

## **Using subjective measures to monitor the systems' capability to manage complexity – evidence from the nuclear industry and health care**

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**Abstract.** The safe and effective functioning of a complex socio-technical system is a result of a continuous learning of how the human and the technology part of the system work and interacts in their unique environment. We argue that the subjective and also vague experiences or feelings of the personnel working in complex, safety critical environments should be taken as valuable information about the functioning or reliability of the overall system. The paper concentrates on one significant finding concerning the subjective feeling of being in control over one's own work. We will discuss the use of the sense of control construct as an indicator of whether the system is operating near the boundary conditions of safety activity. We will provide evidence of the causes and consequences of a lack of sense of control from three case studies in the nuclear industry and health care.

### **1 INTRODUCTION**

Although the variability in human activity is one of the sources of failures it is also of crucial importance in managing complex systems and working in ever-changing conditions. The adaptability is needed for e.g. coping with ill-designed computer systems, conflicting goals and unanticipated technical phenomena (Rasmussen, 1997; Dekker, 2005). We argue that the subjective capability of human beings to perceive and experience the status and dynamics of the system in which they are working is still largely neglected in the management and research of "high hazard" systems.

The safe and effective functioning of a complex socio-technical system is a result of a continuous learning of how the human and the technology part of the system work and interacts in their unique environment. As Woods and Cook (2006) argue, progress on safety depends on providing the workers and management with information about the changing vulnerabilities as well as on the ability to develop new means for meeting these. For that we need measures and indicators. Operational experience processes as well as different condition monitoring programs are tools for learning from experience and anticipating the possible problem areas. It is widely recognized that monitoring, analyzing and predicting human and organizational performance (and thus the overall functioning of the system) is extremely complicated. Although the operating experience tools e.g. incident reporting, usually cover human and organizational performance issues, the usefulness of the information as an indicator of the functioning of the human part of the system is limited. Past failures to manage a situation do not tell us how people can manage the situation in the future. Furthermore, it doesn't necessarily tell how many times the situation is handled successfully or how much effort does that require. Most companies carry out different organizational assessments e.g. working climate

surveys, but the model of how these relate to overall functioning of the system is lacking. Thus, the results are not utilized as fruitfully as they could be.

We argue that the subjective and also vague experiences or feelings of the personnel working in complex, safety critical environments should be taken as valuable information about the functioning or reliability of the overall system. We humans have the benefit (in comparison with the technology part of the system) of being able to compare information with past experience, to sense weak signals – for example worry and emotional exhaustion of the colleagues and oneself – and, most importantly, to express these perceptions to others. These subjective indicators such as worry or stress usually precede the more “objective” indicators such as increase in faults or incidents. They could thus be used to proactively monitor and anticipate the functioning of the system.

The ideas presented in this paper are based on organizational assessments we have conducted in nuclear power industry and health care. The assessments show that every organization has a personal way of defining the risks they are trying to manage, as well as defining the safest and most effective way of working. But we have also found some recurrent findings which we believe deserve further analysis from the point of view of an organizational resilience. We will concentrate on one significant finding concerning the subjective feeling of being in control over one’s own work and its consequences.

## **2 ASSESSING ORGANIZATIONAL EFFECTIVENESS**

### **2.1 Our approach**

We have used the term organizational culture in our attempts to describe the dynamics of different socio-technical systems (see Reiman & Oedewald, in press). The culture of an organization defines and manifests in 1) the visible structures, tools and descriptions that the organization has chosen or created, 2) the conceptions of the goals they are trying to achieve and limits of safe and efficient functioning, 3) factors that regulate the integration of the people working together. Thus, it can be claimed that organizational culture frames the activity of the system.

The dynamics of organizational culture is illustrated in Fig 1 using the graphical presentation format that resembles visually the format that Rasmussen (1997, p. 190) has used to model the migration of human performance toward the boundary of “functionally acceptable performance”. Contrary to Rasmussen, our model depicts the institutional and cultural factors inside the organization influencing the activity in the organization and strives to illustrate how the activity in the organization results from the interaction of the three elements of the organizational culture. The model shows the relation of the current activity of the organization to the boundary of safe and effective activity.

