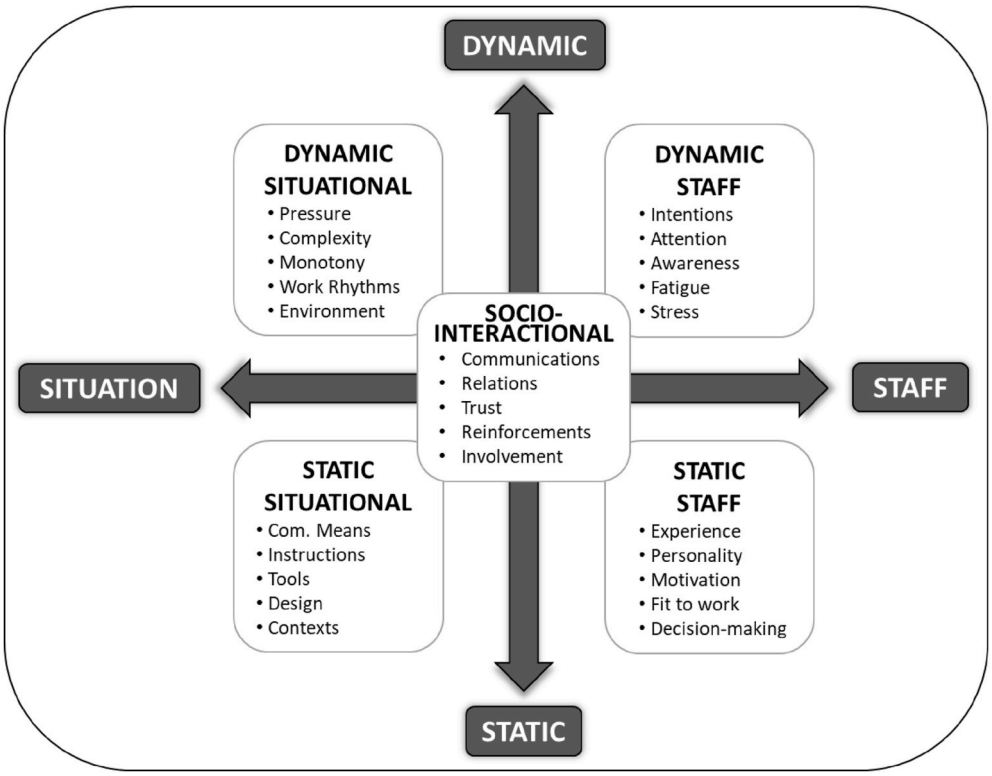

Fig. 1. A pragmatic 5x5 taxonomy to support a HOF mindset.

more immediate attention, earlier in the investigation process, in order to stabilise the evidence. The following sections will describe the different identified factors in more detail.

2.3.1. Dynamic staff factors

With this first set of factors, that covers intentions, attention, awareness, fatigue and stress, we propose to explore whether there are any temporary characteristics of the individuals and teams who have influenced (or could influence – if the questioning is used in a proactive approach) the course of a situation.

It is crucial to understand the persons' **Intentions**, which in the situation (hic and nunc) motivated them to decide and act as they did, as well as the type of the produced variation. Questioning this factor should refer to three aspects: intention during the actions (e.g. what we wanted to do, to achieve, for what purpose, by avoiding what); reasoning in a situation (e.g. in function of what the person(s) had imagined the situation); and, the correct understanding of the type of variability (e.g. (in-) voluntary, type of error, type of violation).

Equally important is to identify all the external and/or personal elements that may have disturbed the **Attention** or concentration of the people concerned. This refers to at least two aspects. One is external and concerns the different concurrent tasks forcing the attentional capacity to be divided or switching, and therefore reduced. The other is internal and refers to the more personal aspects of concentration that can influence the choice of what to focus on at any given time.

Situational **Awareness** (SA) refers to three aspects that enable both the individual workers and teams to represent the situation and thus to base their decisions on. Self-awareness of previous decisions and actions and of the consequences already experienced. Awareness of the situation, of the related risks and how to understand them. Finally, a representation of the real situation based on the information perceived and captured. This factor should indicate what the concerned people have been able to pick up from the available information (1), their understanding of this information and how to process it (2), in order to achieve the desired outcome at the precise moment they had to (3).

The factor **Fatigue**, refers to sleep-related fatigue (in quality/quantity), which is a temporary condition that can lead to variability, for example due to missed information, inadequate analysis or failed action. This factor refers to the search for indicators of fatigue at the time of variability, during the performance itself, as well as in the days preceding it.

