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A Guide for Identifying Human Factors in Accident Investigations

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SINTEF Digital has recently developed a first edition of a guide for Human Factors in accident investigations to be used by The Petroleum Safety Authority, Norway. This paper provides a description of the work that has been conducted in developing the guide, as well as a description of the guide itself. It is underlined that that the aim of the guide is to support the investigation team in identifying why involved persons acted as they did to learn from the incident, and thus not to identify scapegoats. Furthermore, investigation of Human Factors must be an integrated part of the total investigation approach. That is, mapping of the cause of events, mapping of causal factors, analysis, and recommendations for follow-up of the enterprise. The guide is based on an overall model that consists of three main elements: I) decisions and actions, II) situation awareness, and III) performance shaping factors. It also includes samples of questions to help the investigation team. The paper concludes with some thoughts on strengths and limitations of this approach compared to The Human Factors Analysis and Classification System (HFACS), recommendations on combining this approach with HFACS, and further development of the approach.

Keywords: Accident investigation, Human Factors, (Distributed) Situation Awareness, Performance Shaping Factors, HFACS

1. Introduction

Although Human Factors (HF) as physical ergonomics has been accepted as a discipline in Norwegian offshore oil and gas industry, the importance of HF work has not been sufficiently prioritized in practice from safety authorities, management and engineering (Johnsen et al., 2017). The Petroleum Safety Authority (PSA) Norway has identified a need to increase their use and knowledge of HF, and a need for methods and tools to identify and analyse HF in accidents investigations. SINTEF Digital was hired to develop appropriate HF methodology to be used in accident investigations and relevant training curriculum for the PSA.

Our definition of Human Factors is from IEA: "Human Factors is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and other methods to design in order to optimize human well-being and overall system performance".

A guide for identifying HF in accident investigations was developed. The guide is based on relevant approaches, best practices in use, methods, and relevant HF literature. The guide is first and foremost based on the theory of Situational Awareness (Endsley, 1995), the "Human Factors Analysis and Classification System" (HFACS), (Shapell & Wiegmann, 2000), "Demystifying Human Factors" (IOGP, 2018), "Learning from adverse events" (CIEHF, 2020), "Introduction to Human Factors in Accident Investigation" (Bridger, 2021), "Human Factors in the NSIAs safety investigations" (NSIA, 2022) and "Human Factors Investigation Toolkit" (HPOG, 2023).

Important theoretical approaches and tools utilised in the guide are categories of decisions and actions, theories of situation awareness (SA) and distributed situation awareness (DSA), and performance shaping factors (PSFs).

The aims of using HF in general and in accident investigations are to: (1) Improve safety (i.e., reducing the risk of injury and death); (2) Improve performance in safety critical situations (i.e., increase quality, productivity and efficiency); (3) Support satisfaction/usability (i.e., increasing acceptance, comfort and well-being).

A goal was that the guide should be relatively simple to use since many of the potential users are not HF experts. Some of the references to theory and literature is therefore simplified. Using the guide, still requires basic knowledge about HF and accident investigation methods.

The aim of this paper is to document our approach and for inspiration for others that are developing or using similar approaches. More specifically, the aim is to (1) describe how different approaches has influenced this guide, (2) describe judgements behind the selection of theoretical inspirations and choices, (3) describe the approach itself, and (4) discuss future use and development of the guide.

2. Material and methods

The development of the guide was based on two literature reviews, interviews, and workshops with the PSA.

The scope of the first literature review was to identify relevant publications on HF and accident investigations. The review was based on keyword searches for publications in Web of Science, Scopus, and Google Scholar for the years 2000-2022. Relevant publications were analysed, and further relevant papers were selected based on snowballing. Keywords used were Human Factors, accident/incident, and investigation/method/tool/classification.

In the second review, literature on SA was obtained through searches on article titles in Scopus, aiming to identify articles discussing SA in the context of accident investigations as well as articles on DSA.

Individual interviews and group interviews were carried out with experts on HF and accident investigations and representatives of authorities having experiences with HF and accident investigations. In addition to the group interviews with the PSA, 11 experts were interviewed.

The workshops with the PSA were about the overall scope of the project, choosing important approaches and tools to include, and selecting and categorising the most relevant PSFs to include in the guide.

