



# Human practice in the life cycle of complex systems

|Challenges and methods



VTT PUBLICATIONS 582

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ISBN 951-38-6675-0 (soft back ed.)

ISSN 1235-0621 (soft back ed.)

ISBN 951-38-6676-9 (URL: <http://www.vtt.fi/inf/pdf/>)

ISSN 1455-0849 (URL: <http://www.vtt.fi/inf/pdf/>)

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#### JULKAISIJA – UTGIVARE – PUBLISHER

VTT, Vuorimiehentie 5, PL 2000, 02044 VTT  
puh. vaihde 020 722 111, faksi 020 722 4374

VTT, Bergsmansvägen 5, PB 2000, 02044 VTT  
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Technical editing Anni Kääriäinen

Valopaino Oy, Helsinki 2005

Human practice in the life cycle of complex systems. Challenges and methods. Edited by Maaria Nuutinen & Juha Luoma. Espoo 2005. VTT Publications 582. 147 p.

**Keywords** complex systems, human-technology interaction, human practices, safety critical systems, traffic information services, user-centered design, nuclear power, mining, steel industry, pulp and paper industry

## **Abstract**

This book describes the current and near future challenges in work and traffic environments in light of the rapid technology development. It focuses on the following domains: road and vessel traffic, nuclear power production, automatic mining, steel factory and the pulp and paper industry. Each example concerns complex technical systems where human practice and behaviour has an important role for the safety, efficiency and productivity of the system.

The articles illustrate the enormous field of human-related research when considering the design, validation, implementation, operation and maintenance of complex socio-technical systems. Nevertheless, these 14 chapters are only examples of the range of questions related to the issue. The authors of the book are VTT experts in work or traffic psychology and research, system usability, risk and safety analysis, virtual environments and they have experience in studying different domains.

This book is an attempt to open up the complex world of human-technology interaction for readers facing practical problems with complex systems. It is aimed to help a technical or organisational designer, a policy-maker, an expert or “a user”, the one who works or lives within the technology.

# Preface

The idea of this book emerged at the first meetings of the human-technology interaction and safety focus area at VTT in the beginning of the new millennium. We wanted to collect the on-going efforts of VTT researchers concerning the development of methods to recognise and to solve the challenges concerning human behaviour in complex, safety critical systems. This book describes the current and near future challenges in many work and traffic environments in light of the rapid technology development. It focuses on the following domains: road and vessel traffic, nuclear power production, automatic mining, steel production and the pulp and paper industry. Each example is concerned with complex technical systems where human practice and behaviour has an important role for the safety, efficiency and productivity of the system.

This book presents examples of ways to relate human practice and user need studies to the practical development of complex systems, conducted at VTT under the strategic theme Safety and Reliability. This book is an attempt to open up the complex world of human-technology interaction for readers facing practical problems with complex systems. It is written to help a technical or organisational designer, a policy-maker, an expert or “a user”, the one who works or lives within the technology. The articles in this book are like pictures in a kaleidoscope. Different pieces of the human-technology interaction form into a reachable entity according to the applied framework and the writers’ perspective. However, the book is not a manual or a step-by-step guide book in the sense that the readers could pick up a method and use it. Neither is this a comprehensive scientific work, but the articles and their references guide the readers to the sources of additional information.

We thank all the authors for contributing to this book by writing their articles and by commenting the writings of the others. In addition, we would like to thank Ph.D. Anneli Leppänen of the Finnish Institute of Occupational Health and Research Professor Urho Pulkkinen of VTT for the review.

Espoo, October 2005

*Maaria Nuutinen and Juha Luoma*

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# 1. Introduction

Maaria Nuutinen & Juha Luoma

The possibilities and challenges of pervasive technology and attempts to realise the vision of information or knowledge society have promoted discussion about the technology development policy, justification of the technology push, the future of public systems and nature of human work and leisure in technology laden environments. We have witnessed remarkable changes in everyday life and culture enabled by seemingly quite small technical innovations, such as the mobile telephone. We have also seen risks hidden in the present technology (e.g. computer viruses, terrorism, “man made accidents”, disappearance of personal service in certain range of basic society service) – the effects of new technology include almost always at least some disadvantages for some of us: discrimination, stress, uncertainty, health risk etc. Assessing the pros and cons is not easy. However, no-one could any longer deny that we need more understanding of the interaction between the human and technology both for leisure and work. We also need research methods to discover this knowledge, create reliable knowledge and innovative theories for the development of safe, healthy, meaningful and efficient technology. These are the motivations for this book.

The practical challenges related to the rapid technology development have challenged also scientific research paradigms. The relevance of studying human practices is recognised and the interest in studying them e.g in safety critical systems is increasing. This refers to a growing interest of studying what people actually do in their work or need in their everyday activities, e.g. when driving a car. This emphasises the importance of conducting studies in the field and understanding humans more comprehensively. Everyday practices have been in the focus of studies and theory development in the more sociologically, phenomenologically and ethnomethodologically oriented lines of research. They offer a good theoretical starting point to understanding more deeply the role of human practices in the socio-technical systems and methodological ideas for studying them. Discovery of the real practices, however, does not indicate whether they are good or bad or whether they promote the system safety and efficiency or not, or how should we use technology or how the technology could support humans in their daily practices. The needs expressed by the users do not

alone point sufficiently the direction in which the technology or services should be developed.

When considering safety critical systems, such as road traffic or a nuclear power plant, the ability to predict the possible effects of changes caused e.g. by new control room or new traffic signs poses a serious challenge for research. Do the variable message signs increase or decrease safety? What about the effects of in-vehicle information and communication systems? How should these systems be designed so that safety is improved together with other objectives (fluency, economic efficiency, comfort)? The speed of the technology development and the related changes of human practice at work and during leisure tend to increase and much of the changes are gradual, quite subtle and thus difficult to notice, making the future seem like a continuous transition phase. During the life cycle of any of these systems there are many changes which call for understanding of how to support human practice or behaviour so that the system maintains its functionality. We need to be able to get reliable and representative view of the situation to influence the development track. This calls for knowledge instead of assumptions and means, of course, that the knowledge is based on reliable and comprehensive research methods that are adequate for the specific question in hand. This book presents examples of ways to relate human practice and user need studies to practical development of complex systems made at VTT under the strategic theme *Safety and Reliability*.

This book describes the current and near future challenges in work and traffic environments related to the rapid technology development. It focuses on the following domains: road and vessel traffic, nuclear power production, automatic mining, steel factory and the pulp and paper industry. Each example concerns complex technical systems where human practice and behaviour has an important role for the safety, efficiency and productivity of the system.

The following topics are covered:

- understanding of human practice, behaviour, motivations and needs as the starting point for technology development
- safety issues related to technological development: how to recognise risks in the early phases of development, how to evaluate the system in

order to support controlled technology development, how to validate large systems

- benefits of adequate use of simulations during the development process
- importance of integrating domain, behaviour science and technology expertise
- ways to manage change within an existing system.

There are five parts according to the life-cycle of the socio-technical systems. This introduction is followed by the second part dealing with the design of the systems. The third part considers validation and evaluation of the systems and the fourth part their implementation. Finally, the human related challenges of operation and management of change within the existing system are considered. The life-cycle structure is included to emphasise that even if the system had been designed as well as one could from the point of the user and the motivation of the system, there are many tasks left to the later phases of the system. In addition, one could ask whether the design of any new complex system is anything more than a redesign or completion of some existing system. And vice versa, the (re)design is always a unique situation.

The book is a collection of studies made in different domains, with different practical aims, with different methods and with different theoretical backgrounds. There is no attempt to compare the approaches, or to give the reader direct guidance which method to pick for a specific practical problem. On the contrary, the book aims to provide the reader with the same opportunity we have had to discover the similarities as well as uniqueness in the practical problems to be solved, the overall role of technology and the role of human practice and motivation in different domains and contexts. This is a way to explore the reasons behind different approaches and methods. The careful and open-minded reader can also read between the lines throughout the book about the great concern for the technology push and the painful contradiction between knowing that exploring human practice is a never-ending task where significant findings can be expected only after years of extensive research work – and knowing that rapid contributions are needed to keep going with the technology development. The authors share the will to contribute to the development of socio-technical systems in order to reach more humane technology development,

that is safe, appropriate, meaningful, non-discriminating, enabling technology or even questioning the need for new technology.

This book also illustrates the enormous field of human-related research when considering the design, validation, implementation, operation and maintaining of complex socio-technical systems. Nevertheless, these 14 chapters are only examples of the range of questions related to the issue. The authors of the book are experts of work or traffic psychology and research, system usability, risk and safety analysis, virtual environments and they have experience in studying different domains. The impact of the authors' expertise and the different theoretical backgrounds and traditions they represent are visible in the authors' concepts.

We invite you on an adventure of studying human practices in the life cycle of complex socio-technical systems.

## 2. Design

It has been recognised for decades that the user-centred design of technical systems has many benefits, such as improved efficiency, productivity, quality, health, safety etc. Although user-centred design may sometimes result in higher direct costs for the design, it is widely understood that the costs are reduced in the long run. To ensure the benefits of user-centred design, the users should be involved early enough in the process when there are not too many technical restrictions to limit innovative design. Finally, one should recognise that a careful analysis of the domain in question and of the user behaviour is needed for successful design.

Chapter 2.1 focuses on the design of traffic and traveller information services. (The reader without previous knowledge of driver behaviour research can first familiarise him/herself with the approach by reading about the three decision levels in car driving in Chapter 4.1.) The development of these services provides an example of a real test of the user-centred design method. The success or failure of the design can be easily seen when the service is ready: are the users paying for the service or not. The user cannot be “forced” to use the result of poor design as is the case too frequently in working life. The chapter also reminds the readers that user-centred design is something far more than just asking about the users’ needs once. The chapter further demonstrates the design challenges by shortly presenting the potential of digital television for providing traffic and transport information.

Chapter 2.2 introduces the important fact that the overall safety of a complex automated mobile machine application relies strongly on the operators and service men’s behaviour. New automated loading and transport systems in modern mines can include several autonomously tramming and teleoperated machines. The change in the work task of the operator in a modern automated underground mine is quite remarkable: the machine operator has become the system controller as in process plants (see Chapters 3.1 and 5.1). System operation and operating hazards are new issues to the machine manufacturers. The chapter presents the Operating Hazard Analysis (OHA) method that has been developed for automated mining machine systems. Although the mine

applications are always unique, the issues raised in this chapter are relevant also in several other domains.

Chapter 2.3 describes the development of the operating procedures of the new international ship reporting system. The development of this GOFREP system demonstrates a time-pressured, complex design task which has quite remarkable constraints caused e.g. by the international and cross-cultural nature of the system and the long history of seafaring. In addition, this is an example of a domain where the level of technology is not mature enough to allow adequate support for the activity. These are the reasons why the human part of the system was recognized to be worth explicit and quite extensive development efforts. It also illustrates that quite low-level simulation fidelity can be adequate to support the development.

Chapter 2.4, on the other hand, illustrates how simulations reaching reality in some aspect (e.g. virtual environment in this case) can support design and risk assessment. A method of applying virtual environments for safety analysis was developed and tested in the work settings. The results from steel factory cases indicate that the method was applicable for safety analysis in the machinery layout design phase. The safety analysis will clearly benefit from the use of virtual environments.

## **2.1 User-centered design of traffic information services**

Merja Penttinen

### **2.1.1 Introduction**

The development of socially advantageous and economically profitable traffic and traveller information services calls for understanding and knowledge of user needs and requirements as well as the willingness of the users to pay for the information services. No service – no matter how sophisticated – can succeed without users and in the case of commercial services, consumers. The remaining problem is: how to identify the real user needs and requirements early enough to achieve the goals of the service, either socially or businesswise.

### **2.1.2 User needs in general**

In general, one aim of transport politics in Finland is to provide all the citizens with equal possibilities to travel as they need to do to perform their normal daily routines. Given that requirement, there must also exist equal basic traffic and traveler information available for all the citizens regardless of e.g. age, gender, physical ability or disability, residential area or economic and other resources. Therefore, the general information needs of drivers and other road users have been investigated in Finland in several representative interview studies during the last few years. These studies have, however, been mostly for decision making purposes of the Ministry of Transport and Communications or the Finnish Road Administration, and thereby they have concentrated mostly on the content of the traffic information.

### **2.1.3 From user needs to user-centered design**

During the past decade, the development and implementation of new systems and services of transport telematics has increased rapidly. The telematics enable real-time, and therefore totally new services – of which the users are even interacting with, and sometimes should start paying for their use. Consequently the needs and requirements of the users should be explored with a wider perspective than before. The traditional user needs analysis by interviews needs to be complemented with user-centered design techniques.

Currently, quite a few telematic transport services exist for drivers and travellers. It is known that many of them should help travellers with their travelling-related problems, but there are still setbacks from the user point of view. Even if the product or service were made to satisfy the users' stated needs (e.g. knowing how to get from A to B at a specific time by public transport or by car), a lot of things could still go wrong. Why then do people not use this ingenious system that is based on their stated needs? The fact is that there are still a number of pitfalls on the way to a successful transport telematics service or product (Penttinen et al. 1997; Penttinen et al. 2003a):

1. The service does not reach the user, he does not know that the service exists, he does not know where to find the service, or he does not have a device to use the service.
2. Use of the service is too difficult; the user cannot find the information he needs, or finding the information takes too much time.
3. The information is too general; the users do not buy telematics just for the telematics; they expect to get something more than traditional traffic information.
4. The information is not real time; the users' expectations of "digital" information are a lot higher than of printed information.
5. The information includes instructions or phrases the user does not understand; most telematics terminology falls into this category. For example, the instruction to walk northwards after getting off the bus is not very helpful if you do not know where North is.
6. The information has no effect; this must be investigated after people have taken the new product or service into use.
7. Consumers do not buy the new product.

In order to get a successful product or service, the whole development process of telematic applications should be based on the stated user needs. In addition, the requirements and user involvement should be an important part of an iterative design process to achieve a product with user-centred characteristics. To minimise the preceding pitfalls, the users should be included in the whole design process – from the early user need analysis in the context design phase to the evaluation of the real effects of the new systems on the users.

#### **2.1.4 User needs and consumer behavior (willingness to pay)**

The basic assumption of microeconomics and consumer behavior is that the consumer is supposed to be rational; to choose the alternative that maximizes his/her benefits. Finnish people are quite often used to having traffic-related information on several media e.g. on the radio, newspapers, text-television, internet etc. They are also used to getting the traffic and traveler information free

of charge; provided by for instance Finnra (Finnish National Road Administration). Therefore, it may be difficult to persuade them to accept a situation where they should start to pay for the traffic information no matter how sophisticated, real time or personalised it is. It has been said that the consumers unusually buy telematics just to get the latest technology. They want to get services that bring them real value. In addition, each new service will be judged by the consumer while comparing it with other substitutes (paper map – map in the internet – map in the personal navigation device or mobile phone – map in the vehicle navigator etc.).

It is challenging to seek out the users' needs in the case of a brand new product. In general, the respondents tend to consider new products less important than the ones they have experience of (e.g. Tekes 2001). This has to be taken into account in transport-related studies. It might not be the best way to only ask if the user would find some system important or not. A more fruitful approach would be, for example, to find out what kind of problems he or she has in everyday travelling. And when the problem is identified, then it is time to think further towards the possible solutions.

In traffic-related services the investments needed for the measuring and monitoring systems (e.g. traffic weather stations) are huge but still an absolute necessity to get the real-time information produced. The only way to get the customers to pay a part of the price is to get an extensive enough number of users.

In a recent study by Anttila et al. (2001) the respondents were asked about their willingness to buy a device that enables personal navigation on location-based services. The results showed, for example, that the number of mobile phones (or the frequency at which the respondent had bought a new mobile phone) explained the presumable buying behavior better than any other of the background variables (gender, age, education, income, place of residence etc.). Furthermore, the respondents' reported presumable buying behavior divided them into groups that are very close to the groups in the technology adoption life-cycle presented by Moore (1999).

## **2.1.5 A new service on digital television**

### **2.1.5.1 User study method**

The user-centered approach was used to achieve a product that would help the users – including the information needed and being easy to use. The potential future users were invited into the focus group discussions, aiming at planning a new traffic and transportation information service. The participants, in total 42, were divided into 6 groups based on their background as drivers and travellers. One group, however, was composed of only persons who already had a digital television at home.

The information was collected during the focus group sessions both individually and by group discussions. A method named Puzzle (Keinonen 2000; Kaasinen 2002) was used for sorting all the traffic and transportation information – making the menu of the information channel. The method has previously been used for planning the menus for advanced mobile devices. In the Puzzle method, the participants sort the information contents into categories they find to belong together and finally prioritize the pieces of information and give names to each category.

### **2.1.5.2 Is there potential in digi-TV?**

The results of the focus group discussions were promising. The participants found the new service very useful and innovated many services that could be included into the service in the future. The best features of the new service according to the users would be

- a) getting all the information easily at the same place
- b) getting the information quickly – without turning on the computer and activating the connection
- c) getting real-time information.

### 2.1.5.3 Content of the information service on digi-TV

The following structure for the traffic and transport information content was found to be the best compromise according to slightly different structures suggested by the groups:

1. warnings (e.g. bad road weather, disturbances)
2. real-time traffic situation (e.g. traffic congestion, delays of trains)
3. public transportation (e.g. time tables, routes, real time information)
4. all-mode route planner
5. weather and environment
6. travelling, tourist information
7. related services
8. traffic safety and rules.

Warnings were found to be the most important information – and were selected to be the first subject in the main menu of the channel. The next most important ones were real-time traffic information, public transportation information and the all-mode route planner. The next categories were found to be interesting too, but most often placed after the four most important ones. Warnings also included warnings of bad weather conditions – more detailed weather information was however, placed later in the menu. The first version of the service was launched as a compromise between users' expectations and technical possibilities (Figure 1). Even though it could not include all the information expected by the users, it was a good way to test the new information channel.



