Analysis of work practices from the resilience engineering perspective

NORROS Leena

VTT Technical Research Centre of Finland, Systems Research, PO Box 1000, 02044 VTT, Finland (Leena.Norros@vtt.fi)

Abstract: According to the main assumptions of the Resilience Engineering approach, one of the main challenges of safety management in organizations is to strike balance between pre-planned preparedness and situation-driven acting. In order to act in an adaptive way in unexpected situations, and to develop structures and processes, organizations need to create appropriate shared awareness of what they understand by system safety. Beyond this, there must be sufficient understanding of actual work practices and how they support system safety and resilience. An ecological analysis of practice for the facilitation of these aims will be proposed in the paper. It is also important for the control of safety that the used technologies and tools couple smoothly with human conduct. A concept of systems usability will be proposed as the quality criterion for evaluation of technologies. The evaluation exploits the analysis of performance outcome, practices and user experience and focuses on testing the tools' capability to facilitate resilience of the system. Demonstration of the use of the outlined analysis of practices and tools is based on own research in different safety critical complex work domains.

Keyword: safety management; complex sociotechnical systems; interpretative practice; systems usability

1 Introduction

This paper concerns complex sociotechnical systems, especially technologically advanced work organisations. Examples of such systems are industrial process plants, traffic systems, health care systems, or even the food chain "from farm to fork". These systems typically involve a highly specialized personnel distributed in diverse responsibility areas. Because such sociotechnical systems often are safety critical, or/and involve high economical values, there has been an increasing interest of the stakeholders, *e.g.*, owners, operators, regulators, local communities, and individual workers to ensure appropriate management of the systems according to safety, environment, efficiency and health related targets.

Research on the safety of complex organisations started during the 1980's with some ground-braking contributions like the one by Charles Perrow[1] or Barry Turner[2]. Along with the emergence of new organisational theories of safety, it was by 1990 that the intellectual focus of safety research had shifted from analysis of how accidents had happened, towards how safe organisations could be supported or even designed[3]. Safety culture, first introduced to the wider public by the INSAG group[4], is the key concept to indicate this turn of the focus.

While there is no doubt of the necessity to look at safety from an organisational and cultural perspective, it is important to reflect on the methodology of organizational studies. It is not sufficient to analyse safety culture merely via individual attitudes towards safety, or via expressed values, but needed are also analyses of shared cognitions, administrative structures and resources which support organizational understanding and of practices regarding risk and danger[3]. The aim in this paper is to review current attempts to develop systemic approaches to safety management. In particular, the aim is to advocate the idea that as part of a systemic safety management approach more work should be devoted to understanding actual work practices and the role of technologies in shaping practices. A proposal of an approach for analysis of practices and tools for supporting system resilience will be made.

2 Towards system-oriented safety management

2.1 Resilience engineering

An important collective contribution to development of a system-oriented safety management concept is the so called Resilience Engineering approach. The important break-through of this approach in the international forum was the book "Resilience

Received date: November 30, 2012

Engineering – Concepts and Percepts" from 2006[5]. The approach is based on reflections concerning the safety models used in coping with safety threats in complex systems[6]. Analysis of the nature of safety models can be traced back at least to Jens Rasmussen's critical comments concerning the causal explanation of accidents[7]. Causal or linear models typically identify a sequence of events leading to the accident. Linear models may also be more complex ones which take into account latent technical or organisational contributing factors, and focus on identifying break-downs of built-in defences. The well-known "Swiss cheese" accident model proposed by James Reason is an example of such models[8]. Linear models have basic weaknesses particularly with regard to learning from accidents[9]. This is due to the fact that a particular event always is a result of a coincidence of many situational factors. When the focus in analysis is the causal role of such factors, there is a strong tendency to identify remedial solutions that likewise restrict to the particular situation. In the worst case, such fixes will prove to become new sources of failure. Causal analyses also tend to circular explanations in complex events[10]. As a compliment to the use 70of linear models, analysis of the generic functions that maintain the safety of the organisation started to raise interest among researchers and practitioners[11]. The models developed from this perspective were labeled systemic models. Hollnagel elaborates the need for systemic models by the observation that in a complex system, there is always variability in the system's performance. The issue is to identify which variance is beneficial for adaptation and which leads to an uncontrolled situation[12].

Resilience Engineering approach is one of the most attractive system-oriented approaches to safety management. Resilience engineering takes a clear position to shift focus away from things that go wrong to those that go right. Hence, it is interested in understanding the normal functioning of the organisation, how control of safety takes place and how brittle the organisation is.