3. The guide

3.1. *Introduction to the guide for investigators*

The introduction to the guide for the investigators describes the context, overall approach, the aim of the guide, and the system perspective. It is underlined that the aim of the guide is to support the investigation team in identifying why involved persons acted as they did, and to identify PSFs. It is also underlined that the aim is not to identify scapegoats but to guide investigated enterprises in improving HF. Furthermore, it is underlined that the aim is to contribute to a common understanding of HF for the investigation team, and that the investigation of HF must be an integrated part of the total investigation approach. A table is presented to explain how the steps in investigating HF are related to steps in a generic investigation approach (Table 1).

Table 1. Important HF questions related to main steps in a generic investigation approach.

Important steps and questions in a generic investigation approach	*Important HF questions*
A. Mapping of the course of events (What happened and how?)	1.Which actions contributed to the incident?
	2.What type of actions?
B. Mapping of causal factors (Why?)	3.What situation awareness did persons involved have?
	4.Which PSFs influenced the involved persons?
C. Analysis (What was the impact of causal factors, and which connections were there between them?)	5.How were the connections between actions, situation awareness and PSFs?
D. Follow-up of the enterprise (What deviations, advice, decrees etc. should be presented for the enterprise?)	6.Which PSFs should be changed?

3.2. *Model*

The guide includes an overall model (Fig.1) that aims to help the investigators in systematically including HF in investigations. The overall context of the model is to ensure that HF is considered in a systemic perspective, i.e., man, technology and organisation (MTO). The model consists of three main elements: (1) Decisions and actions, (2) SA – individual and distributed, and (3) PSFs.

The model was developed based on the literature review, similar approaches, interviews and discussions with the PSA. This model is inspired by, and similar to, a model used by the NSIA (2022) where Endsley's (1995) theory of SA is central. Other alternatives to this approach were also evaluated, first and foremost HFACS (Shappell & Wiegmann, 2000). HFACS has been applied to multiple domains, provides a consistent structure for accident analysis, but has been criticised for poor levels of inter-rater reliability (Stanton et al., 2013). Based on discissions with the PSA, our assessment was however that HFACS could be too complicated for the multi-disciplinary investigation teams in the PSA. Our judgement was that the suggested approach (fig. 1) has greater potential for producing a common understanding of the approach to HF and accidents among the investigators than HFACS. However, we encourage PSA to utilise HFACS in combination with this tool.

The model is used to analyse actions (or non-actions) that directly or indirectly influenced the course of events. The method examines one decision or action at a time. Often, there are several actions that were central for the event, and the model can be used multiple times. Since actions and the actors are key elements to build understanding of the incident, we suggest that STEP (Hendrick & Benner, 1986) is used to document the course of events.

The understanding of a situation is essential for the decisions that are made, and thus for the actions that are carried out or not. When having identified and described a critical action, one must therefore seek to understand the SA of the involved persons before and during the event. SA not only influence the actual decision but also the decision-making process in itself.

The next step of the model is to identify PSFs that affect the SA as well as the decision-making and performance of actions. The lines between the categories of PSFs in the figure illustrate that there are often relations between PSFs in the different categories.

An actor deals with the situation by making decisions and acting upon them. An action can affect the condition of the elements in the environment, which in turn changes the basis for further SA. This is illustrated in the figure by an arrow from action to environment. The following example is provided in the guide: The members of a ship crew become aware of another vessel with a given direction and velocity (states of the element) and realises that it is on collision course. They contact the crew of the approaching vessel, inform them about the situation, and request that they change their course (affecting the state of the elements). This then changes the understanding of the situation (as less critical).