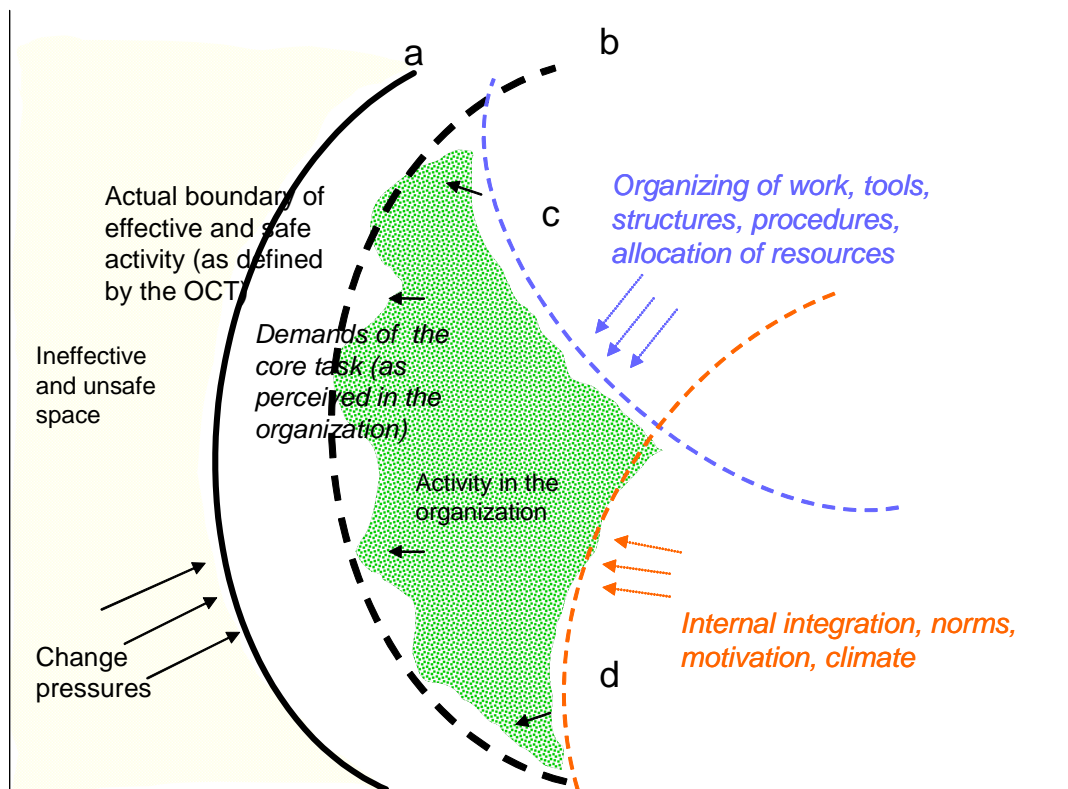


Fig. 1. The activity in the organization is influenced by three cultural elements; perceptions of the core task demands (line B), organizing of the work (line C) and internal integration (line D). The boundary of effective and safe activity is illustrated by line A. The arrows indicate pressures that are gradually and constantly changing the system. Adapted from Reiman and Oedewald (in press).

In the Fig. 1, line A represents the actual boundary of effective and safe activity as dictated by the overall goals the organization is trying to achieve. We call that Organizational Core Task (OCT). Line B represents the demands of the OCT as they are perceived in the organization (the perceived boundary). Line C indicates the influence of resources, tools, organizational structures and procedures on the activity. Line D indicates the influence of the internal integration of the culture (norms, sources of motivation, and climate) on the organizational activity. The space between lines B, C and D defines the area of normal organizational activity. The lines B, C and D are not outside pressures affecting the system, rather they are aspects of the organizational culture created and maintained by the organization.

The assessment process itself consists of iterative phases of data collection, analysis and feedback to the organization. We utilize document analysis and management interviews, but also observation of work, personnel interviews and surveys. With these methods we formulate a picture about the cultural elements; structural aspects of the organization, the limits of safe and effective functioning as the members of the organization see it, and of the rules, norms and climate that affects the everyday work (Reiman & Oedewald, 2006, in press; Reiman, submitted).

