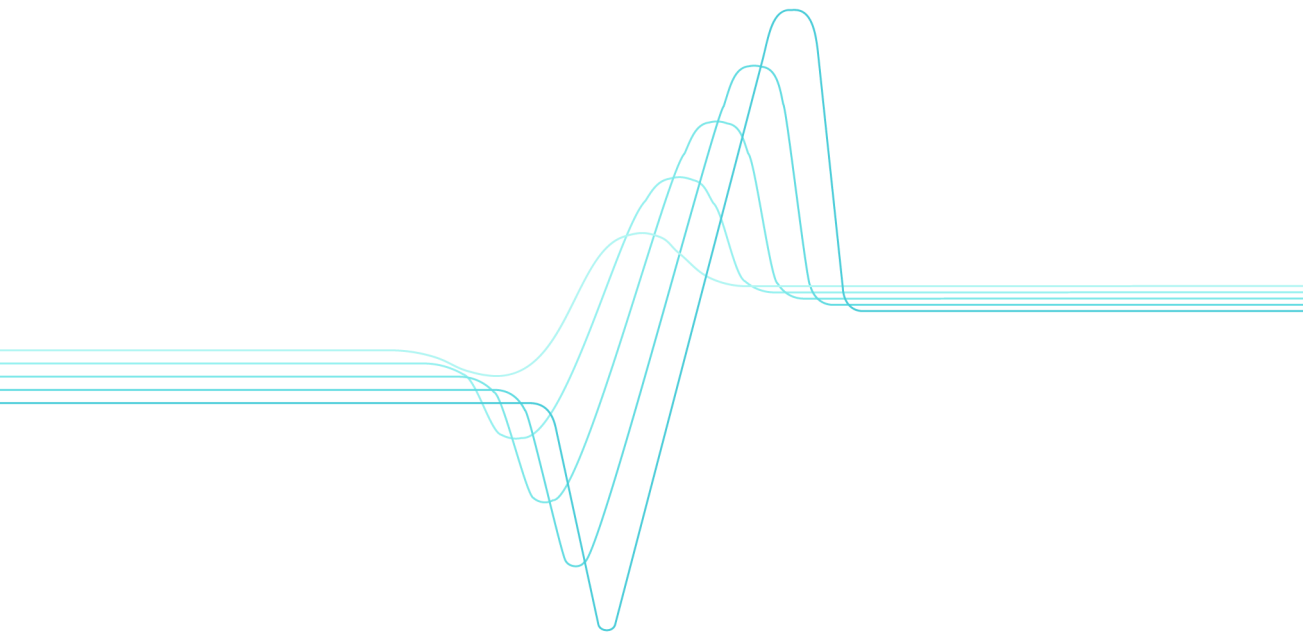


Maaria Nuutinen

# Expert Identity in Development of Core-Task-Oriented Working Practices for Mastering Demanding Situations





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# **Expert Identity in Development of Core-Task-Oriented Working Practices for Mastering Demanding Situations**

Maaria Nuutinen

VTT

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**Keywords** Core-Task-Analysis, conceptual models, Expert Identity model, operator's performance, resources, demanding situations, stress, controllability, metacognitive skills, expertise

## Abstract

The point of departure in this dissertation was the practical safety problem of unanticipated, unfamiliar events and unexpected changes in the environment, the demanding situations which the operators should take care of in the complex socio-technical systems. The aim of this thesis was to increase the understanding of demanding situations and of the resources for coping with these situations by presenting a new construct, a conceptual model called Expert Identity (ExId) as a way to open up new solutions to the problem of demanding situations and by testing the model in empirical studies on operator work. The premises of the Core-Task Analysis (CTA) framework were adopted as a starting point: core-task oriented working practices promote the system efficiency (incl. safety, productivity and well-being targets) and that should be supported. The negative effects of stress were summarised and the possible countermeasures related to the operators' personal resources such as experience, expertise, sense of control, conceptions of work and self etc. were considered. ExId was proposed as a way to bring emotional-energetic depth into the work analysis and to supplement CTA-based practical methods to discover development challenges and to contribute to the development of complex socio-technical systems. The potential of ExId to promote understanding of operator work was demonstrated in the context of the six empirical studies on operator work. Each of these studies had its own practical objectives within the corresponding quite broad focuses of the studies. The concluding research questions were: 1) Are the assumptions made in ExId on the basis of the different theories and previous studies supported by the empirical findings? 2) Does the ExId construct promote understanding of the operator work in empirical studies? 3) What are the strengths and weaknesses of the ExId construct? The layers and the assumptions of the development of expert

identity appeared to gain evidence. The new conceptual model worked as a part of an analysis of different kinds of data, as a part of different methods used for different purposes, in different work contexts. The results showed that the operators had problems in taking care of the core task resulting from the discrepancy between the demands and resources (either personal or external). The changes of work, the difficulties in reaching the real content of work in the organisation and the limits of the practical means of support had complicated the problem and limited the possibilities of the development actions within the case organisations. Personal resources seemed to be sensitive to the changes, adaptation is taking place, but not deeply or quickly enough. Furthermore, the results showed several characteristics of the studied contexts that complicated the operators' possibilities to grow into or with the demands and to develop practices, expertise and expert identity matching the core task. They were: discontinuation of the work demands, discrepancy between conceptions of work held in the other parts of organisation, visions and the reality faced by the operators, emphasis on the individual efforts and situational solutions. The potential of ExId to open up new paths to solving the problem of the demanding situations and its ability to enable studies on practices in the field was considered in the discussion. The results were interpreted as promising enough to encourage the conduction of further studies on ExId. This dissertation proposes especially *contribution to supporting the workers in recognising the changing demands and their possibilities for growing with them* when aiming to support human performance in complex socio-technical systems, both in designing the systems and solving the existing problems.

Nuutinen, Maaria. Expert Identity in Development of Core-Task-Oriented Working Practices for Mastering Demanding Situations [Asiantuntijaidentiteetti perustehtäväsuuntautuneiden työtapojen kehittämisessä vaativien tilanteiden hallintaan]. Espoo 2006. VTT Publications 604. 113 s. + liitt. 141 s.

**Avainsanat** Core-Task-Analysis, conceptual models, Expert Identity model, operator's performance, resources, demanding situations, stress, controllability, metacognitive skills, expertise

## Tiivistelmä

Tutkimuksen lähtökohtana olivat ennakoimattomat, odottamattomat, operaattoreille vieraat tilanteet, jotka aiheuttavat turvallisuusongelman monimutkaisissa sosioteknisissä järjestelmissä. Näitä tilanteita kutsuttiin vaativiksi tilanteiksi. Väitöskirjan tavoitteena oli lisätä ymmärrystä vaativien tilanteiden hallinnasta ja niissä tarvittavista resursseista esittelemällä uusi käsitteellinen malli, ”Expert Identity” (ExId), asiantuntijaidentiteetti, joka pyrkii löytämään uusia lähtökohtia vaativien tilanteiden ongelman ratkaisemiseen, ja testaamalla tätä mallia empiirisissä tutkimuksissa. Lähtökohdaksi otettiin epävarmojen, monimutkaisten ja dynaamisten tilanteiden ja ympäristöjen tutkimiseen kehitetty perustehtävä-analyysi (Core-Task Analysis, CTA) -lähestymistapa. Sen mukaisesti koko järjestelmän tehokkuutta (ml. turvallisuus-, tuottavuus- ja hyvinvointitavoitteet) edistävät sellaiset työkäytännöt, jotka täyttävät perustehtävävaatimukset. Väitöskirjassa tarkasteltiin operaattorin työn vaatimuksia ja stressin vaikutuksia ihmisen suoriutumiseen sekä erilaisten ”henkilökohtaisten” resurssien (esim. kokemuksen, asiantuntemuksen, kontrollin tunteen ja käsitysten) mahdollisuuksia vastata vaatimuksiin. ExId esitettiin mahdollisuutena syventää työn analyysiä ja täydentää CTA:han pohjautuvia käytännön menetelmiä, joilla pyritään tunnistamaan kehityshaasteita ja edistämään sosioteknisten järjestelmien tehokkuutta. ExId:n toimivuutta arvioitiin kuudessa empiirisessä, operaattorityöhön kohdistuneessa tutkimuksessa. Tutkimuskysymykset olivat: 1) Saako ExId tukea empiirisen tutkimuksen tuloksista? 2) Edistääkö ExId-malli operaattoreiden työn ymmärtämistä empiirisessä tutkimuksessa? 3) Mitkä ovat ExId-mallin vahvuudet ja heikkoudet? Asiantuntijaidentiteetin kerrokset ja kehittämisestä tehdyt oletukset näyttivät saavan tukea. Uusi käsite toimi osana erilaisten aineistojen analyysiä, eri menetelmiä ja eri työkonteksteissa.

Empiiristen tutkimusten tulokset kertoivat ongelmista huolehtia perustehtävästä, jotka olivat seurausta työn vaatimusten ja niistä huolehtimiseen käytössä olevien resurssien yhteensopimattomuudesta. Tutkituissa tapauksissa työn muutokset, vaikeus tavoittaa operaattorin työn oleellista sisältöä sekä erilaisten käytännöllisten vaikutuskeinojen rajoitukset olivat hankaloittaneet ongelmia ja vaikeuttaneet organisaation omia kehittämistoimenpiteitä. Henkilökohtaiset resurssit vaikuttivat olevan herkkiä työn muutoksille ja adaptoituvan muutoksiin, mutta tämä muutos ei ollut joko tarpeeksi nopea tai syvä. Tutkitut tapaukset toivat esiin myös useita työympäristöjen piirteitä, jotka voivat vaikeuttaa operaattoreiden mahdollisuuksia kehittyä muutosten mukana ja kehittää henkilökohtaisia resurssiaan, työtapoja, ammattitaitoa ja asiantuntija-identiteettiään perustehtävävaatimuksia vastaaviksi. Näitä olivat: epäjatkuvuus työvaatimuksissa, erilaiset käsitykset operaattorin työstä organisaation eri osissa, ristiriitaisuudet kehitysvisioiden ja operaattoreiden kohtaaman todellisuuden välillä sekä yksilöllisen ponnistelun ja tilannekohtaisten ratkaisujen korostaminen. Discussion-osassa tarkastellaan ExId:n mahdollisuuksia tukea uusien ratkaisujen kehittämistä vaativien tilanteiden ongelmaa ja kykyä tukea käytäntöjen tutkimusta kentällä. Tulosten tulkittiin olevan ExId:n kannalta rohkaisevia ja kannustavan jatkotutkimuksiin. Ihmisen toiminnan tukemiseksi monimutkaisissa sosioteknisissä järjestelmissä tulisi *kiinnittää erityistä huomiota siihen, että autetaan työntekijöitä tunnistamaan perustehtävän muutokset ja parannetaan heidän mahdollisuuksiaan kasvaa näiden muutosten mukana.*



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*Appendices of this publication are not included in the PDF version.  
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## List of original publications

This paper is based on the following four publications and together with them constitutes the academic dissertation of the author:

*Article I* Norros, L., Nuutinen, M. (2005). *Performance-based usability evaluation of a safety information and alarm system. International Journal of Human-Computer Studies*, 63(3), 328–361.

*Article II* Nuutinen, M. (2005). *Expert Identity construct in analysing prerequisites for expertise development: a case study of nuclear power plant operators' on-the-job training. Cognition, Technology & Work*, 7(4), 288–305.

*Article III* Nuutinen, M. (2005). *Contextual assessment of working practices in changing work. International Journal of Industrial Ergonomics*, 35(10), 905–930.

*Article IV* Nuutinen, M., Norros, L. *Core Task Analysis in accident investigation – analysis of maritime accidents in piloting situations. Cognition, Technology & Work. In press.*

In the text the publications are referred to by the Roman numerals (I–IV).

# 1. Introduction

## 1.1 Research area and general aims of this dissertation

In many positions of politics, trade and industry, the decisions made and the actions taken or not taken by a single person or a small group can have an enormous impact on the life of many others. In most times the moments that change the course of events and the ways in which they contribute to the resulting glory or grief, are quite difficult to pinpoint. The important role of human performance has become very palpable in the form of accidents (see e.g. Dekker and Hollnagel, 1999; Dekker and Woods, 1999; Hollnagel, 2004 pp. 17–19; Perrow, 1984; Reason, 1990 pp. 251–257; Turner and Pidgeon, 1997; Vicente, 2004 pp. 9–13) and human performance has gained lots of attention in the safety critical domains, such as aviation and nuclear power production. These can be considered as complex socio-technical systems characterised by: large problem space, social, heterogeneous perspectives and values, geographical and cultural distribution, dynamic and delayed control, potential hazard, coupling with other systems, automation, uncertainty and defectiveness of data, mediated interactions, disturbances and unexpected events (Vicente, 1999 pp. 14–17). The term socio-technical system refers to a set of interrelated technical, psychological and social elements that share a common goal or purpose (see Vicente, 1999 p. 9).

There is no clear definition of this area of research. The terms human factors and cognitive ergonomics are used commonly when referring to the research area in psychology, which is characterised e.g. by a systemic notion of human-environment (or technology) interaction and aimed to improve the performance of the whole system (Norros and Leppänen, 2000; Leppänen and Norros, 2002). In Finland, there are only a few research groups working in this area (Norros and Leppänen, 2000). The differentiation of cognitive ergonomics and human factors from the broad branch of ergonomics is questioned by Wilson (2000 and Wilson et al., 2003). The mission of the ergonomists, “the theoretical and fundamental understanding of human behaviour and performance in purposeful interacting sociotechnical systems, and the application of that understanding to design of interactions in the context of real settings” expressed by Wilson (2000 p. 560) could also describe human factors or cognitive ergonomics. *The dissertation can be placed in the overlapping disciplines of work psychology, human factors and*

*ergonomics. The point of departure is the practical safety problem, thus the adopted orientation is pragmatic. The dissertation is following the “KOTAK”<sup>1</sup> principle (honouring the theoretical value of practical problems) emphasised in our research group.*

On the basis of 30 years of safety research and accident and incident analyses Vicente (1999 pp. 21–22) concluded as the state of the art that events that are *unfamiliar to the workers* and that have *not been anticipated by the designers* pose the greatest threat to system safety in complex socio-technical systems. Based on the literature, Cañas et al. (2003) summarised that most researchers in cognitive ergonomics and in cognitive flexibility research in the area of cognitive psychology seem to believe that *an unexpected change in the environment* is a crucial factor when observing the drop in performance even after extensive practice in a task. They emphasise the relation between the characteristics of the environment in which a person acts and the particular strategy that a person has developed during learning. I shall call these kinds of unanticipated, unfamiliar events and unexpected changes “*demanding situations*” in the following. For example, rare disturbances in automation systems and particularly emergencies can be demanding situations.

There are different ways of promoting human performance e.g. by choosing an adequate automation strategy, human-centred design (HCD) of technology and training. The challenges of controlling disturbances, emergency situations or complex, uncertain and time-restricted or dynamic situations from the point of view of workers have been and are the focus of lively research (see e.g. Janis and Mann, 1977; books of Naturalistic Decision Making, edited by Klein et al., 1993; Zsombok and Klein, 1997; Montgomery et al., 2005b; acting under uncertainty Norros, 2004; judgement e.g. Brecke, 1982; Jensen, 1995; training e.g. Helmreich and Foushee, 1993; Kontogiannis, 1999; Swezey and Andrews, 2001; designing e.g. Vicente, 1999). The workers whose behaviour is the object of interest can be described with the term operators.<sup>2</sup> “Typical” operators are those controlling or supervising large technical industrial processes in control rooms but also pilots and anaesthetists are considered as operators, “the sharp

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<sup>1</sup> Acronym is from Finnish words ”käytännön ongelmien teoreettisen arvon kunnioittaminen”.

<sup>2</sup> They are called operators in this study although the term might be confusing for those more familiar with telecommunication operations (cf. Vicente, 1999).

end” (Woods, 1994a). Also maintenance work is often included under the label of “operator work” (e.g. Jakobsson Kecklund, 1998; Samurcay and Vidal-Gomel, 2002). As noted by e.g. Karlene Roberts everybody’s blunt end is somebody else’s sharp end (Hollnagel, 2002). The definition of an operator can be broadened to include any actor involved in the complex activity of managing a dynamic, complex and uncertain environment or process (DCU, see Norros, 2004 pp. 30–38) at any level in the chain of command (Article III, see Rogalski et al., 2002).

The noted need of adaptation of operator performance both situationally (e.g. Norros, 2004) and over time (e.g. Gauthereau, 2003; 2004; Hollnagel, 2002) in reaching safety has challenged the idea of standardisation (e.g. in terms of proceduralisation; see e.g. Vicente, 1999 p. 22; Dekker, 2003; Norros and Nuutinen, 2002; Norros, 2004 pp. 217–218) as a main means to ensure a high level of operator performance (Article III; Article IV). At the present cognitive engineering and the HCD or designing for adaptation (Vicente, 1999) is perhaps the most rapidly growing research area on which high hopes are expressed in the area of socio-technical systems and safety research. Although every means we have to influence the system (including e.g. training) can be included in the design of socio-technical systems, the primary focus of this area is to support the design of automation, information and communication technology for supporting humans at any level of the system (Vicente, 1999 pp. 338–342). *In this dissertation the emphasis is put on the human side* when searching for new ways, also other than technology, *to support operators in coping with demanding situations* in a given complex socio-technical system. The triple aim of the truly efficient complex socio-technical system as safe, productive and health promoting according to Vicente (1999) is adopted as the frame in which the operator performance should always contribute. Henceforward the efficiency aim is used in this triple meaning.

Although technologically advanced systems greatly extend the range of human capabilities, the other side of the coin is that these systems also increase the demands on the operator (Driskell and Johnston, 1998/2000). The level of socio-technical system performance exceeds human capabilities, but in a technology failure the human operator’s task is to attempt to fill the gap. As noted by Kontogiannis (1999) although the requirement for effective performance under stress has been present for a long time, modern high-technology systems have



increased the stress under which humans perform and aggravated the consequences of poor performance (see also Driskell and Johnston, 1998/2000). The phenomenon under scrutiny is “a drop” in the efficiency (either in safety, productivity or the workers’ well-being) of a socio-technical system related to technology failure that brings along a possible increase in the demands exceeding the human capabilities or the difficulty of maintaining a reasonable expected (e.g. on the basis of one’s experience) level of performance in demanding situations. An important effort to understand this phenomenon is made in the Naturalistic Decision Making (NDM) approach by studying how experienced people actually make decisions in their natural environments or in simulations that preserve key aspects of their environments (Orasanu and Conolly, 1993; Zsombok, 1997; Montgomery et al., 2005a). The characteristics of the naturalistic decision making settings are: ill-structured problems; uncertain, dynamic environment; ill-defined, competing goals; action/feedback loops; multiple players; time stress; high stakes and organisational goals and norms. Several challenges still exist in understanding professional decision making in these environments: the interplay of the key factors, such as situation characteristics, motivation, skill and knowledge and their use in decision making; how the decision maker acquires and develops expertise (Montgomery et al., 2005a; Article II; Article III), definition of specific criteria or models for guiding and evaluating decision making performance (Lipshitz and Cohen, 2005; Articles I, III and IV) and training for decision making under stress (Cannon-Bowers and Salas, 1998/2000a; Article II). “The content” of expertise needed in demanding situations and the ways to reach it are interrelated matters of concern.

The failures of the earlier practical solutions to solve the safety problem of demanding situations have led safety research to its emerging present emphasis (see also Article III). The relevance of studying the real operators (see the comparing experimental study made by Rogalski, 1999) working in their real (or close) work context is emphasised in different lines of study (e.g. Orasanu and Conolly, 1993; Beach and Lipshitz, 1993; Zsombok, 1997; Norros and Leppänen, 2000; Montgomery et al., 2005a; Hutchins, 1995; Gauthereau, 2003; 2004; Vicente, 1999; Norros, 2004; Jakobsson Kecklund, 1998). The problems of information processing metaphor e.g. in describing the adaptive processes of human practice in complex environments (Bannon and Kaptelinin, 2000; Carrol, 1997; Hollan et al., 2000; Norros, 2004 p. 28; Suchman, 1987; Article I), and

laboratory and experimental research e.g. in explaining variability of the performance outcome under stress (Morpheus, 2001), have become increasingly evident. “A practice view”, which proposes to understand safety as a social practice (Gauthereau, 2004) or as an analysis of actions and inquiring “how people ‘master’ the meanings relevant in reaching the outcomes of their work” (Norros, 2004 p. 70; Article III), is also emerging. The tenets of the practice view of safety concluded by Gauthereau (2004) are: firstly, safety can only be understood at the practices of the sharp end and that practice is not constant with time, and secondly, to understand safety is to understand how practice imperceptibly changes over time. A further emerging emphasis is to broaden the object of interest, up to systems in society (e.g. Rasmussen, 1997; Leveson, 2004).