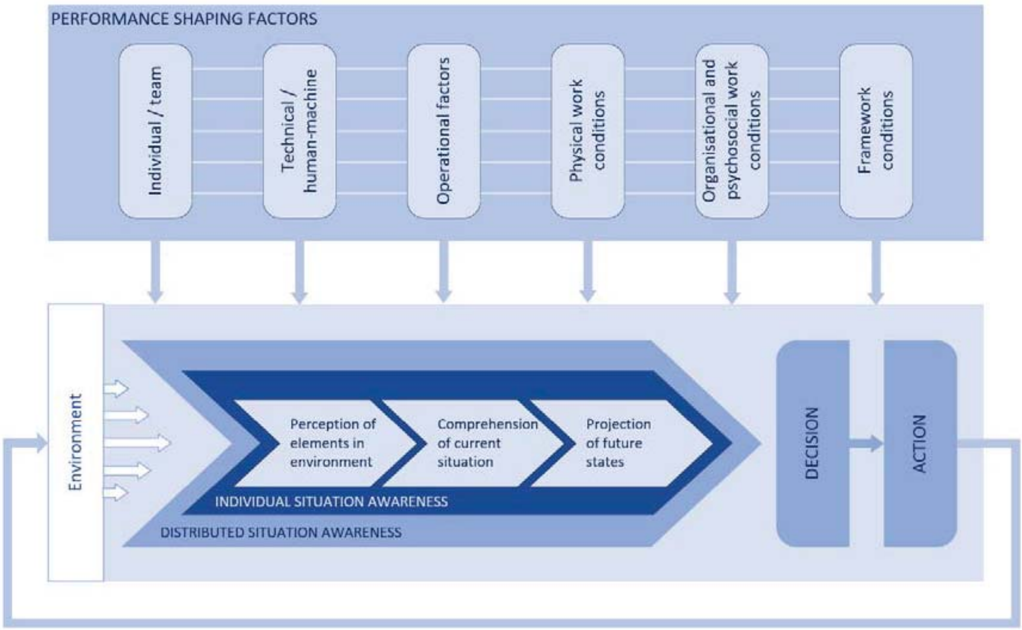

Fig. 1. Model for examining HF in accident investigation (partly based on model by Endsley, 1995).

3.3. *Decisions and actions*

Actions contributing to accidents are traditionally termed "human error" (HE). When used in this paper, the term is written with quotation marks, because the term is often associated with blaming individuals. The guide underlines that the investigators should see actions as consequences, not causes (Reason, 2016), that errors are often a result of error-traps, and that to identify an act that contributed to an accident, is the start, not the end, of an investigation. To identify "human error" is an important step to in the end identify the PSFs that can be changed.

The guide recommends that the investigation team use STEP (Hendrick & Benner, 1986) to identify the course of events, relevant actors, decisions, and actions that contributed to the incident. The guide describes four questions to help the investigation team: (1) Which actions contributed to the incident? (2) How did the actions contribute to the incident? (3) If a similar situation should occur, will a person in a similar situation act differently? (4) What type of actions was it? Five types of decisions and actions based on HFACS (Shapell & Wiegmann, 2000), are described in the guide, namely "decision errors", "skill-based errors", "perceptual errors", "deviations", and "reckless deviations". The aim of identifying the type of decisions and actions is to help the investigators identify potential PSFs that influenced SA, decisions, and actions.

3.4. *Situation awareness*

As highlighted by others before us, the definition of SA has changed over the last decades. Focusing on the individual person, Endsley (1988) provides the following definition: "Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." (Endsley, 1995, p. 36). Later research interest in SA has expanded from the individual level to the team level and, more recently, to the level of sociotechnical systems (Stanton et al., 2017). The guide presented in the current paper include investigations of both individual and distributed situation awareness.

3.4.1. *Individual situation awareness*

The most cited paper on SA is Endsley's (1995) "Toward a Theory of Situation Awareness in Dynamic Systems", in which she presents a theoretical model of SA based on its role in dynamic human decision-making. In accordance with the definition presented in section 3.4, the paper describes SA in terms of a three-level model: Perception of the elements in the environment (level 1 SA), comprehension of the current situation (level 2 SA), and projection of future states (level 3 SA).

That is, individual SA can be seen as a chain of information processing. Information in this context is everything that can be perceived though one's senses, i.e., what is seen, heard, smelled, tasted, or felt. Elements in the environment can be other actors, technical systems, infrastructure, weather conditions and other local conditions at the particular point in time.

To investigate the individual SA held by actors that were involved, investigators ought to seek answers to questions such as: (1) What information was perceived by the person prior to (and/or during) the event? (2) How did the person use this information to interpret/ comprehend the situation? (3) In what way did the person use his/her comprehension to foresee what was likely to happen? (4) What decisions did the person make based on his/her comprehension of the situation and prediction of future states?