In the preface of a recent guidebook to resilience engineering Hollnagel defines resilience as "The intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions"[13 p. xxxvi]. This definition is a synthesis of several earlier contributions to define the concept[5]. In the earlier attempts, resilience – according to the suggestive notion of bouncing quality - was seen in terms of adjustment to disturbance. The idea of anticipatory adjustment was added later. The essential abilities for adjustment are listed to be the ability to address the actual situation, the ability to address (and identify) the critical factors for safety, the ability to (anticipate) and address the potential for safety, and the ability to address the factual experience and learn from it[13,p. xxxvii].

2.2 Resilience and safety culture

One line of research in resilience engineering is the study of organisational safety culture. Among the many approaches to safety culture the one that draws explicitly on the premises of resilience engineering, is the Design for Integrated Safety Culture (DISC)[14]. In the DISC framework "Safety culture is a concept that can be used to denote the organisational capability to manage internal and external variability" (pp. 3018). Such an organisational capability is a result of 10 organisational functions that need to be maintained all the time. These functions are: Work condition management, Work process management, Safety management and leadership, Supervisory support for safety, Proactive safety development, Hazard control, Competence management, Change management and Management of third parties (pp. 3019-3020). All the functions assume deeper safety culture management requirements which are seen to be embedded in four main organisational elements, *i.e.* in Understanding, Structures, Practices, and Collective mind set for safety.

The DISCC framework is targeted to be used as a conceptual reference to accomplishing organisational reviews of safety culture. From the overview of case studies elaborating the DISC framework[14], we learn that the current methods of DISC cover quite well the elements of structures and understanding, but – while observational methods are not included – the approach is weaker in identifying actual practices and their safety relevance.

The problem of the former and many other organisational safety culture approaches to elaborate actual practices may also be linked to minor attention to the physical and technical foundations of the work and to neglecting these as constraints for safety management. Integrating the technical and the human and organisational viewpoints would require models of the system that can be used by both perspectives. Functional modeling[15,16] or also system-dynamic modeling[17] have been proposed for this purpose. An integrative design practice that would exploit these promising modeling approaches is however still lacking. One of the advocates for integrated design is Bernard Papin[18] who acknowledges the relevance of the concept of resilience as a central target of the new design practice to be developed. Papin maintains that the key issue in creating resilience is how the role of human actors is defined. He sees that a certain amount of autonomy for human conduct is necessary for a resilient functioning of a sociotechnical system. From the very beginning of the design of the system more or less explicit decisions are taken that influence the level of autonomy. If autonomy is designed to be high Papin assumes that preparedness for unanticipated situations is good but efficiency of acting in anticipated situations may be reduced. If guidance of acting is very high, efficiency of acting in anticipated situations is better but there might be problems in preparedness for unanticipated situations. In finding an effective balance between autonomy and guidance, and finally creating resilience to the system, three target areas must be managed. First, the organization needs to possess a deep understanding of the plant functioning. Decisions in the technical design of the plant (*e.g*. limiting interactions, or striving for simplicity), decisions concerning organisational design (*e.g*. training and division of labour effecting competences concerning plant behaviour), and finally strategic decisions concerning operational concepts have influence on the overall mastery of plant functioning. The second target area to master is the identification of an adequate prescriptive level for operations. This goal deals mainly with a number of strategic administrative decision concerning safety requirements, procedures, handling of deviations and errors. Finally there is the target for flexibility of operations. This goal is mainly regulated by procedure (and also interface) design within which a number of design issues like sufficiency of information, sufficiency of plant behaviour feedback, or human-system interface functionality, *etc*. may be listed.

Papin's conceptions of how to create resilience in the sociotechnical system have resemblance to those expressed in the DISC framework. In both proposals organisational functions are identified that are responsible for creating the capability of resilience. Both approaches also bring forth the need for understanding those physical, technological and organisational functions and preconditions for safety that characterise the particular domain. As the DISC framework is primarily targeted to support management of operating organisations, it focuses on means to understand the organisational structures for safety management. Papin's ideas focus more directly on the design activity of complex plants and provides design basis to resilient-oriented technologies and work practices.

2.3 Resilient performance

The most explicit elements of culture, *i.e*. practices and artefacts, have so far not been studied very intensively from the resilience engineering perspective. Yet, some interesting observations were already made in the 2006 book on resilient performance: Wreathall[19] provides observations of organisational processes that could be seen to support system resilience. Even though the author does not bring results on analyses of actual resilient performance, he claims in his conclusions that "what seems to be a key factor … is to have a realistic understanding of how work is actually performed, and then engineering all the tools and processes to exploit the beneficial features of that work…"[19,p.282].