Stress, finally, is to be explored in a broad sense. It includes specific emotions as well as other psychosocial or situational factors. Nowadays, a very common reference situation for stress is when people (individuals, groups) feel there is an imbalance between what they are asked to do professionally and the resources they have to do it (time, instructions, competences, tools, …).

2.3.2. Dynamic situational factors

A second set of factors, covering pressure, complexity, monotony, work rhythms and environment, aims at exploring if there are any temporary or even fugacious characteristics of the situation who have influenced (or could influence – if the questioning is used in a proactive approach) the individuals and the teams.

The factor **Pressure** explores two aspects: the pressure generated by uncertainties, changes and the results to be achieved and the pressure linked to the time available to analyse, anticipate, coordinate, decide, act or react, check.

Complexity explores two aspects. On the one hand complexity, with the ambiguity of information, its timing, its interacting activities and actors, and their dynamic evolution. On the other hand, autonomy in making decisions, carrying out actions, recovering them, and the delays before their consequences.

Also the factor **Monotony** mainly relates to two aspects. There is the boredom of repetition of a situation (routine) and also the habit of acting or thinking in a particular way (more mechanical, more automatic). The challenge for people is to get out of the largely dominant normal work logic at the right time, and to act differently, in a way that is no longer necessarily well controlled, hereby taking into account elements that are necessarily rarer or even surprising, temporarily undetected.

The **Work-Rhythms** factor covers the hours or periods of time actually worked. This takes into account the distribution of physical and mental loads during these periods of work (quality of the work repartition within the time of work) as well as the sequence of the actual work periods, with beginning and end, the effective breaks, timing and quality of the work shifts, etc.

The factor **Environment**, finally, explores the variable characteristics of the workplace that can have an influence on the physical, mental and emotional state of the worker including cognitive and social activities in general. This factor relates to e.g. visibility, noise, vibrations, accessibility, working positions, static and dynamic loads, distances to be covered and weather conditions.

2.3.2.1. Static staff factors. With this third set of factors, that contain experience, personality, motivation fit-to-work and decision-making, we propose to explore if there are lasting characteristics, repetitive elements in the concerned individuals and teams that have influenced (or could influence – if the questioning is used in a proactive approach) the situation or other concerned people.

The factor **Experience** refers firstly the level of familiarity with the activities and secondly the individual experience and career path related to the activities and working circumstances (incl. the problematic situation encountered).

The factor **Personality** refers to the individual moral and psychological characteristics of the people concerned. These are fundamental attitudes that influence behaviour at work like self-confidence, confidence in others, openness to experience, conscientiousness, extraversion, agreeableness, emotional stability, etc.

The factor **Motivation** refers to the commitment and adherence of the people concerned to the company's objectives, its values and priorities, but also its organisation, its main rules, and the way it manages risks and major changes.

The factor **Fit-to-work** refers to a good match (sufficient is not always enough) between the people concerned and the requirements of the roles, activities and responsibilities. This includes all the competencies: knowledge, hard skills, soft skills (or non-technical skills, NTS), well-being at work, and health (incl. physical and moral states) as well as their level (which can vary in time), including the necessary periodic checks and monitoring of all these elements.

Decision-making, finally refers to the capability to make decisions based on available information, their interpretation, the context, and who the decision-maker is in particular (e.g. creativity, ingenuity, ability to interpret situations, quality of memory processes, tendency to follow more or less the procedures, tendency to be of service for others, etc.).

2.3.2.2. Static situational factors. With this fourth set of factors, we propose to explore whether there are more lasting or repetitive characteristics of a situation that have influenced (or will influence - if the questioning is used in a proactive approach) the individuals or teams at work, or the context in which the activities take place. These static situational factors cover: communication-means, instructions, design, tools and context.

The factor **Communication-means** refers both to the communication standards and protocols as well as to the technical means and tools, and their influences on the individuals and teams concerned.

The factor Instructions, then explores the directives, regulations, rules, procedures, and instructions produced for the standardised performance of tasks. This includes not only their existence (or not) but also their quality (design, maintenance) to enable the work to be carried out properly while controlling the related risks.

The factor **Design** refers to the end-user based approach when defining the tasks (e.g. allocation, workload, autonomy and significance/meaning), the procedures and instructions, the levels of automation and all the human-machine interfaces and their cooperation from the simplest to the most complex.

With the factor **Tools**, we examine the planning, the availability, the good working order and maintenance, the suitability of the tools to be used for the planned tasks and actual activities in situ. This also includes the checking of the equipment and devices made available to the people concerned before and after the work is carried out.