Figure 1. The first launched version of the traffic information channel in digital television.

The users wished to get an all-mode route planner with possibilities to count not only the distance and travel time by using different modes, but also the expected costs of the travelling and/or driving. The same kind of counter was wished to be developed for counting the costs of taxi trips.

#### 2.1.5.4 Most urgent information needs

To find out the most important gaps in the existing traffic and traveller information, the users were also asked about the importance of various traffic information as well as how easy the information is to get. For the traveller, the information that is the most important and at the same time the most difficult to get is real-time information about the arriving buses, trains and real-time information of the incidents. Analogously, drivers indicated that detailed information of the incidents as well as of road works is important and still difficult to get, especially if the incident is located in a street or a minor road.

### 2.1.5.5 Conclusions

Drivers and travellers have a lot of decisions to make before the intended trip. These decisions deal with e.g. choice of the mode of transportation and of the route as well as the time of departure. These decisions have a great impact on the fluency of traffic, usage of public transport, environmental load as well as on traffic safety. Hence, development of services to support this kind of strategic decision-making is essential.

There is a need for centered sources, “common portals” for information. These sources and portals must be easy to use and at hand for everyone (via digi-TV, via telephone, via Internet). Digital television is a new concept (Penttinen et al. 2003b). It enables more advanced and multifunctional information services than conventional text television. There are still many challenges on its way to become a primary traffic information channel, however. From the users’ point of view it differs from the Internet in several ways. The return channel for interactive use is the biggest issue. What is the best technology for it? The main input device to view the sites on digi-TV is a remote control with a very limited number of push buttons. This requires the information to be grouped into a hierarchy. Furthermore, the watching distance is greater than in the case of a PC. Therefore, the font size must be greater, so not much information can be placed onto one page. There are, however, a few factors that defend digital television against PC and the Internet. Digital television is quicker when one switches on the television; the connection is enabled at the same time. In addition, almost everybody has a television, and therefore a connection. By the end of 2007 analog broadcasting will be entirely replaced by digital technology.

To ensure the success of the transportation channel, the whole development process will be based on the stated user needs. In addition, to achieve a product with user-centered characteristics, the requirements and user involvement will be an important part of an iterative design process – from the early user needing analysis in the context design phase to the evaluation of the real effects of the new systems on the users. Consequently, it is important to continue the development and evaluation work after piloting.

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## 2.2 Operating Hazard Analysis for automated mining machine systems

Risto Tiusanen, Kaj Helin & Jari Karjalainen

### 2.2.1 From manual driving towards system operation

A lot of mobile machinery is used for development, production and support operations in a modern underground mine. Special machines are used for tunneling, production drilling, loading, hauling, dumping, charging and transportation. A manual mining machine driver's typical work includes several tasks, such as start-up routines in the beginning of the shift, functional tests, driving, operation, fault finding, daily maintenance etc.

The driver's or operator's working conditions can be improved by remote control. In the most commonly used version of machine remote control, the operator stands beside the machine or at least in the vicinity of the machine. This is called remote control line of sight. The control commands are linked via a cable or radio transmitter. The distance from the machine can be several hundred meters, and the driving is performed with a video link (see Figure 2).

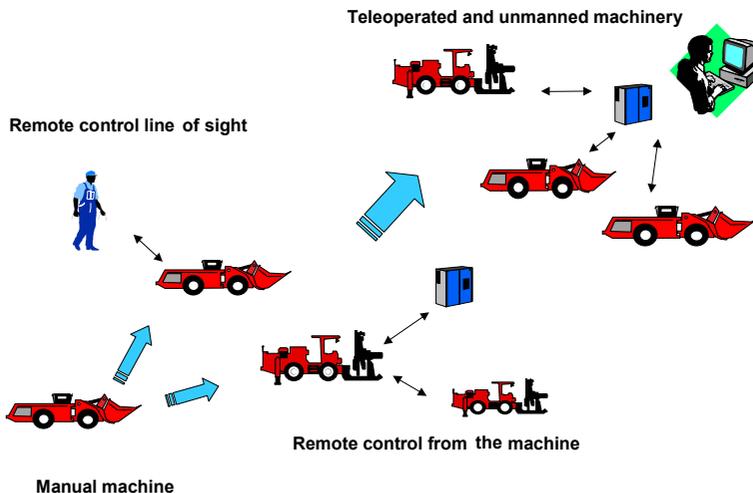


Figure 2. Mining machine remote control applications.

Because of the mine layout the remote controlled vehicles have to drive deep in the stope or round a corner so that the operator cannot see the vehicle. In these cases, tele-remote systems are used (Swart et al. 2002).

New automated loading and transport systems in mines can include several autonomously tramming and teleoperated loading machines. An automated loading work cycle can be as follows: the operator fills the loader bucket in remote control mode. The loader trams automatically to the ore pass, dumps the ore into the ore pass, and trams automatically back to the draw point. One operator in the control room can handle several loaders, dump trucks or rock breakers from his control station.

Manual driving in a tunnel is needed only for moving the machines in or out of the production area and in some special situation (e.g. maintenance, refueling and spillage cleaning). The operator is like a process controller in a factory or in a process plant (Figure 3). This can give the impression that the operator's work is simple and easy – only fill the bucket and monitor the process.

However, reality is different. The operator's daily work and routines were specifically studied by VTT in LKAB Kiruna mine in 2000, during the risk analysis of the entire semiautomatic loading and transporting system. The operator's daily work included over 30 different tasks including machine control, operation planning, inspection, process monitoring, communication with other groups, reporting, documenting etc. A machine operator has become a system controller. (Tiusanen 2001.)



*Figure 3. On the left teleoperated drilling in Kiruna Mine (LKAB 2000). On the right operator station in Sandvik Tamrock test mine in Finland (Pulli 2003).*

The safety requirements cannot be solved by technical solutions in complex mobile machine applications. Safe operation and maintenance rely strongly on risk-conscious behavior and decision making by the operators and other actors. In that sense, it is important to analyse the operating and maintenance procedures to be able to identify possible safety issues and safety risks.

Operating hazards and safe system operation are new issues to machine manufacturers. In typical machine business, the manufacturer is responsible for the technical safety of the machine, according to the machine safety directive. The manufacturer gives the end users practical training in how to use the machine and after that the operating company is responsible for safe operation. In the system business, the system supplier is responsible for that the whole automation system is safe to implement, test, commission, operate, maintain and modify. Driving a machine and working with it is quite simple compared to the operation of an automated and autonomously operating machine fleet. A real need has risen to develop a practical method for operating hazard analysis and risk assessment that takes into account human factors, interactions between the operators, interactions between the operators and all information systems, operating environment factors etc. Application of Operating Hazard Analysis (OHA) is needed to complement the traditional Potential Hazard Analysis (PHA) and subsystem HAZOP studies which are typically used for machine-level safety analysis and are technology-oriented analysis methods.

### **2.2.2 Operating Hazard Analysis (OHA)**

Operating Hazard Analysis (OHA), also called Operating and Support Hazard Analysis (O&SHA), focuses on the hazards resulting from tasks, activities, or operating system functions that occur during use of the system. The hazard is not necessarily the result of a failure of a component or a human operator's error. However, the focus is on the operational event or activity that may be an indirect cause of the mishap. More than likely, the operational event merely allows the subsequent sequence of events to cause the undesired occurrence (Ronald & Moriarty 1983).

The general purpose of OHA is to perform a detailed safety risk assessment of a system's operational and support procedures. The specific goals for OHA can be stated as follows (FAD 2002):

- evaluate operating and support procedures for a given system
- identify hazards associated with those procedures and assess the safety risks
- consider human factors and critical human errors, normal and emergency operations, and support tasks
- identify existing controls
- develop alternative controls and/or procedures to eliminate or control the hazards.

### **2.2.3 OHA for automated mining machine applications**

At the system level risk management, approach OHA integrates the people and the procedures with the automated machinery system. The OHA developed at VTT for automated mining machine systems considers system operation from three levels or viewpoints (Figure 4):

- interaction between the system operators, maintenance people and production management
- interaction with the automation system, safeguarding systems and other external information systems
- individual operating or maintenance work tasks.

The system operation in OHA is handled in four phases: Daily routines carried out at the beginning of a work shift, daily work with the machinery, daily maintenance and repair works. The intention is to cover all the operators' main work tasks:

- preparing the production area for automated use
- marking and teaching the routes for the machinery

- testing the functions
- manual driving, tele-operation, autonomous production
- system extension
- troubleshooting, repair work, maintenance in the production area
- system modification
- system decommissioning.

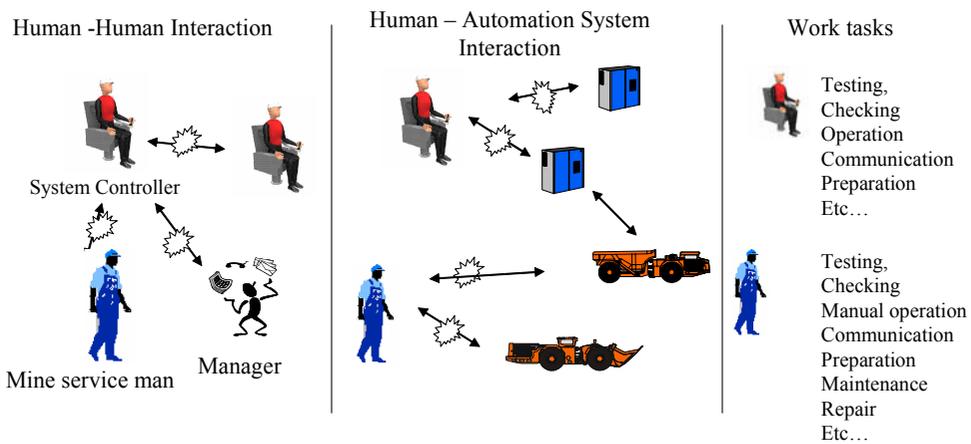


Figure 4. Three human-technology-interaction viewpoints included in OHA for mining machinery applications.

OHA data collection work sheet and an example of the analysis of one work task are presented in Figure 5. A new feature is utilized in OHA. The risk is estimated twice during the analysis. First, the risk is estimated before the safeguarding or protecting measures, as usual, and the second time it is estimated assuming that all the safety measures are implemented. The effectiveness of the different safety measures and the relevant risk reduction capability were assessed in the project team.

<b>OPERATION HAZARD IDENTIFICATION AND RISK ASSESSMENT</b>				<b>RISK RANKING</b> <i>(no controls in place)</i>			<b>RECOMMENDED CONTROLS TO BE IMPLEMENTED BY THE MINE MANAGEMENT OR THE MANUFACTURER</b>	<b>RISK RANKING</b> <i>(after controls in place)</i>		
<b>TASK</b>	<b>HAZARD</b>	<b>CAUSE</b>	<b>CONSEQUENCE</b>	<b>P</b>	<b>S</b>	<b>R</b>		<b>P</b>	<b>S</b>	<b>R</b>
Reacting to alarms generated by the system and informing support personnel as required	System controller does not react to alarms.	Human error. Carelessness, hurry, too much work load. System controller is not in the control room (illegal break)	Damage to machinery.	C	2	8	Alarm information also to support personnel.	D	2	12
			Production loss	C	4	18	Instructions and training.	D	4	21
			Machine fire	D	1	7	Automatic fire extinguisher system in the machine. Manual fire extinguisher.	D	1	7

Figure 5. An example of OHA worksheet.

## 2.2.4 Conclusion

The operator in a modern automated underground mine is like a process controller in a process plant. The roles and responsibilities of the system operators and support persons are difficult to determine in a complex and large automated machinery system. There is a lot of interaction and communication between the operating crew members and several user interfaces to the different operating systems, such as production control, tele-operation, safety system etc.

The hazard analysis of manual machinery typically focuses on technical issues and instructions. Proposals and suggestions for technical improvements and for better instructions are usually given as the result. The system-level approach and OHA raise new issues related to the work process, such as the operators' right actions, clear communication, production planning, maintenance planning and work management. In the case studies it has been clearly recognized that the overall safety of a complex automated mobile machine application relies strongly on the operators' and the service men's behavior. Right and safe operation depends on how appropriate and practical the work procedures and tasks are and how exactly the personnel follow the safety rules.

Practical experiences from the case studies are that clear specifications of the system operation use cases and the maintenance work procedures are essential for operating hazard identification. Mining applications are always unique and the procedures therein are dependent on the mine environment. The procedures and tasks must be defined so accurately so that the system functions as well as the interactions between the operating or supporting crew can be understood and analyzed. In mining automation, project OHA should be done as soon as the operating and support procedures have been defined and all the application and mine-specific operation conditions and procedures have been identified. OHA should also be seen as a validation tool in the system change management process. As in all system safety, methods team work is essential in OHA to ensure that all application-specific aspects are taken into consideration when analyzing the operator's or service man's daily work tasks.

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## **2.3 User-centered design of GofRep system: simulations as motors of design**

Sanna Sonninen & Paula Savioja

### **2.3.1 Introduction**

The aim of this chapter is to describe the method used in the development of the Gulf of Finland mandatory Ship Reporting System (GOFREP) and discuss the use of simulations as a motor of human-centred design (HCD). In the chapter we will first summarize the development of the entire GOFREP system, its objectives, parts and development phases. The development of the GOFREP system is a good example of a time-pressured complex design task that has remarkable constraints (international, cross-cultural, historical development, regulations, technological maturity etc.). We will concentrate on the development of the operational procedures of the system and describe the method used. The constructed method will be described and its strengths and weaknesses will be compared to the principles of human-centred design. Finally, we will discuss the practical challenges of using simulation as a human-centred design method in the development of a large multicultural socio-technical system.

The number of vessels transiting the Gulf of Finland, between Finland, Estonia and Russia, has increased significantly during the last years and is still expected to increase in the future. With the heavy passenger traffic between Helsinki and Tallinn, and the rapid development of the Russian oil terminals, the traffic image has also diversified. The main safety concern related to the increasing ship traffic in the Gulf of Finland is the increase of the risk of collisions between different types of vessels, and the environmental damage due to subsequent oil spills. In particular, the passenger vessel and recreational boat traffic, intersecting the tanker routes in the area between Helsinki and Tallinn, is seen to cause a threat to the safety of navigation and the marine environment. These threats necessitated the introduction of risk control measures for the gulf area. As one of the main measures Estonian, Finnish and Russian maritime authorities implemented the GOFREP system (IMO 2002a; IMO 2003).

### **2.3.2 Aims and principles of the GOFREP-system**

Implementation of GOFREP aims to enhance safe navigation in the Gulf of Finland. The development work described in this chapter included the construction of both the system description and the operational means for executing the description. To achieve the desired positive impact on maritime safety, development of both technical solutions and common operational procedures for the three cooperating countries was required. The procedure development was preceded by a Formal Safety Assessment (FSA) study, based on which the general modelling of the system was done (Nyman et al. 2002). During the modelling stage it was decided that the GOFREP operation shall be developed in workshops that shall be participated by subject matter experts, human factors specialists, and representatives of the relevant authorities (Sonninen et al. 2002). In the workshops the development started with small-scale, low fidelity simulations, proceeded to the use of large-scale real-time simulations and was finalised with operational trials. The aim of the common operational procedure development was the creation of trilaterally joint procedures providing guidance to the daily work of the GOFREP operators.

Joint operational procedures development workshops were attended by representatives from all three co-operating countries. The aim of the workshops was to create procedures for both the GOFREP operators' primary and secondary tasks to the extent required for harmonisation of the operation between GOFREP Traffic Centres and vessel traffic as well as the operation between the Traffic Centres themselves. These are the external procedures (IALA 2000). The internal procedures, e.g. co-operation with national VTS (Vessel Traffic Service) Centres and other relevant stakeholders, such as the sea rescue organisation, were not a part of the procedure development scope. The harmonisation of internal procedures was heavily dependent on the national organisations and culture in each of the countries. Thus, it was decided that each of the nationally responsible authorities will develop the necessary internal procedures after the aims of the operation have been agreed on.

The division of the GOFREP operators' work to primary and secondary tasks is not unambiguous, since the main task of the system varies to some extent between winter and summer operation. In general, the primary tasks include the reception and distribution of relevant information to and from vessel traffic, and

monitoring the vessel traffic to observe dangerous vessel encounters and breaches of regulations (IMO 1989; IMO 2000; IMO 2002b). The secondary tasks may include activities such as reporting of the breaches to the authorities or providing information to organisations that are not a part of the system, i.e. fairway maintenance, shipping agents, port operators, etc.

Creation of technical tools required for effective operation and determination of the number of personnel required for ensuring proper manning of the Traffic Centres were also significant parts of the GOFREP development. The more suitable the technical tools and the developed procedures, the more reliable and effective the work of the operators.

A part of the system development was the understanding and implementation of the international requirements and guidance to the procedures. Some of the procedures were developed to a large extent on the basis of existing systems and guidance (HELCOM 2004; IALA 2000; IMO 1989; IMO 2000; IMO 2001; IMO 2002b). Some of the procedure development issues had relatively few alternatives and an effective procedure could easily be found, but the procedures also included issues to which an ideal solution could not be identified. In these cases, the reason for having to adopt the best available procedure was a technical limitation, the operators' legal liability or the differences of the operational culture in the co-operating countries. (One of the most difficult issues was the level of guidance given to vessels when a risk of collision exists.)