In the same volume from 2006 practices were directly handled by Cook and Nemeth[20]. These authors demonstrate features of resilient performance in two case studies, one from medical care and the other from emergency management. The authors' attempt is to identify generic characteristics of resilient performance. In their conclusions, the authors make two important observations for further search for resilient performance: They state, first, that performance might be resilient without being successful, at least in the conventional sense (p. 217), *i.e.*, in the sense of reaching a pre-defined outcome. Instead, the authors claim that quite contrary is true: Resilient performance itself involves either a tacit or explicit redefinition of what it means to be successful (p. 218). Second, as redefinition of the situational goal is required, resilient performance assumes an ability to traverse along the goal-means hierarchy (here a reference is made to a functional abstraction hierarchy of the process).

An interesting contribution to the issue of resilient practices is delivered by an international research group in two articles[21,22]. In the first article the authors conceptually structure the on-going discussion on resilient engineering, in which they call for more structured and empirically verifiable research in the field. The authors propose that there is a need to define different levels of the system, with regard to which resilient behaviour could be identified. These levels are individual, small team, operational, plant and industry levels. The focus of the research is to find evidence for resilience in the observable behaviour with regard to each of these levels. Required is also to define what type of behaviour could be considered resilient. In searching for behavioural markers for resilience the authors make the point that for being in control of the system and reaching safety goals, it is necessary that there is a good coupling with the capabilities of the human actors and the tools they work with. Following this idea the authors state that their special interest is in understanding the capabilities of tools and instruments to support resilient behaviour. The authors then bring forth interesting results with regard to individual level of performance from micro-world experiments on dispatching fire engines in an emergency response context. The results portray manifestations of resilient performance: The test persons re-organised the information display with the aim to create particular cues that would trigger reliable acting in certain error-prone phases of the task. This tendency was especially clear when the task allowed time and the actors were motivated to reflect the used strategies and to create extra cues.

In the second article[22] the authors focus on methodical issues and propose a framework for analysing resilient performance on the small team level. The article provides first a literature overview of methodically well-mastered studies on small team behaviour in safety-critical environment. Drawing on the literature and own results, a model for analysis of resilient behaviour is then introduced. The framework composes of three-level conceptual hierarchy that is seen necessary for a traceable identification of resilient behaviour of team work in, *e.g.*, process control tasks. The three levels are markers, strategy and observations of resilience. The resilient markers are not specific to any particular context but are rather generalisations of resilient behaviour. The strategies elaborate the markers but even they are not grounded in the specifics of a particular context. The observations of resilience relate to the particular context and express actual observed behaviour.

The authors provide examples of the three conceptual steps: On the basis of analysing selected episodes of 14 teams' managing a challenging situation at a nuclear power plant simulator. An observation of "admitting to follow a wrong procedure "is interpreted as a strategy of "provision of feedback to enable error correction", and it is linked with a marker "recognizing and responding to failures". Another example of an observation is that "the shift supervisor asks the reactor operator to take care of the alarms", which is interpreted as a strategy of "employing additional operator", and linked with the marker "managing workload.

The method even specifies in more detailed the way how to define the strategies, *i.e.* four further conceptual categories are introduced. However, according to the provided case-study example, the strategies were elaborated only with regard to two extra conceptual tools: identified vulnerabilities and available resources in the studied situation. The inclusion of these two categories appears to contextualise the strategies which actually were, according to the authors own report, to be defined context-independently.

The framework was found promising and the authors plan further research on developing a generally agreeable set of resilience markers and strategies. The authors see further that there is also a need to explore the possibilities to expand the framework to enable evaluations on the other levels of the resilience markers approach referred above.

The resilience markers approach corresponds closely with our own attempts. We agree with the authors about the need to define actual behavioural expressions of the potential of an organisation to act safely, *i.e*., manifest resilience. Likewise we share the idea that resilience has manifestations on different levels of the system. The use of the above-described DISC framework has brought useful results on the plant and operational level. The analysis of practices to be introduced in the following chapter tackles resilience features on small team and individual levels. Related to these levels, we have – in agreement with the recommendations of the resilience markers authors - identified the role of technologies in shaping practices. We also fully support the quest for methodical clarity and traceability of reasoning in the analysis of empirical data of actual behaviour of the personnel of complex organisations. The approach that we have created on the basis of equal premises contains several unique features compared to the resilience markers approach, however. We shall now turn to our approach to analysis of practices.

3 Analysis of practices from system resilience point of view

3.1 Background

The analysis approach to be described in the following has been developed with a generic interest to improve understanding of normal human behaviour in real contexts, and especially to support design of technologies and concepts of operations in complex work systems. In earlier work, this approach has been labeled the Core-Task Analysis approach. Its theoretical and methodological foundations were explained in a book by Norros[23], and several other publications describe further developments of the approach[24-27]. Methodologically the approach can be considered as an ecological one: It draws on a naturalistic notion of human conduct in which the environment is considered to take an important role in shaping human experience and action. Technologies are considered part of the environment but the mediating role of technologies and tools in the human-environment interaction is acknowledged. Cognitive functions are seen to be distributed among human actors, between human actors and the tools and technologies they use, and cognition is also distributed over time via accumulation of experience in tools and knowledge of their use. In the next, theoretical assumptions are first discussed that enable the approach to be considered relevant for resilience engineering. Then the approach is presented via describing the analytical steps that it contains. Examples of empirical studies will be given to elaborate each step. (We shall use examples from different studies since no single study provides the best example of all the steps.)