The factor related to **Context**, finally takes into account the influences that the societal and institutional context may have on the people concerned and their work situations. This could be the influences of the regulation of the sector (national, EU), the economy, politics, the media, and societal events (sabotage, terrorism, social climate, security climate, health crisis …).

2.3.2.3. Socio-interactional factors. With this fifth and final set of factors, that contains communications, relationships, trust, reinforcement and involvement, we propose to explore if the relationships between the people concerned and around them have influenced (or could influence – if the questioning is used in a proactive approach) the work situation or the people themselves in their reactions, attitudes, perceptions.

A first factor **Communications** examines the message and content of the communication, the way in which the interlocutors understand each other and coordinate (between workers within a team, between teams, with the line manager, etc.).

The **Relationships** factor concerns the management of the plots of power inherent in any social relationship between people organised in small or larger groups, in particular with issues such as sharing resources, achieving objectives, the context of promotion or career management, the relationship to one's own leaders as well as with collaborators (if any), etc.

The factor **Trust** examines the level of (reciprocal) confidence with which the people concerned (individuals or groups) can rely on information, management, colleagues, technical means … to carry out their tasks and assume their responsibilities.

The factor **Reinforcement** refers to anything that stimulates (positively or negatively) professional practices, in particular concerning safety (directly or indirectly), whether with an individual or group effect.

The factor **Involvement**, finally, examines the consultation, participation and empowerment of individuals or groups through different kind of organisational opportunities for actions and decisions.

2.4. Applying SAFRAN on 55 railway derailments

To validate the above set of identified SPV, a selection of published accident investigation reports has been reviewed in a similar way as was presented for the Sandilands junction derailment above. In application of the Railway Safety Directive (2004), all member states have established an independent accident investigating body (NIB) that analyses railway accident and events with the sole objective of improving the European railway system. The final reports that result from these investigations are published in ERAIL, a database that is hosted by the European Union Agency for Railways (ERA). In this database, the highest number of investigated events represent derailments. At the moment of analysis, the most recent years with a high percentage of finalised reports were 2017 ad 2018. From the 151 available final investigation reports for derailments that occurred in 2017 or 2018, 49 have been randomly selected for review. The review consisted in classifying the in the report identified HOF elements according to the above set of SPV. These classifications were in turn validated by two experts separately and any deviating result was discussed in order to come to an agreed classification. Furthermore, and to ensure that at least one report was taken into account from each NIB that investigated a derailment in the defined period, 6 additional investigation reports were analysed. As a result of this analysis, the following conclusions can be drawn.

18 of the overall 55 analysed reports identified variability in human performance close to the sequence of events as a direct cause (e.g.

turning a switch under a train or over speeding) or contributing factor (e.g. braking patterns, loading) to the derailment under investigation. Almost half of these investigation reports only provide a description of the activities without any reflection that could explain why a certain activity or decision made sense for the involved operators. Often, these reports also state non-compliance with existing rules as the "main cause" for the accident. Only two of remaining reports show an in-depth analysis of the HOF factors and as a result identify both dynamic and static SPV that can explain the identified variability in human performance. The other investigation reports in this sub-group of 18 provide only a limited investigation of human performance, almost always resulting in findings on static SPV, related to poor quality of work instructions, operator (in-) experience or bad weather conditions influencing performance. The remaining 37 derailments were caused by technical failures on the side of the infrastructure, the involved rolling stock or a combination of these. In all cases these technical failures were linked with activities of human performance that involve the control of the status of these technical sub-systems, like pre-departure checks and maintenance activities. With few exceptions, the investigation of the human performance for these activities is limited to findings, without in-depth analysis, and resulting in the identification of no or only static SPV, like again the quality of work instructions, the identification of roles and responsibilities and the available of adequate resources. Finally, in none of the analysed report an organisational analysis could be found that goes beyond what would represent a first or second iteration when applying the SAFRAN method.

Based on the above findings, we can only conclude that in general the actual practice of railway accident investigation lacks proper HOF knowledge, which confirms the findings of Dul et al. (2012) that, despite decades of history, HOF knowledge has not yet found wide-spread recognition nor implementation and the potential of HOF remains under-exploited. The few exceptions that do attest to a thorough analysis of HOF elements show however the potential of a more structured approach. Although through the above and a similar number of less structured tests, we were capable of classifying all identified HOF elements with the proposed taxonomy, this review clearly makes a case to invest in further support for accident investigators, helping them to identify HOF elements at both the operational as well as the wider organisational levels.