We aim at describing a) how clearly and uniformly the personnel see the organizational core task and its demands b) how willing and motivated the personnel are to work on

these demands c) how good the preconditions (tools, standard operating procedures, competence) are to carry out the work appropriately. For these purposes we also utilize “traditional” work psychology tools, such as work motivation measures. Our primary data is interview and survey material which, in essence, consists of subjective conceptions of the personnel. These conceptions are very useful in identifying the prevalent organizational models of safety and risks as well as issues that the organization has not managed to solve, situations where different goals are in conflict, aspects of the work that are considered important for safety, and aspects that are not. Thus measuring personnel’s experiences of their own work can help us identify whether the system has problems in managing the current situation and how hard they have to struggle in order to get the job done. The subjective experiences, however unspecific they are, might be important indicators of the organizations’ capability to manage complexity.

The time perspective is also important. Since most of the elements of culture change slowly (e.g. the conceptions concerning the core task of the organization, norms etc.) we are able to anticipate the capability of the organization to respond to the forthcoming challenges, e.g. new organizational structures and tools. In this sense our approach aims at evaluating the organizational potential for resilience.

## 2.2. Sense of control as an indicator of organizational resilience

An important aspect in terms of work motivation and effectiveness is the person’s subjective feeling of being in control over one’s own work. We define this as a person’s *sense of control*, which indicates to what degree the person feels (s)he is able to carry out his or her work properly. We propose that the feeling indicates how appropriately the cultural elements (see Fig. 1) support the work activity. A recurrent finding in our surveys is that the sense control over one’s own work differs between as well as within organizations considerably and it seems to be sensitive to changes in the organization.

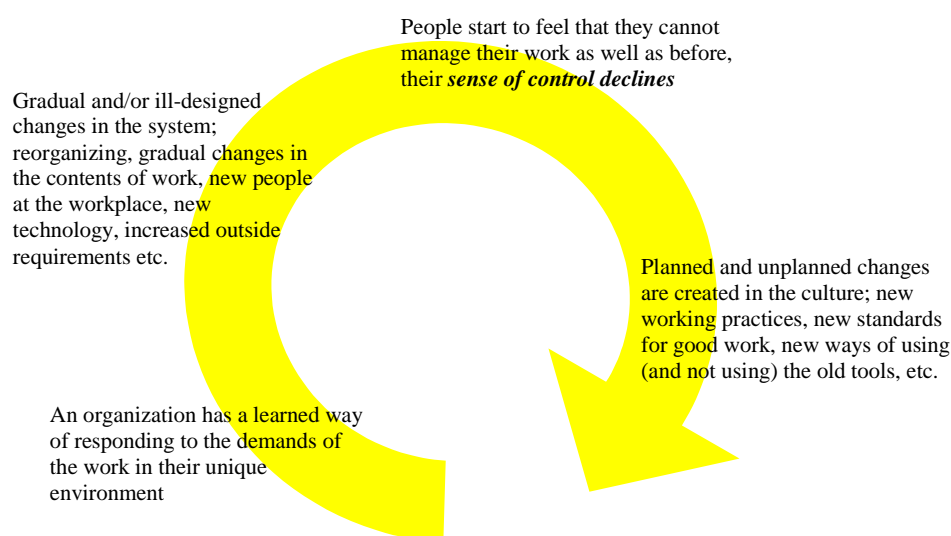


Fig. 2. The role of subjective perceptions in directing activity in a complex system

Woods and Cook (2006, p. 72) suggest that “one part of assessing systems resilience is whether that system knows it is operating near boundary conditions”. The human part of the system has the ability to express its feelings and perceptions. The perception of the personnel that they are not in control over their work might indicate that the system is not in a steady state (see Fig 2.). Because of the complexity of the system people may not be able to explicate what is changed and why they need to put more effort in order to manage their tasks. Thus, a lowered sense of control does not directly reveal the frailties of the system. Rather it suggests that the dynamics of the culture should be analyzed in more detail.