3.2 Connecting the ecological analysis of practices to resilience engineering

The ecological analysis approach has not, in any formal sense, been connected to the resilience engineering approach, so far. Our practice analysis appears, however, to link smoothly with the resilience engineering framework. Resilience engineering needs input with regard to analysis of normal practices that our analysis can deliver. Resilience engineering, again, provides a strong societal motivation and a safety-oriented context for our analysis of practices. We consider “practices” as generic patterns of behavior that focus on *how* people act rather than on *what* they do. Practices can be identified on the basis of “actions” (what) which express situation-specific behavior and are typically analysed as ordered in sequences[23].

When setting the ecological analysis of practices into the context of resilience engineering some basic assumptions of the practice approach needs to be made clear: First, it is necessary that the analysis of practices and evaluation of their potential effect on system resilience must be informed of the strategic decisions concerning plant design and operations. According to Back *et al*.[21], the operational, plant, and the industry levels need to be involved in developing resilience of the system. What should be ensured by the upper level design or policy decisions is that sufficient autonomy exists in the organisation for situation-driven creative actions[28]. Maintaining such conditions in the organisation is an issue that needs continuous balancing between attempts to seek safety and efficiency through standardisation of functions and those that aim at these goals via improving expertise and human decision-making.

Second, it is assumed that only part of practices that are accomplished in the organisation actually exploit the existing potential for creativity, and support resilience. How to identify which practices are such that could support resilience? We see that actors in the organisation need to develop a personal motivation and a capability for making use of the autonomy in their daily work. The qualification of practice that makes this potential effective is labeled interpretative practice. This notion is borrowed from Charles Sanders Peirce[29], and proposed by Norros[23] to indicate such an epistemic attitude of a human actor to the environment in which s/he manifests presence in the particular situation and focus on specific features of the situation, accompanied with a strive to see the situation in a further (not immediately present) connection that makes it meaningful. This attitude enables interpretation as a form of generalization. According to Peirce the contrary attitude, a reactive attitude, is one that manifests a tendency of the subject to be drawn by the external particular events, and also withdrawal from action. Norros proposed a neutral epistemic attitude between these two extremes that expresses a strong reliance on expectations and a tendency to neglect the uniqueness of events but rather take them as given. This attitude is labeled confirmative. Only those practices that portray an interpretative attitude are capable of bringing resilience into the system. This is so, because due to orienting to the particular situation and interpreting its significance with regard to upper level functions, objectives, or connections an appropriate action in the situation may be launched. As a consequence, a human-environment interaction will be facilitated, in which new information is created, and learning takes place. Learning is less effective if personal agency is kept to the minimum, or if the situation is considered as expected and a standard reaction sufficient. We may also assume, that in a less demanding situation the strength of an interpreretative practice in comparison to the other types of practices may not become evident, whereas in demanding or unexpected situations the advantages should become evident. Our current work is focused to demonstrate these expectations concerning the strength of interpretative practices. Interpretative epistemic attitude has connections to reflective acting which was found to be one of the signs of resilient performance according to Back *et al*.[21]. Cook and Nemeth[20] named characteristics of resilient performance to be such that connect to further levels of abstraction and are capable of creating new goals. Also this feature corresponds with our way of comprehending interpretative epistemic attitude in action.

The third assumption to be made is that tools and technologies used in work have an important role of producing resilience into the system. For the understanding of the role of tools and technologies for resilience a conceptualization of the generic functions of tools is helpful. Drawing on Cultural Historical Theory of Activity we have proposed that tools serve instrumental, psychological and communicative functions[26], and that exploiting these functions relate with the ability of actors to maintain control in the system. It can be assumed that the tools' capability of delivering these functions is shaped, *e.g*., via level of automation, characteristics of I&C systems and user interface solutions. Evaluating the tools and technologies with regard to quality criteria related to the generic tool functions is a way to reveal the implications on the activities and culture of organisations, and to understand the role of tools and technologies in creating system resilience.

4 Steps of ecological analysis of practices

As was already mentioned, ecological analysis of practices considers that fundamental for understanding human behavior is to understand the environment in which the behaviour takes place. This is why the domain specific overall objectives of the work and the generic intrinsic constraints of the work domain need to be analysed as prerequisite for more detailed studies of work activity or tools.