Studies on operators in a real context have broadened the view of the human operator and cognition (including e.g. contextual, motivational, emotional and social issues and artefacts). Cognition has also been defined as a characteristic of system performance, namely the ability to maintain control, not unique to humans and the definition has been argued by pragmatic design purposes (Hollnagel, 2003b). Hoffman and Woods (2000; see also Woods, 1994b) describe in their preface to the special section of “Studying cognitive systems in context” in *Human Factors* that “in past the word *cognition* often was taken to refer to an emotionless, private activity, whereas an observer in the field setting would note that practitioners’ cognitive work is public and tightly connected to intensively held goals” (p. 2, original italic). Although the use of the term cognitive is now aimed to be inclusive, the different sides of cognition still seem to be difficult to grasp. *The main overall claim of this thesis is that we need new concepts especially concentrating on the different sides of human performance and cognition in the operator practice. They should not, however, lose their connection to the context of practice and the other sides of cognition. In this way they can enable studies on practices in the field and contribute sufficiently to the practical development.*

*This thesis aims to contribute to the discussion by suggesting that shifting the focus of the analysis to the emotional-energetic side of human performance and cognition can promote new insights into the practical problem of coping with demanding situations. A new construct, a conceptual model called Expert Identity (ExId) is introduced as a way to bring emotional-energetic depth into the work analysis (Article II). ExId tries to open up new paths to explore and*

*support operator performance as supplementing the Core-Task Analysis framework (Norros, 2004). The applicability of ExId is demonstrated in the context of the six empirical studies on operator work. Another suggestion emerged during the development of the construct and its use in empirical analyses; increasing the emphasis on how the operators conceive themselves, the demands of their work and their own resources for coping and learning in the analyses of the content of the expertise and its development.*

*The aim of this thesis is thus to increase the understanding of demanding situations and the resources for coping with these situations by presenting ExId and testing it in empirical studies on operator work. The practical and methodical considerations of ways to support the operators' work and lines for further studies are also discussed. In the following the background and the purpose of ExId are summarised before introducing the construct and posing conclusive research questions for empirical studies.*

## **1.2 Background and purpose of the Expert Identity construct**

### **1.2.1 Core-Task Analysis framework**

Core-Task Analysis (CTA) is a framework developed by the VTT Technical Research Centre of Finland for the analysis of work and organisations. The Core-Task Analysis framework has been developed for analysing the work demands and the construction of the work activity and competence in process control work (Norros, 2004; Norros and Nuutinen, 2002). It rests on more than 20 years of interest in understanding human action and sense-making in dynamic, complex and uncertain (DCU) work environments (Norros, 2004). It has emerged in a sense as a counter-reaction to the information processing and human error approaches previously dominating in safety research. It is an attempt to solve the problem of how human performance can be studied and evaluated from a systemic perspective, contextually, even when the outcome of the performance is too insensitive or complex to separate “good” and “bad”. The framework draws from several theoretical approaches. It exploits ideas of the cultural-historical theory of activity (Engeström, 1987; 1999a; Leont’ev, 1978; Vygotsky, 1978) and the functionally oriented cognitive task analysis tradition

(e.g. Rasmussen, 1986; Vicente, 1999. For more detail, see Norros, 2004). The framework has also adopted methodological principles from the ethnomethodologically oriented approaches for practice (e.g. Suchman, 1987; Hutchins, 1995).

The core task concept and analytical approach have been developed in earlier studies (e.g. Hukki and Norros, 1993; Hukki and Norros, 1998; Klemola and Norros, 1997; Norros and Klemola, 2005; Norros and Nuutinen, 2002; Reiman and Norros, 2002; Oedewald and Reiman, 2003; Reiman and Oedewald, 2004; Articles I–IV). The concept of *core task* means “the shared objectives and the outcome-critical content of work that should be taken into account by the actors in their task performances for maintaining an appropriate interaction with the environment.” (Norros, 2004 p. 17.)<sup>3</sup> The core task model aims to comprise both the demands that should be met and the realised possibilities for meeting them in order to achieve the efficiency aim of the entire socio-technical system in the current societal and economic environment (Norros and Nuutinen, 2002, Article III) and to create potential for development (Article I; Article III; Norros, 2004).

Two different, although interconnected, lines of development and related focus areas of the empirical and theoretical core task studies can be recognised. The first one is the studies on the situational construction of a person’s or small group’s actions and explaining them at the level of the operator work in process control work, e.g. nuclear power plant operators and anaesthetists (Hukki and Norros, 1998; Klemola and Norros, 1997; Norros and Klemola, 2005). The main concepts utilised (in addition to the core task) are orientation, way of acting and course of action (Figure 1, on top). Careful framing of the situation in the empirical study is also emphasised (e.g. Hukki and Norros, 1998). In the analysis of situated actions the pragmatic conception of habit is borrowed from American pragmatism, (see Norros, 2004). Also, the aim to contribute to HCD and “system usability” (Norros and Savioja, 2004a; 2004b) of complex tools are currently emphasised.

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<sup>3</sup> The Finnish translation of the core task term is the same as a commonly used concept in organisational research and consultancy, the meaning of which is slightly different regarding the tradition. The Finnish term can refer e.g. to the primary task that has been important in the Tavistock tradition of action research and consultancy as a heuristic device (Dartington, 1998). The primary task of a system was first defined as “the task which it is created to perform” (Rice, 1958) and then as “the task it must perform if it is to survive” (Rice, 1965; see also Dartington, 1998).

The second focus is on organisational culture, level of organisation and especially maintenance work (Oedewald and Reiman, 2003; Reiman and Oedewald, 2004; Reiman et al., 2005). The Contextual Assessment of Organisational Culture (CAOC) methodology developed for that purpose utilises different methods, e.g. the CULTURE questionnaire (Reiman and Oedewald, 2004). The main concepts utilised are the organisational core task and organisational culture (Figure 1, on bottom).

The core task model of a specific work or activity offers a framework for assessing the operators' working practices and available resources (Norros and Nuutinen, 2002; Norros, 2004 pp. 187–191; Articles I, III, IV) or the organisational culture (Oedewald and Reiman, 2003; Reiman and Oedewald, 2002a; 2002b; Reiman and Norros, 2002; Reiman and Oedewald, 2004), which is considered essential when aiming at practical development. The importance to create and explicitly present the frame of the evaluation is emphasised (see also Article III). The emphasis of the line of development described in this thesis is on the level of the operators (individuals or small groups), but studies focus on a broader context of conceptions of the core-task held by the operators and their working practices. Working practices are defined as a person's or a group's learned way of coping with the different demands of the core task by operating and conceptualising the object of work (cf. orientation, Norros, 2004), co-operating with others and constructing a conception of oneself as an operator, that is, expert identity (c.f. the definition of organisational culture by Reiman and Oedewald, 2002b; Oedewald and Reiman, 2003; Article III). Thus, the efficiency of the whole system is promoted by core-task -oriented working practices.

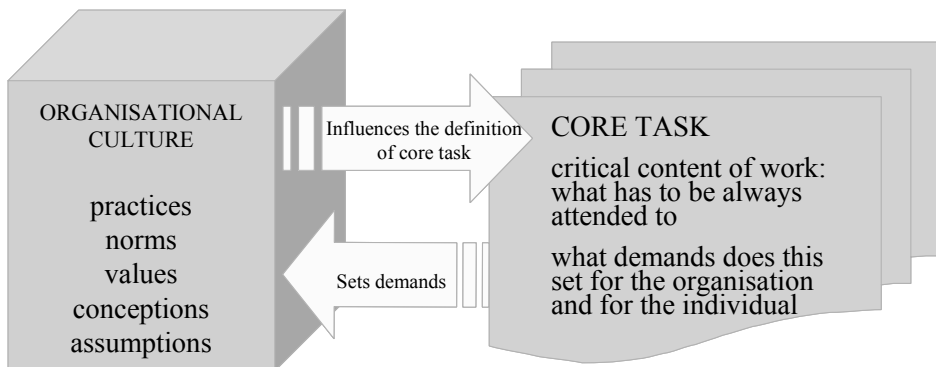
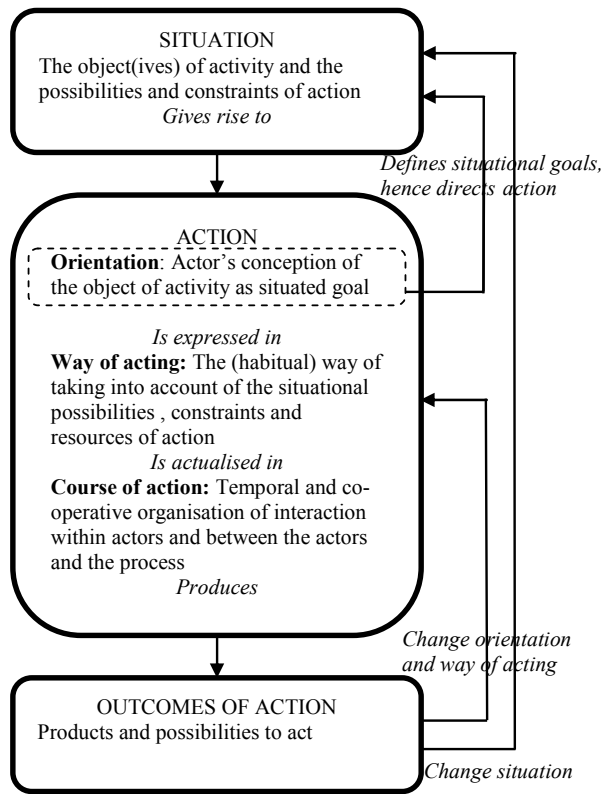


Figure 1. The two different focuses of the core task studies and the main concepts utilised (on top: adopted from Holmberg et al., 1999; see also Norros, 2004 p. 127; and on bottom Reiman and Oedewald, 2002a; 2002b; Reiman et al., 2005).

One of the basic principles adopted in CTA is to attempt to overcome the Cartesian dualism, human being and the environment, mind and body, cognition and emotion (Norros and Nuutinen, 2002; Norros, 2004 pp. 28–30). This has been achieved by adopting the cultural-historical theory of activity according to which the object and outcomes of the activity constitute the societal motivation and meaning of work. The object of activity both motivates and orientates the actions in the situation. (See Norros, 2004 pp. 68–70.) However, in practice the focus of the empirical operator studies has been on “the knowledge aspect” of cognition. The need for a new concept defining the emotional-energetic core task demands of work was evident when we made the usability study (A) of a Safety Information and Alarm Panel (SIAP), which aims at supporting the operators’ disturbance control in a nuclear power plant control room (Article I). Study A was carried out in a full-scale training simulator. A method (Hukki and Norros, 1998) based on the Core-Task Analysis framework was applied to the assessment of the operator performance. The method allows assessment of three interactions. The first two, the operator’s interaction with the process (operation and information seeking) and interaction between the operators (co-operation), were covered well. However, it was quite clear that there is a need to develop an additional approach to improve the method, for example, to better reach stress-related issues in the situational action (Article I). The need of improvement was particularly apparent concerning the power of the third interaction, i.e. the interaction with oneself. Furthermore, the need to cover the productivity and well-being objectives in addition to the safety-critical objectives was also recognised. Subsequent studies conducted in a conventional power plant and in sea piloting (Studies B and C, reported in Articles III and IV) resulted in the important notion that the core task can change quite dramatically. *This resulted in broadening of the focus from coping with demanding situations to developing the personal resources needed in these in the context of the changing core task.*

In the following, the terms *personal* and *external resources* are used for the practical purpose of focusing, although the division is artificial.<sup>4</sup> External resources refer primarily to the available technical and other tools (incl. e.g. procedures) but also to other humans as co-operative resources in the

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<sup>4</sup> This should not be interpreted as incongruous with e.g. the ideas of situated actions (Suchman, 1987) or distributed cognition (Hollan et al., 2000; Hutchins, 1995).

organisation, which both also influence on how the core task demands actualise. The term *personal resources* is used here as a general term referring to that which makes an operator capable of utilising external resources and coping with the demands (the content of which is, of course, very much dependent on the demands and the tools and the social context).

The expert identity concept was developed with the aim to supplement the Core-Task Analysis framework, particularly the methods based on CTA. The introduction of further background of the new construct is organised as follows: firstly a recent attempt to conclude stress and work load studies is summarised and the approaches behind them compared in order to formulate general premises for ExId. Then, we continue by examining how the relevant issues recognised in the former have been approached or touched in the operator studies (primarily in safety critical domains), recognising possible problems and searching for results or theories from other research areas to guide the development further. Two main criteria for selecting these guidelines were used within the general frame set up by the main claim of this thesis (1.1). The first criterion was the potentiality of the guidelines to open up new paths to the problem of the demanding situations. The second criterion was sufficient correspondence of the guidelines with the Core-Task Analysis framework e.g. in a sense that they could supplement the used methods and empirical studies, which aim at supporting the operators in their work to fulfil the core task.

### **1.2.2 Stress and energy in the operator's performance**

“Energetics” is used as a generic term encompassing all mechanisms that energise and regulate the organism and directly or indirectly influence psychological processing (Gaillard, 2001). Computational models of cognitive processing are not able to account for variations in the human performance, in particular when human beings must perform under demanding or threatening conditions. This is the reason why human factors or performance research has been extended with concepts such as “state”, “resources” or “energetical mechanisms” (Gaillard, 2001). For example, Kahneman (1973), Kontogiannis (1996) and Hockey (1997) have presented cognitive models to consider arousal or the energetic mechanism. A central problem from the point of view of



applying these in the supplementing of the Core-Task Analysis is the strong impact of the information processing approaches on the models.

As noted by e.g. Gaillard (2001) and Morpew (2001), the operators are required to perform at their cognitive, physical, emotional, psychosocial and psychological limits and even a small deviation from the optimal energy “state” may result in a performance decrease in complex and novel task situations. For example, the effects of circadian rhythm and fatigue on performance have gained lot of interest, but mainly in laboratory studies (see summary of Rosa, 2001). A central problem of stress as well as workload and fatigue research is that the definitions are quite vague and even contradictory (as noted by e.g. Driskell et al., 2001; Engel, 1985; Gaillard, 1993; 2001; Monat and Lazarus, 1985). Gaillard (2001) presents one recent framework attempting to conclude the results of workload and stress studies and to enhance the construction of a coherent theory. This conclusion is used in summarising the state of the art and exploring the relevance of these studies for operator performance in demanding situations.

#### 1.2.2.1 Gaillard’s (2001) framework

Gaillard’s (2001) framework aims to explain why some types of activation improve performance while others reduce well-being and endanger health. The basis of the framework is the distinction between the state of mind and body and the process. According to Gaillard (2001) mental load and stress are states that are distinguished by the characters (Table 1) and the theories on which they are based. (The difference between theories is considered more closely in the next sub-section.) Both states are induced by a perceived discrepancy between the demands required and the resources available, but differ in the way the individual responds to the situation.

Gaillard’s framework includes three types of energy mobilisation (in addition to such as circadian rhythm, noise, sleep loss, drugs etc.): task-induced activation, mental effort and emotions. According to the framework, under normal conditions the energy mobilisation is generated (automatically) by thinking about, planning and executing a task (task-induced activation). In vigilance situations, neither the task nor the work environment are very stimulating or inherently motivating. Task-induced activation may not be sufficient for task

performance, especially if combined with fatigue. Extra energy may be mobilised through mental effort. However, Gaillard sees that this requires the employee to be well motivated by incentives outside the task, such as salary, social control etc. Under high levels of mental load, when the task is attention demanding, extra energy is mobilised through mental effort, which is a normal and healthy aspect of an active coping strategy to meet work demands that are experienced as a challenge. This type of mobilisation is largely under control of the operator and increases well-being. Under stress, again, the energy mobilisation is dominated by negative emotions over which we have little control and this can result in maladaptive activation patterns (e.g. overreactivity) associated with performance decrease. The situation is experienced as threatening and results in psychosomatic complaints. (Gaillard, 2001.)

*Table 1. Comparison of mental load and stress states (based on Gaillard, 2001).*

<b>State</b>	<b>Mental load</b>	<b>Stress</b>
Energy mobilisation under	Attuned with task demand, aimed at improving performance efficiency by focusing attention, normal and healthy reaction	Enhanced activation is not instrumental to the execution of the task, may be dysfunctional, distracting etc
State regulation	Energy mobilisation limited to the task period	Activation persists outside the task situation
Mood	Experienced as challenge and feelings of accomplishment	As threatening and results in strain and negative emotions
Coping strategy	Oriented toward the execution of the task, actions taken aimed at solving the problems	Self-protection, defensive style, palliative reactions aimed at reducing the negative effects

In Gaillard's (2001) framework a high workload is regarded as important with regard to reduced well-being and increased health risk but not as critical as working conditions that provide few possibilities for control and little social support. Gaillard distinguishes between intensity of activation (low-high), and nature of affectivity (positive – negative). He proposes also dimensions such as the level of control, after-effects, coping strategy and pattern of reactions in order to define finer-grained states.

Discrimination of the responses to these two states and the different types of energy mobilisations do not, as such, give us direct means to promote performance in demanding situations. There is a real threat to the operator's and/or others' well-being originating from the safety-criticality, particularly if the case is a disturbance or an emergency. Gaillard's work can be used to highlight the problems of these situations. Firstly, the actual and the experienced demands of such a situation are probably so high that they require all the operator's resources or even exceed them. Secondly, if the monitoring of automation characterises the operator task, task-induced activation might be even too low for that task. There is empirical evidence that also uneventful situations should be taken into account when considering human performance in system efficiency. Jakobsson Kecklund's (1998) study addressed the work situation (comparing the normal, steady-state and the annual outage condition) and performance of nuclear power plant control room and maintenance operators (based on self-reports) in real work settings. The results indicate problems (more errors, less satisfaction with work performance quality or more frequent use of coping strategies) related to both busy outage situations and stable work situations with increased sleepiness. In safety-critical domains, the potential safety consequences and the related feeling of responsibility could be an extra motivator inside the task as well as a source for promoting social control, but this might not be enough if the characteristics of work are disadvantageous from the point of energy mobilisation. A study made by Reiman, et al. (2005), aimed at characterising and assessing the organisational culture of two Nordic nuclear power plant maintenance units, gives indirect and partial support to this hypothesis. Strong personal emphasis placed on safety and experience of high meaningfulness of the work characterised both maintenance cultures. However, a dimension that did not become directly evident from the data was the sense of personal responsibility (cf. Reiman and Oedewald, 2004). The researchers recognised (with the help of Hackman and Oldham's theory 1980) some characteristics of nuclear power plants that complicate the achievement of a sense of personal responsibility, a feeling of being personally accountable for the results of one's actions. They are strict rules, procedures, and a tendency to emphasise shared responsibility and collective action instead of individual action (Reiman et al., 2005). Thirdly, another problem is that the ability of task- or mental effort-induced activation to prepare us could always be limited when the emergence of a change or event is unexpected and sudden. Many means to cope with this are already developed and in use (and further problems also

recognised) e.g. alarms of automation systems (Stanton and Baber, 1995) without directly suggesting them as a solution to the energy mobilisation problem.

The suitably challenging balance between demands and resources can be an opportunity to a very positive experience of flow. The flow-concept is introduced by Mihaly Csikszentmihalyi (1990; see also 1996). The flow state is an optimal state of intrinsic motivation where the person is fully immersed in what he or she is doing. The components of an experience of flow are: clear goals; concentrating and focusing, a high degree of concentration on a limited field of attention; loss of the feeling of self-consciousness, the merging of action and awareness; distorted sense of time; direct and immediate feedback; balance between ability level and challenge; sense of personal control over the situation or activity and intrinsically rewarding activity, so there is an effortlessness of action. Not all of these components are needed for flow to be experienced. According to an experience sampling study (Csikszentmihalyi and LeFevre, 1989) the flowlike situations occurred more than three times as often in work as in leisure. In general, challenging as opposed to routine activities contributed to flow. According to Csikszentmihalyi (1990) people are most happy when they are in a state of flow. The possibility for the flow experiences at work could have an important positive effect on the operators' well-being. However, some of the components (e.g. distorted sense of time) can be potentially dangerous in safety-critical contexts and others (e.g. direct and immediate feedback) are quite rare in the typical operator work.