### **2.3.3 System description**

The system is operated by three shore-based facilities at Tallinn Traffic, Helsinki Traffic and Saint Petersburg Traffic. The facilities are able to monitor ship movements by means of VTS traffic image and provide improved advice and information about navigational hazards and weather conditions (Figure 6). A common information exchange system was developed for the national Traffic Centres for storing the information on vessels transiting the Gulf. Information obtained from the vessel reports is managed with a software module that has been added to the VTS system that the GOFREP operators use for traffic monitoring (Navielektro 2003). Other relevant technical systems are also utilized. The traffic is influenced through radio communication. Thus, the

operators' communication is the key element in an operation that has a direct and sometimes a very rapid impact on the decision making onboard the vessels.



Figure 6. Gulf of Finland Reporting System (GOFREP) monitoring area and locations of Traffic Centres (picture: Finnish Maritime Administration).

It can be argued, that the operators' primary monitoring task can be accomplished with the equipment available, as all vessels required to participate (ships of 300 gross tonnage or more) can be observed throughout their transit in the Gulf. However, the observance of smaller vessels (less than 300 gross tonnage) is unreliable with the present techniques. Since the traffic image is not comprehensive, it does not enable actual assistance to the decision making on board by means of intervening in the choice of a safe course or speed. This has necessitated the creation of procedures that enhance safety in the best possible manner by giving as much information as possible to the vessels without creating further hazards.

### **2.3.4 Simulator fidelity and contents of simulation scenarios**

Simulator fidelity can be divided into functional and physical aspects (Harvey et al. 2003). Functional fidelity refers to the functions and capabilities of a simulator as compared to the counterparts in the real-world operational system that is being simulated. In the case of GOFREP, the existing VTS systems were considered the real-world counterparts due to the conformity of these systems. Physical fidelity related to the appearance of the equipment used in the GOFREP operation was not considered important since the simulations focused on procedures, not on human interaction with technology. In fact, the participants' (operators) interaction with the equipment was intentionally minimised by developing the simulation scenarios so that the participants would only use five basic features of the simulator. However, even though the requirement of functional fidelity in procedure development was very high, also the level of physical fidelity was increased during the procedure development process.

Another aspect of simulator fidelity in simulator studies is participant fidelity. If the participants do not accurately represent the study population the results may be biased (Harvey et al. 2003). Even though the participants of the simulations represented the best available expertise of vessel traffic management operators, also the assisting participants' fidelity aspects needed to be considered. Communication is a key element in vessel traffic management systems such as GOFREP and thus a very important part of the simulations. Additional personnel was hired to produce the radio traffic from the vessel traffic created to the simulations to allow the participants to take part actively in the simulations or to observe them. During the first workshop simulations persons with very little knowledge of seaspeak assisted in creation of the radio communication. This was possible since the assistants were guided by simulator instructors with good knowledge of seaspeak and the simulation scenarios were fairly simple and the course of events predictable. The simulations proceeded according to manuscripts. In the last three workshops communication from the simulated vessel traffic was created by ship officers from the Finnish merchant fleet or by VTS operators. This was a necessity in order to assure participant fidelity since even though the simulations still followed manuscripts including the desired events for the procedure development, the participants could adapt to the development of situations and thus the persons acting as vessel traffic had to be able to react realistically to the changing situations.

The content of all the used simulations was planned to include situations where the procedures being currently under development could be tested. The decision on which procedures needed to be developed in each of the workshops was based on the GOFREP system development plan. After the first workshop the notes and needs from the previous workshops were taken into account in building up the next workshop programme and in the selection of suitable scenarios. In addition to the obvious situations that were needed in the simulations, events that drew the participants' interest to certain issues were included. Several normal, everyday situations were also added to the simulations to ensure functional fidelity. The participants had to be able to concentrate on their actions while testing the procedures and thus it was very important to keep the simulations clear and rather obvious. It was also important for iterative simulations where the observations for decision making had to be validated with multiple tests.

### **2.3.5 Use of simulations**

The Estonian, Finnish and Russian maritime authorities formed a three-tier organisation for the GOFREP development consisting of an executive level, a preparatory level and an operational level. The task of the operational level was the preparation of procedures in workshops. During the workshops expert groups developed procedures, evaluated and compared the developed procedures during simulations and, chose the best practises in the debriefing sessions based on the observations made during the simulations (Figure 7). Four workshops were arranged during the development process.



*Figure 7. Participants of the third workshop simulation (Operational Exercise III) in a debriefing session (picture: Timo Raunio).*

Simulation was used as a human-centred design (ISO 1999) method for procedure development. The aim of HCD is to produce a system that supports human users in their tasks, and allows them to carry out their work with effectiveness, efficiency and satisfaction. Simulation is a HCD method that can be used for requirements gathering, requirements validation, and also system validation especially in safety critical environments (Savioja 2003). In the development of GOFREP, the simulations provided a medium for acquiring experience of the intended procedures in different kinds of operating situations. Also, the simulations enabled the participants to make comparisons and judge between two or more prospective alternatives. The comparison could be made on the basis of effectiveness, feasibility and quality.

The simulation method was decided to be used in the GOFREP procedure development for many reasons. The basic documentation on the GOFREP operation described the goals and aims of the system but gave very little guidance about the working methods. Simulation enabled the participation of

subject matter experts (VTS operators) from Estonia, Finland and Russia in the procedure development, and their expertise on vessel traffic services could be utilised in the work. Another benefit of simulation was the possibility to measure to a limited extent the workload of GOFREP operators and to use this information for defining the needs for recruiting new personnel. The workshops were attended by operators from the GOFREP countries. These operators could all participate in the simulations, create a common understanding of the operation, and express their national view on the procedures. Consequently, the agreements made in the debriefing and summing up -session could then be presented as trilateral procedure proposals for the preparatory level.

There were five different tasks for which simulation was used: definition of system functions, procedure development, validation of operation, workload assessment, and operator training. All of the arranged workshops included features of these five tasks but the emphasis varied during the process. The importance of defining the system's functions was greater in the first workshops but decreased and played a minor role in the fourth workshop, whereas the importance of validation of operation was less important in the early stages of the process and increased gradually, being with training the most significant aspect during the fourth workshop. The importance of procedure development and workload assessment remained fairly constant throughout the process.

The aims of the four workshops varied according to the development stage and the variation was most notable in the simulations. Also the level of simulation was varied. The first simulations were simple pen and paper simulations and the last ones were carried out with a full scale VTS simulator and in the last workshop, in the actual working environment. The lower level simulation provided basic information about the different stakeholders' roles in the operation of GOFREP, whereas the higher level simulations helped for example to envision the future task load of the GOFREP-operators. The lower level simulation focused on the operators' basic procedures for primary tasks, such as receiving and storing the information from vessel reports, definitions of geographical limits of the system, and management of vessel traffic in a specific monitoring area or monitoring responsibility hand-over situations. No critical or emergency situations were included in the first stage development.

During the second and the third workshop, the level of simulation was increased (Sonninen et al. 2004a; Sonninen et al. 2004b). In these workshops, simulation was still used for the same purposes as in the first simulations, but the development of more complex and safety critical procedures required higher fidelity. During the second workshop full mission VTS simulator was introduced, but the simulations did not cover all of the vast GOFREP monitoring area. Nor were any winter time or emergency situation operations included in the simulations. The third workshop simulations included the entire geographical area and the amount of simulated vessel traffic in the monitoring area was increased to equal almost the frequency of congested traffic in the Gulf of Finland (Figure 8). Some critical situations were also added to the simulations. The fourth simulation was an operational trial but also an operator training session (Sonninen 2004). The aim of the trial was to demonstrate the feasibility of the software developed for the GOFREP operators' work and find possible defects in it (IALA 2002). The software was finalised according to the observations. The simulations in the operational trial were based on real, on-line traffic images of the Gulf but the situations needed for procedure validation were created by adding dummy-targets (virtual ships) to the image.



*Figure 8. GOFREP operators at the third workshop simulation (picture: Timo Raunio).*

As mentioned earlier, the workshops also served as a training session for the participants. The workshops and the simulation exercises used for procedure testing were cumulative; the following workshop used the results of the previous workshop as the basis of development and the simulations during a workshop included the procedures developed both in the previous workshops and previous simulations during the same workshop. The participants gained more confidence in using the previously defined procedures while testing new ones. As a result, the operators noticed details in the previously defined procedures that needed to be changed and thus the development of procedures was continuous through the process.

### **2.3.6 Problems in the simulation method**

Simulated situations, i.e. the scenarios created for the procedure testing are composed of foreseeable occurrences. Although many problems that have been previously overlooked can be observed in a simulated chain of events, the simulation method does not provide a comprehensive aid for definition of procedures for situations that are not anticipated. Another flaw in using the simulation method is that the participants can act differently e.g. be more thorough than in normal work because they know that everything is recorded, and their supervisors are observing.

High fidelity full-scale simulators are undoubtedly an effective medium for teaching, but their multifunctional configuration can also have disadvantages. The variety of equipment provided in a full-scale simulator also provides an endless source of distraction to the participant. The use of a part-task simulator is in these cases justifiable, since it provides the trainee all the necessary tools but no extra load for his vigilance thus allowing him to concentrate on the developed procedure. Due to their complexity, full-scale simulators also have rather often technical failures causing disturbance to the testing process. If two optional procedures are being tested in two separate simulation sessions and during one of the sessions the simulator suffers a technical fault, the comparability of these two tests is impaired since the effect of the fault to the participants' decision making is difficult to estimate. In addition, even high fidelity simulators are somewhat unrealistic from the operations point of view, because the operators are well aware that "this is just a simulation". Thus for example the level of workload or work-related stress is very difficult to measure by simulation.

### **2.3.7 Conclusions**

In the case of GOFREP, simulators provided a necessary environment for the representatives of three countries to discuss, develop, test and make decisions accepted by all, based on the agreement reached during these three steps. It is the writers' belief that the same results could not have been gained in the same timetable if the representatives had tried to accomplish the provision of common procedures by sitting in meetings and discussing. When design is to some extent based on knowledge of existing similar systems which are operated slightly differently in different cultures, it is not a question of who's right but a question of utilising the knowledge of different cultures and trying to build as good a system as possible based on best practices.

Simulation is an excellent tool as the motor of design but it has flaws that need to be perceived. Although simulation generates new ideas and helps the participants to anticipate unforeseen problems, it does not ascertain that the unexpected situations have been comprehensively covered. One should also bear in mind that however seriously the participants take the simulations, they shall still remain only simulations, not the real world, and in some nook of their brain the participants are conscious of this.

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## **2.4 Exploiting virtual environments in steel factory design and risk assessment<sup>1</sup>**

Timo Määttä & Kaj Helin

### **2.4.1 Introduction**

Safety should be considered preferably in all design stages. Initially a design process will involve unknown factors, and decisions must be made under uncertainty concerning possible unintended consequences (Behesti 1993). Project risk management and management of safety and health risks are basic parts of a company's risk management (Wideman 1992). Deficiencies in the design processes have caused unacceptable failures and disasters, many of which could have been avoided by systematic approaches to the management of engineering design (Hales 1995).

Hazard analysis and risk assessments are widely accepted in product and process design (Van Aken 1997). Many manufacturing system design processes have nonetheless shown little evidence of systematic safety analysis (Mattila et al. 1995). Today manufacturers or their representative must carry out risk assessments and take the results into account in the machine design (Directive 98/37/EC).

### **2.4.2 Objectives**

The main objective was to study means for enhancing the safety analysis procedure in the design phase of a machine system with Virtual Environments (VE). The purpose was to establish how VEs affect the analysis process and how visualisation by computer modelling can be effectively used when applying participatory ergonomics.

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<sup>1</sup> This characterisation is mainly based on Dr Määttä's Ph.D. thesis (Määttä 2003) and the materials for this study are the seven cases at a steel factory during the years 1995 to 2000.

The main interest focused on an evaluation of the impact of the VEs and Participatory Ergonomics (PE) (Wilson & Haines 1997) approach on safety analysis during the design phase.

### 2.4.3 Method of machinery safety analysis

A new method (SAVE) for the safety analysis of machinery is illustrated in Figure 9. The method involves a combination of four elements: participatory approach, task analysis, safety analysis and virtual environments. These elements are active concurrently as an integral evaluation procedure (Määttä 2003).

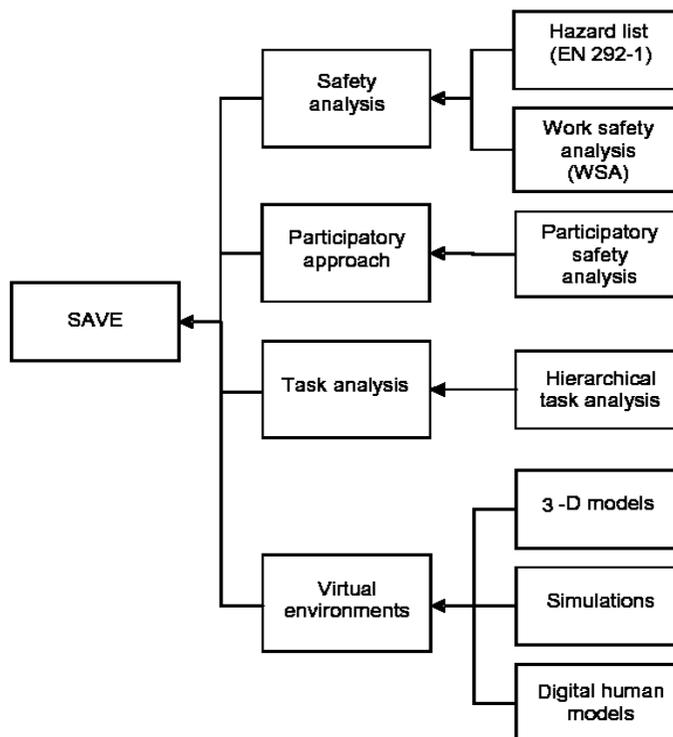


Figure 9. Structure of the SAVE method (Määttä 2003).

The material for this work are the seven case studies performed with the company during the years 1995 to 2000 at a steel factory. All the cases were interconnected to modernisation projects in the company. The aims of these projects were to improve production efficiency and occupational safety. The

steel manufacturing processes and the processes included in this work are presented in Figure 10.

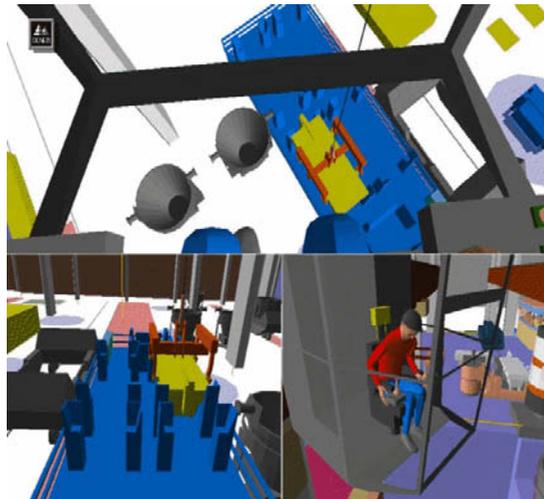
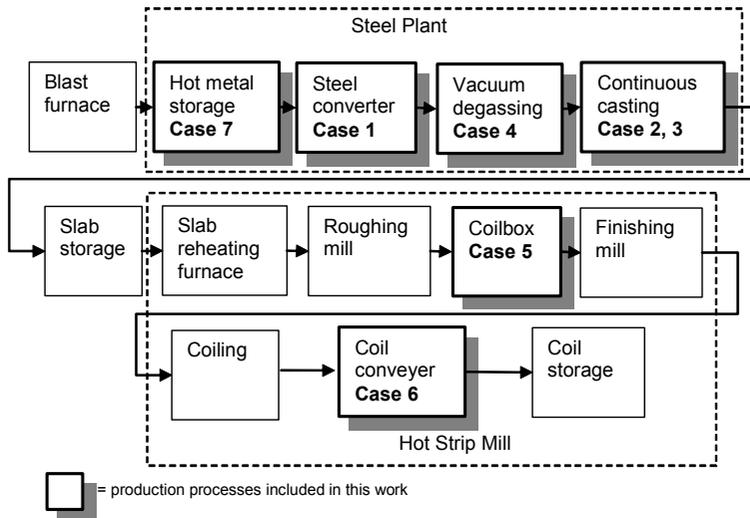


Figure 10. Above: A schematic description of the basic process in the steel works. Below: An example of views applied in Case 2.

The safety analysis groups consisted of project managers, foremen, designers, company's safety specialists, and operators. The project managers and at least three operators participated in all groups and analysis sessions. Other group members participated in most of the sessions. During the meetings the members

were encouraged to participate actively, and to comment and suggest ideas. The solutions were called into question and discussed in detail. The situation of the analysis work in the whole investment project was explained to all the participants. The researcher acted also as a chairperson in order to establish a neutral atmosphere during the meetings. The meetings had a schedule from 3–6 hours, with normal breaks of a working day.

Virtual environments were applied in three modes, i.e. using only 3 D models, using additional simulation and using digital human models in VEs (Viitaniemi et al. 2001; Helin et al. 2000). Three modes for visualising virtual environments were selected to study their implementation in safety analysis, namely screen, simulator with head mounted display and laptop screen with stereoscopic view with special lenses.

After a year of all the safety analysis projects, structured interviews were carried out to collect the participants' experiences and opinions of the implementation of the SAVE method during the investment projects. Altogether 9 participants of the seven cases took part in the interview. The participants were project managers, a maintenance manager, production development technician, safety technician, foreman, and workers from the case projects discussed in this work.

#### **2.4.4 Results**

The group work was active in each case. The activity was higher when the participants had worked together before the safety analysis sessions generally in similar working situations. Discussion during the sessions increased notably when the virtual environment was in use. Especially the workers from the site of the plant participated actively during the use of the virtual environment as a visualising tool.

