

PAPER IV

# **Functional Situation Models in Analyses of Operating Practices in Complex Work**

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# Functional Situation Models in Analyses of Operating Practices in Complex Work

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## ABSTRACT

**Motivation** – In safety critical work it is common to evaluate human activity based on the concrete outcomes it produces. But, in order to understand more thoroughly the possible implications for safety, also profound perspectives concerning the mechanisms producing the outcome are needed. In this paper we introduce a model of control situations that connects human actions with the purposes rising from the domain. This model, labelled functional situation model (FSM) enables analysis of operating activity from the perspective of way of acting i.e. work practice. Analysis of work practices complements the analysis of outcome of activity (e.g. task completeness, errors, time). The aim is to promote adoption of resilient work practices by analysing which ways of acting in a given situation are aiming for the general objective of safety.

**Research approach** – Research approach is constructive: a formative modelling technique has been created which draws from theoretical roots of functional domain modelling. The exploitation of the models in analyses of operating activity draws from the pragmatist conception of habit.

**Design** – A FSM denotes a control situation from the point of view of critical functions which are endangered in a situation. The human actions are also depicted in the model, and connected to the critical functions which are aimed to maintain.

**Implications** – The practical implication of an FSM is that it enables analyses (and evaluation) of operating practices and characterisation of them according to how they take the critical functions and the general objectives of the domain into account.

**Take away message** – Resilience in operating practice assumes that actors are able to make the connection between situational goals of actions and the general objectives of the domain. FSM makes this connection explicit and thus enables analyses of resilience features in practices.

## Keywords

Functional situation model, work practice, resilience

## INTRODUCTION

This paper addresses the issue of situation models in design and evaluation of complex systems in safety critical work. When a new tool is tested (e.g. a control room system in an industrial plant) it is typically put into an evaluation in some particular situation. For example in the safety critical nuclear industry, complex scenarios are run in high fidelity simulators in order to evaluate whether the integrated system, the operating crew and the technological systems function adequately. In this type of test it is usually found important to carry out an analysis of the test situation (the simulated scenario) prior to the simulator run in order to understand what is the desired behaviour of the whole system. The aim of the analysis is to understand the characteristics of good operating performance in the given situation. The model of the operating performance is the result of this analysis and it depicts the expected activity in the situation.

The analysis of operating performance demands can be carried out referring to the results of task analysis, for example, a hierarchical task analysis (HTA). HTA distinguishes task hierarchies by recognising which sub-tasks belong together and which kinds of higher level tasks comprise of the lower level tasks. The problem of hierarchical task models is that they do not explicitly connect the human activity to the phenomena in the environment which is a driver for the activity. Thus, a hierarchical task model is not able to portray the contextual significance of the actions modelled.

We maintain that a model of operating performance is absolutely necessary. But, this model should be such that in it the role of environmental features to the organisation of performance is acknowledged. Approaches that consider human acting as being situated (Suchman, 1987), embodied (Dourish, 2001), distributed (Hutchins, 1995), and socially constructed and driven by meanings that a technology is able to make the users experience (McCarthy & Wright, 2004), are examples of approaches that fulfil this requirement. In addition, we agree with hermeneutic approaches which acknowledge that researchers as external

observers always bring a pre-understanding of the situation with them. The modelling aims at making this pre-condition explicit. By making it explicit it also becomes possible to realise, during the actual analyses, the incompleteness of the initial model. Utilisation of the model in the analyses of operating practices is a process of interpretation in which the model of the situation and the researchers' understanding of the realised practice co-evolve dialogically.

In this paper we present a situation model labelled functional situation model (FSM) which draws from different theoretical roots. FSM has been developed in order to analyse and understand situational work practices in safety-critical industries.

## BACKGROUND

The main inspiration for FSM approach is the Rasmussen's (Rasmussen, 1986) control domain modelling, the abstraction hierarchy (AH). AH represents the controlled system and its environment at multiple levels of *means-end* abstractions. This is fundamentally different from HTA in which the relationship of subsequent levels is *part-whole*. In AH the different levels constitute a qualitatively different abstraction of the system. In AH the specific view point is *constraints* governing the functioning of the system.

