Simulation based team interaction analysis method as a source for system safety

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Abstract

New technology is making fundamental changes in the design of complex socio-technical systems. In high hazard industries safety is trying to be achieved by increasing the reliability of the individual system components. In contrast, modern safety research points out that safety and reliability are characterized as different system properties. This paper presents a resilience-based concept accenting human behavior as potential source of safety. It is based on the assumption that teams in high hazard organizations (e.g. teams in control rooms of nuclear power plants) manage system-safety by building and further developing common cognitive strategies. These strategies can be observed on a behavioral level as "safety-interaction-patterns" (SIP, [20]).
The research of SIP in such teams is enabled by highly sophisticated simulators, which are used to simulate critical situations. In this setting team members can be trained to safely interact which each other in a nearly realistic environment.
In complex systems, state of the art research in team interaction often focuses on observation methods. Even though observation as a research method has many advantages, its disadvantages cannot easily be dismissed. Scientists often lack the knowledge of subject matter experts (SME) to completely understand what they are observing. Their expertise lies in interpreting patterns and behavioral processes, but they are not knowledgeable about the content of the observed work or the context of unexpected system statuses. However, such knowledge might be crucial to the correct interpretation of certain behavior.
We propose an applied research method to reduce the aforementioned problems, using a multimethod approach which includes "think aloud" techniques, gaze tracking as well as

classical observation methods. Research scientists and SME (e.g. simulator controller) should both participate in such scientific observations to achieve more valid observation results.
The combination of state of the art simulators and research methods would make it possible to analyze and improve the SIP's needed for stable sociotechnical systems in high hazard industries.

Introduction

The need to thoroughly analyze team interaction and understand how system-safety is created and designed increases with system complexity. New psychological concepts in team research and safety sciences raise the demand for new research methods. To verify concepts like SIP [20] a researcher needs access to implicit expert knowledge. Otherwise it seems impossible to understand experts' behavior in a complex system like a nuclear power plant control room.
The system-safety in modern high hazard industries like the nuclear power industry is, to a large part, the result of team performance. Teams in power plant control rooms build and develop common cognitive strategies to handle all kinds of tasks in the complex system they work in to ensure its safety. These strategies can be observed on a behavioral level as "safety-interaction-patterns" (SIP, [20]).
Today's high hazard industries are confronted with a highly dynamic technical and economic environment. High hazard industries are highly technical industries such as the nuclear power industry (nuclear power plants), the air-traffic industry (air-traffic control and airlines), the chemical industry (chemical plants), etc. The high complexity of today's sociotechnical systems in these industries makes it impossible for a single person, to understand the system in detail. Coordinated and cooperative teamwork becomes indispensible as a part of the safe management of such systems [21]. Simulators that let these teams train in a realistic environment without an actual danger have become standard especially in nuclear power and air-traffic industries. In the following we will discuss a proposed research method for team interaction analysis in nuclear power plants based on simulation. The objective is to understand and enhance system safety with new knowledge gained by applying this method.

Characteristics of safety in modern times

Many authors depict that technology is changing faster than the engineering techniques to deal with the new technology are being created [18]. New technology introduces unknown variables into systems and brings more complex relationships between humans and automation. Digital technology has changed the nature of accidents [13] by accelerating system processes and increasing interaction complexity. That leads to the assumption that we are designing systems with potential interactions among system components (human and technology) that cannot be thoroughly planned and that are very challenging to control. These rapid changes are leading to new types of hazard (e.g. mode confusion) around which the behavioral context is centered. High levels of complexity and system dynamics provoke unexpected situations in which hazardous phenomena -