The workers who worked as crane operators with overhead cranes in the plant were interested in the simulator used in Case 2. When analysing the work with the simulator each participant took an active role in safety and task analysis. The rise in activation during the analysis was due to a new unfamiliar tool, but also to the easy and concrete way of performing the analysis. The 3-D models for the safety analysis sessions were prepared mostly with less detail. Only the sizes and

the main shapes were according to the real objects. The functions of a model were programmed with the tools of the applied software.

According to the results of the interviews SAVE was a feasible method that could give the assurance that the investment will work as planned and that the functions are safe. All the persons interviewed recommended this method for similar projects. The implementation of the method was evaluated as not being very expensive. The investment in safety analysis with this method and tools was perceived as valuable. VEs also gave a more realistic and easily understandable scaling effect of the target machine system than drawings. Also the visualisation of movements in VEs enhanced understanding of the functions of a machine. VE had positive impacts on the time spent for analysis and on training as well as on the verification of the system plans to the specifications.

#### **2.4.5 Discussions**

The computer simulation of a system and its functions with VEs will benefit the understanding of the critical points especially with a multifunctional machine system. The simulation will focus the participants to concentrate on the relevant issues at each stage of the analysis. A number of defects in the designs were detected using VEs. The views of the operators on the critical points in the process were also estimated by the interviewees as being easy to evaluate with VEs. The usage of VEs is well- suited to participatory design. The systematic mode was an important part of the analysis, especially in analysing complex systems and in training users for the system. The use of VEs opens up possibilities to detect the critical points in a system and forces to check whether there is a fault in the drawing. A realistic picture of the machine was also informative to the workers, who had never before seen anything of that new machine.

The participatory design method is also useful in safety analysis. The positive effects on the quality of analysis were

- wide knowledge among the participants for the analysis process
- effects of appreciation of the workers' opinions and knowledge

- effect of the participants having equal opportunity to have influence on the design
- possibility to concentrate on the task itself rather than on tasks as encountered in the real job.

The participative approach had positive effects also because of the different viewpoints arising in the analysis process. Usually a consensus is quite easily reachable, but the dynamics of group work will still have an influence on the work.

Further research is needed in developing more sophisticated software and equipment for virtual environment technology. New procedures for design using a virtual environment, more versatile digital human models, and effective and validated analysis more suitable to the design process are also needed. Guidelines to optimise computer and software power for safety analysis will enhance the use of virtual environments.

#### **2.4.6 Conclusions**

The use of a virtual environment enhanced the participatory ergonomics approach used in safety analysis. The VE gave a common understanding of the target machine system to all participants, and thus equal possibility to evaluate the functions, work, tasks and safety of a system. VEs support the implementation of participatory ergonomics in safety analysis.

Safety analysis could be performed with more information on the target system when using VEs. The visualisation of the system and its functions are very important to all participants when evaluating the safety of a system. Drawings of the system are still needed during safety analysis with VE. Visualisation with VE gives information on the scale of the target system and the relationships of different parts of a machine to the participants in a safety analysis group.

The results of the case studies carried out in this work indicate that less than 60% of the hazards and hazardous situations in a system can be detected by virtual environments during safety analysis. The visualisation with three-

dimensional models in a virtual environment system is, however, a vital element in creating a common and understandable image of the target system for all partners in participatory design or safety analysis, especially when analysing versatile and complex machine systems.

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## **3. Validation and evaluation**

When designing or redesigning parts of safety critical systems, it is important to predict the effects of new parts of the system and assess the quality of the outcome with adequate criteria.

Chapter 3.1 is about the development of a validation method for nuclear power plant control room modernization. The aim is an evaluation framework that is adaptable to promoting both verification and validation aims. The developed integrated system validation framework is shortly described. The authors emphasise that external analyses of human performance are not enough to achieve validation results that truly predict the future usage of the system. We should evaluate also what kind of user practices the user interface induces on the operators.

The evaluation presented in Chapter 3.2 aims to increase the knowledge for assessing whether transport telematic systems based on variable message signs (VMS) are socio-economically effective, and how they should be developed. VMS are displays on the roadside that can show a range of traffic signs or other messages for the drivers. In Finland, most of them are weather-controlled. A multi-criteria and multidisciplinary evaluation included measurements on driver behaviour and traffic flow.

### **3.1 Integrated validation of complex systems**

Paula Savioja & Leena Norros

Management of complex dynamic processes, e.g. nuclear power production, anaesthesia, paper production, or ship manoeuvring, is a demanding task. Due to the technical possibilities today, the control of many of those processes is highly automated leaving to the humans the tasks of monitoring and responding to either expected or unexpected abnormal process states. This creates an interface design problem: How to portray the process to the different stakeholders in such a way that they are able to take meaningful control actions when needed? Designers address that problem by creating control system user

interfaces and even whole control environments, but as these industries typically impose high risks on society, an unbiased *formal validation* is needed to determine how successful the design is.

In integrated system validation we use an approach that takes into consideration the whole distributed cognitive system, the process, the users, and the mediating control and information system.

### **3.1.1 Context of validation method development: control room modernisation**

The validation method that is described here has been developed in a research project that follows the developments in the Finnish nuclear power plants (NPP). The Finnish NPPs are currently going through extensive automation modernisation projects (Figure 11). A major challenge in the automation modernisation is the renewal of the various information systems within the control room. The most significant technological changes that are at the moment expected to take place in the control room are: adoption of soft control, large screen overview displays, new alarm systems, and renewal of the emergency operating procedures.

As these technological changes take place also the users' (operators, maintenance, engineers) tasks change. The interaction between the technical changes in the information systems and the working practices of the users became evident in our earlier validation study (Norros & Nuutinen 2004). In fact, we expect that when one constituent of an activity system (Engeström 1987) is transformed all the others will consequently be affected. In this sense the designer who is designing the control system interface can actually be responsible for a more profound change in the activity system than he/she could ever have expected. Thus the whole system should be looked at in the validation.



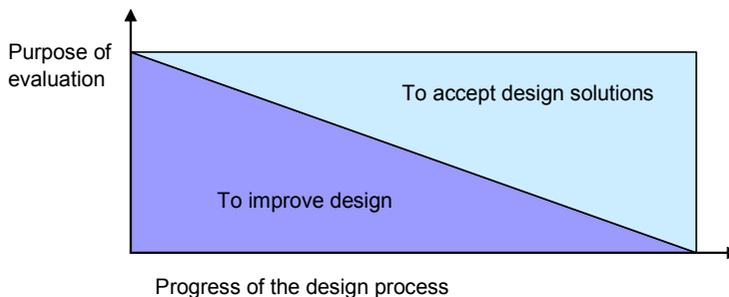
*Figure 11. NPP operators working on a full fidelity simulator. The current control room design depicted in the picture will be modernized during the upcoming years.*

We have developed our validation method on the basis of the international work conducted e.g. by NRC (in co-operation with Brookhaven National laboratory, NUREG) and Halden Reactor Project, in which the need for development of integrated system evaluation methods has been emphasised. Further, this work has drawn attention to the need of methodologically solid validation procedures and to the need of research-based criteria for the judgement of acceptance in validation. In the validation of control room systems the changes induced to the other constituents of the activity system should also be evaluated and their significance relating to safety of operation should be determined.

We have followed two modernisation projects in the Finnish NPPs in our research project that develops the validation concept. We have conducted evaluations that produce input for the design of new control room systems but also produce data about our evaluation criteria and their appropriateness for validation purposes.

### 3.1.2 Development needs of integrated system validation methods

Integrated system validation is a part of verification and validation (V&V). Both verification and validation are assessment techniques that evaluate the performance of a complex system. The difference between them is that verification uses the outputs of the design process as a reference (e.g. requirements specification), whereas the validation reference is formed independently of the design process. So in that sense validation also evaluates the successfulness of the requirements definition. The interaction between evaluation that supports design and evaluation to aid the decision for acceptability of the design solutions is demonstrated in Figure 12. Our aim is an evaluation framework that is adaptable for promoting both verification and validation aims.



*Figure 12. The purpose of evaluation gradually changes along the progress of the design process. First, evaluation is conducted purely to identify design problems and thus to improve design. The purpose of evaluation slowly shifts to acceptance and validation of the chosen design solutions. (Braarud 2004.)*

Integrated system validation is carried out in the end of the design life cycle to ensure that the safety- and acceptance criteria of the emerging technological solution are met. It considers the functioning of the whole operating environment consisting of the user interface, the control system, the operating procedures and the control room personnel. The rationale behind integrated validation is that even though the sub-components have been approved independently their ability to work together must also be evaluated.

Typically a high fidelity simulator is used for the validation and the participants are trained professionals. The operating conditions should be as authentic as possible.

A fundamental problem in validation is the predictive ability of the results (Savioja & Norros 2004). That is to say that we should design the validation procedure in such a way that the results are predictive of the future use of the system. This is because we cannot test all the possible operating conditions of the systems. The predictive ability of the results is affected by the selection of the operational situations and the performance indicators used in the validation, two problems that are described in more detail below. In addition to these, also the overall effort (e.g. number of scenarios, number of crews) needed in the validation and the determination of decision-making criteria are questions that need to be addressed with scientific rigour in order to perform formal validation (Heimdal et al. 2004).

#### 3.1.2.1 Selection of operational situations

The first development need of the validation procedure is the selection of the operational situations to be tested. With operational situations we refer to the simulated scenario and selection of the crew to act as operators in the situation. This selection is not trivial because there are normally external factors (i.e. allocated time and money) constraining the validation process so we cannot use all the intended crews of the plant or all scenarios that the validation team can come up with.

Since all possible operating conditions cannot be used in the validation we have to select situations that reflect the actual usage of the system as correctly and accurately as possible. In addition to the operationally most typical situations, such as full power, start up etc., the scope of validation should be extended to cover also situations from small disturbances to accidents and emergency operations. Most importantly, the situations used should go beyond the design- and operator training basis to ensure validity of the validation. (O'Hara et al. 1997.)

### 3.1.2.2 Selection of performance indicators

The selection of relevant performance indicators is another task that needs to be looked into when developing a validation framework. A wide range of human performance measures have been proposed in the literature. However, there are no guidelines for how to anchor these measures to the criteria of operational safety. Also, the question of indicator prioritisation should be addressed.

Typically, the performance indicators can be divided into process performance and human performance measures. This means that in validation the goal of system performance is twofold. A certain level of process performance must be reached within reasonable human performance. But the question still remains: Which human performance measures indicate safe operations?

The human performance indicators that are usually used in the validation are concepts that measure the human operators' ability to recognise and identify the operational situation or for example their ability to follow pre-learned procedures. The problem with these indicators is that they only show how this one specific crew acted in this one specific situation. Thus, they focus on the specific actualisation of usage but are not predictive of the future usage of the system. They provide no evidence that another crew would in another situation be able to take safe control actions.

### 3.1.3 Proposed validation framework

The basis of the validation framework VTT has used is in the functional modelling of the problem domain. We use a specific analysis method, core-task analysis (CTA) to determine what the motive for the existence of that activity system is and with which functions the objectives of the system can be fulfilled. The emergence of this method at the VTT human factors group was extensively explained in a recent book (Norros 2004). This analysis helps us determine what the core content of the work carried out in that activity system is. This core task is expressed in the result critical functions of the domain that the personnel is responsible for.

The modelling is conducted by an expert group consisting of e.g. operators, designers, trainers, supervisors, and human factors experts. The result of the modelling task is a generic hierarchical model of the domain which expresses what the critical demands of control of the process are. The generic functions portray the intrinsic constraints of the process that the users must always be aware of and take into account in their actions.

#### 3.1.3.1 Support for test case selection

In order to choose which scenarios are suitable for simulator runs used in the validation we have to apply similar modelling to the possible scenarios. We call these models functional situation models, because they illustrate how the generic result-critical functions of the domain are portrayed in the specific situation.

For example, when the scenario is a disturbance, we start with the root cause and its effects on the critical functions of the domain. The models illustrate which functions are threatened and most importantly *why*. The sometimes inadvertent phases of dealing with abnormal situations i.e. detection, diagnosis, stabilisation, and returning to normal are also included in the models. Our models emphasise the goals of the specific phases in the situation at hand.

This analysis of the potential scenarios is helpful in the determination of which scenarios to use in the validation. The models explicate the complexity of the scenarios and also portray how the complexity is constructed in that scenario. That way we can ensure that situations with different demands are included in the validation process. We can also make sure that all the critical functions of the domain will be covered by the selection of the scenarios.

#### 3.1.3.2 Operation-based performance indicators

The indicators of good system (process and human) performance are embedded in the intrinsic physical constraints of the process domain. These constraints are given a situational meaning through functional situation models (FSMs) that describe the central demands of the given operative situation. The functional situation models also form the basis for the performance indicators.

As mentioned earlier, typical human performance indicators reflect the personnel's ability to follow the trained task flow (Vicente 1999) described for that situation. Thus, they measure the number of errors, response time, and correctness of the diagnosis. We call this evaluation of the *external good* of user practices. It is something that can be measured from the outside, without addressing *why* people acted the way they did in the situation. We maintain that also the *internal good* of the user practices is a relevant object for the evaluation. It is manifested in the *core-task orientedness* of the user actions. We therefore propose a second class of indicators that express the core-task orientedness of the practices. This can be evaluated on the basis of the courses of actions in that situation and the operators' ways of using information and other resources from the point of view of *the meaning* that their behaviour implies. In addition to a behavioural analysis we also perform a stimulated process-tracing interview in which the operators justify and reason about their actions in the situation. The reference for the evaluation of the internal quality of user practices is the FSM. We want the users to have a thorough understanding of the situation: its causes, its effects, and the appropriate actions in it. So, ultimately the validity of the user interface is manifested in its ability to mediate these important aspects of the process to the users.

The final point in the evaluation of the practices is the grading of the level of the users' orientation to the core-task. The *Criteria* for good practice with regard to each core-task related performance indicator are drawn from our theoretical notion of the *adaptability* of practices. Drawing on the ideas of C.S. Peirce we maintain that the viability of the human-environment interaction lies on the interpretativeness vs. reactivity of this relationship (Peirce 1903/1998). We have analysed various forms in which the interpretativeness-reactiveness dimension may become manifest in action and developed 3 or even 5 grade scales to indicate the goodness of practices (Norros 1996; Norros 2004; Norros & Nuutinen 2004).

Because system usability is conceived as a balanced and appropriate functioning of the whole human-technology system, we hypothesise further, that the level of achieving system usability also manifests as user acceptance of the artefacts. Therefore, an operation-oriented validation also includes an evaluation of how the users feel about the artefacts that should be used by them in their work. User acceptance is evaluated in such a way that information is provided of the

potential of the artefact to become an integrated part of the human-environment system and to create new possibilities of life. For this reason the term “*experienced appropriateness*” is introduced to substitute for “user acceptance”.

It might be argued that the operators do not need to know the root cause, let alone justify their actions with process function demands and that the operators only need to follow the procedures and act according to them, without questioning at all. However, we strongly maintain that this is not enough and relate this question back to the predictiveness of the validation results. In order to achieve validation results that truly predict the future usage of the system we must go deeper than merely external analysis of the human performance. We must evaluate what kind of user practices the user interface induces on the operators. Practice is a way of acting that is developed during the history of the work and it is the internal resource that people use to deal with unexpected situations. And this is the essence of validation: We must also evaluate how the operators will act in a situation that we cannot test in the validation. The practices they have developed tell about this.

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## **3.2 Effects of variable message signs on driver behaviour**

Pirkko Rämä

### **3.2.1 New technology on the road side**

Current developments in winter maintenance, such as preventive salting of roads based on weather forecasts have required improved monitoring and data collection on the weather and road conditions. New technology has produced smart sensors and automated data collection and modification and processing systems, such as road weather stations. At the same time, the development of transport telematics has provided new tools for traffic information and management. Traffic Management Centres (TMC, in co-operation with the Road Weather Centres) have been established to collect a wide range of data from the roads, to manage and process it, and to deliver information to drivers for example via variable message signs (VMS).

VMS are displays on the roadside that can show a range of traffic signs or other symbolic or textual messages. In Finland, most of the VMS are weather-controlled. The data sources for the control of the VMS are automatic road weather stations, weather forecasts, road weather cameras and observations made by maintenance personnel. The degree of automation of the control system varies. Some control systems provide continuous automatic categorisation of the weather and road condition that correlate to the alternative speed limits or warnings. This information either supports manual control or, in some cases, the speed limits or slippery warnings are changed automatically based on the classifications. The appearance of the speed limit signs varies depending on whether the signs use LED or fibre optic or electromechanical techniques.

In Finland, several road sections, totalling approximately 300 km, have been equipped with variable speed limits. The first individual variable speed limits were installed in the eighties. Since the early nineties also systems including several variable message signs (VMS) on a road section have been implemented.

The use of VMS on certain spots or road sections is motivated by the increased risk in winter due to the drivers' poor ability to recognise slippery conditions and

to adapt their behaviour to adverse weather. Even for a safety-motivated and skilful driver, it may be a demanding task to adjust the behaviour to prevent an increase in the accident risk when the road becomes slippery. The decision-making task of adjusting to the prevailing road conditions is complex and passes through several phases. It is especially difficult when the friction decreases unexpectedly during the trip, which can happen because of changes in the temperature or sudden encounters with black ice spots on e.g. the coast or on bridges. Roadside interviews on slippery road surfaces have shown that only 14% of Finnish drivers estimate the road to be slippery, whereas more than half consider the friction normal (Heinijoki 1994). In terms of speed, the average speeds on a slippery road surface are roughly 4 km/h lower than in good winter conditions (Saastamoinen 1993; Estlander 1995). The reduction is not sufficient to compensate either for the effect of inclement weather (Edwards 1999) or for the reduced friction (Roine 1993; Saastamoinen 1993; Várhelyi 1996; Malmivuo & Peltola 1997). Overall, headways are not substantially affected by winter conditions (Saastamoinen 1993).