AH is a general model of the domain. For the purpose of understanding demands of activity in *particular situations*, specific models of situations are needed. Flach et al. (2004) present a theory-based depiction how Rasmussen's levels of abstraction could be used to describe resources within situations. Petersen (Petersen, 2004) has also developed modelling in order to understand control situations for the purpose of design of human-machine systems. Later Bjørkli et al (2007) have added a level of strategy to Petersen's model based on empirical work in maritime environment.

The development of the FSM modelling approach has been conducted in different research projects in NPP and other safety critical industries. In evaluating quality of human technology interaction it is evident that some kind of model of human activity is needed in order to understand the demands concerning it. The first studies in which we utilized functional modelling of situations are reported in an overview by Norros (Norros, 2004; see also Norros & Nuutinen, 2005). These were studies of human error, process information presentation, and validation of an alarm handling system conducted in the 1980's and 90's. The modelling technique utilised in those studies, aimed at explicating the information concerning the environment (the controlled process) and optional operations which was required to adequately handle the process situation. Later similar situational information requirement modelling was utilised in the development of operator training (Norros, 2004). Already early on, the situation modelling method aimed at describing the characteristics of the environment which afford activity from the operators' part. In the

analyses of operating *practices* this view point is extremely important. What differentiates practice from action is the connection to the *meaning*. The meaning and purpose the action strives for constitute its contextual value.

In the next sections we present the functional situation modelling technique as it has been recently applied (Savioja & Norros, accepted for publication) in the analysis of operating practices.

## FUNCTIONAL SITUATION MODELS

When new technology is introduced as a tool in safety critical work, it is necessary to understand the implications on the work from multiple perspectives and levels of abstraction. It has been outlined that the operating activity shall be examined from three perspectives: performance, way of acting, and experience (Savioja & Norros, accepted for publication). Performance evaluation refers to outcome oriented perspective to human activity and a reference for it can be for example a HTA model of required operator actions. But, in order to understand the way of acting (work practice) a different reference is required which connects the actions and their meaning in the specific situational context. For this purpose we present the FSM approach. A general schema of a FSM is presented below (Figure 1).

A FSM combines two viewpoints to the modelled situation; chronological and functional. These two dimensions define a two-dimensional space in which the most important operator actions and process phenomena are mapped for the purpose of understanding both operating performance and practice.