like “tight coupling” [16] can be only managed successfully by teams. Teams as organizational units have a rich faculty of competencies for this challenging mission that can be described by their unique features: from flexibility to adaptation of cooperation processes to unexpected contextual needs and situational dynamics by using shared mental models. Therefore, the adequate use of communication and other non-technical skills [7] are important resources. In contrast, system designers are trying to achieve system safety by increasing the reliability of individual system components. This approach stands in the tradition of the “ironies of automation” [1] that can be characterized in terms of “replacing human manual control, planning and problem solving by automatic devices and computers”. It seems that we are caught in a paradigm of “human error” [19], which describes humans only as latent source of unsafe acts. But by analyzing safety related events (e.g. Three Mile Island 1979, Alaska Airlines 2000, Forsmark 2006) safety research points out that a system can be reliable and unsafe or safe and unreliable, which makes clear that safety and reliability can be described as different system components: “…making the system safer may decrease reliability and enhancing reliability may decrease safety” [14].

Safety in high hazard industries can be described as the absence of accidents. Weick and Sutcliffe [24:30-31] define safety as *“A dynamic non-event; a stable outcome produced by constant adjustments to system parameters. To achieve stability, change in one system parameter must be compensated for by changes in other parameters, through a process of continuous mutual adjustment”*. As good a definition for safety this may be, it creates certain problems for practitioners and scientists alike. Firstly, as a non-event, safety becomes unobservable and is not directly measurable. Secondly, safety is dynamic and underlies continuous change. It is therefore not possible to define a state in which a given system is safe and will continue to stay safe.
To solve the first problem practitioners and scientists often try to measure safety indirectly by measuring and counting accidents and their predecessors (incidents, unsafe acts) [10]. It seems to be a feasible approach for a lot of questions. A limitation of this approach is its reactiveness. Safety problems will only be seen in hindsight when working with this approach. As a result, proactive action to ensure safety is only possible in a limited way. In addition, it must be clear that the absence of accidents and incidents in the past of a system do in no way guarantee their absence in the future. The measuring of accidents and incidents is therefore insufficient to cover safety in a comprehensive way. To cope with the second problem, safety has to be seen as a process that has to be maintained through continuous training and adaption [24].

Safety Interaction Patterns (SIP)

In their review about “Cognition in Organizations” Hodgkinson and Healey [11] find that the interest in cognitive basis of team functioning has dramatically increased since the year 2000. This increased interest from scientists has helped gain knowledge about team processes on different levels. For example Burke et al. [2] show in their multilevel conceptual model that team adaption is a process involving individual cognitions (e.g.

knowledge) and group cognitions (e.g. shared mental models). SIP as proposed by Ritz and Rack [20] stay in the same tradition of team functioning research.
SIP are cognitive strategies of teams to avoid the creation of safety relevant events (e.g. incidents and accidents). System experts often manage potentially dangerous situations through anticipation and adequate situational awareness [4] behavior before danger emerges. An approach to SIP is seen through shared mental models [9], which, among other things, can be observed in crisis-like situations [20].
SIP is expected to be a key to understanding how safety is generated in organizations. So far safety research in high hazard industries has concentrated on negative events such as mistakes and errors. SIP offers a way to a safe environment in a more positive approach due to analyzing behavior that prevents the emerging of potentially dangerous situations. Most operator trainings in nuclear power plants follow in their focus safety research and concentrate on negative events. Especially operators' trainings could be enriched by reflection and refinement of their own SIP. Training would get more proactive by this reflection, using resilient operations developed in critical situations spontaneously by a team of system experts.

State of the art in research in high hazard industries

In the following section we will (i) specify the use of simulators in research into team behavior in context of high hazard and (ii) discuss two methods, observation and expert interviews, commonly used in combination with such simulators.