### **3.2.2 The Finnish approach to weather-controlled VMS**

The Finnish Road Administration adopted a policy to develop Intelligent Transport Systems (ITS) applications gradually during experiments, with a problem-driven and not technology-driven approach (Finnra 1998). According to this policy, VMS systems have been evaluated from different points of view. The main goal in the evaluation was to get knowledge for the decision-making on whether the VMS systems are socio-economically effective measures, and how they should be developed. Therefore, a multi-criteria and multidisciplinary evaluation was needed including measurements on driver behaviour and traffic flow. As a first step, the Finnish Road Administration decided to carry out experiments concerning individual VMSs for slippery road conditions. Later on, a Finnish test site project on the E18, including the weather-controlled road, was introduced (Pilli-Sihvola 1994).

In the first phase of the research activities, user acceptance of the variable speed limits was studied by roadside interviews (Rämä & Luoma 1997). Driver interviews were necessary because the VMS have features (e.g. control strategies) that the drivers should be aware of.

Secondly, the effects of variable speed limits on driver behaviour were studied (Rämä 1999; see Figure 13). In aiming to get a good description and understanding of the behavioural effects, it was necessary to study comprehensively the various aspects of both driver reactions and the system. Specifically, the studies combined reliability analyses, driver interviews and behavioural measurements. Also the functioning of the system had to be examined because of the complexity of the design. The implementation of a weather-controlled VMS is far more complex than simply erecting a traffic sign. VMSs are technologically intricate and include automatic information transfer and data modification. In addition, the control of the signs is based on an estimate of the road surface condition, and its reliability is usually improved after implementation during field tests. Consequently, the effectiveness of a VMS system is dependent on the understanding of the system, the interpretation of the messages, and the reliability of the system.

The results showed that the VMS system on the E18 road affected driver behaviour according to the goals set for the system. After several years' experience of several deployments, a study on the impacts of the variable speed limits on injury accidents was conducted as well.



*Figure 13. A variable speed limit sign.*

### 3.2.3 User acceptance studies

The user acceptance studies concerned recall of the sign displays, comprehensibility, knowledge and acceptance of control policy, potential behavioural effects, as well as assessment of the usefulness of the systems in general. Drivers were randomly picked from the traffic flow and pointed to a rest area for the survey. In the interviews, immediate perceptions were requested first.

The results showed that the drivers recalled the variable fibre-optic signs reasonably well. More specifically, 83–91% of the drivers recalled the posted speed limit, and 66% recalled the slippery road sign (both the individual sign and the sign on the weather-controlled road). Overall satisfaction with the VMS reported in several other studies (for review see TROPIC 1996 and McCabe et al. 1999) was found for the weather-controlled signs as well. For example, 95% of the drivers interviewed indicated that variable speed limits are useful and enhance traffic safety. Eighty-one percent of the drivers indicated that the prevailing variable speed limit value was appropriate. This conforms to the result indicating that the majority of drivers estimated the prevailing road conditions to be good when the speed limit was high and to be poor when the limit was low. The findings suggest that the criteria used for determining appropriate speed limits were successful, and support the assumption that lowered speed limits due to poor weather or road conditions are accepted even if variable speed limits are used to lower the already-lowered winter season speed limits.

Comparison of the sign technologies showed that the fibre-optic sign is detected and identified much better than the electromechanical sign (Luoma & Rämä 1998). Obviously, a substantial proportion of drivers pay somewhat more attention to the variable fibre-optic signs than to the regular ones. This may be because the fibre-optic signs are highly conspicuous in view of the sharp contrasts on the display. They are also less frequently used than the regular signs (or signs that look regular). In addition, fibre-optic technology improved the identification of variability. It seems that processing the information on these relatively effective speed limit signs demands a greater capacity of attention than processing of fixed speed limit signs. This was demonstrated by a decrease of the recall rate of a fixed warning sign in the vicinity of a fibre-optic speed limit sign (Rämä et al. 1999).

In one case the data were collected from a combination of roadside and telephone interviews (Luoma et al. 2000). A roadside interview sampled drivers who encountered the VMS during adverse road surface conditions. If a driver recalled and comprehended the sign in question, he or she was asked to participate in a telephone interview in the near future. In the telephone interviews, spontaneous reporting of the effects of VMS on behaviour was sought first. Next, other potential effects were asked about following a checklist, the main effects (e.g. speed behaviour) being discussed in greater detail (e.g. speed in curves).

The drivers' reports showed that there may be several other effects in addition to those of driving speeds and headways, the most fundamental ones dealing with the focus of attention towards finding cues of potential hazards, testing the road slipperiness and cautious overtaking behaviour. These reports were assessed to reflect improvement in traffic safety, and are in agreement with the aim of these VMSs to focus attention on the monitoring of risk caused by the slippery road surface. In addition, many drivers reported improved driving comfort.

### **3.2.4 Behavioural studies**

The most important behavioural variable was the mean speed of cars in free-flow traffic. The standard deviation of speed was investigated as an indicator of the homogeneity of speed behaviour, as a decrease of the standard deviation would indicate an improvement in traffic safety (Solomon 1964; Baruya 1998). In addition to the driving distances, the proportion of headways of less than 1.5 seconds were studied. The driving speeds and headways were measured with loop detector-based traffic monitoring stations before the drivers could see the signs, and after the signs.

The designs of behavioural measurements used different types of controls depending on the situation. The factors that were controlled included time (day of the week, hour of the day, month), site (e.g. road geometry), road and weather conditions, and driving direction. The speed analyses were based on comparisons of the speed distribution in different road and weather conditions in the experimental and the control data.

To cover the “novelty effects”, follow-up measurements were carried out in the present studies. Follow-up times for behaviour effects were over 1 year, and the user acceptance interviews were done several months after implementation of the signs. It is likely that the effects of VMS depend both on driver experiences of the current system, but also on more general knowledge about real-time information systems.

### **3.2.5 Conclusions**

The design of the slippery road condition sign proved successful. The sign was well comprehended and recalled. It is also apparent that this type of warning should use the fibre-optic technique with inverted colours. It is recommended that the location of effective variable warning signs be considered carefully. They are usually used on interurban roads, and not only beside intersections or in the vicinity of other important fixed traffic signs.

The slippery road condition sign was controlled manually. The reliability of the control system was not investigated systematically. However, a sophisticated system for recognising adverse weather and road conditions and low friction including automatic road weather stations and CCTV cameras proved to be important even for the manual control. These systems are operated by the TMC. The use of weather-controlled VMS means new duties for the TMCs, especially where control is wholly manual. At the same time, this is a new tool for TMCs to manage the critical time from the detection of adverse road conditions to dealing with them with maintenance operations.

The minimum headway sign affected both the mean speed and the proportion of short headways. Therefore, the minimum headway sign seems to be a promising application. However, there were some comprehension problems with the sign, and this is recommended as a subject for further study.

The variable speed limits were most effective because they had positive impacts both on the mean speed and on the speed variance. Also, the mean speed effect was the greatest of all those produced by the speed limits. The system proved to be most effective when slipperiness was difficult to detect. Consequently, the system functioned most effectively when it was most needed. In addition, the

system proved to be useful and contributed to safer driving also during the summer season, including autumn and spring when higher seasonal speed limits are allowed but the roads may occasionally be slippery.

Because variable speed limits were used both to increase and decrease the speed of the traffic flow it was difficult to anticipate the safety effects of the system. The results suggested that the high quality systems with an elaborate control system seemed to decrease the injury accident risk, especially in winter. It is critical to automatically monitor and efficiently recognise hazardous conditions and provide the information to the road users. In addition, the choice of sign technology may be important as well as the dynamic variable warnings.

It seems that the main application area for weather-controlled VMSs will be the main roads with relatively high traffic volumes. One negative side-effect of variable speed limits is frequently assumed to be delegating responsibility to the system rather than the drivers (e.g. ETSC 1999). Specifically, the drivers may rely too much on sign information, reduce their observation of the road conditions and reduce their anticipation of slipperiness. However, this type of delegation was not found in this study. Nevertheless, a sophisticated and error-free data collection and control system is necessary for both manual and automatic control systems.

The signs, especially variable speed limits, improved traffic safety by decreasing the mean speed. The variable speed limits decreased the standard deviation of speed as well. The effects cannot be regarded as sufficient to compensate for the increased risk in car driving caused by slippery road conditions. This calls for more effective measures, like in-vehicle speed control (Várhelyi 1996; Peltola & Kulmala 2000). However, a clear advantage of the VMS is that it provides the same information to all drivers with no substantial differences in interpretation, thereby contributing also to increased homogeneity of driver behaviour. The use of effective signs is motivated by the high accident risk on slippery roads. However, the danger of information overload prevents the use of effective fibre-optic signs in complex traffic environments. Optimisation of the strength of information must be taken into account when planning traffic control.

In conclusion, the concept of weather-controlled speed limits and displays was successful. Profitability analyses call for the use of systems with the best benefit-

to-cost ratio. The slippery road condition sign is recommended for carefully considered use at critical spots, whereas a system including variable speed limits is recommended for somewhat longer road sections.

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## 4. Implementation

The implementation phase of a new system is economically important. In this phase, there are substantial risks for losing resources, time and money in terms of disturbances and unplanned shutdowns, increased stress of people etc. If the start-up of the system fails, productivity of the system could be much less than expected, no matter how carefully the system has been designed so far. In addition to user-centred design of the system, successful start-up calls for well-trained and/or informed users (e.g. operators and maintenance personnel or drivers). Moreover, there are possibilities to modify and optimise the system in the implementation phase. The costs of these modifications are likely to be much lower than if they were executed during full operation. In addition, there could be better potential to change human practices and realise improvements in work procedures or traffic safety in this phase than during normal operation or use the system.

The first two chapters, 4.1 and 4.2 are about implementation in a traffic context. Chapter 4.1 considers an important sector of the information or knowledge society, that is, transport telematics. It raises an important issue in the technology development: welfare of the people. It focuses on driver information needs and transport telematics. When implementing new systems in traffic, it is important to understand and predict the technical and economical development. In addition, it is important to understand the whole process including the social aspects. The driver needs for transport telematics are a core issue. How will people take the new technology into use in everyday life in traffic? Some potential information needs and information provided by telematic systems for driver decision-making are discussed concerning the strategic and tactical levels of driver behaviour.

Chapter 4.2 discusses in-vehicle information and communication systems (IVIS) that aim to provide drivers with information on e.g. a favourable route from their starting point to the destination. Two examples are given in order to demonstrate the mechanisms of interference and complexity of safe IVIS designs. The analyses are based on Multiple-Resource Theory presented by Wickens and Hollands. The chapter provides an example of showing the value of using a specific theory of driver behavior when making decisions related to traffic safety.

Chapter 4.3 expresses challenges to safety engineering when implementing automated transportation technology in mines. In certain mining methods, such as block caving, the efficient and continuous move of large amounts of ore and continuity of the material flow is essential. The added performance comes partly from the new technology but also from the change of working procedures and better process control. The system supplier or system integrator is responsible for the system functionality but the operational performance of the system and system safety are shared with the mining company and all the subcontractors. The safety analysis and risk assessment of a large-scale mining automation system needs to be integrated as part of the system development project. A system safety concept is designed to affect the total life cycle of a product or a system. The intention of the system safety program is to activate the performance of system safety tasks over the life of the system.

Chapter 4.4 considers to a certain extent the unused potential of simulators when training people for quite challenging “front-end” task in safety critical environments. It focuses on the use of simulators in the training of people in the maritime sector. The problem recognised also in many other domains is that if the controlled object, e.g. a nuclear process, is stable or quite easy to keep under control for most of the time, but there is a possibility of a disturbance or emergency situation in which the demands of the situation rise remarkably, the operators cannot acquire adequate competence to cope with these rare situation in the course of their normal work (see also Chapter 5.1). Simulator training is an example for the attempts to solve this. The question is: is simply “playing” with the simulator or testing people in disturbance scenarios that have come to the instructors’ mind the best way to use this versatile technological creation?

## **4.1 Driver information needs and transport telematics**

Pirkko Rämä

### **4.1.1 Transport telematics in the information society**

Transport telematic systems collect, modify and process huge amounts of information on which different services are based. The transport telematic systems used when driving vary from informative to intervening. This presentation focuses on the informative systems. The change in the amount of available information means a qualitative change in the driver information services and leads to a discussion of the driver task.

Usually, the aim of transport telematics is to improve traffic fluency and safety. Transport telematics is a part of the phenomenon called information society or knowledge society, and traffic is one of those everyday life sectors which the new technology penetrates. Traffic is a technical system that has to be accessible to every citizen. In general, the development expectations from the information society have been exaggerated, and the use of new technology has spread more slowly than expected by technology developers (Tuomi 2001). The same also holds true for the transport system. There are high expectations for transport telematics to contribute to safer and more sustainable road traffic in Europe, expressed e.g. in the White Paper (European Communities 2001) or eEurope plan confirmed by the European Commission. Still, only a few safety-focused ITS have been developed and are available Europe-wide. Moreover, many research scientists have addressed the issue of whether there is a risk that transport telematics may reduce safety on roads (ETSC 1999). One main factor decreasing the positive safety effects of telematic systems is an insufficiency in their user-centred design. The importance of user-centred design of intelligent systems was identified quite early in the discussion of transport systems (e.g. Rumar 1990; Owens et al. 1993). In a recent analysis of research topics relating to a knowledge society, Tuomi (2001) emphasised the social context and human dimension of technology. Tuomi (2001) names “the user” as a missing link in the chain of socio-technical evolution: “Users are not only passive consumers of technology. They are active producers who make technology meaningful in their

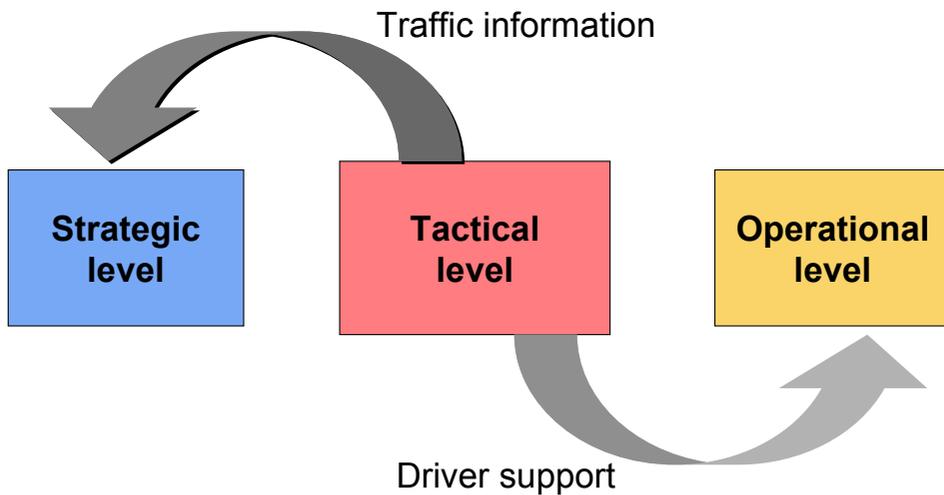
everyday life, often in ways that surprise engineers, entrepreneurs and policy makers.”

When implementing new systems in traffic, it is important to understand and predict the technical and economic development. In addition, it is important to understand the whole process including the social aspects. The driver needs for ITS are a core issue. How will people take the new technology into use in everyday life in traffic, and what are the consequences on the traffic system level, for example on the demand of different modes, effects on the traffic flow etc.?

#### **4.1.2 The three decision levels in car driving**

The driver’s basic task is to drive the vehicle safely from a starting point to a destination. It has been suggested that information processing in the driving task should be studied at three levels (Michon 1985; Molen & Botticher 1987). The levels include strategic, tactical and operational control of car driving. Examples of the functions at the strategic level are trip planning, route finding and route selection in order to achieve objectives such as minimising time, avoiding traffic congestion etc. Decision-making on the tactical level includes interaction with other road users and the environment, e.g. gap acceptance when entering a main road. The decisions include speed choice and yielding for other road users at intersections, for example. This decision-making is based on perceptions, estimation of distances and velocities, and anticipation of traffic situations in a couple of seconds. The operational level includes vehicle control, i.e. keeping the track, steering and braking.

The information needed for the decision-making is different at each of the three levels (Figure 14). Furthermore, for each driver sub-task, there are specific needs not only for the information content but also for quality of the information and the human machine interface (HMI). It is self-evident that the information provided must meet some quality requirements at all levels, such as being reliable and consistent.



*Figure 14. The information needed for decision-making is different at each of the three levels.*

In the following, some potential information needs and information provided by telematic systems for driver decision-making are discussed for the strategic and tactical levels of driver behaviour. On each level the information may be obtained from the driver, vehicle, environment and other road users (Table 1). For most of the suggested needs there is only partial or indirect evidence, and the suggested needs should be verified in careful user studies.

Table 1. Driver information needs on three levels of decision making.

	<b>Strategic level</b>	<b>Tactical level*)</b>	<b>Operational level*)</b>
Driver	State of driver (e.g. illness, fatigue, blood alcohol concentration), identification of driver.	State of driver (e.g. fatigue, vision, driving position).	Sensations (vision, hearing etc.).
Vehicle	Manoeuvrability, defects, tyres, load, weight, length, fuel consumption.	Dimensions, acceleration, defects, load, displayed information.	Speed, acceleration (deceleration), friction, controls.
Environment	Mode of travel, route (urban, rural, road types), effects on environment, weather forecast.	Road characteristics, road signs, traffic lights, animals, details of environment.	Distance to relatively close objects, road edge.
Other road users	Traffic volumes and usage rates, predictions concerning incidents, congestion, travel time etc.	Distance to other road users, speed, acceleration and intentions of others, use of space, incidents, queues, accidents.	Relatively close distances and corresponding movements.