In conclusion, because of the above problems and risky nature of the work, the danger that the extra energy needed in demanding situations is mobilised by negative emotions over which the operator has little control is unavoidable. However, this does not mean that we have no ways left to support the operators. Central ways are to contribute to match between "objective" demands and resources, e.g. the design of the technical systems and the work and training. We can also try to reduce the perceived discrepancy between the demands and the resources in order to prevent experience of threat (or negative appraisal) and to support challenge appraisal. (When considering the long run effects on health, over-resources, e.g. competence, are not desired [Gaillard, 2001; cf. Csikszentmihalyi, 1990].) There are many ways for increasing the possibility of good performance. Gaillard (2001) lists several relevant ways. One is to reduce

the uncertainties that, in combination with fatigue or threat, create competition from other goals than execution of the task. Among those factors are uncertainty of the goals of the task, our success in meeting the criteria, or the rewards to be gained. Gaillard (2001) further mentions emotions as playing an important role in motivating people to initiate and maintain a task, but also as interfering in the cognitive processing. In addition, the worker strategies (see also Cañas et al., 2003) and the feedback received are factors mentioned for modulating the current energetic state in Gaillard's (2001) work.

*The motive for developing a new construct was to find new ways to help counteract stress. On the basis of the ideas summarised here we can direct our efforts to exploring how to develop solutions to the problem of demanding situations – and perhaps also to the related problem of uneventful situations. In line with the core task framework one way is to clarify the core task and to support both the personal and other resources of the operators to meet the core task demands.*

#### 1.2.2.2 Comparing theories behind the states and defining general premises for ExId

The comparison between cognitive-energetical and stress approaches is presented in Table 2. It also summarises the premises of ExId in relation to the other two constructs. The boundary between stress studies in health research and studying stress or work load or mental load from the point of view of performance in the operator research, is not always clear, because both of these can focus on stressful events (or situations) at work and include wellbeing and performance concerns. Moreover, stress theories from health research are often borrowed to explain situational behaviour (Proulx, 1993) or decision making (Kontogiannis, 1996). However, there are differences in the emphasis between the approaches and the time-scope of the interest. In health studies the longer time span of the effect on the result, a person's health or mortality, has guided the stress researchers to adopt significantly broader models and maintain their emphasis on seeking general "laws". The strength of the stress approach, from the point of view of the present study, is its broader focus including the social aspects, the human-environment relation and particularly the impact of subjective appraisal. However, the problem is that stress research has quite long overlooked the contextual and situational factors, particularly in operationalisations of the different constructs.

The workload research, on the other hand, focuses on a moment of performance and has too often neglected the long-term factors and broader organisational and social context when focusing on explaining the situational performance. Both the terms stress and workload have mainly been used in the operator work studies to explain the situational performance, particularly its failure in safety-critical domains (Article II). Furthermore, when we have recognised e.g. that safety builds not only on situational adaptation of a performance, but also on adjustment of practices over time, *the broader focus and time-perspective of stress approach is preferred here but the contextual nature of the studies should not be lost. This is a further reason why ExId is related to the definition of the core task.*

In stress studies the central question has been positive appraisal of one's own resources in comparison with the demands that might be more or less in line with the "objective" (Lazarus, 1999). On the other hand, a central question for a positive outcome in safety research is how to encourage the operators to perceive or be aware of the demands of the situation and the available resources as accurately as possible, or at least on an adequate level in order to make the necessary decisions. The problem of incompatibility between the operator's assumptions and the real status of the situation in terms of mental models (e.g. Burns, 2005) or situation awareness (Endsley, 1995; Endsley, 1999; Endsley and Garland, 2000) has received considerable attention and the way the models are used has also been criticised (Dekker and Hollnagel, 2004; Norros and Klemola, 1999; 2005; Theureau, 2000; Vicente, 1999 pp. 50–55). The studies based on the Core Task Analysis framework and theoretical underpinnings of Leena Norros (2004) offer a potential solution to this evaluation problem: The interpretativeness or reactivity of habits of action is the central dimension that characterises the situated appropriateness of the actions (promoted by the former end), while the core task orientation defines the contextual coherence of the actions.

*Table 2. Comparison of cognitive-energetic (in operator research) and stress theories (in health research) (based on Gaillard, 1993; 2001; Lazarus and Folkman, 1984; Karasek and Theorell, 1990). The table also summarises the premises for ExId.*

<b>Theory</b>	<b>Cognitive-energetic</b>	<b>Stress</b>	<b>ExId</b>
General aim	Better insight into the factors that determine the workload of an employee and the risk for overload and errors	Understanding of the influence of work environment on well-being, psychosomatic complaints and health risks	Understanding of the emotional-energetic factors of operator work performance
Practical aim	Develop procedures to reduce workload and to redesign the work environment in order to improve performance efficiency, support situational performance	Impact for healthier work environments and reduce work related diseases Reduce long term negative impacts	Impact on the development activities aimed to support operators in their work by assessing resources and working practices against core task demands Support efficiency of the socio-technical systems
Operator task: resolve mismatch between demands and resources either by reducing the demands or increasing the resources	Increase the available resources by mobilising extra energy through mental effort or change the work strategy either by changing the speed-accuracy trade off (i.e. making more errors) or concentrating on the most relevant aspects of the job	Adaptation to the situation or change of task, physical and social environment.	Focusing on the core task, attempt to define the core task and develop in the long run own ability to take care of it and use available resources efficiently
Describes	The interaction between a computational and energetic process	The person-environment relation, the evaluation of the situation (appraisal guided by goals we have) or perceived controllability of the situation are central, decision latitude	Conceptions of oneself as an operator, the person-self relation in person-environment interaction
Concern	The efficient work performance of a complex or demanding task, mostly in technical environments	Work-health relation in a psychosocial working environment	Efficient work performance The definition of efficiency includes productivity, safety and wellbeing
Basis	Cognitive-energetic models based on human factors and cognitive psychology	Theories adopted from industrial, social and personality psychology	Core-Task Analysis framework, safety and operator research and tentative adaptation of theories from health research (control), emotion, ethnographical oriented practice research.
Relevant	When the capacity of the operator is just enough or not sufficient to get the requested work done, operator work	In every work environment	Operator work

Since stress is defined as the person's perception of the balance or 'transaction' between the demands and the abilities to cope with them (see e.g. Kontogiannis, 1999), we should emphasise how the persons themselves conceive the demands and resources (Article II). The different approaches and methods of task and work analyses aim to discover the objective (as related to the efficiency of the outcome) tasks, demands or constraints of work (Brauchler and Landau, 1998; Hoffman and Woods, 2000; Hollnagel, 2003b; Kirwan and Ainsworth, 1992; Vicente, 1999 pp. 61–113; Wilson and Corlett, 1995, Article III). However, too strict limitation of the demands and the workers' task with regard to achieving particular organisational goals is also criticised by e.g. McCarthy et al. (2004). They recognised, for example, that the ambulance controllers' actions in calming people down had benefits beyond obtaining adequate information from the caller. The actions can also be a way of reducing the stress of those present at the scene. Recognition of these kinds of emotionally-laden and socially formed work demands is a challenge.

There is empirical evidence that supports the efforts to include the operator's conceptions of the work in the work analyses. Sandberg's (2000) study of optimising engineers demonstrated that the workers' conceptions of their work affected, or as Sandberg states "constituted their competence". He discovered three different conceptions of the optimising of work with different focuses and six key attributes of their competence. These do not have a fixed meaning but acquire meanings through the specific way that the work has been conceived. The conceptions of work also stipulated which particular attributes were developed and maintained in accomplishing the task. He concludes that a change in the conceptions of work appears to be more fundamental to developing competence than the linear progression from novice to expert that has traditionally been proposed (see corresponding ideas on the summaries of the current learning theories by Hakkarainen et al., 1999; also a critique on novice – expert comparisons presented by Norros, 1995; Norros and Klemola, 1999). Variation in the ways to conceive a particular job explained why some performed better than others. He suggests that the training and other development activities should be conducted in a way that actively promotes changes in the workers' conceptions of their work. (Sandberg, 2000.) This supports the previously suggested way to support the operators by clarifying the core task. The positive impacts of improving the conceptual mastery (e.g. the logic of process parameters, their interdependencies and ways to control them)



on well-being and mastery of work by a development program building upon cooperative conceptual modelling of the work process is shown by Leppänen in the paper production (Leppänen, 1993; Leppänen, 2000; 2001; Leppänen et al., 1996). The modelling of the work processes is also demonstrated to contribute positively on performance outcome (quality, productivity and efficiency) and the economy of the company (Seppänen, 2003).

*ExId* tries to take into account how the operators conceive their work and themselves and the objective constraints and possibilities in a sense of the aimed triple efficiency of the outcome when considering the ways to support them. These different perspectives of “objective” and “subjective” demands and resources need not be in contradiction. If we enhance both resources (so that they correspond with the core task demands) and support the operators in conceiving their core task demands accurately, positive appraisal and performance are supported (although the issue is, of course, much more complicated see e.g. Vegchel et al., 2005). According to the present approach, the task of the operator (Table 2) is to focus on the core task and utilise the available resources (personal and external) efficiently in the situation and attempt to define the core task and develop his or her own ability (personal resources) to take care of it in the long run. The following literature review focuses on the personal resources which were assessed to own potential to counteract stress and support core-task oriented working practices in demanding situations.

### **1.2.3 Controllability as a counterforce to stress in demanding situations**

There are many different constructs around a person’s belief of controllability and the subjective meaning of events in the efforts to explain stress and the related effects on one’s health in stress research (for reviews and comparisons between different constructs see e.g. Antonovsky, 1988; Bowsher and Keep, 1995; Peterson and Stunkard, 1992). *This “control view” was recognised as a promising direction for the development of ExId* and Antonovsky’s (1988, 1993a, 1993b) concept “*sense of coherence*” from health research was chosen for further consideration.

In operator studies, the importance of the control for operator performance is noted in two senses, as control over a situation (Hoc and Amalberti, 2005; McLennan et al., 2005) and self-control of the cognitive activity, knowing, monitoring and controlling one's own resources or decision-making processes, often called with the term metacognition (e.g. Cohen et al., 1996; Cannon-Bowers and Bell, 1997; Hoc and Amalberti, 2005; 1999; McLennan et al., 2005). According to a study made by McLennan et al. (2005), awareness of a felt sense of being in control is associated with good decision of domain expert, whereas a felt sense of not being control and awareness of intrusive negative affects and self-critical thoughts with poor decision making (McLennan et al., 2005).

Langer (1983) has emphasised that the illusion of control is not necessarily maladaptive or irrational (pp. 25–26). She refers to several studies which have indicated how the experience of control itself is adaptive in that it leads to many beneficial results in several areas of life. Further, in normal life (contrasted to laboratory settings) there usually is not enough data to assess accurately whether or not control is possible. Although the unrealistic positive appraisal of one's resources or the controllability of the situation might prevent stress and provide positive energy for performance, in the safety critical context, the unrealistic positive appraisal can have negative results, if it e.g. prevents asking for help or recognising the need for personal development.

*The adopted assumption for ExId is that the realistic sense of control is essential for human ability to cope successfully with the demands.*

### 1.2.3.1 Sense of coherence

Antonovsky's (1988, 1993a, 1993b) concept *sense of coherence* (SOC) offers a salutogenic (in contrast to pathological) orientation to health. Antonovsky claims that SOC is a major determinant in maintaining one's position in the health ease/dis-ease continuum and in the movement toward a healthy end. SOC refers to a quite stable generalised orientation in the relation to perceiving and controlling the environment for meaningful and appropriate action (Antonovsky, 1988). The three components of SOC are: comprehensibility (the stimuli deriving from one's internal and external environments in the course of living are structured, predictable, and explicable), manageability (the resources are available to meet the demands posed by these stimuli) and meaningfulness (these

demands are challenges, worthy of investment and engagement). These definitions seemed promising when searching for theoretical support to the first formulations of ExId (Nuutinen, 2000).

However, a crucial challenge is that in these DCU environments (Norros, 2004), the human operators have neither full control over their environment, nor knowledge or information about the real state of the environment or consequences of actions (e.g. Norros, 2004; Rogalski, 1999). Thus, there is a danger of stress situations. Nevertheless, the operators still have a responsibility and a role in reaching the aim, efficiency. In the studies of anaesthetists Klemola and Norros (1997; 2001; Norros and Klemola, 1999; Norros, 2004 pp. 146–179) have found particular evidence that identification of the very uncertainty of the controlled object is an important issue both in the sense of acquiring adaptive, situationally adequate performance and in the sense of development of the expertise. Simulation studies of experienced nuclear power plant operator teams also suggest parallel results (Hukki and Norros, 1993; Norros and Hukki, 1995; Norros, 2004 pp. 104–145). Next, we shall shortly review two related issues of safety research: metacognitive skills and development of expertise.

#### **1.2.4 Metacognitive skills and emotions in managing one's own actions**

Metacognitive (often defined as monitoring one's own decision-making process; reflection on and regulation of one's own thinking or cognitive activity) skill is one of the skills particularly emphasised in decision-making in novel and uncertain situations and used in explaining adequate situational performance (e.g. Cohen et al., 1996; Cannon-Bowers and Bell, 1997; McLennan et al., 2005). Considerable effort is directed to describe the phases of metacognitive processes and to use them in analysis on decision making. Hoc and Amalberti (2005) have recently emphasised that human operators not only manage technical processes but also their own resources in terms of the work load and vigilance, and e.g. competence. They emphasise three aspects of metacognition: management of internal risks; management of internal costs and metapanning and included them into their coding scheme. Refusal to adapt one's own plans for reasons related to resources, cognitive cost and motivation are a part of internal risk management (Hoc and Amalberti, 2005; Hoc and Amalberti, 1999).

A problem with metacognition research is that the information processing approach is strong. Thus, the metacognitive processes are difficult to measure, a characteristic of common-sense “folk models” described by Dekker and Hollnagel (2004). Moreover, there exists a central problem in assuming different levels of cognition, expressed by Kivinen and Ristelä (2001 pp. 163–166; 2003) referring to the works of Gilbert Ryle (1949/1984): if the knowledge of one’s cognitive activity is based on the meta-level process, then because the activity of this level cannot be observed from the outside, we have to assume yet another level that observes the meta-level and so on. The authors, of course, do not deny that we are aware of our own cognitive activity, but they emphasise that we are aware of it *because it is our own activity*, not because we have observed cognitive processes from the meta-level. The metacognitive discussion in the context of the operator work raises, however, important questions of the role of human self-control, effort and the mechanism which allows the operators to interrupt their actions and to adapt them to the situational changes and the importance of self-knowledge in situational process control performance. A suggestion that ExId offers into the discussion of the first question of self-control is to emphasise the functional role of emotions presented by functional emotion theories (see e.g. Oatley, 1992; Laird and Apostoleris, 1996; Parrot and Harré, 1996; Article II).

#### 1.2.4.1 Functional emotions

Functional emotion theories emphasise for example that emotions are involved in giving information about to self and others, and regulating one’s actions (Laird and Apostoleris, 1996 and Oatley, 1992; 1996). According to Oatley’s and Johnson-Laird’s communicative emotion theory (1987; 1995) emotions signal the likelihood of achieving a goal or a plan. They make it possible to concentrate, to configure mental resources and to prepare certain kinds of actions. A positive emotion connected with the achievement of sub-goals signals encouragement to the self to continue the current action. When the possibility of attaining a goal is decreasing a negative emotion interrupts the course of action (Oatley, 1992; 1996). The role given to emotions in the functional theories differs significantly from those mainly negative views adopted traditionally in safety research (Article II) and might thus open up new paths. Emotions could offer subsidiary (Polanyi, 1958/1974 pp. 88–92) cues (see also Norros, 2004 pp. 39–41; Laird and Apostoleris, 1996) resulting from the internal environment (cf.

Antonovsky, 1988) and if their purpose is accepted they could support the decision-making in two senses: firstly, by increasing comprehensibility of the stimuli from the internal environment and thus perhaps counteract with stress reactions, and secondly, by increasing the controllability of actions according to their success, thus promoting one's adaptive performance. In addition, emotions could be related to development of expertise, related to tacit knowledge. Polanyi (1958/1983) uses the term tacit knowledge to refer to the formation of patterns or cues that signify the features of the environment that are relevant for the action. Because these cues are not within the focal attention during action, but rather in a subsidiary position, the resulting knowledge is tacit, implicit but yet operative. This is due to the comprehension of the meaning of the cues in the context of the whole (see also Norros and Nuutinen, 2002).

Seeing the impact of emotions on decision-making as mainly negative has been based solely on the occasional findings of safety research, that is, mainly accident-related observations in which poor performance in demanding situations has afterwards been explained (likely correctly) to have been caused by extreme stress and the related negative feelings (Article II). This impairment in performance has been further "explained" by negative emotions or stress-produced irrelevant information as taking capacity from task-related information processing (see. e.g. Stokes et al., 1997). Hasegawa's and Yoshimura's (1999) study is among the few studies noting especially emotions in the safety research area. The study aimed to integrate emotions to their system simulating human cognitive processes and decision-making in order to invent countermeasures for human errors. The questionnaire study was conducted by requiring the subjects to select the types of emotion and behaviour they expected to experience corresponding to 51 situations categorised as plant conditions, operations and human relations. The results of the study showed some correlation between the situations and basic emotions. One of the results was that when negative emotions, such as discouragement, dislike or irritability were activated, the most commonly chosen behaviour was "Cannot decide what should be done". Hasegawa and Yoshimura concluded that negative emotion tends to cause human errors that are especially related to the thought process. However, another interpretation for indecision rather than error could be that this is evidence of the functionality of the negative emotion in the sense of giving an opportunity to redirect one's activity. Furthermore, e.g. Jensen's finding that emotional factors (including positive) tend to bias the decision in the direction of following

through with prior plans and commitments (Jensen, 1995 p. 24) could be reinterpreted e.g. as describing a situation where the operator is unaware of or neglects the clues from the environment (and has a positive feeling that everything is going well) or him/herself (feeling negative emotion) indicating the inadequacy of his/hers plans. Thus, the conclusion for practical solutions is not to control emotions as such (as suggested by Hasegawa and Yoshimura, 1999) but to take advantage of them by understanding their functions. (Article II.)

There are increasing efforts to bring emotional features to technology (e.g. Aibo and Microsoft paper-clip agent) or to develop computer systems capable of recognising and responding to user's emotional states and interest to study these as a way to improve human-computer interaction (see e.g. Bartneck and Reichenbach, 2005; Nasoz et al., 2004; cf. Hollnagel, 2003a) Further, the emotions are also a subject of interest in design of everyday things (Norman, 2004) and their important role at work is widely noticed (Briner, 1999b; 2004) in other than safety critical domains. Emotion is already a part of many studied work behaviour phenomena, such as job motivation or teamwork, but as Briner (1999a) further notes, in the past we have tended to ignore or play down its relevance. The same situation seemed to be in the safety research noticed also e.g. by Hasegawa's and Yoshimura's (1999). When it is realised how important emotions are at work, there is a danger that their studying is separated from other aspects of working and competence and approached uncontextually (Article II). *This is the reason why the ExId construct aims to integrate emotional issues to the existing CTA framework and relates them to operator performance and development of expertise.*

### **1.2.5 Development of expertise**

In the operators studies both the role of experience and training are regarded as essential for acquiring expert performance and the competence needed (e.g. Zsombok, 1997; Kontogiannis, 1996; 1999). The research on which kind of expertise produces good performance and on conclusion of the premises for operator training has been and is extensive, whereas empirical studies particularly focusing on the development of the expertise or learning in the process control contexts, are rare (Norros and Leppänen, 2000). There are many open questions of which I shall only consider a few.