The use of simulators

Supported by the ecological approach [17] it is believed that a person's contribution/behavior can be understood best in the context of the emergent properties that arise from the interaction with an environment. It is believed that the environmental features strongly influence a person and his or her actions. Therefore, the more realistic a simulated environment is, the more natural the behavior of persons acting in that environment will be.
The research of teams in high hazard industries is enabled by highly sophisticated simulators, which are used to simulate critical situations in which team members can be trained to safely interact which each other in a realistic environment. Without simulators the researching of behavior in critical situations in high risk industries would be impossible because critical situations happen too rarely and an intentional provocation would, for obvious reasons, not be feasible. Modern simulators let people act as if they were in a real world situation not just in an artificial simulation. Due to the high fidelity of simulations, problems of reactivity can be reduced (if not completely eliminated).
One reason for using simulator based research methods in high hazard industries is obvious. Through simulation it becomes possible to confront operators with situations that in non-simulation circumstances would be impossible to create without danger to human integrity. In addition to this obvious advantage there are also others. Simulators often offer observers possibilities like recording or different angles of view to observe what is happening in a critical situation that are not possible in a non-simulated

environment. Events can be paused to discuss and questions can be asked. Planned system changes can be implemented in a simulator environment to test their impact on behavior before implementing them in a real environment.

Observation

Scientific observation methods [8] are characterized by (i) intention including a plan to achieve certain objectives, (ii) selection of certain aspects while neglecting others, (iii) results orientated and systematic analysis.
In complex systems, state of the art research in team interaction in high hazard industries often focuses on observation methods (e.g. [6], [12], [23]). Advantages of observation methods are primarily the possibilities of a direct measure of actual behavior, no subjective intentions and elimination of reporting bias. Additionally, certain data can only be collected through observation (personal interaction, gestures, facial expression). Disadvantages of observation as technique for data collection are in general its time and cost intensity. In addition, the main disadvantage of observation is the selective perception of the researchers [8] and the inability in capturing cognition and perception of the observed subjects.
Even though observation as a research method has many advantages, its disadvantages cannot be easily dismissed. Scientists often lack the knowledge of subject matter experts (SME) – experts of a certain domain **-** to completely understand what they observe, as their expertise is in interpreting patterns and behavioral processes, but not in their knowledge about the content of the observed tasks. However, such knowledge might be crucial to the correct interpretation of certain behavior.

Expert Interviews

Another method commonly used in research with high hazard industries is the expert interview. SME provide answers to researchers' questions. The insight of SME in the why and how of working processes is naturally much more elaborate than the insight of researchers can be. Verbal data as collected in interviews gives insight in experts' explicit knowledge. Expert interviews are also used to analyze simulated or real incidents and accidents retrospectively (cf. Critical Incident Technique in [22]).
Despite the realization of the importance of less conscious aspects of cognition in organizations (implicit knowledge and intuition) there has been little advancement in the methods assessing these forms of knowledge [11].

A new multimethod approach to team interaction analysis

We propose an applied research method that reduces the problems and limitations of the aforementioned research methods and enables researchers to assess implicit knowledge. A multimethod approach which would include "think aloud" techniques, gaze tracking as well as classical observation methods is proposed. The use of highly sophisticated simulators as an enabling technology is indispensable because of the advantages mentioned above. Both research scientists and SME (e.g. simulator controller) should participate in such scientific observations. The objective when applying this method is to identify SIP. Although the proposed method is designed for the specific use with nuclear power plant control teams an adaption for different teams especially in high hazard industries seems feasible.

Data collection

As a base for the proposed multimethod approach a classical observation should be conducted. The intention of using this method is the direct visual and audio observation of SIP. Data for the observation should be collected per video to ensure repeatability of the analysis. The observation should take place during a simulated critical incident or accident scenario.
As a second method we propose the usage of “think aloud” [5]. A SME (e.g. simulator controller) is instructed to observe the control room team in the simulator from a separate observation point and think aloud during the whole observation. The SMEs verbal data should be recorded for later usage when analyzing the observation videos. SMEs think aloud data helps the person analyzing the observational data to understand processes and behavior of the control room team on a qualitatively higher level. It allows easier classification and interpretation of the observation data due to the researcher’s better understanding of the observed situations.
The third method to deliver useful data is gaze tracking [3]. The SME, who is thinking aloud, would also wear a head mounted eye tracker to capture his gazing data during the observation. The function of gaze tracking in this approach is twofold. On the one hand, if in a situation it is unclear what the SME is talking about while thinking aloud the point of view during talking gives additional information on how to interpret this situation. On the other hand, the SME’s gazing data gives clues on what an expert considers important. While the think aloud method may fulfill this purpose to a certain degree, gaze tracking also registers data an expert is not able to explicitly express. The gaze tracking of an SME observer has the potential to literally give researchers an expert’s view what otherwise can only be acquired by many years of training.