\*) Only situations in which the driver has decided to drive by him or herself.

In addition to the three-level hierarchy, the information needs vary according to the driving situation. Drivers vary in their characteristics (age, driving experience, lifestyle etc.), and so does the context in which the information is used. The most important factors are the environment and how familiar it is to the driver, and the purpose and the length of the trip (e.g. Luoma 1986).

#### **4.1.3 Effective use of information at the strategic level**

It has been proposed that strategic decision-making is largely memory-driven, and requires little if any new information (Norman & Bobrow 1975; see also Ranney 1994). However, transport telematic systems provide information for strategic decisions that may simplify the driving task, especially when used before the trip. In this way transport telematics may contribute to safer driver behaviour, less congestion, pollution and environmental inconvenience and increased comfort.

Route planning, answering how to get from the starting point to the destination, can be done before the trip for example on the Internet, and during the trip with an in-vehicle navigation system. The basic information needs for route finding have been identified as (Streeter et al. 1985): direction in which to turn, distance to that turn and street to turn onto. In addition, notable landmarks have been identified as useful. If a route-finding system is used during the trip, this places special demands on the human-machine interface. The relevance of route guidance elements for the driver workload rests in the ease with which the driver must match the information provided to the driving scene (Tijerina et al. 2000). Maps are difficult to use for many people, and turn-by-turn displays are less demanding on the driver and might support good route-finding performance. It seems that voice displays can be very effective in route guidance, but their benefits depend on their content and method of implementation (Tijerina et al. 2000). At the strategic level transport telematic systems respond to the drivers' information needs for optimal route finding.

Transport telematic systems may provide information for strategic decisions as the choices of travel time and mode. Advanced dynamic systems may include real-time information on traffic fluency, incidents, available parking areas, and information on the road and weather conditions. Several Finnish user acceptance studies have shown that drivers appreciate weather information and report this information quite often to influence also their willingness to make the trip at all, to change the time of the trip, or to change the mode of travel. The choice of driver is a strategic decision too. Telematic systems may also provide information on the drivers themselves, driver impairment, and use of seatbelts (ETSC 1999).

In summary, it seems that the information provided by transport telematics on the strategic level is useful and increases efficiency in driving and systematic use of the information. This decreases memorising and uncertainty while driving and at its best de-allocates information processing capacity for the primary driving task. Effective use of information supports safe, efficient and sustainable driver behaviour.

#### 4.1.4 The danger of information overflow at the tactical level

The tactical and operational control levels are based on data on the immediate driving environment. Most of the information at the tactical level is obtained visually and there is a danger of information overload. In normal urban driving (and sometimes also on rural roads, at intersections especially) the driver has to perceive and process large amounts of information (Luoma 1986). The driver's capacity to process all the necessary information is limited, and sometimes even important items for decision making are not perceived or processed. A revealing example comes from a recent study in which a fixed warning sign, a general warning sign with a supplementary panel "traffic investigation", was recalled on average by 6% of drivers randomly selected from the traffic flow. Consequently, increasing the information processing workload while driving is questionable.

Transport telematics can partly simplify the driving task and lower the driver's task load. Intervening telematic systems can be used to take care of some functions (e.g. distance keeping, lane keeping, intelligent speed adaptation) which may lower the workload. However, especially when *information* is provided while driving it should be asked in which way the information supports safe driving, and whether the information provided burdens the driver too much or in the wrong way.

With practice, driving becomes partly automatic and the driver workload is decreased. An experienced driver can use skill-based (automatic) behaviour in familiar places and situations and the information processing does not burden the driver too much. Subjective uncertainty is viewed as the mechanism that triggers a shift in the allocation of attentional resources. Novel or unexpected situations may disrupt the automatic processing and necessitate knowledge-based (controlled) processing (Ranney 1994). Provision of information by telematic systems may be this type of intervening action that can move the processing from automatic to the controlled domain. It has to be considered very carefully whether this intervention is well motivated. Information provision has to meet the real needs of the driver, especially from the safety point of view. In many cases this means provision of information that influences motivation and focuses the driver's attention to risk perception.

Automatic driving has been characterised as experienced and efficient driving. The disadvantage is routine driving, usually in familiar environments, including inadequate response to the many varying circumstances in the environment. Sometimes, it may be well motivated to focus the driver's attention on carefully selected important aspects. Perception of slipperiness of the road is one example. To perceive slipperiness is difficult as such, as there may be minimal visual cues indicating the hazard. It is especially difficult when friction decreases unexpectedly during the trip, which can happen because of changes in the temperature or sudden encounters with black ice spots on e.g. the coast or bridges. In addition, a human operator is in general conservative and changes his or her initial hypothesis or opinion only slightly with subsequent sources of evidence. The decision-making task to adjust to the prevailing road conditions could be effectively supported by adequate real time information (Rämä 2001). In many cases the role of a telematic information system is to complement more general information and other measures.

The limited information-processing capacity of the driver decreases his/her need for information, and motivates the development of transport telematics that can take over control of the driving task in situations of increased crash risk. The information provided by a telematic system focuses attention, e.g. on a danger such as a slippery road or on the driver's own behaviour like exceeding a speed limit etc. In addition, it also focuses attention on the device used in the telematic system. According to our experience, even a very simple task with an in-vehicle device may distract drivers (Luoma & Rämä 2002). It has also been shown that handling a telematic system (RDS-TMC system) while driving appears to be a dangerous task, even when there was no (explicit) time pressure to finish the task (Verwey 2001).

Various transport telematics applications included in the actual driving aim to reduce the crash risk by means of information (and intervention). Some monitor the driver or the vehicle and inform the driver of the deficiencies detected. Some warn about risk-increasing circumstances or situations. A list of transport telematic systems at the tactical level could cover the following information needs:

- telematic systems informing driver impairment such as drowsiness, or whether the driver is devoting less attention to the driving task

- feedback on the quality of the driving performance (by means of verbal messages, accelerator pedal etc)
- information on the safety status of the vehicle (data on brakes, tyres, lights and warning of unsafe conditions) and cargo
- variable speed limits
- variable message signs (VMS) on incidents, elk, slippery warnings, feedback of speed compliance, recommended headways
- vision enhancement during night time, in rain or in fog
- inter-vehicle distance warning and collision warning
- emergency call in traffic accident (Mayday system).

Many user acceptance studies have shown that drivers appreciate traffic information. In 1996 (Penttinen et al. 1997), more than half of the drivers interviewed were willing to pay for traffic messages. The most popular information content was weather and road condition information (46% regarded it as important or very important); second, information on fluency of traffic; third, road works; and fourth, information on routes, travel time and schedules. Information on the weather and road conditions has been reported to e.g. decrease speed, increase headways, and increase carefulness in overtaking behaviour. In a later study concerning mobile services (Anttila et al. 2001) the most popular service was an automatic emergency call, followed by navigation information, information on congestion and fluency of traffic. Also route optimisation information and service information were regarded in this study to be more important than road and weather condition information. The percentage of respondents who were willing to pay for a service that they had indicated as important varied from 66% to 91%. In the EU project Travel-Guide, 74% of the test drivers were willing to pay for an in-vehicle system providing information to support perception of traffic signs (Luoma & Rämä 2002).

#### **4.1.5 Conclusions**

To summarise, information provision at the strategic decision level is favourable, and there is room for more information and more efficient use of the

information. At the tactical decision level the information provision entails some risk, and it should be considered very carefully whether new information is really needed. The hierarchy in the model presented by Michon (1985) assumes a dynamic relationship among concurrent activities at the strategic and tactical levels. Consequently, the information provided (before or during the trip) may have more substantial and widespread effects on driver behaviour than expected.

The criteria for information provision and also transport telematics in general should be the welfare of people. In addition to the expressed needs of individuals the welfare of society has to be assessed. The welfare can be improved in different ways. However, it is obvious that if transport telematics reduces traffic safety markedly, it will not increase the welfare.

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## **4.2 HMI concerns of in-vehicle information and communication systems**

Juha Luoma

### **4.2.1 Introduction**

Transport Telematics or Intelligent Transport Systems (ITS) have been proposed as possible solutions for reducing congestion and improving traffic safety and driver comfort. (Transport Telematics stands for the application of information and communication systems in transport.) In-vehicle information and communication systems (IVIS) represent one area of transport telematics and aim to provide drivers with the information on e.g. a favourable route from their starting point to the destination, road weather, road works, crashes and even connection to the Internet. Obviously these systems should be designed so that the users will be able to assimilate and comprehend this information in a timely and efficient manner. In addition, it has been argued that allowing the drivers to interact with devices while driving may be unsafe. For example, there is evidence that the probability of a lane departure is elevated when reading detailed maps or when entering destinations into an in-vehicle device. Consequently, Human-Machine Interaction (HMI) with increasingly more complex in-vehicle systems is a major concern.

Multiple-Resource Theory (Wickens & Hollands 2000) provides some insight into dual task performance. The theory suggests that the resources available to perform a task may be defined by three dimensions: (1) encoding modality such as auditory or visual, (2) processing code such as verbal or spatial and (3) response modality such as manual or vocal. Each combination of these dimensions may be thought of as having a particular capacity or resource availability. Furthermore, if two tasks are characterised by non-overlapping combinations of these dimensions, the person engaged in the two tasks could be expected to perform as well performing them concurrently as he/she would if they performed them separately.

In the following, two examples of IVIS with potential improvements are briefly discussed in order to demonstrate the mechanisms of interference and

complexity of safe IVIS designs. First, the use of a mobile phone while driving with two options, namely hand-held and hands-free, will be discussed. The second analysis concerns the route guidance systems involving either conventional (a) manual controls and visual displays or (b) voice input and auditory displays. These comparisons are of interest because it has been argued that most HMI problems caused by IVIS are connected with the first options involving manual controls and visual information.

#### **4.2.2 Use of mobile phone while driving**

The driver information can be characterised mostly as visual, although auditory information has some role as well. Consequently, it is quite obvious that the use of additional visual displays use the same resources as the driving task (the same modality). However, if we compare the use of a hand-held mobile phone and hands-free mobile phone, there is no difference in this respect and therefore there is no reason to expect that the hands-free mobile phone would result in a decreased workload.

The same conclusion concerns the role of the central processing code. According to the Multiple-Resource Theory cognitive processing can be characterised as either verbal or spatial. It can be assessed that the driver information includes mostly spatial information but also some verbal information. On the other hand, the phone conversation involves verbal information and therefore one could expect that there is no overlap between the two tasks. However, the information may include spatial information as well. Tijerina et al. (2000) give an illustrating example about an architect listening to some changes that have been made to some plans over the phone. This may draw upon his or her spatial processing resources in order for him to understand what has been done. If the architect is driving at the same time, this has the possibility of reducing his/her spatial processing resources available to survey the scene through the windshield. A worse case could be if the architect begins making important decisions and planning changes that could use a combination of verbal and spatial processing, which would be very resource demanding. This situation could draw a significant amount of the architect's attention away from the driving task even if the mobile phone is hands-free and despite the fact that speaking over the phone is an auditory or vocal task.

Thirdly, if we compare the responses needed by hand-held and hands-free mobile phones, there is a clear difference. The use of a hands-free phone requires no manual responses during the conversation, although the vocal response is actually a complex motor response that has the potential to interfere with other manual responses. However, there is no substantial differences while dialling or hanging up.

Overall, the above analysis suggests that the hands-free mobile phone does not solve all the HMI problems related to the use of a mobile phone while driving. In addition, there is a danger that the use of a hands-free mobile phone decreases the subjective risk of the driver and thereby increases the phone use while driving.

### **4.2.3 Route guidance systems**

A conventional way to present route guidance information to drivers by IVIS while they are en route is based on visual displays involving electronic maps or turn-by-turn displays. The content of the auditory displays ranges from turn-direction only, to distance to turn plus turn direction, to systems or prototypes that also provide street names and landmarks (Tijerina et al. 2000).

If the information provided by the route guidance system is auditory, there are reasons to assume that this sort of route guidance would be beneficial in reducing the driver workload. As indicated earlier, the information needed for driving is mostly visual and therefore the auditory guidance will interfere less with the primary driving task (i.e. different modality). Audio route guidance systems allow the drivers to bestow more attention to the road. However, the information provided by the audio systems is discrete whereas visual systems can update information continuously (Verwey 2001). In addition, it is difficult to provide overall route or network information with audio messages.

Moreover, verbal directions should be very effective as route navigation aids as they eliminate the need for many spatial cognitive transformations that may arise with maps. The verbal navigational aid provides instructions in terms of a language of actions whereas a map requires the driver to interpret the spatial information into a set of actions.

Because the route lists are presented verbally, they can be mentally represented in working memory as a phonetic or verbal code. The multiple resources theory of Wickens and Hollands (2000) predicts that keeping a driving instruction in working memory as a verbal code reduces competition for the spatial visual processing resources.

The conventional destination entry (or more generally data entry) is based on manual responses (Figure 15). An interesting alternative is voice input while the vehicle is in motion. The automotive industry is actively working to adopt voice recognition technology. The use of this technology is appealing because voice recognition technology allows the driver the possibility of performing tasks such as destination entry without visual or manual demand. However, even though there is no visual or manual demand, voice transactions may still be distracting to the driver as indicated earlier.



*Figure 15. A route guidance system based on manual responses.*

Before this technology is implemented, several important questions must be asked. What benefits are accrued by voice transactions and when do they arise? What problems does a given voice transaction create for drivers and under what circumstances? What functions should be available or not available using voice technology? And finally, under what conditions does this technology interact with driver age? (Tijerina et al. 2000.)

#### **4.2.4 Conclusions**

In summary, it is becoming clear that the use of a mobile phone while driving has the potential to distract the drivers enough to increase the risk of a crash and the risk of distraction is not entirely avoided with the use of a hands-free device as the driving task and phone conversation may require the same processing resources.

The research on dual task performance suggests that voice technology may provide a means of performing a second task while driving which may produce relatively less interference with the primary driving task than performing the equivalent task without the use of voice technology (Tijerina et al. 2000). This is encouraging if voice technologies are going to be used for automotive applications. An additional benefit of voice technology is that it may be helpful for older drivers when performing a second task while driving.

However, all of the research indicates that performing a second task always has an adverse effect on the primary task performance compared to performing the primary task alone. Consequently, the important question is how much interference is there and is it acceptably small? Recent investigations of mobile phone usage while driving provide some evidence that the use of voice technology has the potential to distract the drivers enough to increase the risk of a crash (Goodman et al. 1999).

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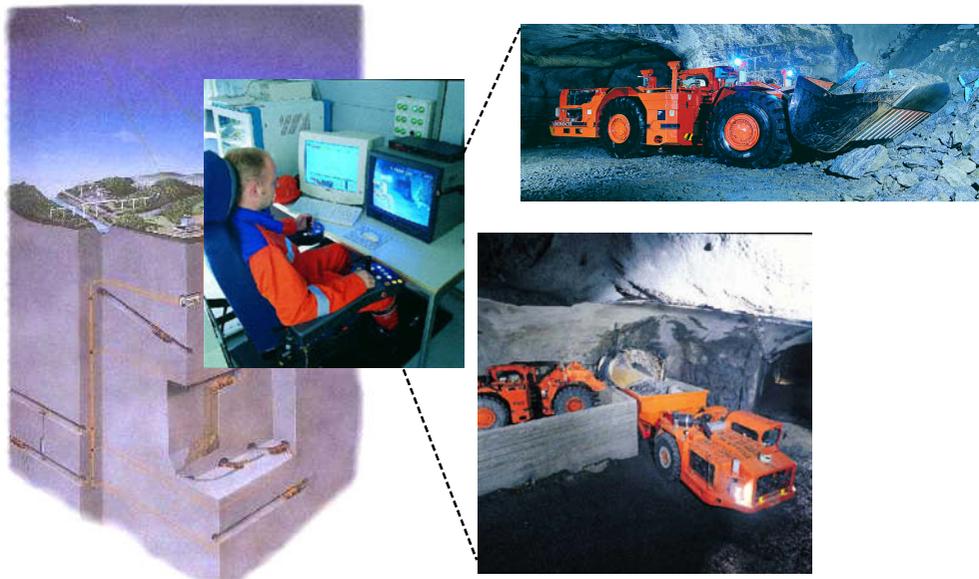
## **4.3 Implementing automated transportation technology in mines – challenges to safety engineering**

Risto Tiusanen, Jari Karjalainen & Kaj Helin

### **4.3.1 Introduction**

Automation has been playing a great roll in process and manufacturing industry. Automation is used to increase resource utilisation and decrease operative costs. Automated mobile machines are no longer stand-alone manual machines but parts of an automated production system. Distributed control systems and communication networks are used increasingly to machine automation applications, as well. In some cases, unmanned machines equipped with the latest navigation and control technologies are moving and working autonomously in mines or in quarries.

At Brunswick mines in Canada, two autonomous trucks are used to transport ore in the 400 m long haulage area. In this application all the system information is brought to the control room near the loading chute where the operator can verify vehicle operations in real time using a multi-video screen (Swart et al. 2002). In 2004 Codelco and Sandvik Tamrock announced that Codelco's El Teniente mine is running its first three TORO Loading machines using Sandvik Tamrock's Automine™ system. (WME, October 2004.) An overall view of the Automine™ system in an underground mine can be seen in Figure 16.