In the next section we will briefly review the results about perceived manageability of work in different safety critical organizations. Analyzing the level of sense of control was not originally the primary focus of these case studies. Rather, the findings about low level of sense of control were secondary and caught our attention because of their recurrence.

### **3. CASE EXAMPLES**

#### **3.1 Case organizations**

We will illustrate our arguments with three case examples. First case is a *neurosurgery department at a university central hospital*. The department has been established more than 70 years ago and it has a top class expertise in all areas of neurosurgical care. More than 3100 annual operations make the department one of the busiest in Europe. The department has around 200 employees. The organizational assessment was done in a project where the goal was to study the effect of a new anaesthetic and acute care information system for patient safety culture. The system is used at the operating room and also at the intensive care unit. The new system allows an automated recording of the vital functions and structured formats for instructions and prescriptions. The information concerning the patient’s state as well as treatments during the operation and intensive care is available only in electronic format. The new system had been in use for four months at the time of the study.

The second case is a *maintenance department in a Nordic nuclear power plant (Plant A)*. The organizational assessment was conducted two times: just before a major reorganization of the entire plant and one year after the reorganization. The power plant has been in operation for over 25 years with good operating records during the last years. It has two reactors and the maintenance department is centralized in a sense that they are responsible for both units. The permanent in-house staff of maintenance department decreased from 200 to 160 during the reorganizing period.

The third case is a maintenance department of *another Nordic nuclear power plant (Plant B)*. It has two reactors and at the time of the assessment the plant employed around 140 maintenance technicians and experts. The plant has one of the highest average load factors in the world. The assessment was part of a benchmark with other Nor-

dic nuclear power plants and there was no clear organizational changes going on during the time of the study.

### 3.2. Methods and data

The CULTURE-questionnaire (Reiman & Oedewald, 2004; Reiman, submitted) consists of four measures; (1) perceived organizational values, (2) conceptions concerning one's own work, (3) conceptions of the organizational core task and (4) ideal values of the organization. The second measure includes five dimensions: Meaningfulness of the work, knowledge of expectations concerning one's own work, working climate, sense of personal responsibility, and sense of control. The sense of control scale is composed of questions such as "I always have enough time to do my job properly" and "I can cope with my tasks". All the measures utilize a six-point scale with "1" indicating disagreement and "6" agreement with the statement.

**Neurosurgery department** had 50 respondents (questionnaire was delivered to 110 personnel involved in the implementation of the new system). Their mean score on sense of control was 3.14 (SD=0.69). In addition to the questionnaire, 9 semi-structured interviews were carried out.

In the first measure at **Plant A** (n = 135), the mean score on sense of control was 4.28 (SD=0.74), and in the second measure (n=100), the mean score was 3.67 (SD=0.76). Response rate was 70 percent in both samples. In addition to the questionnaire, 23 semi-structured interviews were carried out during the time of the first measure. The results of the first measure were further discussed with the personnel in a seminar with 100 participants and the results of the second measure were discussed with the personnel in a seminar with over 50 participants.

At **Plant B** (n=84) the mean score of the sense of control at the whole sample was 3.71 (SD=0.80), but a statistically significant difference ( $F(3,53)=2.90$ ,  $p=.044$ ) was found between the tasks. Especially foremen (M=3.05, SD=0.71) and technicians (M=3.80, SD=0.75) had a large difference in the mean scores. In addition to the questionnaire, 20 semi-structured interviews were carried out. The results were further discussed with the personnel in three seminars.

### 3.3. Causes and consequences of low sense of control

The average level of sense of control at the **neurosurgery department** was relatively low. Especially the nurses reported that they do not have enough time to do their work properly. This is paradoxical in a sense that the new information system was supposed to ease the tasks of the nurses in the department (now they don't have to document the parameters all the time). The results indicated that staff resources were quite scarce at the first place and the implementation of the new system was an extra challenge. Learning a new system takes time, but no extra resources were available during the initial phase of the implementation. The system had also some usability deficiencies which delayed the daily actions. The information system affected also the division of respon-