A central problem of the expertise studies in general is the definition of expertise (Cañas et al., 2003; Norros, 1995). The expertise studied can be ‘laboratory-created’ (Cañas et al., 2003), or real, such as driving a car (e.g. Dreyfus, 1997) or playing chess (Klein, 1998 pp. 161–168) or something “rare” that can be reached only after years and hours of deliberate practice and training (e.g. Ericsson, 2005; Saariluoma, 1997) or something mainly characteristics of specific expert jobs or professions in society and companies (Kirjonen, 1997a; 1997b; Konttinen, 1997). This is followed by quite different conceptions of the target of development and the ways to reach it. Uncertainty (e.g. in terms of incomplete information available of the state of the object of work) is among the factors normally used in describing safety critical domains and demands of the operator work (Orasanu and Conolly, 1993; Lipshitz and Strauss, 1997; Montgomery et al., 2005a; Vicente, 1999 p. 16; Cannon-Bowers and Salas, 1998/2000b; Norros, 2004 pp. 37–39) and thus also included in the many models of expertise and in different kinds of stress training (Kontogiannis, 1999; Article II). Uncertainty, in more ways than one, is present in demanding situations. Why is experience, and particularly experience of the disturbances and emergencies, considered so important that e.g. extensive simulator training is required by the authorities (e.g. YVL, 1995) to compensate the lack of these experiences in normal work in safety critical domains?

The essential role of experience is explained e.g. by providing opportunities to gather experience on the basis of which one can recognise a new situation similar to the one before (Recognition-primed decision, Klein, 1993; 1997), and by offering opportunities for acquiring operational knowledge (Hollnagel et al., 1995), and constructing knowledge in the daily practice when one orientates to the object of activity as something unique and worth exploring (Norros, 2004 p. 176) (Article II). Rogalski et al. (2002) claim that direct work experience is not an effective way of developing the needed competence, particularly collective competence, for dealing with rare or unpredictable situations in dynamic or risk environments. They further argue for simulator exercises, because operators in these environments generally have few, if any, opportunities to acquire competence by directly experiencing emergencies and disturbances, nor for developing into competent teams by sharing multiple experiences (Rogalski et al., 2002). The need for particular stress training is also emphasised (e.g. Driskell and Johnston, 1998/2000). Two issues emerging from these studies

were explored further: the personal experience of the uncertainty and the collective or social aspect in development of the person's expertise.

#### 1.2.5.1 The role of uncertainty in personal expertise

There is evidence among the studies that are focused on real operators or their training, that coping with uncertainties of the object of the work includes issues that concepts based on the information processing approaches or emotionless cognitive approaches do not reach well. My interpretation is that the notion of the importance of military pilots' initiative in the control of uncertain, complex and time-restricted situations made by Brecke (1982), for example, and the dynamic intuition needed in military command and control (Bakken and Gilljam, 2003), and the importance of maintaining control of the situation (Hoc and Amalberti, 2005; see also McLennan et al., 2005) all extend the perspective of how far the purely cognitive explanations bring us (Article II). These together with the previously mentioned review of the studies of metacognition refer to some aspect of expertise that is difficult to specify or name (Article II). Why is facing uncertainty crucial for personal expertise? The importance of the experience might also become manifest in that under favourable circumstances it could offer possibilities to gradually create skill and self-knowledge-related self-reliance, *courage* that is needed for acting in disturbance situations where the consequences of one's failure might be severe (Article II).

Building performance confidence is one of the goals of the stress training aimed to prepare the individual to maintain effective performance under stress (Driskell and Johnston, 1998/2000). The approaches that try to systemically inoculate trainees against stress are presented for example by Driskell and Johnston (1998) and Brecke (1982) (for review see e.g. Cannon-Bowers and Salas, 1998). As noted by Driskell et al. (2001) a paradox of stress training is that it aims to provide practice under conditions similar to those likely to be encountered in the real-work settings, but, in these complex environments, the events to be encountered cannot be defined completely in advance. The effort put on stress training shows the important role of stress in operator work. However, not as much attention has been directed on the daily work in the enhancement of human performance under stress (Article II). The importance of identification of the uncertainty of the object for performance and the expertise development might also lie in its possible counterpart: locating the uncertainty to oneself,



developing ways to cope with that thereby losing the sensibility of the emotions referring to the success of one's control actions.

There are some potential problems in being exposed to uncertainty. There are signs of a more frequent than occasional belief among the operators that the true professional (e.g. pilot or air traffic controller) is never distressed, overloaded or terrified (Helmreich, 1984; Helmreich and Foushee, 1993; Merrit and Helmreich, 1996; Palukka, 2003). Thus, training approaches to enhance human performance under stress, that focus on training the individuals to rely on their teams and to adapt team communication and structure to the changing circumstances (Kontogiannis, 1999) might fail. The above "super human" belief has been used as one explanation why a broadly adopted "philosophy" for operator training, cockpit or crew resource management (CRM) from aviation (Helmreich and Wilhelm, 1991; Jensen, 1995; and its applications to other domains e.g. bridge crew resource management, BCRM or BRM, see Perdok and Wewerinke, 1995), does not always reach its targets and has met with resistance (Helmreich and Wilhelm, 1991; Helmreich and Merrit, 1996). An ethnographic study of the cultural context of air traffic control (ATC) work made by Christine Owen (2001) could demonstrate some possible reasons behind the problems. She identified three collectively held beliefs in the three ATC centre studies. The first belief was that inborn ability, sometimes associated with attributes such as arrogance and egoism, is the foundation of expertise in ATC. The second belief was that a necessary but not sufficient element of good controlling is confidence in the way one is performing the job. The third belief was that performance is the way to demonstrate capability and self-worth. Experience was regarded as the most valuable, even the only way to learn air traffic control (Owen, 2001).

A possible explanation for "the super human" belief might be that this kind of thinking is not only an occasional finding in the particular cultural context studied by Owen (2001), but e.g. a result of the previous theories of expertise and the practical solutions related to these theories. Moreover, if mastery of work, and particularly coping with uncertainty as a part of it were inborn, then it would be natural to walk a newcomer "through the fire" as soon as possible in order to test if she or he has that ability or not. If the newcomer then scrambles or sails through the test, he or she would hardly call one's abilities or this belief into question. If the newcomer has succeeded without having any or only little

preliminary training in a real or close context etc. but he or she has already passed e.g. different psychological evaluations, the belief might appear also as a promise of success, that he or she must then continuously prove for him/herself and others. If he or she continues with success in situations where the demands exceed the competence and the skills reached, could this help strengthen the belief and promote the development of “a skill” to ignore one’s own uncertainty? Could this result in the ability to work but also in the loss of sensibility for emotional cues from the success of one’s action? For example, the importance to increase gradually and systemically the demands of the pilot’s task by controlling uncertainty, complexity and stress (in terms of time constraints and finally the possibility of death) in order to reach the aimed initiative (needed in situations where the procedures do not apply) is noted by Brecke (1982).

Owen’s (2001) study also resulted to the notion that confidence is essential in human performance, particularly in co-operation. The necessity of displaying confidence was recognised for smooth operation of the air traffic system but also the problems of exuding confidence or believing one should always prove one’s ability and never display doubt (Owen, 2001). An interview study of emergency decision making on an offshore platform made by Flin et al. (1996), also refers to the importance of displaying confidence. The interviewed offshore installation managers (who have experience of real emergencies) reported that they were aware of being observed by the crew, who paid more attention to the manager’s reactions than listened to what was said during an emergency. Owen (2001) also demonstrated the role of organisational structure and socialisation and the importance of cultural norms such as “the lone ranger” (in comparison with team-based culture) sub-culture, also when adopting exuding confidence. The dangers of strong confidence are recognised and fought against in CRM training emphasising e.g. the necessity to open one’s decisions to criticism from the other team members (see e.g. Helmreich and Foushee, 1993).

There is a danger for burn-out in operator work if an unbalance between the work demands and individual capacity lasts a long time. A Finnish study based on data covering more than a 10 year period in the wood processing industry found that individual resources were more important than the work conditions when identifying the differences between workers managing well and those who were critically burnt-out (Kalimo et al., 2001). The sense of coherence

(Antonovsky, 1988) predicted best of any of the measures (self-esteem, sense of competence, working conditions) used in the study how the worker was managing at work. (Kalimo et al., 2001.)

*The ExId construct attempts to offer a frame to focus particularly on these kinds of issues as a part of work analyses. The method chosen for further development of ExId was to consider the development of personal expertise as a change in the professional identity, in the conceptions of who we are in the operator work.*

### **1.2.6 Professional identity**

Professional identity is a common object of research in studies focusing on professions such as psychologists, therapists, doctors and teachers. According to CSA PsycINFO thesaurus professional identity is “a concept of self within a professional domain”. Without involving ourselves deeper either in the concept of profession (see e.g. Konttinen, 1997) or the concept of identity and the different theories behind it (see e.g. Kärkkäinen, 2001), we can use it as highlighting some aspect usually neglected in safety research. In the above-mentioned professions the practitioners are responsible for the wellbeing or education of others. Certain detachment or control of one’s feelings is supposed to be needed when facing human suffering or acting as a role model for the younger generation. Identifying to a profession (e.g. Kari, 1988) or adopting a specific career or professional role are assumed to be essential, thus demanding also changes in the subjective self-conceptualisation associated with that role (see e.g. McGowen and Hart, 1990).

The responsibility for the wellbeing of others is always present when working in a safety- critical domain and never more than in a disturbance situation. In addition, particular pressure for self-conceptualisation can arise resulting from e.g. a negative public opinion and media interest focusing on domains such as nuclear power production. Although professional or occupational identity has rarely been in the central focus of the safety and operator studies (with the exception of a social constructivist study of the identity construction of air traffic controllers made by Palukka, 2003) there are studies related to the subject. The role of identity (who they are and what they represent) in a crisis of sensemaking was visible in the Mann Gulch disaster, where the firefighters refused to drop

their tools and change their “status” from firefighters to victims (see Weick, 2001 p. 465; Weick, 1993). This can be seen as evidence of a professional “role” to which certain ways of acting and fulfilment of one’s obligation are strongly related. In the classical book “The Age of the Smart Machine”, Shoshana Zuboff (1988) has also demonstrated the importance of tangible entities, such as a piece of operating equipment, marking a worker’s sense of occupational identity and experiences of continued opportunities to master new objects (p. 62). In that transition case of the older paper and pulp mills, it was the immediate knowledge one could gain of these tangible objects that engendered feelings of competence and control (Zuboff, 1988). The book illustrates the various problems to humans resulting from the profound change caused by automatisisation. The new tools of modern technology increased mediatedness of the work, changed the skills and competence needed and thus also threatened one’s occupational identity.

The existing work or task analyses (for cognitive engineering purposes, Vicente, 1999 p. 13) are mainly motivated by recognition of the functions, demands and tasks that should be met in order to achieve the aimed outcome. The efficiency of socio-technical systems could benefit from ways to integrate identity into the analyses. This could be a way to bring some of those emotionally-laden and socially formed work demands emphasised by McCarthy et al. (2004) to the task descriptions. As they have pointed out, people may have preferred ways of performing their work that emerge from a sense of fairness, consistency, community or duty. “Given that our sense of self depends on the creative tension self-other dialogic, these value judgements are not separate from emotionally-laden, creative activity of specifying the self that we are at work” (McCarthy et al., 2004).

Since Erik Erikson’s (1902–1994) classical theory of psychosocial development through eight phases, each marked by a conflict (Erikson, 1950; 1994/1980), the term identity has been used extensively and often without explicit definition. Identity has a central role also in Lave’s and Wenger’s work on situated learning and communities of practice (Lave and Wenger, 1991; Wenger, 1998/1999). Identity is “a way of talking about how learning changes who we are and creates personal histories of becoming in the context of our communities” (Wenger, 1998/1999 p. 5). With the term *identity* in the ExId construct, attention is called to the construction of one’s conception of him or herself also in the work life and

in particular in positions where the person is responsible for the wellbeing of others, such as process control of risky environments. The concept of identity serves a pivot between the social and the individual, and it avoids a simplistic individual-social dichotomy (Wenger, 1998/1999 p. 145). The construction of professional or occupational identity can be seen as a part of every job. However, it is claimed that in environments where there is a possibility (however small) of severe disturbances causing human suffering or significant economic loss and responsibility assumed by those in “the frontline”, controlling these incidents calls for achieving *professional courage* and the related construction of identity.

### **1.2.7 Theory of interrelated development of expertise and identity in communities of practice**

When considering the social or collective aspects of the development of expertise together with identity construction in “a real world”, Lave and Wenger’s theory on situated learning (Legitimate Peripheral Participation, LPP) gives us a good frame of reference (Lave, 1991; Lave and Wenger, 1991; Wenger, 1998/1999). The theory emphasises that the mastery of knowledge and skill requires newcomers to gradually move toward full participation in the socio-cultural practices of a community. The legitimacy of the mode of participation is a requirement for being able to learn, and it also determines the content of the learning. ‘Peripherality’ emphasises that there are multiple, more or less inclusive ways of being located in the fields of participation. The aim is to move from peripheral to full participation. Deeper participation in the community requires increasing use of time and skills, and a sense of the ‘identity of a master practitioner’. According to Lave and Wenger, the development of identity, knowledge and skills is a part of one and the same process. In practical action, both the individual and the community shape themselves and each other. In this process the effort of developing an identity serves the development of skills by providing motivation, formation and meaning. The purpose of the development is the ‘identity of a master’, which gives full membership in the community. Peripherality may be regarded as positive in comparison with unrelatedness or irrelevance. Learning means becoming a member. (Lave, 1991; Lave and Wenger, 1991.)

The primary focus of the above theory is on learning as social participation. Participation refers to a process of being active participants in the practices of social communities and constructing identities in relation to these communities (Wenger, 1998/1999). The LPP theory and the communities of practice concept offer a good frame to consider identity development together with expertise development. The theory is, however, criticised e.g. by Kivinen and Ristelä (2001) for being too generous to offer a basis for viable and practical solutions for promoting learning. Further, Yrjö Engeström (1995) has made an important point that a characteristic of qualitative change in work is “a leap into the unknown” (p. 87). This kind of change forces the work community to learn something new which does not yet exist and this aspect is not reached well by the theories focusing on communities of practice.

Calling the construct *expert identity* emphasises its close connection to expertise; its gradual development hand in hand with the skills and knowledge needed in a social community of work as well as its loss when e.g. the demands of the work, or technology, change profoundly and the acquired skills become irrelevant thus collapsing the expert identity. With the choice of the name of the conceptual model the role of a person’s own work experience and gained expertise is emphasised more than a particular occupation or task in the work.

### **1.3 Expert Identity**

To conclude, the expert identity construct was developed for defining the emotional-energetic demands of work in order to supplement the Core-Task Analysis framework. ExId aims at explaining and promoting the development of expertise related skills and courage especially needed to cope with demanding situations.

Expert identity is defined as consisting of three interrelated layers: *meaningfulness; professional self confidence and sense of control* (Figure 2) (Article II). Expert identity is a worker’s conception of who he/she is as an operator or as a pilot etc. and the corresponding terms operator identity or pilot identity are also used.

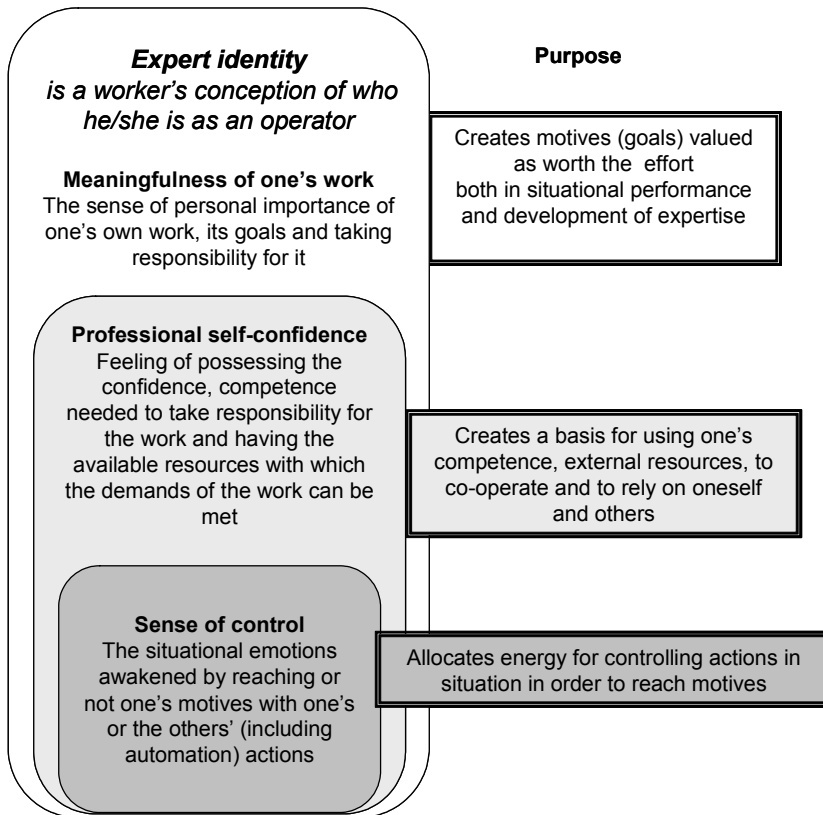


Figure 2. Definitions of the layers and their purposes.

The outermost layer, meaningfulness, creates the goals, objectives, and motivation guiding a person's efforts both in the situational performance and development of expertise. The second layer creates confidence by which one can exploit external resources (including technical and human resources) and one's own competence for these goals. On the basis of the inner layer, the sense of control, actions and energy can be focused in order to reach the goals.

The outermost and middle layers of expert identity resemble the three components of Antonovsky's sense of coherence construct (SOC, 1988; 1993a; 1993b). The DCU nature of the controlled object makes expert identity development challenging. Unlike the SOC concept, recognition of the uncertainty of the controlled object is emphasised as an important issue promoting the development of expertise (Norros, 2004; Klemola and Norros,

1997; Klemola and Norros, 2001). The stimuli derived from the DCU process or internal (emotions) environment are not always well structured, predictable or explicable (cf. Antonovsky, 1988). However, coping with this fact is important.

The innermost layer of the expert identity, sense of control, is situational. It exploits the functional emotion theories that emphasise the role of emotions in giving information about and regulating one's actions (Oatley, 1992; 1996; Laird and Apostoleris, 1996). The underlying assumption is that the sense of control is essential for the human ability to act. According to ExId, the feeling of negative emotions, such as fear and anxiety, associated with a decreasing sense of control is a possibility to redirect one's actions: to change the target or change the methods of controlling the DCU object. According to ExId the decrease or maintenance of the sense of control by controlling the object (e.g. start-up of a feedwater pump and observing the increase of the water level in a tank) awakens emotions. The emotions thus awakened can offer subsidiary cues supporting the decision making. Effects of the decisions, again, affect the sense of control and the related feelings. The increasing possibility of attaining the goal awakens positive emotions and signals encouragement to continue the current actions. Both negative and positive emotions are thus important when controlling the DCU object. They can "tell" whether one is obtaining control or not in the control of the DCU object and whether one's actions are successful or not.

The essential question is not whether or not high expert identity (cf. SOC) can be established but what is the match between the expert identity and the actual (and perceived) core task of the work and the actual resources? Thus, an operator identity (conception of oneself as a process operator, pilot etc. defined according to ExId), in which the source of meaningfulness is the core task, is assumed to promote better work performance. Likewise, better performance is expected if the self-confidence is based on a realistic conception of one's competence and resources, and these match with the core task demands. From the assessment point of view, for example, situational sense of control related to the core task is better than non-core-task-related situational sense, e.g. saving one's face. The assumption is made that some degree of self-confidence is needed in order to be able to act. However, in a co-operative and demanding work situation one should also avoid being too confident and open up one's decisions to criticism from the other team members (see e.g. Helmreich and Foushee, 1993).