3.4.2. *Distributed situation awareness (DSA)*

The investigators also need to assess the DSA: "When loss of situation awareness seems to have played a role in an adverse event, accident investigators need to examine why the system's DSA was degraded, not who lost awareness." (Salmon, Walker, and Stanton, 2016).

Whereas Endsley (1995) mentions how SA can be understood also on a team level, Garbis and Artman (1998) were the first to argue that SA is distributed also throughout the artefacts that team members use. The idea that SA is held by sociotechnical systems is often referred to as distributed situation awareness. Stanton et al. (2006) define DSA as "activated knowledge for a specific task within a system" (p. 5). From this perspective, SA is a dynamic and collaborative process which can be understood through analyses of interactions between agents in the system. Agents can be both human (e.g., colleagues within the same company or persons from other companies) and non-human (i.e., technological artefacts). Non-human agents have some level of SA at least in the sense that they hold contextually relevant information (Stanton et al., 2006).

Stanton and Harvey (2017) state that "most, if not all, accidents and near misses are caused, at least in part, by the failure to communicate information between agents and tasks." (p. 231). In a paper analysing the Air France 447 accident, Salmon, Walker, and Stanton (2016) explain how transactions between agents is what enables a system to maintain DSA throughout the course of a task. Transactions represent exchange of situation awareness between agents, thus referring to more than just communication of information. The authors distinguish between four forms of transaction failures: I) *Absent transaction*: a transaction in awareness is required but is not initiated. II) *Inappropriate transaction*: a transaction in awareness is initiated, but the content is incorrect. III) *Incomplete transaction*: an appropriate transaction is initiated, but the content is incomplete. IV) *Misunderstood transaction*: the receiver misunderstands what is being transacted (ibid. p. 74). In the guide, these categories are however simplified, pinpointing that DSA must thus be understood in terms of relevant, correct, and timely exchange of information.

The current guide includes several questions to help the investigation team in examining transaction failures: (1) What (human and non-human) actors were relevant for the course of events? (2) What information did these actors need in order to perform their tasks? (3) What critical information did each of the actors have themselves? (4) What information needed to be exchanged to other actors? (5) What necessary exchange of information was either not initiated, initiated with incorrect or incomplete content, or misunderstood? (6) What are probable links between identified failures in information exchange, actions, and course of events?

Salas et al. (2005) systematise what research know about teamwork in five main components and describe how these build on three central coordinating mechanisms: I) *Shared mental models*, i.e., that team members have sufficiently similar and compatible mental models (e.g., of available resources, the members' competence, likely scenarios, etc.) that guide them toward the same objectives. II) C*losed loop communication,* i.e., ensuring that sent communications are heard and accurately understood. III) *Mutual trust* to ensure that all team members exchange important and critical information without hesitation.

To analyse the DSA with respect to coordination mechanisms, accident investigators can look for answers to the following questions: (1) Did the team members have clear and sufficiently similar understandings of each individual's role, the available resources, shared information, and each member's competence? (2) Was there a perception among the involved persons that the communication within the team was good, especially with respect to affirmative communication in critical operations? (3) Does the person describe mutual trust to his/her team members? (4) Does the person describe mutual trust to other actors that were involved in the event? (5) Was all important and critical information exchanged timely to all relevant actors? The last question is closely related to those on transaction failures above.

3.5.*Performance shaping factors*

HF can be described as "… simply those things that can influence what people do" (IOGP, 2018 p. 9). These "Performance Shaping Factors" may include factors relating to the job people do (e.g., time available or control panel design) personnel factors (e.g., fatigue, capability) and organisational factors (roles, manning levels).

To decide which PSFs should be included in the guide, and in which categories they should be put, a workshop with the researchers and the PSA was arranged. Beforehand, the researchers had presented lists of different often used PSFs, and categories of PSFs, based on literature and other approaches (e.g., Bridger, 2021; NSIA, 2022; Shappell & Wiegmann, 2000). In the the PSA related to their overall approach to accident investigations, their roles, tasks, and regulations. The result of the workshop was 82 individual PSFs organised in six categories of PSFs: (1) individual/team, (2) technical/human-machine interface, (3) operational factors, (4) physical work environment, (5) organisational and psychosocial work environment, and (6) framework conditions. The aim of the categories and lists of single PSFs is to help investigators identify *which* PSFs shaped situation awareness, decisions, and actions, as well as *how*.