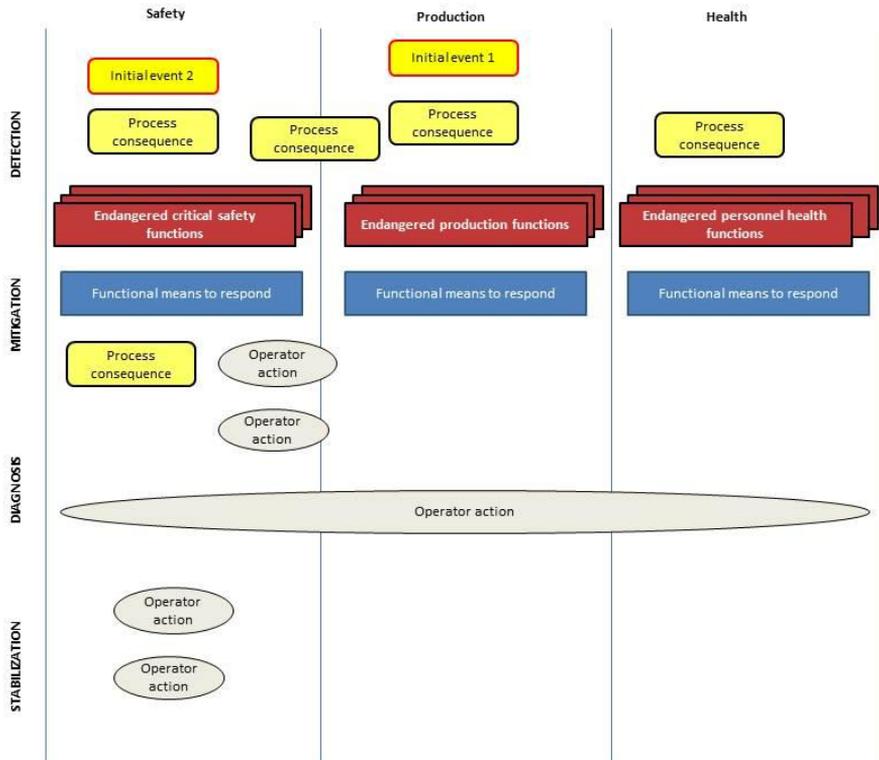
### Chronological View to the Situation

The chronological view is the most obvious way to analyse the operating activity. In the chronological view the scenario is divided roughly into different phases in which the operating actions have a specific goal. In the FSM the chronological phases are labelled according to the goals: Detection, mitigation of effect, diagnosis, and stabilising the process state.

Although the distinction is made between the phases it must be acknowledged that in real activity all the goals are somehow present simultaneously. But for the purpose of making sense of the process situation the distinction is nevertheless made in FSM modelling. Also, in a different circumstance the phases might have different goals, thus different labels for the phases could be utilised.

### Detection

In the model, detection phase denotes that the crew identifies some process events requiring operator actions. The process information presented to the operators is typically alarm information and notifications. Simultaneously, monitoring of all process information is conducted by the crew.



**Figure 1. The general schema of a FSM. In modelling a scenario with an FSM, the boxes describing process events and information (yellow), critical functions (red), and operating crew actions (grey) are depicted connected to the critical functions (read: safety, production, health) and the operative means to mitigate the functions (blue). The description is organised according to the chronological phases (detection, mitigation, diagnosing, and stabilization) according to the scenario in question.**

In the FSM the detection phase is concerned with the information that is available for the operators to understand the deviations in the process. It is also important to identify and explicate the initial event(s). The most important alarms informing the operators are included in the model. The implications of the initial event on the process state are depicted on parameter and overall process level.

**Mitigation of the effect**

The line between mitigation and detection is not always distinct as the operating activity actually constitutes a continuous cycle of monitoring and acting. Thus, the exact point in time when the mitigation phase “starts” is not so important, but we want to make a distinction that some operating actions are tuned more towards mitigating the situation than perceiving information about the situation. It is also typical that automatic functions handle some of the actions in this phase. In this case important operator actions are to confirm the fulfilment of the automatic functions. In the mitigation phase of an FSM the operating actions that mitigate the

process situation are mapped under the specific process information and initial events of the detection phase that they are connected to.

**Diagnosis**

As the ultimate operating goal in an accident situation is to bring the process into a safe stable state, diagnosis related actions are required from the operating crew. It is important to realise what the process situations is, in order to identify the required actions. In the diagnosis phase these actions are depicted in the model under the specific parameters of detection phase that they are related to.

**Stabilisation**

Stabilisation phase refers to the operating activities which aim at bringing the process into a safe and stable state. These actions are connected to the relevant initial events also.

**Functional View to the Situation**

A functioning sociotechnical system has the objectives of production, safety, and health (Vicente, 1999). These

objectives form the basis of the functional view of the FSM (the three “lanes” in Figure 1).

The most important items in the functional view are the critical functions (see e.g. Norros, 2004 p.111) of the process which are endangered in the specific situation. These functions can be, depending on the initial events, related to safety, production, or health. Typically, in a complex situation there are critical functions related to all of the above objectives which are endangered.

Operating activity, on a high level, is oriented towards maintaining the critical functions of the process. Thus, the operating actions required in the situation can be collated under general means to respond to the endangerment of the critical functions. This is depicted in the FSM by presenting a specific functional level in the model “functional means to respond”. This level connects the individual operating actions to the critical functions. The relationship with critical function level upward and with individual actions downward is of type *means-ends*.

### **Connecting the Chronological to the Functional**

By connecting the individual level actions of the crew and the functional view to the situation it is made explicit what is the *meaning* of each action in the wider context of the scenario. This is the important aspect of an FSM which enables the analysis of operating activity on the level of *practice*. We maintain that making this connection in action, is actually what makes operating practice *resilient* in a situation.