The idea is that a person's ExId should grow gradually and should rest on a realistic base (Figure 3). In this development, participation in the social community is important in line with Lave and Wenger's (1991; Lave 1991) theory. The layers are assumed to differ from each other in the ways in which they develop (Figure 3). Appreciation of the work expressed in an organisation or society and based on a realistic view of the content of the work is assumed to support the development of meaningfulness. Uncontrolled or profound and rapid changes in the work are assumed to endanger ExId (cf. Zuboff, 1988), whereas *harmonious continuity* (see Antonovsky, 1988 p. 50) of the work is supposed to support it. The reflections of the core task and its changes are ways to support meaningfulness (Norros and Nuutinen, 2002). The balance between the work demands, resources and competence (Kontogiannis, 1999; Article II; Antonovsky, 1988) and a systematic, gradual increase of the demands and responsibility by e.g. training (see e.g. Brecke, 1982) or participating practice (Wenger, 1998) are supposed to support self-confidence in spite of recognising the uncertainty of the object of work. The development of sensibility to the sense of control is closely related to the nature of the work. Gaining experience of controlling, seeing the results of one's control actions and getting knowledge of one's own reactions and the limits of one's expertise in different situations are expected to promote the development and to counteract the need for illusion of control. A process that requires active controlling instead of only supervising is assumed to be more beneficial in this sense. This can be supported by adequate feedback of one's control plans and actions. Experience of managing or failing in demanding situations can have a corresponding impact on one's identity development. Since the layers are interrelated, the changes in a layer are supposed to affect also the other layers. Sensibility of the changes and the ability to exploit them as well as the persistence in seeking a core-task-related sense of control, i.e. to keep trying in a demanding situation, is assumed to be stronger if the other layers are viable and strong. This principle applies to all the layers. Basically, the ExId construct operates in a broad time window, from a process of many years of expertise development to situational and dynamic decision making under stress.

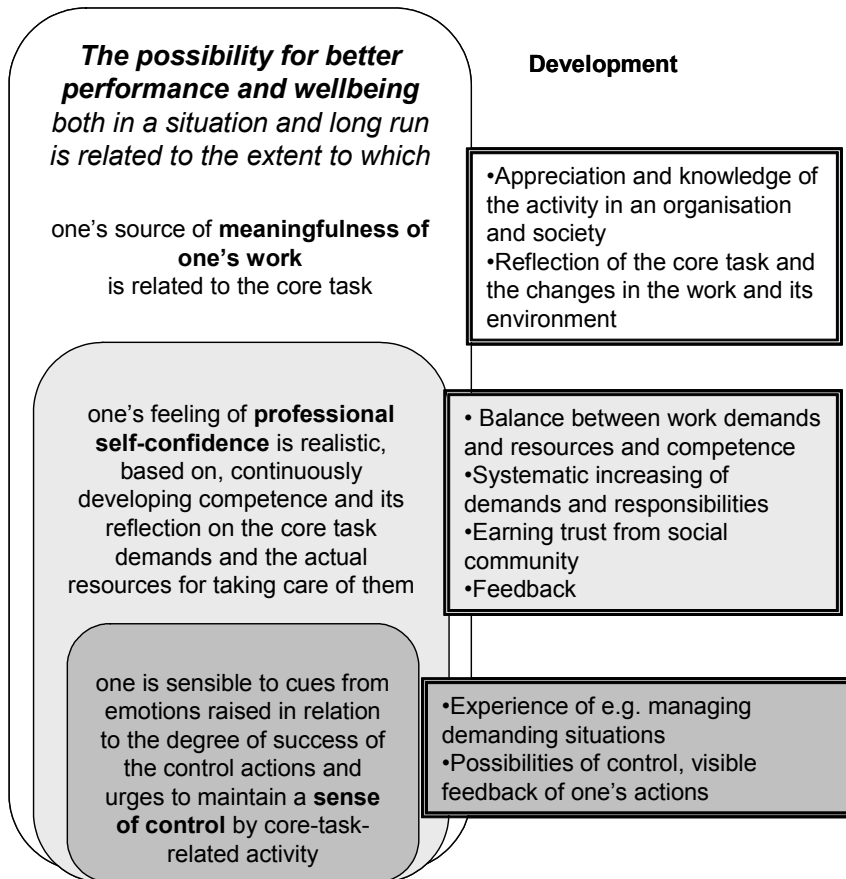


Figure 3. Assumptions of positive ExId development and connection to performance and wellbeing.

## 1.4 Research questions

The general aim of the ExId stated in Section 1.1 is *to open up new paths to explore and support the operators' performance, particularly in demanding situations, by bringing emotional-energetic depth into the work analysis*. ExId touches various broad issues, which have been and are of the object of extensive research, and utilises theories from different lines of research. The state of the presented construct should be considered as tentative. The main purpose of the empirical studies is thus to test if the construct has enough potential to justify further testing and development.

The concluding research questions for this thesis and the articles were:

1. Are the assumptions made in ExId on the basis of the different theories and previous studies supported by the empirical findings?
  - a. Do the three layers (their purpose and definition) get empirical support? Article II.
  - b. Do the assumptions of development get support? Mainly Article II.
2. Does the ExId construct promote understanding of the operator work in empirical studies?
  - a. Does it work, produce valuable results or enrich studies on the operator work by pointing out what promotes or complicates the mastering of the core-task? All articles.
  - b. Does it supplement the practical methods based on the Core-Task Analysis framework? All articles.
3. What are the strengths and weaknesses of the Expert Identity construct? This question is discussed regarding the more general, concluding question whether ExId opens up new paths without losing its connection to the context of the practice and the other sides of cognition and whether ExId enables studies on practices in the field and thus contributes adequately to practical development.

## 2. Methods

### 2.1 Research strategy and empirical studies

Six empirical studies on different domains were conducted (Table 3). These studies can be considered as a purposeful sample of the operator work (see Section 2.1.1). The research strategy was case study in each study but the first study (A) was a case study with an experimental setup (Article I). To be more exact, the research strategy was mainly explanatory case study, although it consisted of also exploratory and descriptive phases (see e.g. Yin, 1994 pp. 4–17).

The studies were:

*Study A: The Usability of a Safety Information and Alarm Panel (SIAP) in a Nuclear Power Plant Control Room. (Article I)*

*Study B: Human Factors on Production Reliability: A Conventional Combined Power Plant. (Article III)*

*Study C: Development of a Socio-Technical System Based on Accident Analysis: An Investigation of 10 Accidents Occurred on The Finnish Fairways During Piloting. (Article IV)*

*Study D: The Change of the Operator Generation in a Safety Critical Domain: On-The-Job Training Practices of a Nuclear Power Plant. (Article II)*

*Study E: Developing New Service Business at the Industry: A Remote Expert Service of One Company Offering Production Support Services for Pulp Mills. (Article III)*

*Study F: Harmonising Practices of Six Vessel Traffic Service (VTS) Centres. (Article III)*

#### 2.1.1 Motivation for choice of cases

There were two main criteria for choice of the cases. First, they had to allow for reaching the diversity of the studied phenomena, that is, they had to be representative of the several different dimensions relevant to the operator work.

The dimensions are described in the following section (2.1.2). Secondly, they had to support specific methodical aims and offer a good testing environment for the methods and the ExId construct. An important premise in the development of the practical methods based on Core-Task Analysis was to broaden their applicability. Thus, the case domain was differentiated and also the diversity of different practical problems was emphasised. The empirical studies considered also different kinds of challenges for the management and the development of work. The pressures can originate from technological development or modernisation (Study A), changes in the business environment (Study B and Study E), accidents (Study C), an (international) authoritative environment of the system (Study F) or a relatively simultaneous change in the staff inside the socio-technical system (Study D). The studies also considered and contributed in different ways to management of the pressures and to supporting of the work: learning from accidents by accident investigation (Study C), design of technology (Study A and Study E in Article III) and training (Study D and F).

Also the methods and the nature of the data gathered were different (see 2.2). The studies were conducted in sequential order and additional requirements that emerged during the conduct of the studies were taken into account. In this sense, the dissertation applies the premises of the grounded theory approaches (Charmaz, 1995). The studies represent different domains where the possible safety consequences differ regarding the number of possible victims or the nature of the threat (own life, human lives or environmental). The safety classes were roughly formulated based on this. The domain code, order of studies, practical aim, emphasis and safety criticality class are presented in Table 3. The presentation order of the studies in the tables follows the order in which they were conducted.

### **2.1.2 Differences of the studied operator tasks**

The studied domains fall into different categories regarding the safety criticality but also regarding the other dimensions (Table 4). The studied work can all be considered operator work, because all tasks normally included (more or less exclusively) managing of complex, dynamic environments (Rogalski et al., 2002). The classification presented by Hoc (1993) can be used to illustrate the differences, although a more accurate categorisation according to this typology

is not carried out and the nature of Table 4 is tentative. The terms, high, low and medium, characterise relations between the studied domains. The studied operator tasks in different domains differed with regard to the control scope (the range of the set of key variables the operators can supervise from both the information and intervention point of view), the directness of control (the range of possibilities remaining open to the operators for handling the crucial process variables more or less directly), process (the controlled object) information accessibility, the level of automations and the time constraints. The time constraint is not very tight in any of the studied tasks in comparison with e.g. fighter pilot's task, but the time constraints differ according to situations. All the tasks can be considered control of continuous dynamic processes that more or less evolve without intervention of the operators (Hoc, 1993), but the nature of the main controlled process/object differed including only the technical process or also the humans. The other differing dimensions (Rogalski et al., 2002) are the level of required qualifications, the role of training and the role of procedures in disturbance control. The role of the operator team cooperation is important in every studied task (except in the some VTS centres where the operator is alone on duty, Article III).

Table 3. Empirical studies.

Empirical studies	Study A	Study B	Study C	Study D	Study E	Study F
<b>Code</b>	<b>NPP CR</b> (nuclear power plant control room)	<b>CPP</b> (conventional power plant)	<b>Pilot</b> (accident occurred during piloting)	<b>NPP OJT</b> (nuclear power plant on the job training)	<b>ES</b> (expert service for pulp mills)	<b>VTs</b> (vessel traffic service)
Source article	I	III	IV	II	III	III
Conducting order	1.	2.	3.*	4.	5.	6.
Practical objective	Validation of the new safety information and alarm system	Recognition of the main challenges related to human factors on the plant's production reliability	Development of socio-technical system based on an accident analysis	Recognition of the challenges in the change of the operator generation situation: Development of on-the-job training practices	Explaining the difficulties in developing new service, supporting further development	Harmonise VTs operations by recognising the main obstacles for it, supporting current development actions
Safety criticality class**	A	C	B	A	D	C
The emphasis regarding the studied phenomena	Control of disturbances Relationship between tools, way of acting, conceptions and outcome	Control of dynamic process situations, conceptions of work Relationship between work demands, working and conceptions	Failed control of dynamic situations Relationship between prerequisites (situational demands and external resources), working practices, their history and the outcome	Conceptions of work, self and competence development Relationship between work demands and development of expert identity in a social community	Conceptions of work, control of vague object Relationship between work demands, resources created or supported by organisational development actions and development potentials in a new profession	Conceptions of work, control of uneventful situations Relationship between work demands, resources, development history and expert identity in an emerging activity

\*The study was finalised and published last; \*\*Classification (A = the most critical – D = the least critical)

*Table 4. Different dimensions of the operator work and characteristic of the operators' tasks in studied domains. A relative comparison between the domains.*

<b>Domain Dimensions</b>	<b>Nuclear power production</b>	<b>Conventional power production</b>	<b>Sea piloting</b>	<b>Expert service on pulp and paper industry</b>	<b>Vessel traffic service</b>
Control scope	High	High	Medium	Low	Low
Control directness	Medium	High	Medium	Low	Low
Process inform. accessibility	Medium	Medium	High	Low	Medium
Level of automation	High	Medium	Medium	Low	Low
Time constraints	Medium	Medium	High	Low	Medium
Nature of controlled process	Dynamic, man-made	Dynamic, man-made	Dynamic, incl. nature	Dynamic, incl. humans	Dynamic, incl. humans
Qualifications	High	Low	High	Medium	Medium
Training	High	Low	Medium	Low*	Medium
Procedures	High	Low	Medium	Low	Medium
Co-operation	High	High	High	Medium	Medium
	Permanent teams, officially defined division of work	Permanent teams, division of work adaptive	Ad hoc teams, members from different organisations	Remote co-operation, division of work adaptive	Permanent teams, division of work based on surveillance sectors

\*The needed level of education is high.



## 2.2 Data and analysis methods of the cases

Table 5 describes the data of the studies and Table 6 the main phases of the analysis. In all but Study D the data gathering and at least the pre-analysis were carried out by an interdisciplinary research team.

Study A was carried out in a full-scale high-fidelity training simulator. The SIAP system was tested in an experimental study with a design according to which six crews each performed four accident scenarios. The purpose of the SIAP is to provide an overview of the state of the plant in a severe disturbance or accident situation and to aid the use of the emergency operating procedures. Each crew managed two test situations with, and two without the aid of SIAP. An integrated validation concept was used that included a new approach to measuring system and operator performance in complex work environments (Article I).

Study B focused on the “ordinary” operators at a conventional combined power plant, that had survived many modernisation projects and ended up as a combination of old and the newest technology. In Studies B, E and F the Contextual Assessment of Working Practices were developed and utilised (Article III).

Study C aimed at promoting the development of a complex socio-technical system based on accident analysis. The primary material of Study C was 10 accidents that occurred to foreign ships during piloting on Finnish fairways. In this analysis a new accident investigation method was utilised (Article IV).

The practical challenge of Study D was the change of the operator generation. The study focused on the trainees’ abilities to develop an operator identity through daily work during their on-the-job training in a nuclear power plant operating at base load with a high load factor. In this analysis ExId was utilised in the analysis of the interview data (Article II).

Study E concerned quite new activity that is still taking shape. The study focused on the remote expert service business of one company offering production support services for pulp mills. The expert service was divided into the main organisation and local organisations near the customers. There was a

direct remote connection to the customers' process and excellent video and web meeting possibilities.

Study F concentrated on the other quite new activity, vessel traffic service (VTS). The VTS operators serve vessel traffic on Finnish territorial waters by monitoring traffic safety and flow, giving relevant information and guiding vessels (Gulf of Finland. VTS Master's guide). The study was concerned with the VTS operators' working practices at all six VTS centres in Finland.

According to the methods used in the data collection and the situations studied, the studies can be placed on an emergency (Study A, C) – normal (others) axis, a simulated, controlled (Study A) – real (others) situations axis and a retrospective (Study C) – simultaneous data gathering (others) axis.

Table 5. Data of the empirical studies.

Studies / Code	Study A: NPP CR	Study B: CPP	Study C: Pilot	Study D: NPP OJT	Study E: ES	Study F: VTS
Participants	6 crews, 4 members from each (24)	3 plant engineers, 15 operators	Pilots and bridge crew (masters and/or first mates) involved in studied 10 accidents.	3 experts and managers, 7 shift supervisors, 3 field operator instructors, 11 trainees/new operators	Representatives of tasks on different hierarchical levels of both organisations	VTS operators and supervisors in 6 different centres; persons responsible for the development efforts
Interviews	6 group interviews; recorded and transcribed	18; recorded and transcribed	(Conducted by AIB*, when possible); memos	24; recorded and transcribed	11; recorded, notes	12; recorded and transcribed
Observations	6 crews each in four different scenarios (24); videoed; expert observations based on structured protocol	5 different crews in 6 real start-up situations; videoed	–	–	5 (control room crew, 2 local and 2 head service experts)	6 crews in change of shift situations
Debriefing interviews	Group debriefing interviews after each simulator run, total 24; recorded	Stimulated recall 12; videoed	–	–	Contextual inquires 8; recorded	Contextual inquiries 12; videoed
Contextual inquiry/stimulated recall						
Workshops	1 (Feedback for participants)	1 (18 participants from the plant)	2 (Feedback sessions for FMA** and FinnPilot)	–	4 (8–14 participants from the research project)	1 (10 participants from VTS centres, local offices and VTS authority); videoed
Documents, presentations (given by persons from the studied organisations) and other material	Registered major process parameters	Process logs and trends, shift books, incident reports	Accident investigation material of 10 accidents, over 60 historical documents	Authority instructions	Presentations 3 Marketing procedures, contracts, service reports	Presentations 5 VTS master guides, IMO*** material, maps, shift books

\*Accident Investigation Board; \*\* Finnish Maritime Administration; \*\*\* International Maritime Organisation

*Table 6. Characteristics and phases of analysis.*

<b>Studies / Code</b>	<b>Study A: NPP CR</b>	<b>Study B: CPP</b>	<b>Study C: Pilot</b>	<b>Study D: NPP OJT</b>	<b>Study E: ES</b>	<b>Study F: VTS</b>
Analysis of data	quantitative and qualitative	qualitative	qualitative	qualitative	qualitative	qualitative
Process performance indicators used	Yes, 4 different sets (for each scenario)	Yes, one set	Accident	No	No	No
Functional situation models	4, (for each scenario)	1 (for start-up)	Situational demands analysed	No	No	Situational demands analysed on a general level
Core task modelling	No, indicators of operator practice based on earlier studies	Whole and start-up situation	Whole	No, identified demands based on the operators' conceptions	Partly, functions defined, one function modelled as whole, including competence demands	Functions defined on the basis of the operators' conceptions, no formative modelling
Description of external resources	Yes, with respect of the safety information and alarm panel	Yes, as different ways to produce power	Yes, as prerequisites for safe piloting	Yes, as possibilities for developing competence and expert identity	Yes, as a form of recognition of different cornerstones essential to service	Yes, as a form of issues affecting the construction of current practices
Description of working practices in terms of	Situational course of action cycles, way of acting, using assessment criteria, conceptions of the panel	Demands taken into account or overlooked in working, recognised or not in conceptions of work	Situational reconstruction of navigation and co-operation on bridge during accident voyage	On-the-job training practice, conceptions of work, self-expertise and learning	Conceptions of work, grounded-theory like	Conceptions of work, grounded-theory like

*Table 6 continues.*

<b>Studies / Code</b>	<b>Study A: NPP CR</b>	<b>Study B: CPP</b>	<b>Study C: Pilot</b>	<b>Study D: NPP OJT</b>	<b>Study E: ES</b>	<b>Study F: VTS</b>
The focus of assessment of the working practices	Differences regarding to the availability of the panel, crews, situations	Strengths and weaknesses of the shared practices	Strengths and weaknesses of the shared current piloting practices,	Adequacy of the on-the-job training practices regarding the conceptions of the demands, possibilities to learn	Demands taken into account or overlooked in working, conceptions of work	Sources of meaningfulness of the work, the functions regarded by the operators as an important part of the core task
Explanations based on the analysis of	Coherence and situativeness of the assessment items, design model of the panel, complexity of the scenarios	The current organisation, marketing environment, history	Two ways of navigating, history, tensions in activity system (Engeström, 1987)	History of the plant, nature of the operators' experience, opportunities, procedures	Cornerstones, tensions preventing efficient service	Development history of the centres, available resources, feedback sources, local demands

## **3. Results**

### **3.1 Support to the ExId construct**

#### **3.1.1 Empirical support to the layers (Article II)**

The definitions and purposes of the different layers found some support in Study D. The content of ExId was related to the creation of motives that define the content of the activity for which the operator (or trainee) feels mainly responsible (e.g. studying). The purpose of the outermost layer (meaningfulness) in creating motives (goals) valued as worthy of effort was supported by the result that the trainees found learning meaningful; meaning was provided by factors essential for reaching the competence and confidence for taking care of the operator work. Learning and studying instead of the duties of a field operator or operator work dominated in the trainees' responses. The sources of motivation among experienced supervisors were related to e.g. the responsibilities of shift supervisor and resolving disturbances. The state of professional self-confidence as creating a basis for using one's competence, for co-operating and for relying on oneself and others got some support. The trainees expressed the need to obtain self-confidence and seemed to have a realistic idea of their own insufficient competence. Moreover, admitting ignorance was not regarded as a threat. When everybody had a trainee status or their licence was still fresh, this was also socially accepted, even supported. In the narrative of the trainees, the importance of a sense of control was mostly related to the ability to operate in disturbance situations. The sense of control and self-confidence seemed to be anchored to external instruments rather than to one's known limited experience. There were differences between the generations when considering closely the sources of the sense of control and confidence. The trainees identified limit values, safety systems, instructions and others, whereas the experienced operators emphasised experience in process operation, non-dependence on the instructions and self-knowledge. The energetic role of the innermost layer in regulating one's actions did not get direct support which, of course, is the expected result of an interview study (Article II). However, in Study A the new tool was experienced to reduce stress and enhance e.g. operative structuring of the supervisors' own actions (Article I), indicating a possible connection between energy mobilisation and regulating one's actions.