In the next section the five main steps of the Core-task analysis approach will be described and examples of our research provided. These steps are also depicted in Fig. 1. It is important to note, that the analysis steps are logical elements of the analysis and may be accomplished in varying order. In the presentation we shall follow Fig. 1 and start from the step depicted as the outermost and work towards the centre, but the reader may notice connection between the steps.

4.1 Analysis of the objectives of work

Drawing on Activity Theory and Developmental work research approaches (see recent description[30]) we see work organisations as historically developing societal systems that typically contain diverse tensions between and within its elements, and with regard to the future objectives and course of the development. By modeling the work system (Depicted in Fig. 1 as the outermost step) it is possible to identify the global tendencies of its development, and understand the demands that the optional, and possibly contradictory objectives put on the work organisation and its processes. On these bases, general hypotheses concerning the requirements for the control of the system can be formulated.

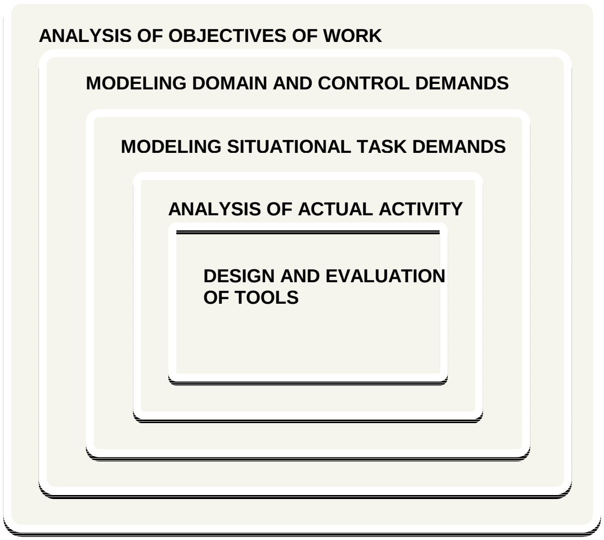

Fig. 1: Overview of the ecological analysis of activity.

An example of exploiting such an analysis as basis for understanding risk-prone practices is a comprehensive accident investigation in the maritime domain, in which we participated[9]. The accidents under analysis had all taken place in so-called piloting situations in which an expert pilot, who does not belong to the regular ship bridge personnel, had entered the bridge to support the personnel in difficult parts of the routes. We started our actual investigation work by analysis of the practices of the pilot and the master in each piloting situation that had lead into grounding (step "Analysis of actual activity" in Fig. 1). In order to find explanation for risky performance patterns we found in the material, *e.g.*, reduced collaboration among the pilot and the master as the control of the ship was worsening in a difficult situation, we conducted an activity system analysis of the organisational preconditions of the piloting activity (the outermost step of analysis). Nine generic tensions in the activity system were identified. Among them we found a reduction of safety margins when bigger and bigger ships enter into traditional coastal fairways. The emerging safety challenge can be tackled by introducing technological tools and technically-mediated practices, and good communication on the bridge. These demands for practice are, however, not met as the strength of the dominant piloting practice is seen to lie on a skill-based tacit adaptability, and it does not include collaboration in the currently demanded degree.

4.2 Modeling of the intrinsic control demands of the system and inferring core-task demands

In the second step of analysis "Modeling domain and control demands" the attempt is to identify the core-task demands that the work puts on the actors. A modeling tool is used that identifies particular control demands typical of the domain with regard to three generic system features, *i.e.* dynamicity, complexity and uncertainty. The generic means of tackling these control demands on individual and team level are seen to call for three types of resources, *i.e.* skills, knowledge and collaboration. When connecting each of these resources with each of the control demands nine types of work demands, *i.e.*, core-task demands emerge. The core-task demands are first defined on a generic level based on conceptual analysis, and these are then elaborated on the basis of empirical material (observations and interviews) of the studied work domain and particular work. The generic core-task demands that we have identified in several safety critical domains are listed below:

Control of dynamicity involves

- readiness to act in situation (skill-related)
- anticipation and identification of weak signals (knowledge-related)
- effective sharing of resources (collaboration-related)

Control of uncertainty involves

- flexibility and re-orientation (skill-related)
- interpretation in action (knowledge-related)
- dialogical communication (collaboration-related).

Control of complexity involves

- focusing on critical features (skill-related)
- conceptual mastery of the domain (knowledge-related)
- shared division of responsibility (collaboration-related).

The above-mentioned generic core-task demands have emerged in our careful analyses, *e.g*., in maritime and nuclear power plant domains. One of the most developed analyses of core-task demands is available in our study on telecommunication network operators' practices[25]. A number of concrete expressions each particular demand under each of the nine categories could be identified and operator practices characterized by the actual coverage of the demands.