The investigators are also encouraged to use other tools and approaches to analyse some issues more in depth, first and foremost HFAVS and CRIOP. HFACS is especially useful to analyse management and leadership. CRIOP (Johnsen et al., 2008) is a methodology to verify and validate the ability of control centres and the like to handle all modes of operations safely and effectively. CRIOP consists of two parts. First, a list of best HF practices/requirements – describing "work as imagined" and second, a CRIOP "scenario analysis" exploring safety critical tasks together with users discussing "work as done". CRIOP is a useful methodology to both ensure that HF is included in the early concept and design phases but also in operations to ensure that best practices are followed. Adapted versions of HFACS and CRIOP are included in a toolbox with other tools for analysing HF more in depth.

3.6.*Analysis and follow-up*

In the analyses, the model (Figure 1) should be used to map connections between actions, situation awareness, and PSFs. The results of the analysis of the human factors can be very useful in the follow-up of the enterprises investigated regarding deviations, improvements, advice and decrees. The follow-ups should prioritise preventing individuals coming in similar situations, remove error-traps, and hence reduce the probability of "human errors".

Recommendations in a HF perspective should be directed at the level in the system that is most relevant, e.g., equipment design, interfaces, tasks, working environment, and organisational factors. Recommendations directed at the system level have more potential effect than recommendations directed at the sharp end and frontline workers.

In the follow up of the enterprise a version of the hierarchy of controls adapted to HF (see HPOG) can be utilised. Questions that should be asked in developing recommendations ad measures are: (1) Can the hazard be removed? (2) Can the role of the human be eliminated in safety critical situations be reduced or removed (e.g., by automation)? (3) Can consequences of "human failure" be prevented, e.g., by additional barriers? (4) Can human performance be assured by using interlock or other engineered means? (5) Can the factors that shape and motivate behaviour be optimised?

4. Discussion

The aim of this paper was to (1) describe how different approaches has inspired this guide, (2) describe judgements behind the selection of theoretical inspirations and choices, (3) describe the approach itself, and (4) discuss future use and development of the guide.

The central elements chosen for this guide is a relatively simple approach based on a taxonomy of decisions and actions, situation awareness (Endsley, 1995) and PSFs. The model was developed based on the literature review, similar approaches, interviews, and discussions with the PSA. Other alternatives to this approach were also considered, first and foremost HFACS (Shappell & Wiegmann, 2000), and HFACS for oil and gas (Theophilus et al., 2017). HFACS has been applied to multiple domains, provides a consistent structure for accident analysis, but has been criticised for poor levels of inter-rater reliability (Stanton et al. 2013). Based on discussion with PSA our assessment was that the approach presented here (fig.1) has greater potential for producing a common understanding of the approach of HF and accidents investigated among the investigators at PSA then HFACS. We think that HFACS is better at identifying and analysing leadership and management factors, and at analysing samples of accidents. For other users, HFACS can therefore be a better choice. We recommend however that the PSA combines the two approaches and use HFACS in accidents when there is a need of analysing leadership and management factors more thoroughly.

One possible risk with such a specific HF approach in investigating accidents, is that the HF approach is not connected to the rest of the investigation approach. The guide therefore underlines that the aim is to contribute to a common understanding of HF for the investigation team, and that the investigation of HF must be an integrated part of the total investigation approach to ensure a systems perspective.

One possible limitation of the guide is that it is relatively simple and that some of the literature described and methods used are simplified. The reason is that a goal was that the guide should be relatively simple to use since many of the potential users are not HF experts. To investigate HF more thoroughly, we recommend that a smaller group of PSA investigators receive more education in HF, and that another guide for investigating HF more in depth is produced.

Another limitation using frameworks with fixed factors in accident investigations, is that you find what you are looking for (Lundberg et al. 2009). Therefore, the guide underlines that the investigators also must look for factors not included in the guide and must be trained in looking for human factors. Combining this approach with other approaches like HFACS is encouraged in the guide.

The guide has so far been tested by investigators in the PSA in one case. We recommend that the guide is tested on several cases and adjusted to the needs of the PSA investigators.

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