*Figure 16. Ore transportation process control in an underground mine – an overall view (Pulli 2003).*

LKAB's Kiruna is said to have the first LHD (Load-Haul-Dump) automation system in production use in real production environment. In LKAB's system several Sandvik Tamrock's TORO 2500 loaders are tramping and dumping autonomously and only the bucket loading is done using tele-remote-control technology with video cameras onboard (WME, April 2002). The Mining system at the new Kiruna Underground main level came into operation in the spring 1997. The ore body in Kiruna is an enormous slice of magnetite. It is approximately four kilometres long, has an average width of 80 metres, and extends to an estimated depth of around two kilometres at an incline of roughly 60 degrees. The main haulage level is at a depth of 1045 metres. Mining of the orebody between levels 1045 and 775 will continue until about the year 2018. Up to the present, about 940 million tonnes of ore has been extracted from the Kiruna ore body. Approximately 20–23 Mt of crude ore is mined every year from the ore body (Figure 17).

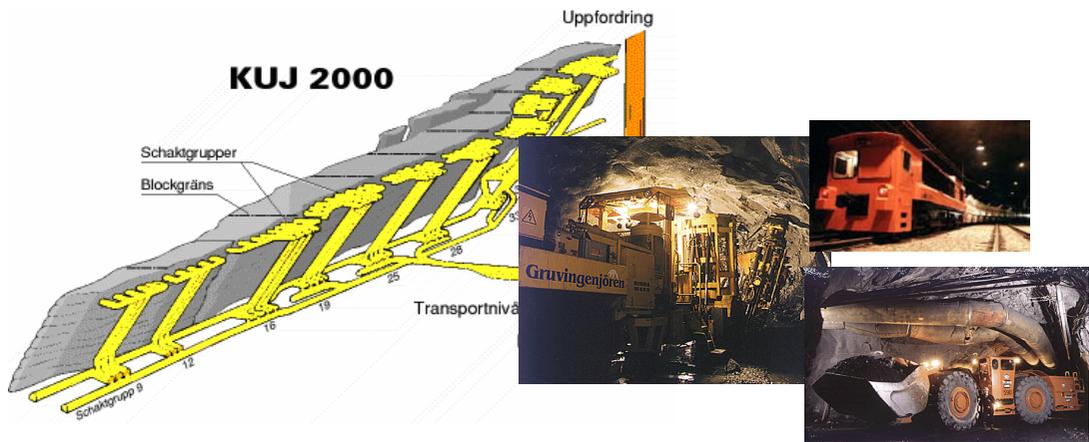


Figure 17. Mine automation applications in LKAB Kiruna mine in Sweden (Tyni 1999).

In certain mining methods like block caving the efficient and continuous move of large amount of ore and the continuity of the material flow is essential. Over 100 000 tons daily production is a material handling process where monitoring, real time process control and automation can show their full benefits and improve mine profitability (Puhakka & Soikkeli 2001).

The added performance comes partly from the new technology but also from the change of working procedures better process control. Puhakka and Soikkeli (2001) claimed that mechanising machinery can add 50% to the performance of the work and another over 30% improvement can be achieved by applying the right working procedure. It is easy to understand that automation is best applied to new mines or mining areas where all the support infrastructure and support functions can be designed originally specified for automated operation.

Semiautomatic loading and transport system can include several autonomously tramming trucks and loading machines. A simplified work cycle proceeds as follows: the operator fills the loader bucket in remote control mode. The loader trams automatically to ore pass, dumps ore into the ore pass or into the truck's box, and trams automatically back to draw point. One operator in the control room can handle several loaders and rock breakers from his control station. Machine operator has become to a system controller.

### **4.3.2 Automated operation – challenges to safety engineering**

Large automated mining machine systems are made up of several subsystems such as production control system, teleoperation stations, wireless communication system, machine onboard systems and local safeguarding systems in the production area.

The system supplier or system integrator is responsible for the system functionality but the system operational performance and system safety are shared with mining company and all the subcontractors. In this sense mine automation projects do not differ from applications in process or manufacturing industries. The system supplier delivers the automated machinery and their operating and control systems. The mining company builds the application environment and all necessary infrastructure with their local subcontractors.

To be sure that the automated machines are safe to use and maintain, the system supplier and end users must know all the hazards and risks related to the intended use of the system. Because the technologies are new and the applications are unique, all risks cannot be singled out in the mine safety regulations or safety standards. This is why only a systematic analysis of safety-related factors can fully ensure that all necessary measures and procedures regarding safety have been implemented.

Manual mining machines or single line of sight remote controlled machines can be analysed with the traditional machinery safety analysis tools like work safety analysis and list of hazards. Tele-operated machines and production systems with autonomously moving machines must be analysed like process automation systems. They are no longer individual machines they are parts of production system controlled from a control rooms via communication networks. In the complex machinery systems the risk assessment should be conducted in operational level to be able cover the entire machine system (Tiusanen 2001). Operating environment, intended use of the system, operators' tasks, system-level control functions and machine automation safety features should be considered.

Safety related control functions in highly automated machine systems include multi-dimensional aspects such as operator's actions, communication protocols and machine onboard control signals. They can be compared with those used in

automation systems in process industries. In such a context, safety aspects must be understood to be an important part of systems engineering.

To clear the difference between safety related factors with single machines and automated machinery here are some new safety issues in automated mining machine applications not in any particular order.

Risks and safety issues related to the commissioning stage:

- operating and support procedures, system level training and instructions
- operating mode and area status changes and reset
- safety critical information between subsystems
- interaction between operating groups
- traffic control in the production area
- trouble shooting and support inside automated area
- system level modification management.

### **4.3.3 System safety approach – new approach**

Methodology for safety design and risk assessment for automatic robot systems has been studied in VTT for several years. The risk assessment approach for single manual mobile machinery has been developed and applied in VTT with mobile machine manufacturers since 1995. The focus in this development has been on stand-alone manual machinery and their remote control (Tiusanen 2000).

Safety engineering standards e.g. ISO 14121 (ISO 14121, 1999) and IEC 60300-3-9 (IEC 60300-3-9, 2000) provide the basic principles and procedures for risk assessment for a single machine. They do not, however, supply instructions on how to apply the principles into the machine system level. These standards do not link the risk analysis to machine or machine system life cycle stages.

System safety concept is designed to affect the total life cycle of a product or system. The system safety programs intention is to activate the performance of

system safety tasks over the life of the system. The focus in system safety is on hazards from the system's beginning through the evaluation and control of the hazards. The system safety principles and concepts have been introduced since 1960 beginning from the military and aviation systems (Ronald & Moriarty 1983).

System safety approach for automated mining machine systems has been developed in co-operation with mining machine manufacturer Sandvik Tamrock Corp, mining companies LKAB (Sweden) and DeBeers (South Africa) and their subcontractors. System safety management principles commonly used in process industry were applied to mobile machine system (Figure 18). The approach includes three different analysis methods that are used in different stages of the system life cycle. The methods are Potential Hazard Analysis (PHA), Operating Hazard Analysis (OHA) and subsystem Hazard and Operability Analysis (HAZOP) (Tiusanen 2004).

In the complex machinery systems the risk assessment must be done in several levels to be able to cover the entire machine system. One must consider use of the machinery, operators' actions, system level control functions, and machine onboard safety issues. The automated machine system must be divided into sub systems such as the local safeguarding system in the production area, machine onboard systems, factory-wide communication system, the production control system and the remote control stations. This means more co-operation between machine manufactures, their subcontractors and the end users.

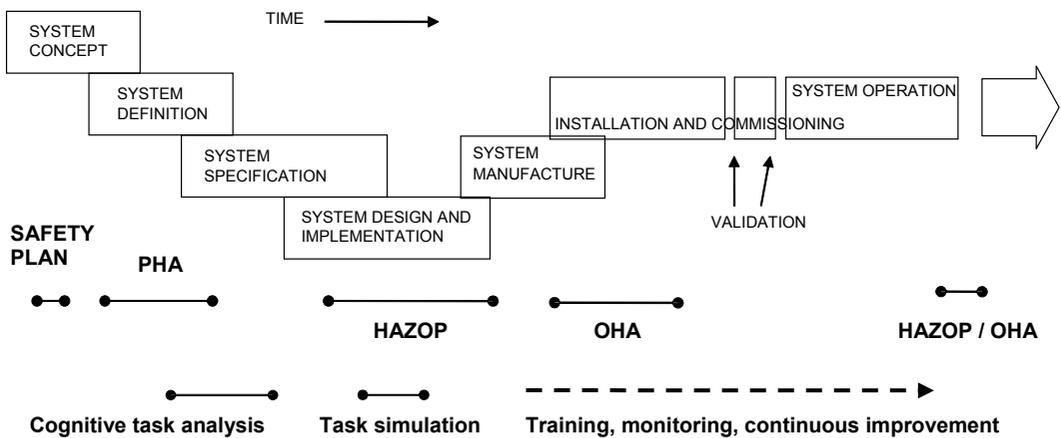


Figure 18. System safety management tasks related to machine application lifecycle modified from Ronald and Moriarty (1983).

#### 4.3.4 New safeguarding principles

Safety rules for mine automation applications are basically simple and clear. Automation system must be isolated when it is operating in automatic mode. Automatic machines and autonomously moving machines must be isolated from the surrounding operations. Tunnel must be closed physically with gates and safety devices. All automated machines must be stopped and switched to a safe state when manual operations are performed in an automated area.

The implementation of these rules so that the system availability is maximised and production effectiveness is optimal need new innovations.

To ensure effective and continuous operation it must be possible to take a machine out of the automated area while the other machines are operating autonomously. The whole system can not be stopped because one machine needs to be refuelled. New innovations have been made to enable these features in these mobile machine systems. One example is the “Air lock” principle for machine transfer (Figure 19).

However the safety system can not detect everything. Traffic control and safety rules for all persons working in the production area are essential. Technical solutions can not solve all the safeguarding problems. Safeguarding systems must be designed so that all foreseeable human errors and possible misuse or bypass has taken into consideration.

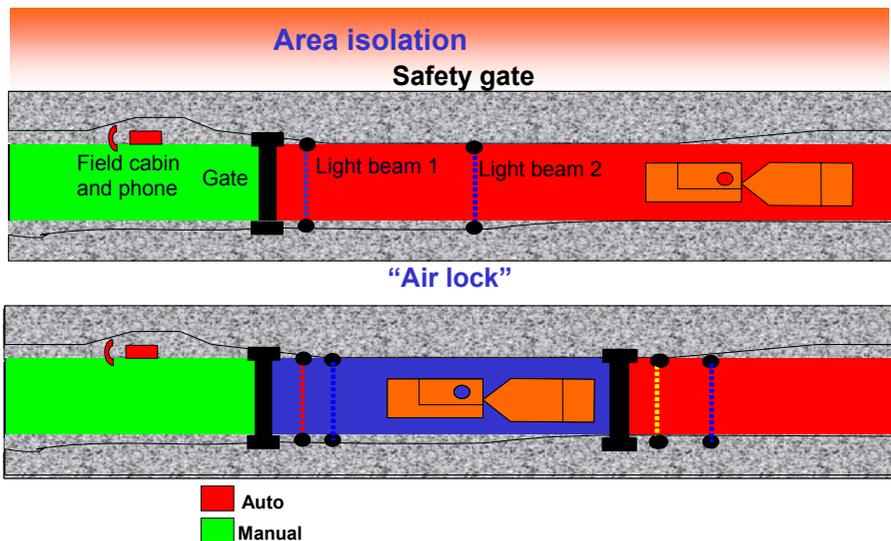


Figure 19. Safeguarding principles for automatic production area isolation in AutoMine™ concept (Pulli 2003).

#### 4.3.5 Conclusions

Automation has not only changed and improved the work conditions in the mine but also brought out new safety risks and safety problems. Mistakes made by operators or support persons or system failures can directly cause hazardous situations to other people working on the production area. It is also possible that an error or a system failure has a critical effect only in certain circumstances or in certain operation situation.

Implementing new technology into mine that has been working long time with manual machines means changes in mine daily practices like production control,

maintenance management, shift change procedures, communication practices etc. These are all developed for manual machine operations and need to be assessed taking into account that part of the excavations or transportation process will be automatic or even autonomous.

Safety analysis and risk assessment of a large-scale mining automation system needs to be integrated as part of the system development project. Analysis and assessments must be synchronized to the system development and implementation to be able to get the best possible benefit out of them. The changes and corrections are easier and cheaper to do in the design phase than during operation. Systematic analysis also helps to understand sub system functions and interrelations between different systems. Team work and co-operation between system designers, operators, maintenance people and subcontractors' experts is essential.

In complex mobile machine applications safety requirements can not be solved by technical solutions. Safe operation and maintenance relies strongly on operators and other actors risk conscious behavior and decision making. In that sense it is important to analyze operating and maintenance procedures to be able to identify possible automation related safety issues and new safety risks.

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## **4.4 Use of simulators in training**

Sanna Sonninen & Tapio Nyman

### **4.4.1 Introduction**

The origin of using high fidelity, large-scale dynamic simulation to train operational personnel is in the industries where safety is of the utmost importance. The first full-scale training simulators were built in the 1970s to supplement the training of flight pilots and nuclear reactor operators (Lappalainen et al. 1999). Since then the use of simulator-based training has spread widely and even in some industries gained a mandatory status in the certified training of personnel. The primary objective of introducing training simulators was to enhance training and to effectively accelerate learning. Simulation was added to the training programmes to fill the gap between theory and application by creating an interactive environment where trainees can actively participate in the demonstrations of applying theory to the real world. The benefits of simulator training for the trainee have been listed to include for example practicing new techniques and skills with repetition if necessary, transferring theory to practice in a risk-free environment, dealing with multiple problems concurrently rather than sequentially, learning to practice multiple tasks under present and changing conditions similar to the real operation and obtaining insight from peers and instructors (Barber 1996). However, it should be noted that the obvious benefits of simulator training may not be as obvious as they are considered if some essential aspects are not taken into account when planning and implementing the training.

It can be argued that to a certain extent there are unused potentials in the utilisation of simulators for training people working with challenging “front-end” tasks in a safety critical environment. As observed in the studies of many domains the problem seems to be related to working environments where the controlled object, e.g. nuclear process, is generally stable or quite easy to control, but a possibility exists for occurrence of a severe disturbance or an emergency situation. In these situations the demands of the situation control instantly rise remarkably and it is impossible for the operators to acquire adequate competence to manage these exceptional situations in their normal work. Even though simulator

training is incontrovertibly one of the best ways to train control of abnormalities, the question still remains whether simulator training is being put into practise by merely “playing” with the simulator or even worse, by testing situations where the operator’s competence is being validated in simulated stressing disturbance scenarios before the best practises have even been taught to him. Exercises using a rather high-fidelity simulator are about performing an entirety of tasks in a realistic situation, not about playing a video game.

#### **4.4.2 An example: training of people in the maritime field**

Simulators are traditionally used in the training of people in the maritime field and simulators of varying fidelity have been developed for training of different occupational groups within the shipping industry. The main emphasis has been in bridge operations but simulators for the training of many other tasks have also been developed. A relatively new player in the maritime branch is the maritime traffic control i.e. Vessel Traffic Service (VTS). Similar features to the simulators for bridge operations are being included into the simulators developed for the training of VTS-operators. The maritime sector is one of the industries where simulator-based training has gained a mandatory status in the certified training of ship personnel and the assessment of competence (IMO 1996; IALA 1999). It is the responsibility of the national maritime administration to approve the training simulators used for certified training or assessment of competence (IMO 1996).

The terminology used to describe or classify simulators varies greatly within the maritime industry. Det Norske Veritas (DNV) has developed the standardisation of the marine simulators which was, however, not approved by the IMO (International Maritime Organisation) for implementation. The purpose of the standard was to ensure that the simulations provided by any maritime simulator include an appropriate level of physical and behavioural realism in accordance with the recognised training/assessment objectives (Cross & Olofsson 2000). According to the IMO, the simulators used under certain conditions shall fulfil six general performance requirements (IMO 1996). The essential of these six requirements for simulators are (Cross & Olofsson 2000):

- suitable for training or assessment objectives

- physical realism appropriate to training or assessment objectives
- sufficient behavioural realism
- capable of producing a variety of conditions (operating environment)
- the learner can interact
- the instructor or assessor can control, monitor and record exercises.

Maritime simulators are utilised for the training of bridge operation, machinery operation, radio communication and cargo handling. The training simulators can be categorised according to the scale of the task that can be trained with them and the fidelity of the simulators. The International Marine Simulation Forum (IMSF) has suggested use of the following four categories (MB/CETS 1996):

Category I – Full Mission. Capable of simulating full visual navigation bridge operations including the capability for advanced manoeuvring and pilotage training in restricted waters. (Figure 20.)

Category II – Multi-Task. Capable of simulating full visual navigation bridge operations but excluding the capability for advanced manoeuvring and pilotage training in restricted waters.

Category III – Limited Task. Capable of simulating an environment for limited (instrument or blind) navigation and collision avoidance (e.g. Radar Simulator).

Category IV – Special (Single) Task. Capable of simulating particular bridge instruments or limited navigation manoeuvres but with the operator located outside the environment (e.g. a desk top simulator using computer graphics to simulate a bird's eye view of the operating area).

These categories are suggested to be used within bridge-related simulators systems. In addition to the basic, advanced and refresher training and the assessment of competence, simulators are applied to the teaching of special expert skills, training of critical situations of low frequency of occurrence and training of a particular type of vessel with certain manoeuvring characteristics or with a complex integrated bridge system. In some of these simulations very high fidelity is a prerequisite; e.g. in Finland some shipping companies provide

this kind of special type of training for certain navigational bridge configuration for their officers.