If and when operating crew is tuned towards the critical functions of the domain they always take into account them in their actions and follow how the critical functions behave and are affected during the course of complex process control activity. This is a characteristic of resilient practice. Resilience means that activity is able to respond to external events that may not have been rehearsed or pre-planned. We maintain that in order for the operating crew to be able to handle all possible situations they must make the connection always, even in a situation which is well rehearsed or planned.

In order to identify the critical functions in a situation it is important, first, to analyse the domain on a general level. We therefore consider the domain from the point of view of three general characteristics. These are the dynamicity, complexity and uncertainty of the system (DCU characteristics). The core task of a work accomplished in the particular work domain composes of taking these characteristics into account in all situations. Coping with the DCU characteristics requires that the actors are capable and willing to mobilise resources related to skills, knowledge and collaboration. (Norros 2004). The central reference of appropriate practice is that the DCU features are taken into account. *Resilience* emerges from the ability of the actors to tackle the DCU features of a *particular situation*, and thus to fulfil the core task. Hence, in Functional Situation Modelling the DCU features need to be

considered, and the practices of tackling the situation are assessed with reference to managing the core-task demands.

### **UTILISING FSMS IN ANALYSES OF OPERATING PRACTICE**

As stated above in this paper, earlier versions of functional models of operating situations have been utilised in analysis of human errors, alarm system designs, control strategies etc. This particular form of FSM which is introduced in this paper has been utilised in the evaluation of control room adequacy from the point of view of *systems usability*, concept that we have created to define the quality of complex technologies from a holistic point of view (Savioja and Norros, accepted for publication).

In the study, a series of reference tests was carried out in a nuclear power plant full scope training simulator prior to main control room modification. The aim was to gather evidence of the current control room functioning in a way that comparisons could be made with the new design solutions. One view point in these evaluations was the control room’s ability to support and promote core-task oriented work practice. Altogether 12 operating crews took part in the usage experiment and conducted each three simulated scenarios producing over hundreds of hours of video material.

The FSMs had multiple other roles in the test series in addition to enabling evaluation of operating practices. The FSM, first of all, provided the researchers an excellent opportunity to understand what is going on in the complex process system, and how the operating crew is expected to manage the situations. Second of all, as the FSM depicts the most important process events it guides focusing of the detail level analysis of operating activity.

### **Construction of an FSM**

In the experiment series the most detailed scenario model was constructed for a loss of coolant accident (LOCA) which is a design bases accident typically well-rehearsed by the professional operating crews. The particular FSM is depicted in below (Figure 2).

As the experiment was conducted under the yearly training program of the particular plant the scenario design was mainly conducted by the simulator trainers of the plant. In the experiment, there were specific research questions concerning the usage of emergency operating procedures and thus the LOCA situation was chosen to be one of the scenarios to be conducted.

The following is an explanation of the FSM depicted in Figure 2. In the particular LOCA the initial event is a leak in one of the primary loops. The leak is of size 50kg/s. The process consequence visible to the operating crew is that the pressurizer level drops dramatically. Also some alarms go off but they are not depicted in the model. Another initial event was also included in the scenario. This was a failure in a plant protection signal which governs the automatic protection systems of the plant. The failure was such