2.5. Further steps

As has been argued by Reinach and Viale (2006), a theoretical driven approach to investigating accidents, involving human performance, is needed for a consistent and formal structure to data collection and analysis. Teperi et al. (2017) come to a similar conclusion when introducing their taxonomy-like HF tool for the reporting of operational events in the Finnish nuclear sector. Yet, although they may explain human performance, a taxonomy that is summarising concepts from literature is not what an investigator can directly observe or grab when performing an accident investigation.

When it comes to understanding a work situation, i.e. identifying the SPV, one can easily turn to two streams of references. The "thick descriptions" approach (Geertz, 1973; Dechy et al., 2012; EUROCONTROL, 2014) integrates the organisational circumstances in which decisions and actions were taken by the individuals and teams involved. These decisions and actions are seen as behaviours that, in order to be made intelligible, require an understanding of the organisational and cultural context. To reach this, it is necessary to collect not only the facts and evidences but also the comments and interpretations of the individuals and teams concerned. Next to that, ergonomic or psychological analysis of work situations recommends a systemic and multi-stage approach, effectively taking into account workers' perceptions; in particular, through observation, questioning, substitution, etc. and focusing on the study of the real activities (Leplat, 1997; Singleton, 1978; Faverge et al., 1958). The foundations of Ergonomics are end-user-centred. One of its recent developments can be shown in the "You are not the user": a mission statement of user experience for designers (Daumal, 2018).

Next to analysing the recordings of performance parameters, Dekker (2006) recommends the debriefing of participants as a good source to gather HOF data of an event under investigation in order to help reconstruct the situation that surrounded people at the time and to get their point of view on the situation. This, however, should be done with caution as it would be an illusion to think that an exact and reliable reconstruction of a past event is possible based on the memory of persons involved in the event – if even possible at all. As explained by Shaw (2016), our memory of an event is built on how we perceive the world with all our senses as well as on past experience in a similar situation. Since all our senses have limitations and no two situations can ever be exactly the same, our memory will be flawed already from the start. Furthermore, our memory in not stable when time passes. Every time someone tries to remember an event from his or her memory, this memory will be vulnerability for transformation or loss. Possible sources of contamination that will have to be taken into account when debriefing participants is the use of guiding questions or pictures, the sharing of information with others and the phenomenon of "verbal overshadowing" where the verbalising of previously seen visual stimuli may impair subsequent recognition. Namely for some of the more dynamic SPV, where the memory of participants may be the sole source for collecting relevant HOF-data, this could be an indication that a debriefing should be organised as soon as possible after the event. Unfortunately, a similar approach is not possible for many of the often not-explicitly documented decisions that are taken within an organisation and that, with hindsight, may appear to have contributed in creating the context that lead to an event. But even here, interviewing the concerned actors can still lead to the identification of relevant HOF elements.

In order to guide investigators to structure such debriefings or interviews, a set of supporting questions has been developed for each of the twenty-five factors in the proposed taxonomy, that can help to identify whether they have (the potential to) generate(d) some variability in a specific function under analysis. Of course, these questions developed need to be adapted by the interviewer case by case. And it should be noted that other skills are further needed to professionalise the interview (e.g. practicing rewording, silences and non-critical behaviour, dealing with the retrospective bias risks), and to build the necessary trust and respect with the interviewee(s). Such methods of questioning HOF factors already exist and can be learned during appropriate training courses (e.g. RSSB, 2019; Carpinelli et al., 2021). An example of this questioning, for the SPV "Pressure", is proposed in Table 2. In addition, in support of the SAFRAN logic, and for each of the 5x5 SPV factors, the best-known processes (to explore further) that could manage the SPV were identified. This should contribute to better mitigating the critical variability of the function and achieving sustainable management of the overall system performance.

The authors believe that the proposed, structured approach of combining both individual (i.e. the SPV) and system analysis can be used also in other settings than accident investigation as a practical instrument to enable non–HOF–experts to recognise the different HOF elements that introduce (critical) variability in operational performance and decision-taking. In this context, the initial feedback on using the structured questioning from two operational services within a European infrastructure manager, in charge of coordinating field activities with safety as a top priority, is very positive: the list of questions was well received, understood and perceived useable for exploring the interactions between HOF and other parts of the railway system. Furthermore, more recently, pilot sessions of a training module that is developed to introduce the proposed approach, indicate that the 5x5 logic of structuring the HOF elements, with the dynamic-versus-static and the staff-versus-situation dualities, is easily captured and remembered. Testing the identification of HOF elements on pictures and in a railway incident case before and after the introduction of the taxonomy,

Table 2
An example of the SPV questions to nurture the processes analysis.