4.3 Modeling situational task demands and mapping the core-task demands to phases of process control

The further step of analysis is "Modeling situation task demands" (Fig. 1). We have developed the so-called Functional Situation Model method for concretising how the core-task demands portray in a particular temporally ordered process control situation. Susch a situation may be one that is planned and simulated by the researchers, or it can also be a real situation that will be modeled and the activities analysed post-hoc (*e.g*. in incident or accident investigation). With regard to the temporal perspective of situations we identify process events, available information from the process, and optional control measures. The connection of each of these elements of the task to upper level control functions and objectives is also indicated. This is the functional perspective of the modeling technique.

The modeling tool is explained in more detail in the following reference in which a particular nuclear power plant process control situation is used as an example[31]. The important aim of the functional situation model is to enable analysis of the possibilities and constraints that the situation puts, and their relation to the generic core task demands. The model does not depict a sequence of correct actions. Instead it is a reference against which the actual realised actions of operators can be analysed. We found some resemblance of this modeling step with the detailed analysis of strategies explained by Furniss *et al*.[22].

With the aid of above-described modeling steps (steps 1, 2 and 3) it is possible to create a reference against which actual behaviour of teams and individual operators can be understood, analysed and evaluated. This reference defines a best possible conceptualisation of the possibilities that the environment provides for action. The reference is not necessarily available when real behavior is observed. We see however, that such a conceptualization needs to be accomplished for making sense of observed behavior.

As has become evident, analysis of actual behavior complements the expert-driven work in creating the models. This means that analysis of actual behavior may have to be accomplished several times, for different analytical purposes. With regard to Fig. 1 we may note that the analysis may run in both directions, *i.e*. from outside inwards, or inside outwards.

4.4 Analysis of actual behavior of actors and identification of practices

Our analysis of practices is based on comprehensive empirical data from the field or from simulated real-like situations. Collected are interviews concerning the core-task demands (we call them "orientation interviews"), observations of performance (video recorded), and process tracing interviews (the actors post-hoc accounts of their performance). All data is used to reach an understanding, first, what was each actor's or team's performance sequence and performance outcome. Out of these analyses of actions, and using the functional situation models, we then select episodes for further scrutiny.

The next phase of the analysis, again, abstracts from the situation specific level of action to the level of practice. The purpose is to identify a more generic pattern of behavior on the basis of the particular instance. The analytical tool that is used here is the semiotic model of habit that we have borrowed from Charles Sanders Peirce[23,29]. The semiotic structure of habit is composed of three elements that connect the environment and the actor in a meaningful relationship. The three elements are the environmental cue (sign), the object or issue it refers to (object), and the interpretative act (interpretant) that manifests the connection between the cue and the object. Using this structure we analyse the environmental cues in the episodes, find out what behavioural reactions were released with which objectives. We call these behavioural patterns *habits of action*, the content of which portray different aspects of activity, *e.g.* habits of searching information, or habits of communicating with the crew, *etc*., depending on the episode under analysis. In our analyses we have found, as is to be expected on the basis of the Peircean theory, that habits of action may vary so that same cues may be linked to semiotic connections that portray different levels of interpretative power, *i.e*. there may be interpretative, confirmative or reactive reactions. Which one is the case can be identified on the basis of the objectives and actions connecting to them. The reference in judging the level of interpretative strength of the habits of action is how well the core-task demands of the work are fulfilled in the particular case.

As an example of this analysis step we may refer to our study on expert anaesthetists' practices. The semiotic triadic notion of habit from Peirce[29] was adopted, and it was used to structure the continuously on-going doctor-patient interactions during the selected episodes of the anaesthesia process. Indicators were constructed by defining semiotic structures on the basis of the observations and interviews with the participants as follows: Indicative signs of the patients *e.g*. during induction, *i.e*. blood pressure and heart rate, were connected to alternative possible objectives of the anaesthetic treatment, *e.g*. realisation of pre-determined plan, control of the level of consciousness, control of reactions as indications of sufficiency of sleep, or adequacy of the does for the particular patient; and to corresponding alternative possible actions of the anaesthetists, *e.g*. induction of standards mean doses on weight bases, induction of a sleeping doses, induction after controlling the reaction to laryngoscopy, induction after experimenting. The registered performances of the different anaesthetists was analysed by 8 such semiotic indicators, *i.e*. habits of action indicators. The whole material was then classified according to the developed criteria and it was determined what kind of solutions each anaesthetist had used, *i.e*., in what sense the anaesthetists had acted on the patient. These observations were summarised as a description of habits of action that exist in the professional practice of anaesthetists (more details see [23]).