sibilities. Most doctors were reluctant to use the system because they felt it made difficult to picture the overall state of the patient. Thus, especially in the operating rooms the nurses were responsible for documenting the operation (e.g. selecting the drugs from the database) in to the system at the same time they monitored the patient. Furthermore, the work was organized so that the anesthetists were responsible for many patients at the same time and they have to leave the operating room once in a while. This emphasizes the responsibility of the nurses to maintain the overall picture of the state of the patient. When the anesthetist is present, instead of reviewing the data in the computer, (s)he usually asks the nurse for information regarding the patient. The nurses must be able to sum up the main parameters quickly and judge whether everything is in control or not. This is a new task for nurses. An important finding is that picturing the overall state of the patient was experienced as requiring more effort because of the new system. Since the nurses didn't have to write the vital function parameters down anymore they had difficulties in piecing together and remembering relevant data. In the end, the information system both increased the tasks and responsibilities of the nurses and deteriorated the resources to take care of the new task.

At **Plant A** the results indicated that the change in the organizational structure lowered the sense of control among the personnel. This was due to several reasons: First, the plant had operated with the same organizational structure for twenty years and the way of working at the plant was based very much on an unofficial organization and personal contacts (see Reiman & Oedewald, 2006). The reorganization broke down the communication structure of the culture. Secondly, some tasks were outsourced and a few people were fired. The same amount of work had to be done with fewer men and with a different division of labour. Thirdly, the reorganization was experienced by the personnel as driven mainly by financial needs. The underlying philosophy of the personnel had always been "safety first" and thus the change attempts were interpreted as not being appropriate for a nuclear power plant. The management, on the other hand, interpreted the personnel's reluctance as simple change resistance.

The lack of control thus stemmed from an incongruence between the demands of the maintenance task as the personnel perceived them and the demands placed by the new organizational structure. Furthermore, due to the reorganization, the internal integration was not compensating the weaknesses of the official structure, worsening the situation. The lowered sense of control led to increased prioritisation of one's own tasks at the expense of possibly more urgent tasks coming from another area or tasks that belonged to the "grey area". On the other hand, the change and the sense of lack of control forced the organization to clarify the overall goals of the maintenance department and the organizational processes.

**Plant B** had intensively developed organizational procedures and information systems to facilitate the transparency and smooth functioning of the maintenance activities. They had few fault repairs and well functioning program of preventive maintenance. Plenty of small changes had been made to the plant organization during the years of its operation. The sense of control among the foremen was low compared to the other groups. On a closer analysis, it was noted that the foremen considered their work as changed from being on the field to paper work and computer analyses. This did not fit their conception

of motivating and good maintenance work. They also conducted work planning, a function previously allocated to separate work planners. Furthermore, their legal responsibilities toward their subordinates had not changed; they were still supposed to supervise and be responsible for the quality of their work. Their roles had drifted to a position where they considered themselves to be unable to act in the space of activities allowed by the three elements of culture (see Fig. 1). They considered themselves unable to fulfil the requirements of the maintenance task (to conduct proper work planning without being on the field), the structural requirements (to conduct the necessary computer analysis), and the requirements of the workplace norms (to show example to their subordinates by putting their own hands to the grease).

The experience of not having enough time embodies a lot more than the pressure to hurry in order to be more productive. It tells us that the organization has problems in coping with the complexity and maintaining the dynamic stability. Although e.g. maintenance of a power plant or intensive care in a neurosurgery department are tasks that contain variability and are difficult to plan in advance the personnel did not feel that the current practices and pace of work were optimal or inevitable. The sense of control scale correlated with worry about patient safety at the neurosurgery department (-0.43,  $p=.002$ ). Such findings legitimate and facilitate the questioning of the current organizational premises if taken as a real indicator of system capability and not “just opinions”.

#### **4 DISCUSSION**

It seems that safety management approaches have not utilized the fact that people are very sensitive to changes and are able to express their perceptions and feelings, even vague ones. Occupational psychology treats workplace stress mainly as a negative phenomenon which should be reduced by e.g. improving working climate or by individual rehabilitation. In safety critical domains little research has been done to understand in what way does stress indicate the actual difficulties in managing the work or maintaining safety.