SPV factor	Exploring question	Process to explore further
Pressure	• At the moment you decided to act as you did, what were your uncertainties, your doubts? It could be about the information you received, the procedure to apply, some resources unavailable, the priorities, the risks involved or some recent changes? • In your opinion, were there any conflicting, opposing objectives? How would you describe them? How did you know what to favour? Were these priorities clear to you? And did you agree with these priorities? Did you see clearly how to achieve them? Did you see any obstacles or difficulties in getting there? Could you talk about them and did you want to? • Was there any pressure on the results to be achieved? (If yes) How would you describe this pressure? Would you say that you were under time pressure to decide, to act; and more generally to analyse, anticipate, coordinate, or react? How did this pressure manifest itself (via other agents or managers, service requests, site requirements, equipment constraints, management of certain risks, a question of punctuality or other)? • What effect(s) do you think this pressure may have had on you at that time, when you think back now? Would you have found it useful to be able to "stop", or to ask another colleague or manager? Do you think it is it possible in your work environment?	Implement > Train > personnel performing the defined process are competent on the basis of appropriate education, training, and experience > Equip > resources > Organise > process purpose/output > process performance objectives > process performance planning Specify > responsibilities/authorities > for performing the process

during the same training sessions, further indicates that the scope of identified HOF elements that might require further investigation increased significantly. Once these sources of variability have been identified, it becomes logical for participants to ask how the SMS manages or is expected to manage them. This is where the SAFRAN logic, when strictly followed in its SMS-oriented questioning, demonstrates its value: participants say they feel guided in the systemic and systematic questioning of the HOF elements that can explain the decisions and actions of the safety management functions involved, sometimes quite distant from the sequence of events. As the case study has shown, this is a depth of analysis that is most often lacking in the current railway accident investigation practice. Further efforts to train and disseminate this approach, with the aim of testing and improving it where necessary, will be continued. In addition, the taxonomy is proposed to be integrated in European legislation on occurrence reporting in the railway sector.

3. Conclusions

As pointed out by Dekker et al. (2011), the very act of separating important or contributing events and decision from unimportant ones is an act of construction, strongly influenced by the analyst's background, preferences, experiences, biases, beliefs and purposes. Rather than following a chain of causal reasoning or trying to reconstruct conditions that may no longer exist, the effort put in the organisational accident investigation should therefore focus on assessing the capability of organisations to manage (critical) variability and thus the actual daily functioning of the socio-technical system.

The SAFRAN method (Accou and Reniers, 2019) is developed with exactly this objective in mind: starting from findings close to the event, and in particular the related HOF-elements, an investigator will be guided in identifying the relevant implementing and control processes; an investigation logic that can then be repeated for all relevant processes throughout the entire socio-technical system.

This paper has presented the SAFRAN method with its related HOF taxonomy and supporting questions as a vehicle to enable non-experts in human and organisational factors to identify the different elements that introduce variability in all relevant processes. It has been shown that the SAFRAN method nurtures and structures the repetition of classical "why's" questions, guiding investigators both through the socio-technical system processes and through the potential influences of/on HOF. In other words, it offers the combination of both human and system analysis.

Performing this type of analysis, that covers several dimensions of an entire system, requires however knowledge from different disciplines to interpret data at several strata of complex socio-technical systems (Le Coze, 2013). Like Le Coze, the authors believe that this requirement is more likely to be met when several specialist or experts interact on the same accident analysis (if needed including HOF experts).

By explicitly and repetitively linking performance variability of one process with the analyses of underlying management processes, the SAFRAN method creates an analytical trace, offering the same advantages that are characteristic for ATSB's link-to-link approach (ATSB, 2008): 1) more safety issues being identified and communicated, particularly those more remote from the occurrence, 2) a richer description of the factors involved in the development of an occurrence and thus better learning opportunities, 3) less potential for determining blame or liability and thus less potential for the existence of barriers to learning. A similar, structured use of the proposed approach is possible in the context of audits or other techniques for organisational diagnosis and could help to overcome the obstacle that possible signals of danger are only visible to an analyst with hindsight, after an event. As argued by Dechy et al. (2012), the generic issues of organising work and managing safety are similar, whether analysed before or after an event, and these similarities are the key points that could guide data collection, analysis and interpretation with adequate HOF skills.

This proposed approach is fully in line with the main strategy direction Dul et al. (2012) have put forward towards the world-wide application of HOF excellence, namely, to strengthen the demand and application of high-quality HOF by building partnerships with main stakeholders. The author therefore are convinced that the SAFRAN method is a practical tool, that can be used in different settings, for better integrating HOF knowledge in railways and other high-risk domains. With the aim of not only optimising human performance and well-being but optimising performance of the socio-technical system overall.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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