Data analysis

To analyze the observation videos properly a coding system should be used. In a first step we suggest the use of an already known coding system containing codes according to the background concepts of SIP (shared mental models, communication, cooperation, coordination). A system like this was already used for the development of a generic model for “Taskwork and Teamwork strategies in Emergencies in Air traffic Management” (T^2EAM) [15]. Based on this coding system an iterative process of analysis and reflection on the collected data including the verbal data of the think aloud and video data of the gaze tracking should lead to a refined coding system. This refined system should be able to capture the essential information needed to portray SIP.

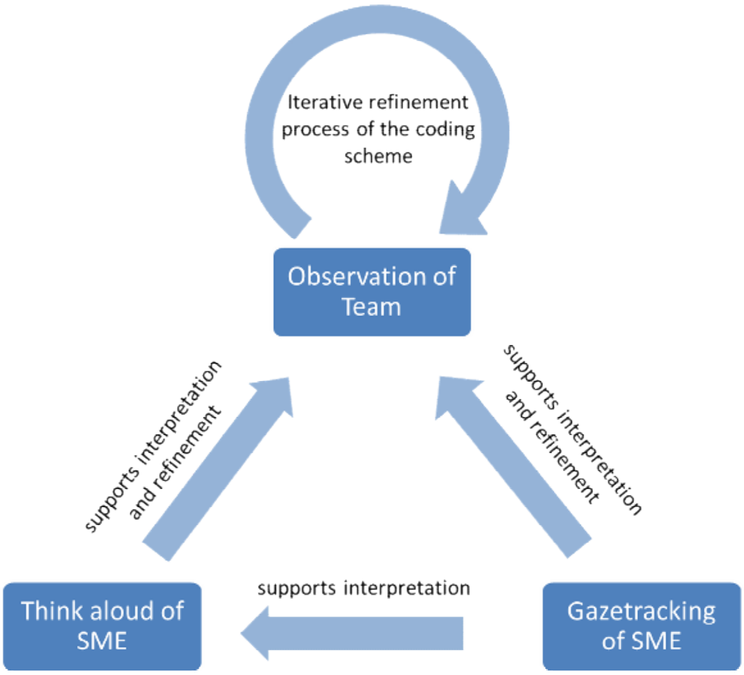

Figure 1: Interaction of the three methods

One of the problems in research of complex systems is getting access to the subject matter expert's knowledge. It is often implicit and therefore not easily verbalized. Due to the use of think aloud technique and gaze tracking it will be easier access to this implicit knowledge. These two methods are primarily used to support the interpretation of observed team behavior due to the expert's information (implicit and explicit) about the situational context (figure 1). With this knowledge the refinement of the used coding scheme will be easier for the researcher. Additionally, with the knowledge of what an SME focuses on and what he/she is thinking while observing, the external validity of data analysis and interpretation can be improved.

Conclusion

The need for safety in high hazard industries is undeniable. To understand, maintain and improve safety, new concepts like SIP are developed. The examination of such concepts often requires new research methods. State of the art simulators often take an indispensable part in this research. It is impossible for the researcher to understand a complex system the way an SME does, but SME knowledge is needed for the correct interpretation of observed behavior. To examine SIP, a multimethod approach as proposed in this paper. Due to the better insight given with such multimethod research methods research questions, that could not be answered up to now with the help of conventional methods may be researched in the future. The combination of state of the art simulators and new research methods would make it possible to analyze and improve the

SIP that are needed as a flexible supplement to reliable system components for stable sociotechnical systems in high hazard industries.

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