### **3.1.2 Empirical support to the ExId development (Article II)**

The results of the development of ExId are all indirect, since none of the studies was longitudinal. Comparisons between the operator generations made in Study D were considered. The trainees could be classified on the basis of their conception of themselves, the main activity the trainees felt responsible for, their source of motivation (the outermost layer), their conception of their own competence and the aims they were targeting (the middle layer) and their sources of sense of control (the innermost layer). The conceptions of experienced shift supervisors differed from the trainees and could be used to illustrate the difference between the generations. Moreover, there seem to be more indicators pointing to the operator identity in the most experienced trainee group than in the other trainee groups expressing the possible movement from trainee identity towards an operator identity. The importance of experience of managing disturbance situations and having possibilities to control were evident in Study D. A disturbance situation was often seen as the true test of professional competence – and acquiring experience of disturbance situations as the only way of becoming a true professional. The opportunities for learning were seen to have changed and this was combined with e.g. the limited opportunities to learn through exceptional situations and by doing. (Article II.)

Balance between the work demands and competence, systematic and gradual increase of demands and responsibilities, and earning trust from the social community could all be found in the interviewees' narrative of current on-the-job training practices and development of expertise. The recognised key challenge and motive in the development of professional competence was to achieve not only an adequate degree of competence but also personal reliability; to construct confidence in being able to cope with a potential disturbance situation. The narrative of disturbances refers to the recognition of the uncertainty of the process among the trainees. Instructions and limit values, as well as faith in being able to control the uncertainty of the object with their help, may promote the sense of being in control. This is not necessarily negative at the stage where the trainee has little competence to rely on – and little responsibility. When considering the ways to reach confidence and a sense of control, experience and simulator studies were mentioned. The on-the-job training practice at the time of the study was such that the trainees gradually familiarised themselves with each task under the supervision of an experienced employee,

somewhat like apprentices. The trainees gradually progressed via examinations to various posts, possibly even to the most challenging task of shift supervisor. The opportunities for actual work performance are limited by official regulations in the first place, but the trainee must also first earn the trust of his ‘master’, his instructor. The trainee gradually progresses from watching to doing things under supervision, and, finally, having earned the trust of his instructor, also to doing things independently. Both the trainees and the more experienced employees listed ensuring safety by a more experienced employee as a key demand for the training period. The trainees themselves also emphasised the acquisition of personal confidence as a goal for the practice periods and training.

The two further issues “Appreciation and knowledge of the activity” and “Reflection of the core task and the changes in the work and its environment” hypothesised to affect the development of ExId are considered in the next section.

## **3.2 Use of the new construct in empirical analyses and the main results**

### **3.2.1 Summary of the main results of the studies and the use of ExId, all articles**

The six empirical studies aimed to contribute to the practical development of work. Their results expressed how the core task is taken care of, what explains this and where to focus in the development efforts in each particular context. Table 7 summarises the use of ExId and the main results of the studies from the point of view of the research questions stated in this dissertation.



*Table 7. Summary of the use of ExId, particular findings promoted by it and the main results of the studies. (On next three pages.)*

<b>Studies / Code</b>	<b>Study A: NPP CR</b>	<b>Study B: CPP</b>	<b>Study C: Pilot</b>	<b>Study D: NPP OJT</b>	<b>Study E: ES</b>	<b>Study F: VTS</b>
Practical objective	Validation of the new safety information and alarm system	Effects of human factors on the production reliability of the plant	Development of a socio-technical system based on accident analysis	Change of the operator generation: Development of on-the-job training practices	Explaining the difficulties in developing new service, supporting development	Harmonise VTS operations, supporting current development actions
Use of ExId in	Not yet available Recognition of challenges of studying the 3 <sup>rd</sup> interaction	Definition of the core task demands of work	Definition of the core task demands of work	Assessing possibilities to develop operator identity	Definition of the core task demands of work	Recognition of sources of expert identity in analysing the obstacles to harmonising practices
Summarised usability of ExId	In the used method there were 6 indicators for the 3 <sup>rd</sup> interaction of a total of 37 (16%) and 4 (11%) were used in the analysis	In defining indicators related to competence addition to indicators for situational process control and conceptions of work	In defining indicators for and analysing of the third interaction: 10 of a total of 27 (37%); including indicators related to both situational and expertise development; 3/10 (30%) indicators for the 3 <sup>rd</sup> interaction were usable in less than 40% of accident cases in comparison with 4/10 (40%) for the 1 <sup>st</sup> interaction.	In defining current state of the trainees' identities and analysing possibilities and challenges to develop identity and expertise needed in operator work	Utilised as a part in defining general indicators related to practice and competence and analysing adequacy of resource development	Utilised as a part in recognising differences between centres and the conceptions of core task, related practices, competences and operator identities developed in the centres
Methodical results	Integrated validation concept	Contributed to the development of the CAWP -method	Accident investigation method based on Core-task Analysis	Expert identity - construct	Contributed to the development of the CAWP -method	Contributed to the development of the CAWP -method

CAWP = Contextual assessment of working practices

Studies / Code	Study A: NPP CR	Study B: CPP	Study C: Pilot	Study D: NPP OJT	Study E: ES	Study F: VTS
Particular findings promoted by new emphases of or/and contributed to ExId	Process performance level (outcome) remained unchanged when the operators changed over the system. Adding new technology affected many parts of the operators process control and co-operation negatively, but was still experienced beneficial because it was <i>felt to reduce stress</i> . This feature was supposed to have enormous impact in real disturbance situation	Core task changes when activity environment changes: working practices and competence should change correspondingly Focus of the analysis should widen to take into account the issues affecting the possibilities to follow the changing core task	When the core task changes and resources and practices do not follow that adequately, there seems to be a tendency for traditional practices (only partly corresponding with the current demands) to get even stronger when situational conditions become more demanding; the relative drop was most visible in ExId-related indicators	The strengths (provides safe environment to gradually build operator identity and competence) and weaknesses (inefficient if individual responsibility is emphasised together with experienced difficulties to learn from daily work) of apprentice-master model in supporting competence development In development of expertise there exist other sources than those related to one's own competence for sense of control and confidence, e.g. procedures, safety systems or more experienced workers, which might have an important role in making it possible to accept the uncertainty of the object	Development of prerequisites for new activity should take into account all critical "cornerstones" of that activity. Neglecting or overemphasising some could result in a situation where the core-task and aimed future are unclear and the operators have to try to cope with different tensions endangering their wellbeing and the development of new business	When the official definition of the core task is vague or missing, and the activity is self-constructed, local characteristics of the object of the work and the resources for taking care of it, lay down the conditions for the activity –and for the practices and the professional identities to be constructed. Available sources of feedback and finding content of work most strongly related to the aimed outcome (safety) affects development.

<b>Studies / Code</b>	<b>Study A: NPP CR</b>	<b>Study B: CPP</b>	<b>Study C: Pilot</b>	<b>Study D: NPP OJT</b>	<b>Study E: ES</b>	<b>Study F: VTS</b>
<p>Characteristics or issues that might promote or complicate mastering of the core-task</p>	<p>Complicated, at least momentarily, by changes in the available tools affecting the practices.</p> <p>Promoted by availability of the tools that are felt to reduce stress in a demanding situation and that support also coherence and situationally attentive action both in clear and diffuse task context.</p> <p>Implementation of a new tool into professional practice is complex. The benefits gained from the tool differed regarding to the correspondence between it and the content of practices (coherence vs. situativeness) and situation.</p> <p>Promoted by reflection on the nature of the tools (incl. procedures).</p>	<p>Complicated by change of core task demands originating from changes in the business environment.</p> <p>The operators and organisation need support in this even in a work context where they are used to the modifications of the plant and the related changes in the work. Support is also needed in opening new solutions to old, long recognised problems.</p> <p>Permanent shifts had created co-operative strengths into a shift's practices but complicated communication with other shifts.</p>	<p>Complicated by change of core task, resources lagging behind it.</p> <p>Tendency for traditional practices to get stronger when situational conditions become more demanding: increases the negative effects of change.</p> <p>The exploitation of technical tools requires comparable co-operative practices.</p> <p>Solving tensions in the whole activity system could promote the mastery.</p>	<p>Complicated by the actual and conceived difference of demands between daily work and disturbance situation.</p> <p>Complicated if daily work is not regarded as contributing to the development of expertise.</p> <p>Promoted by gradual expertise and confidence development in line with "legitimate peripheral participation".</p>	<p>Complicated by discrepancies between official visions and definition of the work and the reality faced by the operator: affects the development of resources and complicates recognition of the core task guiding personal development efforts.</p> <p>Supported by the operators' participation on the development of the activity.</p>	<p>Complicated by discrepancies between the official definitions of work and experienced sources of meaningfulness among the operators.</p> <p>What is considered as core task guides the development of practices and own competence.</p> <p>Potentially promoted by supporting construction of new operator identities corresponding with a new, shared core task.</p>

### **3.2.2 Issues promoting and complicating mastering of the core task, all articles**

#### **3.2.2.1 Change of work endangers the core task**

The results of Studies C and B showed most clearly the problems resulting from the changes that affect the conditions of the work, the correspondence between the demands and the resources (Table 7). The results of Study C showed, that the changes can cause tensions in the activity system that directly affect the possibilities of coping “at the sharp end” and can result in accidents. The studied tasks (Studies C and B) were both considered as quite “old” worktasks, although the history of piloting extends several hundred years and power plant operating only some decades. Many individual operators and other personnel have witnessed many changes before, thus the phenomenon is not new for them. The results of Study C showed that when conditions become gradually more demanding during piloting, there is a tendency for the traditional practice (characterised e.g. by pilot-centred piloting) to get stronger. The third interaction, the relationship to a person’s own actions, appeared to be the one most deeply connected to the traditional practice. The third interaction got lower scores than the others in performance assessment. In the group where the traditional practice was interpreted as the strongest the drop was also the biggest.

As could be expected on the basis of earlier studies, the results provide evidence that practices adapt over time. One of the strengths of the conventional power plant operators’ working practices was coping with the technical diversity of the plant. Another strength was taking care of the transitions and disturbances of the process. These tell about the ability of the operators to adapt to changes and develop practices and the needed competence through experience (Study B). Indications that a new piloting practice is emerging were found in the piloting (Study C). However, in light of the cases the adaptation of the operators’ practices and competence to the changed work demands is not deep (Study C) or quick enough (Study B). A common explanation for the part of the weaknesses in practices endangering the reliability of the production was found in Study B: the environment was significantly changed after the deregulation of the electricity market resulting in a new, unrecognised demand for the operators’ working practice. The operators had neither the competence nor the tools to

make the needed short-time production decisions that had previously been taken care of by the plant engineers' strategic plans.

The change of work can also result from changes in the external resources. In Study A the new tool did not impair the outcome of process control, but changed the working practices of the crews. The results of Study A indicated that the operators can be quite good in assessing the strengths and weaknesses of the new tool – at least after the test situations when reflection is promoted by the interview. The subjective evaluations corresponded to the effects observed in controlling the simulated disturbance. In spite of noticing the weaknesses and the training they had got, the operators did not manage to avoid the negative effects of the new tool on their process controlling and co-operation, especially in the more complex and diverse disturbances. In Study B the same demand was sometimes recognised (in interview) but not taken care of in action.

There are also problems in finding adequate solutions within the organisation for the long-recognised weaknesses in the practices, as Study B indicated. A weakness, communication between the shifts, was well recognised as something that could endanger the reliability of the plant but the attempts to solve this problem by procedures had failed. The study resulted in new explanations for the old problem: the operators did not have a common competence base or shared conceptions of their work. Furthermore, the responsibilities of transforming information in the change of shift situation were unclear.

To conclude, there is clear evidence that extra support is needed in order to be able to take care of the core task.

### 3.2.2.2 Deficient external resources

The results of the studies showed deficient external resources for taking care of the core task demands (Table 7). The conditions (e.g. fairways and navigation equipment) for piloting were found impaired in many of the accident cases (Study C), the tools did not correspond to the new demand of making production decisions in the conventional power plant (Study B), the development of resources for the expert service had focused on the technical possibilities to make remote control possible, which was insufficient with the real demands of the work (Study E), and the VTS centres had partly different resources for

operating more or less comparably with the operative area or the aimed functions of the whole service (Study F).

In Study E, it was clear that the visions and the actual content of the work differed quite remarkably. Seven strongly development-oriented critical functions of expert service business were recognised. One of them was closely scrutinised and several challenges were recognised in the current practices. Four critical cornerstones of the expert service were recognised: trust between the expert(s) and the customer; context knowledge of the mill; expertise and the technical cornerstone. A major obstacle for handling the core task was that the development activities of the service had overemphasised the technical prerequisites and neglected, or not even recognised, the others. In Study F, the official definitions and the actual content of the work and the adopted practices differed between the VTS centres.

Thus, the discrepancy between the demands and the resources is not only a consequence from rapid changes in the activity system. One reason for the discrepancy appears to be the inability to reach the real content of the work from the point of view of the operator and thus to focus development efforts adequately.

### 3.2.2.3 Limited possibilities for the operators to develop personal resources

The results also showed issues that complicated the operators' possibilities to grow into or with the demands. They are: discontinuation of the work demands, discrepancy between conceptions of work held in other parts of the organisation, the visions and reality faced by the operators and emphasis on the individual efforts and situational solutions. Study D showed that the possibilities of the new generation for learning in the daily work and acquiring the needed competence and confidence were regarded as limited and the emphasis was put on individual study. The conceived and actual, demands and possibilities to develop expertise in the daily work and disturbances were found different. In Study E, overemphasis of the technical cornerstone of the service business had resulted in a situation where the future direction of the service business and the work of the experts were unclear and the experts had to try to cope with seven tensions. This endangered both the wellbeing of the experts and the development of the service

into a profitable business. The negative effects of unsolved problems and putting emphasis on individual effort and situationally made solutions were evident in Studies C, D and F.

Study F offers an example of both negative and positive effects of self-constructing activity. General definitions of the new service and locally coordinated development enabled the service to answer the local needs and actually define by practice what VTS is. However, the development resulted in a situation where most of the operators' personal resources (competence and operator identities) which they had succeeded to develop during the first years of the service were more an obstacle than an accelerator for adopting common practices. More specifically, the VTS study indicated that the characteristics of the object of the work (the operative area), and the resources for taking care of it, laid down the conditions for the activity – and for the practices and the expert identities to be constructed. The results of Study D, Study B and Study E support this conclusion. The two new activities (Study E and Study F) also highlighted the important role of visions in the development.

Both issues, “Appreciation and knowledge of the activity” and “Reflection of the core task and the changes in the work and its environment”, seemed to be important when aiming to affect the development of ExId. A further aspect recognised was the importance of visions of the aimed future for the development of personal and other resources.

#### 3.2.2.4 Limits of the development means

The studies provided examples of the possibilities and limits of the different kinds of practical means to support core task management: design of technology, procedures, organisational solutions and on-the-job training (Table 7).

The results of Study A demonstrated that even a well-designed tool is linked with the model on which its design is based. The change of practices was in many (assessed) aspects negative although the new tool can be considered as an example of user-centred design. There were indications that the tool might have a crucial effect on reducing stress and thus supporting the third interaction (which the method did not cover adequately). The SIAP was experienced to provide help in the operational structuring of the supervisor's own and the

crew's actions, in the use of emergency procedures and in maintaining an overall situation awareness. The system was considered as an extra source of information and it had the ability to highlight novel events. Also negative aspects, e.g. in co-operation, were recognised by the crews. The amount of experience the supervisors had working with or without the panel corresponded with their experienced difficulties either with or without the panel.

The results of Study C highlighted the importance of the ability to use technical tools and comparable co-operative practices on the bridge as a solution to increasing demands.

Study B provided evidence that the same organisational solution, permanent shifts, can be both negative in some senses and positive in others. The communication problem was a negative side effect of keeping the shifts the same for many years and allowing them to develop their own, implicit ways to e.g. divide work. The positive aspect of permanent shifts was the co-operative strengths of the current practices within the shifts. Study D showed both strengths and weaknesses of the apprentice-master model in the studied NPP context (Table 7). Development of the on-the-job-training practice such as it in particular supports the construction of the operator identity by utilising all possible learning opportunities could improve the possibilities to construct the needed (living) expertise and confidence. However, the possibilities for learning through daily work are restricted by the actual content of the work and by how these possibilities are considered. This and the results of Study F emphasise the importance of taking into account how the operators conceive themselves, the demands of their work and their own resources for coping and learning.

The above problems are related to the used methods to explore and develop and the ability to grasp the diversity of the phenomena. The results of the studies from the point of view of supplementation of the work analysis and development methods are summarised next.

### **3.2.3 Exld in supplementing methods based on Core-Task Analysis**

The studies also resulted in methodical findings (Table 7). Article I (Study A) presents a CTA-based emerging integrated validation concept (see also Norros



and Savioja, 2004a) and the method for evaluation of the appropriateness of the new system performance through simulator exercises. The method and the used assessment indicators are based on earlier studies (Hukki and Norros, 1998; Norros, 2004 pp. 104–145). As already noted, Study A expressed the weakness of the used assessment method in reaching the stress-related effects on the working practices. Article II continued with that theme and presented a suggestion for a solution, the new construct Expert Identity. The construct worked well in the analysis of the prerequisites for expertise development in Study D and the assumptions made in the model got some support based on the empirical findings, as already noted in Section 3.1.

The usability of the ExId construct as a part of the Contextual Assessment of Working Practices (CAWP) method was tested in the studies summarised in Article III. CAWP is a method for defining what good practice is in a particular context and for assessing and explaining it so that the practical ergonomic interventions and development can be guided. It is intended for co-operative use for human factor researchers or ergonomists and practitioners. CAWP is based on CTA and originates from the method used in Study A. It was developed originally for evaluating nuclear process operators' ways of acting in simulated disturbance situations and for supporting their training (Hukki and Norros, 1998; Norros, 1989; Norros, 1998). CAWP proved to be applicable for different practical purposes in different kinds of real operator work contexts based on different levels of analysis. It also appeared to be promising in recognising competence demands (Study E). (Article III.)

Article IV presents the second step in the development of a new, systemic method for accident investigation. This method is also based on core-task analysis. The first attempt was made in connection with analysing several air-traffic control incidents (Norros and Nuutinen, 1999; AIB B 8/1997; AIB 2/1993). Here, this method was used and developed further in the context of an extensive investigation of maritime accidents (see also Nuutinen and Norros, 2001). The new main elements in the method were explicit use of the indicators based on the Core-Task Model (c.f. Article I) and of the ExId construct as a part of the model. Moreover, the activity system model was used in the analysis of the organisational background. The developed method fulfilled well the requirements of generalisation and of reaching the point of view of the actors at the sharp end without losing the global perspective of the activity system. The

importance of the integration of expert work emerged during the investigation and the ability of the method to meet this requirement was not proved although some positive indications were found. (Article IV.)

ExId worked reasonably as a part of the methods in the modelling of the core-task demands, in assessing the external resources and the working practices, in explaining the practices and in concluding the development challenges in several cases with different practical aims (Article III and Article IV). The applicable demands for the third interaction could be created (Table 7).

## 4. Discussion

The aim of this thesis was to increase the understanding of demanding situations and of the resources for coping with these situations by presenting a new construct as a way to open up new solutions to the problem of demanding situations and by testing the construct in empirical studies on operator work. The premises of the CTA-framework were adopted as a starting point: core-task oriented working practices promote the system efficiency and that should be supported. The essential question was why the unanticipated, unfamiliar events and the unexpected changes are the problem and how the workers can be prepared for them. The starting point was the suggestion that shifting the focus of the analysis to the emotional-energetic side of human performance and cognition could promote new insights into the practical problem of coping with demanding situations. The negative effects of stress were summarised and the possible countermeasures related to the operators' personal resources such as experience, expertise, courage, conceptions of work and self etc. were considered. The ExId construct was proposed as a way to bring emotional-energetic depth into the work analysis and to supplement CTA-based practical methods to discover development challenges and to contribute to the development of complex socio-technical systems. The applicability of ExId was demonstrated in the context of the six empirical studies on operator work that all had their own practical objectives with the corresponding quite broad foci of the studies. Another suggestion emerged during the development of the construct and its use in empirical analyses; focusing more in the analyses on the content of the expertise and its development on how the operators conceive themselves, the demands of their work and their own resources for coping and learning. The concluding research questions were: 1) Are the assumptions made in ExId on the basis of the different theories and previous studies supported by the empirical findings? 2) Does the ExId construct promote understanding of the operator work in empirical studies? 3) What are the strengths and weaknesses of the ExId construct? The results of the studies are summarised and their limitations discussed shortly before addressing the strengths and weaknesses of the ExId construct to rise to the stated challenge.