4.5 Evaluation of the systems usability of tools

The final step of analysis of practices is to study the relationship between operator behaviour and the used technologies. As was already mentioned, we consider tools to serve three main functions in activity. The instrumental function is related to the effectiveness of the tool in its main purpose. The psychological function relates to the tool's role to shape human acting and to the need to design tools so that the tool-user system is as smooth as possible. By communicative function we mean that the tool enables collaboration and mediates shared forms of acting and thinking within the community of practice, and even wider. Furthermore, we consider that the capability of tools in the above three functions can be evaluated via their usage. Usage needs to be evaluated not only with regard to the performance outcome it enables, but also with regard to the practices it facilitates, and finally according to how promising the users experience the tool to be with regard to their needs and values. A 3 by 3 grid is formed out of these two dimensions and 9 different types of measures for the comprehensive quality of "systems usability" emerge. Using the metrics we may evaluate which tool functions are fulfilled best, and also identify whether the tool supports the pre-defined performance outcome, or whether it also has capabilities to facilitate interpretative practices and is experienced to provide added value for work in the future.

The exploitation of the systems usability metrics in a comprehensive empirical evaluation of a nuclear power plant control room was recently finalised[26]. In the study we observed that performance-based criteria delivered important information of the tool's instrumental capabilities. The practice-based and user experience-based measures were particularly valuable in informing of the tools capabilities what regards the psychological and communicative functions. For example we could draw attention to the users' difficulties to exploit the features of the new digital medium, or we discovered clear differences in the exploitation of process information among the teams. These measures revealed, further, that a confirmative attitude towards work is dominant within the crews.

Differences were found in communication and collaboration. These results are important in judging the tool's capability to support resilience in the organisation.

A further step of the ecological analysis of tools and practices is currently under development. It deals with a more design-oriented exploitation of the practice-based measures so that we could specify more concretely *e.g*. which features of the technology are responsible for better or worse communication of messages from the process.

5 Conclusions

The above presentation of the ecological analysis of practices and tools was the first explicit attempt to connect the core-task analysis methodology with the resilience engineering approach. As an ecological approach the core-task analysis methodology provides solutions to a number of requirements set in the literature for methods to identify resilient features of a system. For example, the proposed approach enables analyses on both higher strategic-organisational level, and team-individual level. This is accomplished by utilising functional modeling of the organisations and connecting the results of this analysis when reasoning about operators' and teams' practices. We also consider promising for the proposed method that generic core-task demands identified within this frame appear to have a good resemblance with features reported in the literature as indications of resilient practice.

The most unique feature of the method is that it provides a way to specify criteria for resilient practices. This is accomplished by introducing the semiotic concept of habit which is used as a tool for empirical identification of the interpretative strength of peoples' reactions to external events. According to our approach, resilience of a system can be supported only if actors are capable of making use of the available autonomy in the organisation, and act in an interpretative way.

In the near future we hope to be able to provide proposals to identify characteristics of technologies that enable delivery of the tool functions we have identified. We also hope to be able to demonstrate how the presented methodology should be integrated in a more global design approach that is needed for crating symbiotic human-technology systems.

Acknowledgement

The research approach described above has been developed in the human factors research group at VTT including Iina Aaltonen, Jari Laarni, Marja Liinasuo, Hannu Karvonen, Hanna Koskinen, Paula Laitio, Paula Savioja, Mikael Wahlström, and Leena Salo (presently at Fortum Oyj).

References

[1] PERROW, C.: Normal Accident. Living with High-Risk Technologies. New York: Basic Books, 1984.

[2] TURNER, B. A.: Man-made disasters. London: Wykeham Science Press. London: Wykeham Science Press, 1978.

[3] PIDGEON, N.: Systems thinking, culture of reliability and safety, Civil engineering and environmental systems, vol. 27, 2012: 211-217.

[4] INSAG, Safety culture: a report by the International Nuclear Safety Advisory Group. International Atomic Energy Agency, Vienna1991.

[5] HOLLNAGEL, E., WOODS, D. D., and LEVESON, N. Eds.: Resilience Engineering. Concepts and Precepts. Aldershot: Ashgate, 2006.

[6] HOLLNAGEL, E.: Resilience - the challenge of the unstable, in Resilience Engineering. Concepts and precepts, E. Hollnagel, D. Woods, and N. Leveson, Eds., ed Aldershot: Ashgate, 2006: 9-17.

[7] RASMUSSEN, J.: Risk management in a dynamic society: a modelling problem, Safety Science, vol. 27, 1997: 183-213.

[8] REASON, J.: Human Error. Cambridge: Cambridge University Press, 1990.

[9] NUUTINEN, M., and NORROS, L.: Core-Task Analysis in accident investigation - analysis of maritime accidents in piloting situations, Cognition Technology and Work, 2009: 129-150.

[10] FAHLBRUCH, B.: Vom Unfall zu den Ursachen. Empirische Bewertung von Analyseverfahren, Maschinenbau und Produktionstechnik, Technische Universität, Berlin, 2000.