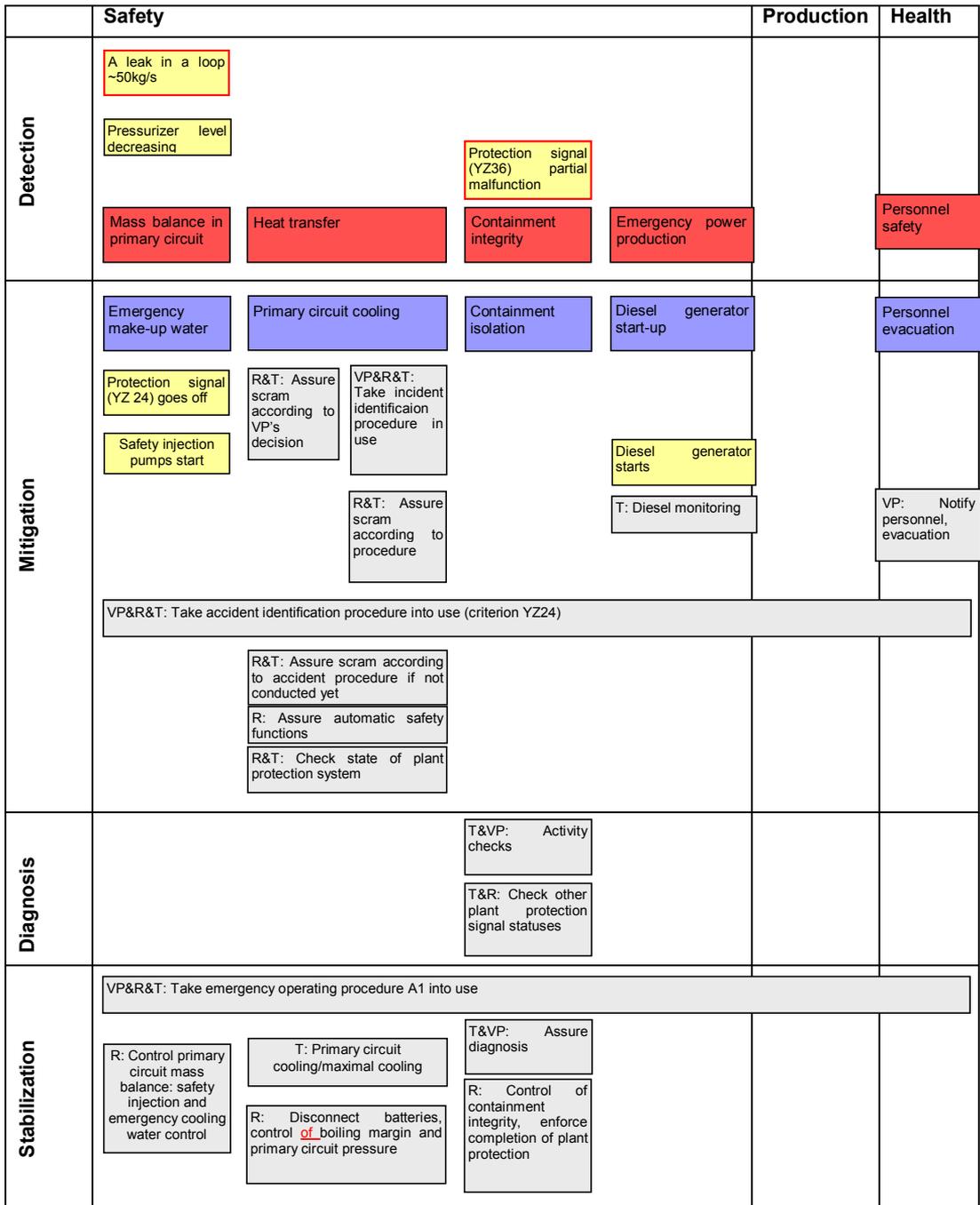


Figure 2. A LOCA conducted in the experiment depicted as an FSM. T= turbine operator, R=reactor operator, VP= shift supervisor. Yellow refers to process events, grey to operator actions, blue and red to functional means ends relationships concerning the process situation.

that the signal was initiated but it failed to launch the implications.

A critical function which is primarily endangered in the LOCA is that of primary circuit mass balance. This function is supposed to maintain that there is always enough of mass (cooling water) in the primary circuit in order to cool down the reactor core. In addition heat transfer is endangered as the coolant is leaking in the containment building and is not capable of transferring the heat to the secondary circuit. Although there is no failure in the systems related to heat transfer.

The failure in the plant protection signal (modelled as secondary initial event) endangers the critical function of containment integrity. When the automatic plant protection system is not functioning correctly the containment is not isolated properly.

The critical function of emergency power was also considered to be endangered because power systems are crucial in any accident situation in order to enable functioning of safety systems which require electricity.

Production related critical functions were not considered in the LOCA scenario as it is an accident and operating activities are mainly directed towards ensuring safety.

A personnel well-being related function was identified as in a LOCA situation the whole plant is evacuated for safety reasons.