## 4.1 Summary of the results

There were three kinds of results in this dissertation: those concerning the potential of ExId; the issues that complicated or promoted the mastering of the core-task and the methods developed to explore and support the operators' work.

The state of the presented construct was considered tentative. The main purpose of the empirical studies was to test if the construct owns enough potential to justify further testing and development. The first research question "Are the assumptions made in ExId on the basis of the different theories and previous studies supported by the empirical findings?" and the second one "Does the ExId construct promote understanding of the operator work in empirical studies?" both gained a promising positive answer. The layers and the assumptions of the development of expert identity appeared to gain evidence. The new construct worked as a part of an analysis of different kinds of data, as a part of the methods used for different purposes, in different work contexts.

The results showed problems in taking care of the core task resulting from the discrepancy between the demands and resources (either external or personal). Some of the problems originated from the changes that affect the conditions of the work, either the demands or the external resources and thus also the correspondence of the personal resources. In light of the evidence from the cases the adaptation of the operators' personal resources to the changed work demands is not deep or quick enough. The studies revealed a serious problem in recognising a change in the activity system and interpreting it into new demands for practices and expertise by the practitioners themselves or within the organisation. There was clear evidence that extra support is needed in order to be able take care of the core task.

The other reason for the discrepancy appeared to be the inability to reach the real content of the work from the point of view of the operator (in general). Thus, there might be serious difficulties in focusing the development efforts adequately in the upper levels of the organisations. Also, the same practical mean to support core task management appeared to have both positive and negative effects. The studies provided examples of the possibilities and limits of the different means regarding the particular context. Among the factors that were relevant are the demands and learning opportunities of the work, the current (co-

operation) practices, the personal history of experience and the conceptions of work and self. Furthermore, the results showed issues that complicated the operators' possibilities to grow into or with the demands and to develop practices, expertise and the expert identity matching the core task. These issues were: discontinuation of the work demands, discrepancy between conceptions of the work prevailing in other parts of the organisation, visions and the reality faced by the operators, emphasis on the individual efforts and situational solutions.

The above problems are related to the methods to explore and develop and their ability to grasp the diversity of the phenomena. These supplementing methods were shortly described.

## **4.2 Limitations of the studies**

The studies reported in this thesis have some limitations that need to be considered. The nature of the discussion presented here is concluding over and comparing between the different studies, since the more detailed discussion of the validity and reliability of each case is described in the corresponding article. The gained results are discussed in more detail from the point of view of the aims of the dissertation in Section 4.3.

The first limitation of the studies was their broad scope. The original articles present rich material of various issues related to the mastery of work, only some of them were selected to be summarised in this dissertation. The broad scope of each study resulted from the strong pragmatic motivation of this dissertation and the VTT link in conducting the studies. The choice of the case study for the research strategy for individual studies was also motivated by the pragmatic orientation in addition to the contextual emphasis of the CTA-framework and the targeted opening of new paths. There is no clear set of criteria for differentiating poor and high-quality cognitive task analysis and cognitive field work (Hoffman and Woods, 2000). The broad focus contributed positively to the practical applicability of the results but negatively to the depth of the analysis of single issues or the ability to test specific assumptions of ExId in the studies. Although there were no follow-up studies, the gained results were accepted in the studied organisations and some actions were taken on the basis of them (Article III)

indicates the practical applicability of the results. Thus the studies met the “satisfying” criterion usually used in the evaluation of studies of cognitive systems in context (see Hoffman and Woods, 2000).

The second closely related limitation was the relatively small number of cases in comparison to the important themes related to the demanding situations discussed in the introduction. The cases can be considered representatives of operator work and to complement each other. The other than methodical generalisation from case studies is always difficult and not always even needed. The studies were considered as a purposeful sample of the operator work and thus careful generalisation into that group can be conducted regarding the issues that affected the operators’ possibilities to master the core tasks. The studies can be identified into domains that differ with regard to their safety-criticality and the characteristics of the studied work were different in many dimensions. The NPP studies represent a typical critical domain and object of safety research and Study A also utilised the commonly used method: simulated disturbance exercise. Study D considered a practical problem of learning through daily working in the same domain. The CPP-study represented a counterpart of the NPP: production of power, but in a non-safety-critical domain. The studies, however, covered only some of the many possible combinations of the differences and dimensions in the operator work (cf. Hoc, 1993; Rogalski et al., 2002). Also the studied situations differed. The piloting accidents can be regarded as extreme cases of real accidents – with corresponding problems of data and analysis (Article IV). The service expert case represented another kind of extreme: stretching the concept of operator work. However, the possibilities to confirm findings in other studies were limited by the number and the many dimensions by which the cases differed. Because of these, generalisation of the findings should be made with care and considered tentative. Following the process of generalisation (Xiao and Vicente, 2000) would require to get acquainted with the original articles. The importance of characterising the studied work, situation or boundary conditions is emphasised by many authors (Hoc, 1993; Xiao and Vicente, 2000), but there is a lack of common agreement on how to generalise, how to define what the studied situation is a case of (Hoffman and Woods, 2000). The choice of different tasks and different practical challenges under empirical study was also motivated by their purpose: to test if the construct owns enough potential to justify its further testing and development.

The third limitation of the studies is the diversity of their conduct. The research frame (Table 3), the data collection methods and the analysis differed (Table 5 and Table 6) resulting partly from the different objectives, the constraints set by the studied organisations and funding – the realities of ergonomic studies. This is also related to the serial (and partly parallel in the sense of publishing the results) conduct of the studies: the analysis of the first study was conducted already in 1997 and the last study was finished at the end of 2005. The mostly qualitative methodological orientation employed in these studies places specific value on the operators' own conceptions of their work, themselves and their own and external resources. This emphasis gradually increased during the studies and it was influenced by the methodological ideas of the rethinking psychology and grounded theory presented by e.g. Strauss and Corbin (1998) and Smith (1995). The other change during the studies was the increase of use of the developed, phased methods together with the ExId construct in order to frame the analysis and thus increase the efficiency and transparency of the analysis, e.g. in terms of warrants for conclusion (Hoffman and Woods, 2000) and prescription (Lipshitz and Cohen, 2005). In the different phases (or aspects) of analysis different methods reflecting different philosophical assumptions and strands of qualitative inquiry (Henwood, 1996) were used, but 'a methodologically aware eclecticism' (Hammersley, 1996) was pursued.

The fourth limitation is about the relationship between the development of ExId and the studies, which complicated their use as a test of ExId. The basic structure and definitions of ExId are based on the theoretical constructs and the empirical findings behind them, stemming mainly from other research areas. However, the definition as it was presented in this thesis is also based on the studies included in the thesis. Many of the basic assumptions are already founded on our own empirical findings as well as the literature and studies of this domain. This and the broad focus of the studies were a reason why concluding analysis of the studies was conducted from the point of view of the research questions of this thesis. The development of ExId was cumulative, but the supplementing phases of the development were not systemically documented in detail (cf. Table 7). The studies were presented in the tables according the order in which they were conducted to make the process of development more visible.

## **4.3 Strengths and weaknesses of the Exld construct**

### **4.3.1 Opening up of new paths**

One of the key problems recognised by the industry is the management of rare, yet expensive, disturbance situations, which are an example of demanding situations. The safety problem of a demanding situation can be described by the discrepancy between the demands of the situation and the resources available to cope with the demands. If the designers have not anticipated the situation, the tools do not support the working adequately; if the event is unfamiliar to the operator her or his expertise or practices that are based on experience do not give the best resources; if the change is unexpected, “the energetic state” is unoptimal, the human performance can fail to meet its target, to promote the efficiency of the whole system. This dissertation focused on the operators’ personal resources, particularly the expert identities as a part of the working practices.

The results (Study D) suggested that the development of expert identity is a real challenge related to the competence and confidence needed in coping with disturbance situations, at least in the domains where the demands of daily work and disturbance situations are very different and the opportunities for learning through experience are considered limited or non-existing (see also Nuutinen, 2003). It is reasonable to hypothesise that this challenge is relevant also in other industries with highly automated and reliable processes. If technical reliability continues to improve and fine-tuning is also increasingly managed by automated process control tools, there is a risk that the operators cannot develop or maintain adequate competence and, especially, the reliability and confidence required in disturbance situations (irrespective of the informatisation of the object, Zuboff, 1988). Knowing the state of the process might not be enough if active control is not needed. Full-scale simulators, extended initial training, regular examinations stipulated by the authorities and demonstration of professional competence all help ensure the development and maintenance of sufficient competence in safety-critical domains. Although the demands of the emergency and the skills required to cope with a disturbance or emergency situation might differ considerably from the daily work and specific training is always needed (e.g. Kontogiannis, 1999), there is a question one could ask: Could we also do something for the daily work in order to make a continuum of



the demands and thus enhance learning of the aspects of expertise needed in disturbance control from the daily work? The Expert Identity construct was offered as a new way to explore the possibilities offered for expertise development.

The assumptions made about the community- and object-related nature of the development of expert identity found some support. The studies indicated that the characteristics of the object of the work, and the resources for taking care of it, laid down the conditions for the activity – and for the practices and the identities to be constructed. This is in line with the theories of distributed cognition (Hutchins, 1995), learning by expanding (Engeström, 1987) and the communities of practice (Lave and Wenger, 1991; Wenger, 1998). The main difference between ExId and these theories is that ExId focuses primarily on the individual's subjective experience. This quite narrow focus can utilise the different foci of the other theories: the focus on a group work, distributed cognition between humans and automation and information systems in performance; the focus on historically constituted activity system, the constituents that must change in collective learning and the focus on the components of a social theory of learning, identity, community, practice and meaning.

The contribution of the ExId construct to the discussion of demanding situations is to highlight also other ways than training when aiming at building and maintaining preparedness for unexpected and unfamiliar events and changes in the environment by gradual construction and maintenance of a healthy, realistic, core-task-based expert identity. The most important aspect is to consider how one's daily work can provide the basis for expert identity development. The most obvious conclusions are, for example, to increase the possibilities for controlling actions and to facilitate the feedback of one's actions and their success with respect to the core task. At the first look these conclusions do not seem to include anything new (cf. classical work of Hackman and Oldham, 1975; 1980 e.g. pp. 72–82; Hackman and Lawler, 1971). However, the point is that the *same* content and demands of the work that are present in a disturbance situation should be present in the daily work (although in a moderate form) and *they* should be able to promote the feeling of meaningfulness, the sense of personal responsibility and the sense of control, etc. Thus, for example the tempting solution to promote job motivation in supervision and monitoring work

by adding (or taking on) extra tasks and responsibilities for making the job more interesting is not a sustainable solution from the point of view of disturbance control. On the contrary, it could obscure the core task.

The results showed problems in taking care of the core task resulting from the discrepancy between the demands and the resources (either personal or external). Changes in the work were a reality in the studied context, and there were difficulties in reaching the real content of the work and the limits of the practical means of support complicated the problem. The personal resources seemed to be sensitive to the changes, adaptation is taking place, but not deep or quickly enough – and likely not always in proper direction. The rapid change of work is a serious problem if or when neither the external nor the personal resources are following. The difficulties of workers related to the change of work has long been, and still is, a subject of great concern (Boreham, 2002; Paulsson et al., 2005; Zuboff, 1988). The speed of change in safety-critical domain in general might be slower than others, since these environments are highly controlled. However, it is a relevant problem also in safety-critical domains as e.g. Study C and the vivid discussion of the need of adaptation of the practices indicated (e.g. Gauthereau, 2003; 2004; Hollnagel, 2002). It is important to distinguish which adaptation is beneficial and which is not (Gauthereau, 2003; Hollnagel, 2002), or to develop the surrounding system correspondingly. In safety research the gradual adaptation of practices and the need to monitor them are recognised as important in order to prevent accidents. Using the core-task model as a reference is a way to assess the current practices. In systemic accident models human performance variability is seen as necessary for a user to learn and for the system to develop (Hollnagel, 2002). The ExId concept also tries to build a bridge between man's situational adaptive interaction with the environment and the need of continuous adaptation over time; that is, learning in the changing socio-technical system (Article III). The results of Study C and Study F indicated that operator identity could also hinder the development of the working practices or be a weak link in the performance when not congruent with the core task. However, the operators could be the first ones to recognise, if supported, the needed changes in the system, because they have to cope with the results of the changes.

The management of safety in dynamic, complex socio-technical systems or risk management in a dynamic society can be seen as a control problem (Rasmussen,

1997; 2000). For example Leveson (2004) approaches safety in terms of a control problem and introduces a new accident model based on systems theory. In her model “systems are viewed as interrelated components that are kept in a state of dynamic equilibrium by feedback loops of information and control” (Leveson, 2004 p. 250). However, the success of dynamic controlling, as well as monitoring the evolution of practices, is dependent on e.g., the identification of controllers, the objectives and on getting correct information on the actual state of affairs. This is of course, challenging when a complex socio-technical system is concerned (Rasmussen, 1997; Article IV). The tasks of total risk management in society and supporting the workers are not identical, although related. As noted by, e.g Rasmussen (1997 p. 184) “the models we create by bringing together results from several disciplines can be very useful for design of work support systems for the individual actors and decision makers, but they are not very useful for analysing the performance of the total risk management system”. According to Rasmussen (1997) an explicit identification of the boundaries of safe operation together with effort to make these boundaries visible to the actors and to give them an opportunity to learn to cope with boundaries is the most promising general approach to improved risk management.

It is reasonable to hypothesise that the speed of the change is rather increasing than decreasing – also in safety critical domains. This would result in the increase of demanding situations, situations which are unanticipated and unfamiliar to the operators. The problems of the two quite new activities (Study E and Study F) could resemble those waiting for the older activities that enter into the phase of rapid changes. The difficulties to keep up with the change with training courses, changes in the procedures and design of technology will more probably increase than decrease. A paradox of the introduction new technology is that, as such, it creates new competence demands and thus breaks up the personal resources –and affects on the possibilities to develop them. Expert identity could be in particular danger (Study C; Study D; Weick, 2001 p. 465; Zuboff, 1988), but perhaps taking it into account in design and training is a way to better support operators coping with demanding situations (Study A). In order to better follow the rapid changes in the work a stronger contribution in designing the systems, whether technical or large socio-technical systems by their nature, is emphasised by many authors in addition to recognising problems in the existing systems (e.g. Clegg, 2000; MacLeod, 2003; Rasmussen, 2000; Wilson, 2000). A possible solution to the increasing speed of change, proposed

here, is to improve the workers' own possibilities to grow in their daily work and support them by offering reflective assessment of the core task and the current practices but also visions of the future of the work (see also Nuutinen et al., 2005; in press). The visions, in a sense of "best guess of the future" or more systemically analysed "zone of proximal development" and supported by expansive visibilizations of work (Engeström, 1999b), can give more time to the operators to develop their personal resources. Visions, and also instruments for their concretisation, are important in realising changes in an organisation, as shown by Teperi and Leppänen (2001) in the paper industry. The importance of visions has long been recognised in business purposes, but their importance from the point of view of safety has not gained equivalent interest.

In the introduction I hypothesised about the important role of facing the uncertainty of the controlled object in the development of expertise, which would allow for realistic recognition of one's own limitations and retaining or attaining sensibility to the cues from the success of one's control operations. In this state of the development of ExId, the hypothesis was not yet directly studied. However, the results of Study D supported the idea of gradually increasing responsibility in line with the development of expertise and the related self-confidence. It also highlighted the role of safety systems and procedures and the social community in the development of an operator identity. The results of Study D were in line with the findings of Owen (2001) that beliefs held within the community have an important role in the human performance and in the success to have an impact on it by e.g. training programs. The courage to face uncertainty *both* in the controlled object *and oneself* could be a way to reach the ability to overcome our limitations in demanding situations by recognising better the adequacy of our control actions and by exploiting better other human resources (co-operation). If so, how can we create *the safety net* for this development in changing work that continuously nibbles away the nascent courage?

Figure 4 concludes ExId and offers a suggestion of how to improve the resources for coping with demanding situations by supporting the development of expert identity. In order to develop countermeasures for stress we should understand the whole continuum and spectrum of the work demands and take into account the fact that they are changing. This dissertation contributed to this huge task. According to the present approach, the task of the operator is to focus on the

core task and utilise the available resources (personal and external) efficiently in the situation as well as to attempt to define the core task, share the recognitions and develop his or her personal resources to take care of it in the long run. The task of the developer is then, both to enhance the resources, particularly the development of personal resources, and to support the operators in conceiving their core task demands and the resources accurately.

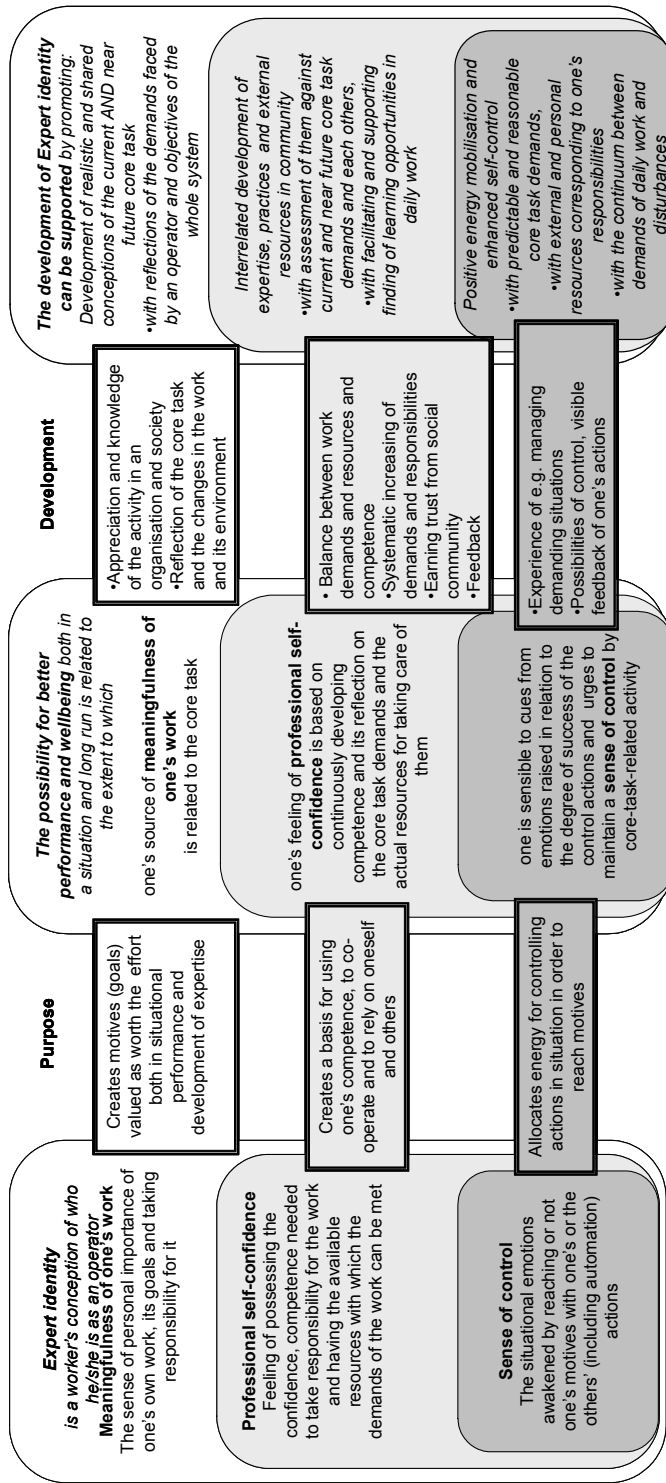


Figure 4. ExId model for supporting operators in creating personal resources in demanding situations.