[11] RASMUSSEN, J., and SVEDUNG, I.: Proactive risk management in a dynamic society. Karlstad: Swedish Rescue Services, 2000.

[12] HOLLNAGEL, E.: Understanding accidents - From root cause to performance variability, in IEEE 7th Conference on Human Factors and Power Plants, Scottsdale, Arizona, 2002: 1-6.

[13] HOLLNAGEL, E., PARIES, J., WOODS, D., and WREATHALL, J. Eds.: Resilience engineering in practice: a guidebook. Burlington: Ashgate, 2011: xxxvi - xxxvii.

[14] REIMAN, T., PIETIKÄINEN, E, OEDEWALD, P. and GOTCHEVA, N.: System modelling with the DISC

framework: evidence from safety-critical domains, Work, 2012: 3018-3025.

[15] VICENTE, K.J.: Cognitive Work Analysis. Toward a Safe, Productive, and Healthy Computer-Based Work. Mahwah, NJ: Lawrence Erlbaum Publishers, 1999.

[16] LIND, M.: Challenges to Cognitive Systems Engineering: Understanding Qualitative Aspects of Control Actions, in ECCE 2009 – European Conference on Cognitive Ergonomics, Espoo, 2009: 37-44.

[17] LEVESON, N., DULAC, N., ZIPKIN, D., CUTCHER-KERCHENFELD, J., CARROL, J.M., and BARRET, B.: Engineering resilience into safety-critical systems, in Resilience engineering. Concepts and percepts, E. Hollnagel, D. Woods, and N. Leveson, Eds., ed Aldershot: Ashgate, 2006: 95-123.

[18] PAPIN, B.: Operator guidance in plant operation: Characterization and orientations for better team performance and socio-technical systems resilience, in Enlarged Halden Programme Group Meeting, Storefjell, Norway, 2010, p. C1.6 (10 p.).

[19] Wreathall, J.: Properties of resilient organisations: An initial view, in Resilience engineering. Concepts and precepts, E. Hollnagel, D. Woods, and N. Leveson, Eds., ed Aldeshot: Ashgate, 2006: 275-285.

[20] COOK, R.I., and NEMETH, C.: Taking things on one's stride: Cognitive features of two resilient performances, in Resilience engineering. Concepts precepts, E. Hollnagel, D. Woods, and N. Leveson, Eds., ed Aldershot: Ashgate, 2006: 205-221.

[21] BACK, J., FURNISS, J., HILDEBRANDT, M., and BLANDFORD, A.: Resilience markers for safer systems and organisations, in Safe Computing 2008.

[22] FURNISS, J., BACK, J., BLANDFORD, A., HILDEBRANDT, M., and BROBERG, H.: A resilience markers framework for small teams, Reliability Engineering and System Safety, 2011: 2-10.

[23] NORROS, L.: Acting under Uncertainty. The Core-Task Analysis in Ecological Study of Work vol. Publications 546. Espoo: VTT, Available also URL: http//www.vtt.fi/inf/pdf/, 2004.

[24] SAVIOJA, P., and NORROS, L.: Systems usability - promoting core-task oriented work practices, in Maturing Usability: Quality in Software, Interaction and Value, E. Law, E. T. Hvannaberg, G. Cockton, and J. Vanderdonckt, Eds., ed London: Springer, 2008: 123-143.

[25] NORROS, L., and SALO, L.: Design of joint systems - a theoretical challenge for cognitive systems engineering, Cognition Technology and Work, 2009: 43-56.

[26] SAVIOJA, P., and NORROS, L.: Evaluating Tools in Safety-Critical Work: CASE Hybrid Control Rooms in NPP Industry, Cognition Technology and Work, vol. Online first, 2012: 1-21.

[27] NORROS, L., NORROS, I., LIINASUO, M., and SEPPÄNEN, K.: Impact of Human Operators on Communication Network Dependability, Cognition, Technology and Work, vol. On-line first, 2012.

[28] PAPIN, B.: Integration of human factors requirements in the design of future plants, in Enlarged Halden Programme Group Meeting, Storefjell, 2002: C3/1/1-10.

[29] PEIRCE, C. S. Ed.: Collected papers of Charles Sanders Peirce. Cambridge, Mass.: Harvard University Press, 1958.

[30] SANNINO, A., DANIELS, H., and GUTIÉRREZ, K. D. Eds.: Learning and expanding with activity theory. New York: Cambridge University Press, 2009.

[31] SAVIOJA, P., NORROS, L., and SALO, L.: Functional Situation Models in Analyses of Operating Practices in Complex Work in European Conference on Cognitive Ergonomics, Edinborough, Scotland, 2012.