Several means to mitigate the endangered safety functions were identified. In order to maintain mass balance in the primary circuit it is necessary to take the auxiliary feed water systems into use. This happens via automatic plant protection functions and the operating crews' responsibility is to monitor and detect that safety injection pumps are starting. Heat transfer is mitigated by concentrating on primary circuit cooling. In the beginning the important operating task is to assure that the automatic scram has functioned correctly. This can be done either by shift supervisor's decision or based on an emergency operating procedure. Containment integration is mitigated by the means of isolation and emergency power by the means of manually assuring the starting up of the diesels. Personnel safety is mitigated by evacuation means.

In the diagnosis and stabilisations phases the relevant operating crew actions were picked from the relevant emergency operating procedure and depicted under the critical function which they mostly refer to.

In the LOCA FSM depicted in Figure 2 process events are depicted as yellow boxes. The initial events have red line. The endangered critical functions are marked as red boxes and the relating operative means are depicted below as blue boxes. The operating crews' actions are marked as light grey boxes. In the text it is always marked whether the action is the duty of the turbine operator (T), reactor operator (R) or the shift supervisor (VP).

## **The Procedure of Utilising a FSM in the Analyses of Operating Practices**

### *Data collection methods*

During the simulator run meticulous recording of each crew's activity was conducted. Each crew member carried a head mounted camera which enabled post hoc analyses on a detailed level for example, direction of gaze. In addition the whole activity of the crew was recorded with two overview cameras from which the crew members' discussions and movements in the control room could be discovered.

During the simulator run a process expert (simulator trainer of the plant) acted as an expert judge of crew's process control activity. The process expert judged whether the crew conducted all the expected actions. This analysis constitutes part of the assessment of the performance of the crew.

Later, after the simulator run had been completed a process tracing interview was conducted in which the crew members gave their own account about what had happened in the scenario.

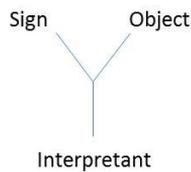
### *Data analysis methods*

The analysis of operating practices was conducted selectively. First one crew's conduct was transcribed on a detailed level including nearly all operations, communications, directions of gazes and movements. Analysis for this one particular crew was conducted initially from the point of view of utilising operating procedures (Salo, Norros, & Savioja, 2009).

Based on both the FSM and this one crews activity, several episodes in the process control activity were selected for more thorough analyses concerning every crew participating in the experiment.

In the analyses of operating practices the semiotic model of habit (Peirce, 1991) was exploited (Figure 3). In this model *interpretant* refers to how people make sense of the signs of the environment. This is perceived in the realised behaviour of actors (operations, communications etc.) The *sign* identifiable in the environment always refers to an *object*. The way people use (interpret) signs reveals the objects they strive for. Thus; sign, object, and interpretant pattern (habit) emerges as a result of a continuous action-perception-interpretation cycle which connects the actor and the environment (Figure 3) (Määttänen, 2009).

In the analysis of operating practices we utilised the semiotic model as proposed by Norros (2004) and looked at crew members' behaviour in connection to the signs exploited in activity. Based on this information we deduced which was the object in the activity. And this object is a characteristic of the practice. The object can be either such that it promotes resilience in practice or such that it is more tuned towards realising lower level immediate goals of actions.



**Figure 3. The semiotic model of habit (Norros, 2004; Peirce, 1991) utilised in the micro level analysis of operating practices.**

For example, in the situation described above in Figure 2 one of the essential actions in mitigation phase is to take into use the correct emergency operating procedure (EOP). In the experiment most of the crews took the correct EOP into use (interpretant), but there were differences between the crews in the information (signs) based on which they took the EOP into use. While some crews utilised information that was related to alarm texts pointing directly to the particular EOP others utilised in addition process information relating to the operational means of responding to the endangered critical functions(object).

*The method of making an assessment of operating practice*

Based on the analysis described above it was possible to evaluate the operating practices. In this form we differentiate *practice* from *action* by reference to the purpose. Action can be judged by understanding whether it was completed or not, but in judging practice the reference is the objective it strives for.