### 4.3.2 Folk model or promising model?

The general question stated was whether ExId enables studies on practices in the field and contributes adequately to the practical development. Dekker and Hollnagel (2004) have considered how to distinguish folk models (common-sense models) and promising models. As they noted, human factors may be specifically vulnerable to the use of folk models, since it is both a science and a practice. Is ExId a folk model? Did it generate useful empirical results or could it do so if only given the time and opportunity? The studies were used as a kind of test of the ExId construct in two senses: to show its applicability in the analysis of the data and in making interpretations and practical conclusions on the one hand; and to examine if the basic assumptions were supported by the results, on the other. The studies illustrated the usefulness of ExId in the analysis, both as a part of the CTA-based methods (Article III and Article IV) and by itself in Study D (Article II). It worked in the analysis aiming at recognition of the challenges and guiding the development in several cases with different practical aims. The empirical results also provided evidence that supported ExId. The characteristics of folk models as expressed by Dekker and Hollnagel (2004) are used in the following to reflect ExId more closely. These characteristics are: *explanation by substitution instead of decomposition; immunity against falsification and overgeneralisation.*

A feature that distinguishes ExId from folk models is the effort put in the definition of the construct: it is decomposed into parts, the three conceptual layers, which are defined on the basis of more fundamental theories of human behaviour and better-known concepts. The presented ExId is an attempt to integrate several lines of research and theories from different sources. Theureau (2000) recognised a trend towards eclecticism in the development of methods for studying human factors in nuclear power plant control room simulators. “But if it is considered that it reflects both recognition of a complexity and the limits of the methods and theories available for controlling this complexity in a given scientific and technical conjuncture, eclecticism is certainly preferred to dogmatism, from the points of view of the future and of the resolution of immediate practical problems” (Theureau, 2000 p. 99).

The present ExId construct is certainly guilty of borrowing ideas from different branches of research. However, we are reminded of the importance of social,

emotional and political aspects in addition to (pure) cognitive aspects and their role in the research and practical development of work with increasing frequency (e.g. Montgomery et al., 2005a). It is a real methodical and practical challenge to take them all into account thoroughly in ergonomic development – particularly when work is continuously changing with regard to the ways in which it is organised, the business environment, and the rapid introduction of new technology (e.g. Carayon and Smith, 2000; Clegg, 2000; Hollnagel, 2001; MacLeod, 2003). This dissertation suggests that we can also try to exploit theoretical efforts and empirical findings from other lines of psychological studies. These efforts and findings need to be modified and carefully tested by comparison with the theories and findings of our own research line and with new studies of a narrower focus – a task which this dissertation has only started. The integration of disciplines (Kontogiannis, 1999), different theoretical frameworks (Jacobsson Kecklund, 1998), lowering of the boundaries between different domains and approaching human performance from a multidimensional perspective (integrating different sub- and disciplines and views of researchers and practitioners) (Morphew, 2001) are suggested also elsewhere in order to improve our understanding of human performance, and especially to find efficient countermeasures against stress. The change of the subject of process control studies to e.g. emotions is not recommended as such in this dissertation. However, completing the systemic analysis of work with contextual studies in which the emphasis is on emotional-energetic issues and emphasising the subjective experience of the operators is advised. The strong belief behind this dissertation is that safety critical domains would also benefit if they would emphasise more on the emotional side of cognition. The starting points of ExId, the positive, “salutogenic” orientation (following Antonovsky’s 1988, example) and the integration of the study of emotions in the existing operator and safety research (following Briner’s, 1999a suggestions) are proposed here also for future lines of study. Reaching efficiency without losing depth of the analysis needed for adequate practical solutions in rapidly changing work can be achieved by the development of new integrating concepts (within a discipline or close to one) that focus in particular on the human side and work with and supplement existing (more interdisciplinary oriented) methods. In this dissertation the connection to the other sides of cognition and the entire socio-technical system was reached by studying working practices together with core task. The core task could be also a potential link to cross-disciplinary studies of the vertical interaction among the levels of the socio-technical systems



suggested by Rasmussen (1997; 2000) for risk management in the dynamic society.

Dekker and Hollnagel (2004) suggest focusing on the characteristics of performance, more specifically performance of a joint cognitive system (e.g. joint pilot-aircraft system of which we have records) rather than on inferred and uncertain states of mind. ExId offers us a quite comprehensive frame of reference for examining the emotional-energetic side of human expertise and performance and for calling practical solutions into question. The other side of the coin is that the entire model is not easily *testable* although individual hypotheses can be formulated. The analysis of ExId is analysis of the operators' actual *performance*, in the sense of working or expressing conceptions, not measurements of intermediate internal states as is the case with e.g. workload (see Dekker and Hollnagel, 2004). However, since the stress studies in health research have had a great impact on the present approach and the balance between the *demands and resources* of the work is in its centre, ExId can be placed in some respect to the category of cognitive mediation (Stimulus-Organism-Response) way of thinking<sup>5</sup> (cf. Lazarus, 1999 p. 5). Following the example of Lazarus, subjective appraisal is seen as a compromise or process of negotiation between the objective conditions of work (including social, physical etc) and what people hope for or fear. The analysis of ExId is also closely related to the performance of the human(s)-technology system with the concept core task and object of analysis, namely human-environment interaction, in the empirical studies. Although the systemic notion of human activity and the ecological human-environment interaction perspective of CTA described by Norros (2004) are not all the time evident in this dissertation, they are not challenged. The target of ExId within this frame is to bring more *subjectivism* into the picture: To emphasise what people think and feel about themselves, their work, the demands of the situation and their own ability to meet the demands and how they feel makes a difference in their performance – both in a particular situation and in the long run. Studies on working practices also create a link between the two different perspectives of the core task studies: situational actions and organisational culture (see also Nuutinen et al., 2003).

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<sup>5</sup> This does not mean that I consider human as a passive receiver of stimulus from environment.

The stress approaches affected also the way in which the well-being objectives were taken into account as a part of efficiency. The logic was that recognition of the real current work demands and understanding of the current state of the practices guides the development activities into a direction in which the resources and competences match better the demands, which in turn promotes the workers' wellbeing and their ability to do their work well (Article III). This could also have an impact on the realistic recognition of one's own personal resources, which could, again, contribute to well-being (Leppänen, 2001). Although, the productivity objective was not particularly in focus, in the cases based on the material from working in real, natural situations, it was very much present (Article III and Article IV) and affected the core task models.

*The best applicability* of ExId is supposed to be in studies of 'typical' operator work, although it can be used also in the upper levels of control, when the controlled object includes also operators controlling their own processes (e.g. VTS). Several authors have expressed that there are features corresponding the operator task in many kinds of tasks in the modern society (e.g. Norros, 2004 p. 205; Swezey and Andrews, 2001; Vicente, 1999). ExId is not limited only to the safety critical domains and the service expert study demonstrated that it can be utilised also for tasks in which the object of the work is quite vague, although this is more difficult than in more typical operator tasks. The link of ExId to the core task is also a countermeasure against overgeneralisation: what is supposed to promote good performance is always limited to the context and time of study, since the core task demands of a group of workers is dependent on e.g. the present technical as well as organisational solutions. ExId offers the conceptual model to guide one's analysis: three different aspects on which to focus as a part of the analysis of the operators' performance, their expertise or its development.

A criterion for promising models is that *falsifiability* should increase instead of decrease in comparison with previous explanations of the phenomena that was under study (Dekker and Hollnagel, 2004). The phenomena under scrutiny was "a drop" in the efficiency of a socio-technical system related to the increase in the demands above the human capabilities or the difficulty of maintaining a reasonable level of performance in demanding situations, expected e.g. on the basis of one's experience. One of the biggest problems of the cognitive mediator models assuming performance to mediate mental states, such as stress or workload, is the difficulty to measure them either retrospectively or concurrently

(Dekker and Hollnagel, 2004). Although in the case of accidents explaining the operator's (failed) performance by the condition of mental stress or high workload does not explain anything (see e.g. Dekker and Hollnagel, 2004), the feeling of "stress" qualifies as a subjective experience. In Study A the panel was experienced to reduce stress among the operators. The related experienced benefits of the panel gave us hints for a potential connection of this subjective experience to the performance. As already noted, the conceptions held by the operators or their working are reachable and measurable, and so are also their expressions of emotional experiences. Thus the model referring to them is falsifiable. The third, innermost layer of ExId is the most difficult to study. The studies did not provide direct support to the functionality of the sense of control in regulating one's actions. This was expected, since the studies investigated expert identity as a part of a larger system and the methods chosen for that. However, the third layer is still claimed to open up a different, functional perspective for emotions in safety research. The ExId -construct can be used for coming up with other suggestions to support the operators than control of emotions – taking advantage of them. How to practically achieve this in demanding situations needs further study. For example, in the study made by Flin et al. (1996) already mentioned in Introduction (Section 1.2.5), many of the offshore installation managers reported that they became aware of their feeling only after the imminent danger was over. A weakness of ExId is that although it considers both negative and positive emotions, the emotions are still quite unspecific (c.f. Briner, 1999a).

The target of the development of expertise in operator work and the ways in which this is assumed to be achieved are open questions. This dissertation proposes supplementing the analyses of the content of the expertise and its development by emotional-energetic emphasis and how the operators conceive themselves, the demands of their work and their own resources for coping and learning. The Expert Identity -construct is offered for focusing on these aspects of cognition and practise. The essential parts of the construct already have at least theoretical but also promising empirical support, as described in this dissertation and the articles. ExId worked also as a part of CTA method and contributed to the understanding of operator work. The results were interpreted as promising enough to encourage conducting further empirical studies to verify the assumptions of ExId.

## 4.4 Conclusions

The information processing metaphor is slowly but surely losing its place in explaining human behaviour in the operator research. More systemic approaches are introduced, including both human and technical parts of the system. Further guidelines are searched e.g. from system theory. Although they offer a promising solution from the point of view of the risk management of the entire system, do they offer the best way to discover ways to support humans within the system? The danger is that our way of thinking of humans as parts of socio-technical systems remains analogous with machines, something that could be controlled only by having “a perfect model” or feedback loops (e.g. from incidents), not something that are active, conscious, developing actors continuously creating the whole system. A promising direction to search a new development strategy for the changing safety-critical complex socio-technical systems might be a combination of bottom-up self-construction in terms of reflective, confident, competent and responsible operators and top-down control and support in terms of defining, reflecting and creating resources, e.g. by technical development and training.

The rapid changes in the work are recognised as challenging for the approaches and methods used in ergonomic development. The focus of this dissertation, demanding situations, brought up two important aspects to take into account: the emotional-energetic side of cognition and how the operators conceive themselves, the demands of their work and their own resources for coping and learning. If the rapid changes in the work continue, the importance of coping with demanding situations can be assumed to be rather increasing than decreasing in those many positions of politics, trade and industry. This dissertation proposes especially *contribution to supporting the workers in recognising the changing demands and to their possibilities for growing with them* both in designing the systems and in solving existing problems. The formula offered for that in this dissertation is: Coping with the present and preparing for the future grows from understanding the past and present, and envisaging the future. On this basis the required interdependent development of core-task-oriented working practices and other resources with special support to the continuous construction of expert identity could be achieved.

The alarming pattern – “technology that is well tailored to the physical world but too complex for human beings to handle” – is found not only in everyday gadgets but also in larger, safety- critical technological sectors (Vicente, 2004 p. 18). The position of VTT at the leading edge of technology development opens up good possibilities to change this situation – a mission that has been recognised and valiantly defended, but is far from being completed (Norros et al., 2003). This dissertation also contributed to this broad mission by increasing the applicability of the available methods for understanding human practice and by increasing knowledge of the situations that are the most difficult to human operators, both considered important supplements for interdisciplinary development of complex socio-technical systems.

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Author(s) Nuutinen, Maaria			
Title <b>Expert Identity in Development of Core-Task-Oriented Working Practices for Mastering Demanding Situations</b>			
Abstract The point of departure in this dissertation was the practical safety problem of unanticipated, unfamiliar events and unexpected changes in the environment, the demanding situations which the operators should take care of in the complex socio-technical systems. The aim of this thesis was to increase the understanding of demanding situations and of the resources for coping with these situations by presenting a new construct, a conceptual model called Expert Identity (ExId) as a way to open up new solutions to the problem of demanding situations and by testing the model in empirical studies on operator work. The premises of the Core-Task Analysis (CTA) framework were adopted as a starting point: core-task oriented working practices promote the system efficiency (incl. safety, productivity and well-being targets) and that should be supported. The negative effects of stress were summarised and the possible countermeasures related to the operators' personal resources such as experience, expertise, sense of control, conceptions of work and self etc. were considered. ExId was proposed as a way to bring emotional-energetic depth into the work analysis and to supplement CTA-based practical methods to discover development challenges and to contribute to the development of complex socio-technical systems. The potential of ExId to promote understanding of operator work was demonstrated in the context of the six empirical studies on operator work. Each of these studies had its own practical objectives within the corresponding quite broad focuses of the studies. The concluding research questions were: 1) Are the assumptions made in ExId on the basis of the different theories and previous studies supported by the empirical findings? 2) Does the ExId construct promote understanding of the operator work in empirical studies? 3) What are the strengths and weaknesses of the ExId construct? The layers and the assumptions of the development of expert identity appeared to gain evidence. The new conceptual model worked as a part of an analysis of different kinds of data, as a part of different methods used for different purposes, in different work contexts. The results showed that the operators had problems in taking care of the core task resulting from the discrepancy between the demands and resources (either personal or external). The changes of work, the difficulties in reaching the real content of work in the organisation and the limits of the practical means of support had complicated the problem and limited the possibilities of the development actions within the case organisations. Personal resources seemed to be sensitive to the changes, adaptation is taking place, but not deeply or quickly enough. Furthermore, the results showed several characteristics of the studied contexts that complicated the operators' possibilities to grow into or with the demands and to develop practices, expertise and expert identity matching the core task. They were: discontinuation of the work demands, discrepancy between conceptions of work held in the other parts of organisation, visions and the reality faced by the operators, emphasis on the individual efforts and situational solutions. The potential of ExId to open up new paths to solving the problem of the demanding situations and its ability to enable studies on practices in the field was considered in the discussion. The results were interpreted as promising enough to encourage the conduction of further studies on ExId. This dissertation proposes especially contribution to supporting the workers in recognising the changing demands and their possibilities for growing with them when aiming to support human performance in complex socio-technical systems, both in designing the systems and solving the existing problems.			
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Nimeke <b>Asiantuntijaidentiteetti perustehtäväsuuntautuneiden työtapojen kehittämisessä vaativien tilanteiden hallintaan</b>			
Tiivistelmä <p>Tutkimuksen lähtökohdat olivat ennakoimattomat, odottamattomat, operaattoreille vieraat tilanteet, jotka aiheuttavat turvallisuusongelman monimutkaisissa sosio teknisissä järjestelmissä. Näitä tilanteita kutsuttiin vaativiksi tilanteiksi. Väitöskirjan tavoitteena oli lisätä ymmärrystä vaativien tilanteiden hallinnasta ja niissä tarvittavista resursseista esittelemällä uusi käsitteellinen malli, "Expert Identity" (ExId), asiantuntijaidentiteetti, joka pyrkii löytämään uusia lähtökohdita vaativien tilanteiden ongelman ratkaisemiseen, ja testaamalla tätä mallia empiirisissä tutkimuksissa. Lähtökohdaksi otettiin epävarmojen, monimutkaisten ja dynaamisten tilanteiden ja ympäristöjen tutkimiseen kehitetty perustehtäväanalyysi (Core-Task Analysis, CTA) -lähestymistapa. Sen mukaisesti koko järjestelmän tehokkuutta (ml. turvallisuus-, tuottavuus- ja hyvinvointitavoitteet) edistävät sellaiset työkäytännöt, jotka täyttävät perustehtävävaatimukset. Väitöskirjassa tarkasteltiin operaattorin työn vaatimuksia ja stressin vaikutuksia ihmisen suoriutumiseen sekä erilaisten "henkilökohtaisten" resurssien (esim. kokemuksen, asiantuntemuksen, kontrollin tunteen ja käsitysten) mahdollisuuksia vastata vaatimuksiin. ExId esitettiin mahdollisuutena syventää työn analyysiä ja täydentää CTA:han pohjautuvia käytännön menetelmiä, joilla pyritään tunnistamaan kehityshaasteita ja edistämään sosio teknisten järjestelmien tehokkuutta. ExId:n toimivuutta arvioitiin kuudessa empiirisessä, operaattorityöhön kohdistuneessa tutkimuksessa. Tutkimuskysymykset olivat: 1) Saako ExId tukea empiirisen tutkimuksen tuloksista? 2) Edistääkö ExId-malli operaattoreiden työn ymmärtämistä empiirisessä tutkimuksessa? 3) Mitkä ovat ExId-mallin vahvuudet ja heikkoudet? Asiantuntijaidentiteetin kerrokset ja kehittämisestä tehdyt oletukset näyttivät saavan tukea. Uusi käsite toimi osana erilaisten aineistojen analyysiä, eri menetelmiä ja eri työkontesteissa. Empiiristen tutkimusten tulokset kertoivat ongelmista huolehtia perustehtävästä, jotka olivat seurausta työn vaatimusten ja niistä huolehtimiseen käytössä olevien resurssien yhteensopimattomuudesta. Tutkituissa tapauksissa työn muutokset, vaikeus tavoittaa operaattorin työn oleellista sisältöä sekä erilaisten käytännöllisten vaikutuskeinojen rajoitukset olivat hankaloittaneet ongelmia ja vaikeuttaneet organisaation omia kehittämistoimenpiteitä. Henkilökohtaiset resurssit vaikuttivat olevan herkkiä työn muutoksille ja adaptoituvan muutoksiin, mutta tämä muutos ei ollut joko tarpeeksi nopea tai syvä. Tutkitut tapaukset toivat esiin myös useita työympäristöjen piirteitä, jotka voivat vaikeuttaa operaattoreiden mahdollisuuksia kehittyä muutosten mukana ja kehittää henkilökohtaisia resurssiaan, työtapoja, ammattitaitoa ja asiantuntijaidentiteettiään perustehtävävaatimuksia vastaaviksi. Näitä olivat: epäjätkävyys työvaatimuksissa, erilaiset käsitykset operaattorin työstä organisaation eri osissa, ristiriitaisuudet kehitysvisionien ja operaattoreiden kohtaan todellisuuden välillä sekä yksilöllisen ponnistelun ja tilannekohtaisten ratkaisujen korostaminen. Discussion-osassa tarkastellaan ExId:n mahdollisuuksia tukea uusien ratkaisujen kehittämistä vaativien tilanteiden ongelmaa ja kykyä tukea käytäntöjen tutkimusta kentällä. Tulosten tulkitettiin olevan ExId:n kannalta rohkaisevia ja kannustavan jatkotutkimuksiin. Ihmisen toiminnan tukemiseksi monimutkaisissa sosio teknisissä järjestelmissä tulisi kiinnittää erityistä huomiota siihen, että autetaan työntekijöitä tunnistamaan perustehtävän muutokset ja parannetaan heidän mahdollisuuksiaan kasvaa näiden muutosten mukana.</p>			
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This academic dissertation was made for the University of Helsinki, Department of Psychology. The point of departure was the practical safety problem of unanticipated, unfamiliar events and unexpected changes in the environment, the demanding situations which the operators should take care of in the complex socio-technical systems. The aim of this thesis was to increase the understanding of demanding situations and of the resources for coping with these situations by presenting a new construct, a conceptual model called Expert Identity (ExId). The potential of ExId to promote understanding of operator work was demonstrated in the context of the six empirical studies on operator work. Each of these studies had its own practical objectives within the corresponding quite broad focuses of the studies. The new conceptual model worked as a part of an analysis of different kinds of data, as a part of different methods used for different purposes, in different work contexts. The results showed that the operators had problems in taking care of the core task resulting from the discrepancy between the demands and resources (either personal or external). The changes of work, the difficulties in reaching the real content of work in the organisation and the limits of the practical means of support had complicated the problem and limited the possibilities of the development actions within the case organisations. Personal resources seemed to be sensitive to the changes, adaptation is taking place, but not deeply or quickly enough. This dissertation proposes especially contribution to supporting the workers in recognising the changing demands and their possibilities for growing with them when aiming to support human performance in complex socio-technical systems, both in designing the systems and solving the existing problems.

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