Our case organizations have taken the results concerning the low sense of control seriously, probably because they feel that e.g. slips and lapses may increase if the workload increases and work motivation declines, or that increased sick leaves make the system more vulnerable. Though it is true that the feeling of not having enough time to do one's work properly is a stress factor and erodes work motivation in the long run, it (the feeling of the personnel) is also an important signal that the system has faced a situation where it needs more effort to maintain the dynamic stability. Furthermore, it signals that the human part of the system has difficulties in accomplishing that. Understanding the vulnerabilities requires more specific analysis based on a valid model on how different elements of the organization can affect worker's perceptions and the organizational resilience.

The case study results show that the low sense of control has different sources. In some cases there were contradictory views on what was considered important in the work and where the resources and effort should be directed. Some (new) demands of the work (e.g. documenting the work, conducting fault history analyses) were considered as un-



important extra work and as taking time from the “real work”. Also the reluctance to change working practices was a source of lack of time. The personnel did not want to give up of some tasks they had used to perform even though management warranted that eliminating some phases does not erode safety. The criteria for proper work thus differed. In the medical sector the resources are scarce due to economic pressures and haste has become taken for granted in the organizations. Furthermore, the organizations had difficulties in balancing acute and chronic tasks. They lacked a model on how to organize work efficiently in case of unanticipated situations. Usually the unexpected acute tasks were prioritized; lots of resources were put on them, and the more routine-like tasks were carried out with less time and effort.

A theory that would be able to anticipate and prevent accidents should be “sensitive to the creation of deficiencies, not just to their eventual presence” (Dekker, 2005, p. 34). If people are forced to work for a long period in circumstances where they feel a lack of control they start to adjust the frames of their activity. This is an important mechanism for organizational drift. Low sense of control can change the conception of what is considered as important in the work, the structural elements of the culture such as tools and practices, and the norms and internal integration of the culture. Therefore early detection of declined sense of control is important for long term performance.

Using subjective measures as indicator of resilience is practical because most organizations already measure workplace stress and wellbeing regularly. It is important that the surveys enable the comparison between different organizational groups. The problem with this kind of a measure is that it is subjective, i.e. people have different tolerance for disruption and change. The change in the sense of control does not indicate necessarily the intensity of the actual changes in the system. Sometimes it may be that some members of the organization have dislikes for e.g. new requirements or practices. Their answers to the questionnaires may be slanted to stress their opinions. It is also important to take into account that small and temporary decline in sense of control is normal when the requirements of work change. We cannot define a limit for “normal” sense of control. But we can state that if people in a safety critical organization express that they do not have enough time to carry out their tasks properly or that they are not otherwise in control over their work, attention should be paid to it.

## REFERENCES

- Dekker, S.W.A. (2005). *Ten questions about human error. A new view of human factors and system safety*. New Jersey: Lawrence Erlbaum.
- Rasmussen, J. (1997). Risk management in a dynamic society: A modelling problem. *Safety Science*, 27, 183-213.
- Reiman, T. (submitted). Assessing organizational culture in complex sociotechnical systems – Methodological evidence from studies in nuclear power plant maintenance organizations. VTT Publications.

Reiman, T. & Oedewald, P. (2004). Measuring maintenance culture and maintenance core task with CULTURE-questionnaire – a case study in the power industry. *Safety Science*, 42, 859-889.

Reiman, T. & Oedewald, P. (2006). Assessing the maintenance unit of a nuclear power plant – identifying the cultural conceptions concerning the maintenance work and the maintenance organization. *Safety Science*, 44, 821-850.

Reiman, T. & Oedewald, P. (In press). Assessment of Complex Sociotechnical Systems – Theoretical issues concerning the use of organizational culture and organizational core task concepts. *Safety Science*, doi:10.1016/j.ssci.2006.07.010.

Woods, D.D. & Cook, R.I. (2006). Incidents – markers of resilience or brittleness? In E. Hollnagel, D.D. Woods, N. Leveson (Eds.), *Resilience engineering. Concepts and precepts* (pp. 69-76). Aldershot: Ashgate.