In the example of taking EOPs into use, the crews which were striving for the objective of understanding whether the initial situation assessment is valid i.e. interpreting process parameters thoroughly had a more core-task oriented operating practice than those crews which simply took the EOP into use based on alarm information solely. The process information reflection of which was considered significant in the analysis was that depicted in the FSM and connected to the specific action of taking the EOP into use.

Thus, inspired by the semiotic model of habit and the interconnection of sign, object, and interpretation we compared the signs that the crews exploited in their activity to the FSM. If the crew utilised information that was related either to the functional means to respond to critical functions or the critical function as such the operating practice was considered more adequate than in the case when such information was not utilised. The analyses were completed with the data gathered via process tracing interviews in which the operators had explicated their activity right after the scenario.

We maintain that good operating practice is such that it is oriented to the core-demands of the domain. These rather permanent characteristics of the domain can be identified by analytical work i.e. core-task modelling (see also Karvonen et al., 2011; Norros, 2004). For

example, in an accident situation we maintain that good operating practice is orienting to maintaining the endangered critical safety functions. This is a contextual interpretation of the concept of practice. By applying FSMs in analyses of practices it was possible to evaluate the contextual relevance of each crew's operating practice

**DISCUSSION**

The way of analysing human activity in a situation presented in this paper, aims at understanding the demands and possibilities that the environment sets on the operating activity in a specific scenario (The FSM). The models are situational instantiations of the more general domain models such as abstraction hierarchy of Rasmussen and the DCU description of the domain.

In the field of human computer interaction several modelling methods to depict tasks and also the wider organizational context have been developed (Beyer & Holtzblatt, 1998). These models however, do not show the connection of the task to the meaning and objective. And additionally, they are models of specific instantiations of actions in a situation whereas the FSM aims at depicting the generalized demands on actions in the form of critical functions of the process.

The modern understanding of human behaviour is that it is contextual. The power of FSMs is that they portray human activity in connection to the environmental phenomena toward which the activity is oriented. The environment is the context in which the activity takes place. In practice, in the example described above, the environment is the process system which is controlled by the automation and human operators. By describing the functioning of this joint system the FSM connects the description of human activity and a technological system. This makes the model compatible with the principles of ecological psychology which strives for understanding the joint functioning of human and the environment.

The FSM also addresses the collaborative and distributed character of human activity. In the model activity is portrayed on the level of an operating crew but the actions of individual persons can also be depicted. Similarly, connections that exist between the actions of different individuals can be modelled. In complex work, cognition can be interpreted to be distributed among human actors, automation systems and for example operating procedures. In an FSM the role of each of these actors can be depicted in connection to the critical functions of the domain. In fact, cognition is in our semiotic analyses not comprehended as internal processing of information but rather from the point of view of how meaning related to the appropriate control of the process is created as a function of a collaborative activity of the team, and how meaning of the situation is distributed within the team and, with further participants of the activity.

In the end, the most important feature of an FSM is that it makes explicit what is the *meaning* of each specific

action carried out by the human actors and the process automation systems in the *situation*. The meaning is the objective to which the action is connected, and acting is required to make sense of the situation, perception alone is not enough. This approach liberates the analyst from utilising and specifying the concept of situation awareness. Evaluation of awareness is not necessary because adequate sense making in the situation is explicit in the actors' behaviour. We maintain, that the orientation of practice towards the critical functions of the domain makes the practice resilient.

Creating FSMs about operating situations, it lays ground for different kinds of data collection and analyses methods which are oriented towards understanding meaning making processes in an activity. Previously the FSMs have been utilised in selecting the most important process events for micro level analyses operating activity (Salo et al., 2009). We believe that this kind of explications of the meaningfulness of actions could be made use of also in training and teaching situations. Some evidence of FSM applicability was gained later in another reference study in a different nuclear power plant, where the simulator trainers created the FSMs with only short introduction by the researchers to the modelling technique.

## CONCLUSION

In this paper we have introduced a model that is needed for describing human activity in a situation. This model is labelled functional situation model (FSM). FSM depicts the activity in connection to the environmental phenomena which is aimed to be controlled by the activity. By enabling connecting actions to their purpose FSM supports analysis of operating activity on the level of practice.

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