*Figure 20. Full mission bridge simulator at the Meriturva Simulator Training Unit (picture: Timo Raunio).*

#### **4.4.3 Implementation of simulator training**

As mentioned earlier, in addition to training purposes, simulators are used for the assessment of competence. These two applications require the use of different methods from the instructor and different technical characteristics from the simulator. Validation of the suitability of the simulators is important before the implementation of training. When used for training, simulator exercises are almost invariably used as a part of the overall studies. Many courses using simulation have merely inserted the use of simulators into the curricula (Barber 1996). This should not be the case as the need and objective of the use of simulation should already be determined when determining the overall training needs.

The aim of simulation is simply to learn something and thus simulator training should complement the theoretical studies and vice versa. If the trainee has not received proper theoretical education that can be applied to the tasks included in the simulation or if the trainee does not have a clear understanding of what is expected of him, the situation may end up in confusion, frustration and negative learning. A major attribute of a competent operator in a safety-critical environment is self confidence (Brecke 1982; Muirhead & Tasker 1991). At its best, the training process supports the building up of the novice trainee's self confidence.

In general the learning process should include 1) familiarisation of the trainee with the task(s) and how they should be carried out; 2) letting the trainee practise the tasks numerous times while providing guidance; 3) evaluate and assess the trainee's performance; and 4) provide feedback to the student based on the performance during the evaluation (Côte & Hardy 2002; MB/CETS 1996; Fang 1996). A clear description of the functions that the trainee should be training must be provided to the trainee in thorough briefing before the simulation. Unexpected events may be included to the simulations, in fact the simulator provides superb possibilities for the training of those, but the trainees must already possess the skills for managing these events. During the actual training the instructor should be readily available for assisting the trainee if needed (Figure 21). After the simulation, an extensive debriefing should be organised, including an overall verbal evaluation by the instructor, general discussion on the successes and failures by all participants and everybody's personal description of how they estimate their own actions. The debriefing should end up in a summary with a positive atmosphere where the successes are highlighted and the needs for improvement summed up. For the failures the correct ways of action must always be explained by the instructor. The reasons why a certain action is correct or incorrect should also be stated. In addition to being a good learning session, a debriefing can be highly motivating to the trainees.



*Figure 21. Instructors' coordination room at the Meriturva Simulator Training Unit (picture: Timo Raunio).*

In addition to the traditional vocational training, continuous development of technology induces needs to implement simulator training to new generation experts. In some industries a vast majority of the personnel have during their career seen the development from manual operation to new technology. Their understanding of the process they are controlling is a result of years of experience, originating from the state when each operation was made “on site” and the results of one’s actions could be in most cases observed both visually and audibly. This problem is discussed by Nuutinen and Reiman in Chapter 5.1 from the management of competence during a change of operator generation point of view. In the early years of nuclear plant operation disturbances occurred more frequently than today and the retiring generation of operators developed high professional skills for managing these disturbances. Technology has made continuous progress, and new employees now enter a more stable plant. There is a risk that the new generation operators cannot develop adequate competence. 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. (See Chapter 5.1.)

#### 4.4.4 Problems

In most of the industries where training simulators are used, they are used for both training and assessment of personal proficiency. However, since simulator training is quite expensive, a dilemma arises: proficiency must be practically demonstrated (with a simulator) but there are not enough resources to provide simulator time for both training and assessment of proficiency. Unfortunately, the requirement of demonstrated proficiency may overrule the importance of quality training and the available time is used only for the testing of competence to achieve either the required certification for the first time or to be able to renew one's certificate.

There is a risk that training institutes expect that simulator training, regardless of its quality, automatically provides the trainees with an understanding and sufficient knowledge of the issue to be learned. The idea that the higher the fidelity and category of the simulators, the better the training, is sometimes taken for granted. Instead of the grandness of the simulator, attention such be paid to matters such as the description of the trained issue, provision of various models for problem solving, aims of the simulation, what rules should be applied, etc. These matters have to be explained to the trainees thoroughly before starting the simulation. In general, the creation of a learning experience instead of a testing situation has to be achieved. The problem is emphasised by the fact that many of the simulator training instructors have a background in the field of operation which they are teaching and they may have very little pedagogical skills. One of the results of a European project (Harmonisation of Maritime Education and Training Schemes in Europe, METHAR) identifying areas of improvement in education and training facilities, was the lack of pedagogical training for lecturers at European maritime education and training institutions (Muirhead 2000). Pedagogical training is not offered to the instructors and they are learning by doing. One conclusion of the results of the same project was that a common simulator instructor training course should be developed.

The instructor's task in the debriefings after the simulations is to make sure that no negative learning or erroneous procedures have been adopted during the simulator exercise. The debriefing is as important a learning situation as the trainee's familiarisation to the exercise before starting it or the simulation itself; maybe even more important since if the events and incidents during the exercise

are not analysed retrospectively, the judgement of the proper conduct is merely left to the trainee. A training process including the four steps mentioned in Chapter 4.4.3 supports the trainee's growth to a competent operator with a good self-confidence.

Simulator training may also overemphasise the learning of technical skills even though it can be argued that in high reliability industries, the technical skills should be combined with the non-technical skills or applicable aspects of human factors. The importance of training non-technical skills to supplement technical instruction is generally agreed (Klampfer et al. 2001). As stated earlier, simulator training is almost invariably used only as a part of more extensive studies, and it is too often merely been inserted into the curricula as a detached training module. Due to this the theoretical studies and simulations do not complement one another effectively. As an example, in many training institutes the bridge resource management (BRM) training is a separate course and the use of learned BRM skills is not highlighted during the simulator training. The need and objective of the use of simulation should already be determined when determining the overall training needs.

#### **4.4.5 Conclusion**

Simulation is an excellent medium for learning new skills, enhancing existing skills and for reinforcing the knowledge of skills that are very seldom required. The use of simulators for training has been well developed and implemented in many fields, e.g. aviation and medicine. One of the benefits of simulator training is also the possibility to provide a real-world working environment to a novice who, when entering the work life, must rather rapidly be able to independently master his or her tasks. In some industries the culture of surviving by oneself, with no guidance or support, still exists. However, by implementing an effective instructional process and providing sufficient training for the instructors, the training institutes have the possibility to train their students in a manner that by the end of the studies results in skilled professional with a healthy self-confidence. The benefits of simulator training can only be achieved by providing the trainees good basic theoretical studies and including thorough briefing sessions to the training, both before and after the simulations.

In addition to the use of full-scale simulators, the use of part-task simulators should be emphasised, especially when the trainees are not yet skilled in the trained issue. Simulators of varying categories are successfully utilised in the simulator training of flight pilots. Whether training with a full-scale or part-task simulator, the method of training by testing should not overrule the method of training by learning, understanding and by applying the learned into practise. In the words of a simulator training expert, Mr Peter Barber, “simulators by themselves do not train; it is the way the simulator is used that yields the benefit”.

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## 5. Operation and management of change

In spite of all the effort made in the design and implementation phases of the system, knowledge of human practice and human-technology interaction is essential during the actual system operation and maintenance. System operation is a continuously changing and developing process. This raises a need for taking the human into account in this development. Changes are caused by the gradual implementation of new technology, societal and economical pressures for change, continuous strive for improvement of efficiency, organisational changes and the change of staff or generation.

The most important aspect in well-being and system safety is management of change in the work practises. The starting point of change management is the understanding of the present state of practise; i.e. how well the present practises, equipment etc. correspond to the demands set by the system efficiency, safety and well-being of the employees, and how this state has been achieved. Only this understanding makes it possible to comprehend the needs of the future and to create “appropriate/correct” aims for system development.

Chapters 5.1 and 5.2 are both related to the change of the worker generation at Finnish nuclear power plants. They emphasise the importance of managing change in safety critical domains and present ways to reflect the current practices and culture in order to provide information to development initiatives. Chapter 5.1 illustrates how different approaches and theories can complement each other and give new insight to the practical problems. It describes the management of operators’ competence and change of generation at a nuclear power plant. The greatest challenge in competence management is to ensure that new personnel are able to achieve sufficient competence of disturbance situation management i.e. how to operate when no guidance or instructions are given. The value of this study was especially that it tried to grasp the nuclear power plant operators’ daily work. The problems highlighted in this chapter can be considered a trend in “the industry and society in more general”, not an occasional finding.

Chapter 5.2 views the management of change from the point of view of organisation culture. It describes the developed methodology for modeling the

organizational core task, characterizing the culture of the organization and explaining the effect of the culture on the effectiveness of the organization.

Chapter 5.3 deals with a (large) change in the operation when a traditional manufacturing company broadens its services to expert service in the context of pulp and paper industry. The chapter emphasises the significance of work and practice analysis when a business enterprise is facing major development challenges. It highlights this point by describing shortly a case study of new expert service business. The study raises a serious question of the technology push as the main development strategy. It also claims that the (over)emphasis of technology when aiming to enhance efficiency is not only an occasional finding, but a dominant trend in the industrially developed countries. The shortcomings of this strategy are even more serious when (as demonstrated in the study) the official definitions and visions of the particular activity and the actual content of fulfilling the work and practices differ quite considerably. The chapter demonstrates the value of assessing practices with the proper frame of reference in order to discover development challenges.

Chapter 5.4 discusses the problem of how the human role in the accident can be thoroughly investigated. This last chapter of the book presents an approach to analysing the human role in accidents and incidents in complex socio-technical systems<sup>2</sup>. A key point of the approach is that incidents and accidents should be considered as samples of normal practice which in most cases produces safety and efficiency of the system. The authors raise an important issue: even excellent accident investigation methods can lose their power if the investigators do not have full access to all the material considering the accident and possibility to interview the survivors. A crucial challenge for the entire society is that financial or juridical implications would not hinder the profound analysis of human role in accidents. Ending our book with this theme reminds us about what could happen if human practice and behaviour are not taken into account in the development of the systems during their life-cycle.

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<sup>2</sup> The Contextual Assessment of Working Practices method shortly described in Chapter 5.3 as well as the Organizational Core Task method described in Chapter 5.2 and the accident analysis method introduced in Chapter 5.4 originate from the same research tradition as the Integrated System Validation method described in Chapter 3.1.

## **5.1 Management of operators' competence and change of generation at a nuclear power plant**

Maaria Nuutinen & Teemu Reiman

### **5.1.1 Introduction**

The demographic structure of the Finnish labour force has focused concern on the well-being at work of aging individuals and their position in the changing labour market, the transfer and preservation of competence in organisations undergoing a generation change, and the tightening competition for young employees (discussed, for example, in an article on aging and competence in the Finnish Institute for Occupational Health newsletter *Työterveiset* 1/2001). The importance of these issues is further emphasised in safety-critical, high-reliability organisations. In the nuclear power industry, the relatively simultaneous change in the expert generation as a result of the age distribution of the staff has been pinpointed as one of the key changes in the operating environment. The generation change presents a challenge for retaining the know-how necessary for the safe operation of nuclear plants (KTM 2000). In the nuclear power domain, studies and surveys on competence retention have focused on the highly educated expert resources employed in areas such as technical design and plant management. One of the key responsibilities in a nuclear power plant is process control. In the next few years the majority of the older operator generation will retire. At the same time, process management is undergoing indirect and direct changes caused by the increasing demands for cost-effectiveness, aging technology and the modernisation of the plant and the control room. (Nuutinen et al. 2003.)

After the early years of Finnish nuclear power production plant technology has made continuous progress, and new employees now enter a more stable plant than before. The plants' load factor is quite high and disturbances are few and far between. Information and control systems have been integrated, and the ways in which information is presented are the result of years of development. These may affect the new operators' learning opportunities. The approval of nuclear power plant operators and the content of the training are determined by official regulations (YVL 1.6, 1.7), which serve as the basis for the training programmes and operating instructions prepared at the plants.

### **5.1.2 A case study at NPP**

This article summarises a case study that focused on the competence management and the change of the operator generation at a Finnish nuclear power plant (NPP). The emphasis of the study was on on-the-job-training practices. The first aim of the study was to develop a general model for analysing the operators' possibilities to learning in work. This means that we had to clarify the mechanisms and factors that were assumed to affect the development of the operators' expertise. The considered mechanisms were emotional and cultural control of behaviour and two different approaches were utilised. The first one was an expert identity model that has been developed for the defining emotional-energetic demands of the work. It is assumed that the expert identity is connected with the work performance, particularly in a challenging situation, and with the development of professional competence (see e.g. Nuutinen 2003 and Nuutinen 2005). The other was a cultural approach for organisations. This approach is described in more detail in the next chapter (5.2). On the basis of the developed model the study also tested the applicability of two current learning theories for the development of practical training.

### **5.1.3 Two learning theories**

Heiskanen has emphasized the importance of the selection of the learning concept for development activities and research (Heiskanen 1999). How we perceive the nature of process control work and how we define competence and learning steer our perception of effective development measures. The selected theories were Lave and Wenger's (1991) theory on situated learning (Situated learning: Legitimate peripheral participation; LPP) and the problem-based learning model (TOM) by Hakkarainen et al. (1999), which builds on the work of Bereiter and Scardamalia (1993, 1997). While the theories are not mutually exclusive, their emphases and perspectives are different. The LPP 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. Deepening 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 part of the same process. In practical action, both the individual and 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 is becoming a member (Lave & Wenger 1991). As for the TOM model, it employs the perspective of school learning; the purpose is to modify the learning practices to better correspond to genuine knowledge construction practices. The goal is to organise the learning community to function as a science community. The model analyses the learning process as reciprocal learning and knowledge construction, linked by the solving of conceptual or knowledge problems related to knowledge or understanding. The key elements of problem-based learning involve anchoring the learning content, problem setting, establishing the learners’ individual working theories, critical evaluation, acquiring new knowledge and sharing expertise (Hakkarainen et al. 1999). The theories were analysed with relation to the operators’ work demands, the possibilities of learning and the current practices.

#### **5.1.4 Results**

A result of the study was the model of learning process, which defines factors and mechanisms interacting in the development of operator trainees into skilful operators in high reliability organizations (Figure 22). The central mechanisms were earning the trust of the social group and constructing self-confidence. (Nuutinen et al. 2003.)

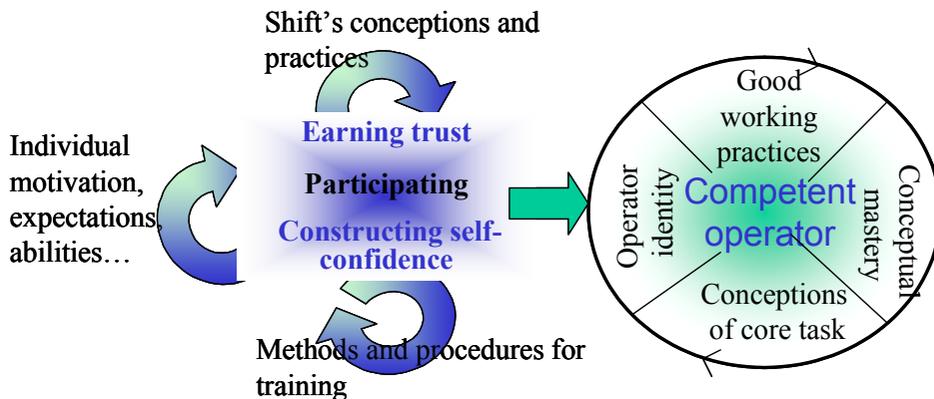


Figure 22. The model of learning process (Nuutinen et al. 2003).

The study brought out a central challenge of practical training: the trainees and operators experienced their daily work demands and learning possibilities as different from those in a disturbance situation. The demands of and competence and confidence needed in coping with disturbance situations were seen as different from those needed in the daily work. A real disturbance situation is 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 underlying factor for this was that learning by doing was a highly valued way for the development of professional competence among both generations. Yet the opportunities for doing – except for exceptional situations – were found limited. This challenges especially the construction of the sense of control (Nuutinen in press). The results showed that from a cultural point of view, earning the trust of the shift was essential in the socialisation of the new operator. Also, the particular shift had a significant influence on the operator trainee’s acquisition of a realistic sense of control (self-confidence) of one’s own work.

Quite surprisingly, the different generations have quite similar views of the learning possibilities and the demands of the work, but the trainees’ possibilities of learning in the work were considered poorer. The training was considered developed. An apprentice – master relationship characterised the current practical training practices although the trainee’s or operator’s own responsibility was strongly emphasised in development of the expertise. The results showed that continuous development of the expertise and construction of one’s expert identity are essential demands of the operator work. (Nuutinen et al. 2003; Nuutinen 2003.)

### 5.1.5 Conclusions

Based on the results of the study, there is a challenge to develop common tools and practices for the trainees' goal-oriented, question-directed and gradually deepening learning (c.w. TOM-model) and legitimate participation in the social group in a NPP (c.w. LPP-theory). As a conclusion, a stronger emphasis on the community and the intentional enlargement of normal process situations into inquiring situations would promote learning during the practical training. This could also support the development of the younger generation's expert identity. (Nuutinen et al. 2003.)

The dichotomy of work demands and the perceived learning opportunities may also apply to other kinds of work characterised by surveillance and rare occurrence of disturbance situations. One of the key problems recognised by the industry is the management of rare, yet expensive, disturbance situations. If service reliability continues to improve and fine-tuning is also increasingly managed by automated process control tools, there is a risk that the new generation operators cannot develop adequate competence and, especially, the reliability required in disturbance situations (Nuutinen 2003). 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. This is not the case in financially significant but less safety-critical domains, however. Various learning systems, desktop computer simulators and disturbance management support systems have been developed as problem-solving tools in disturbance situations. However, their benefits may remain fairly small if their use is not integrated with the daily work and they remain unused or as tools for separate independent "study assignments". On the basis of this study, the key challenge for research and development is how the daily work can become the kind or be constructed in a manner that facilitates the development of competence and identity. This requires investigation of the daily work demands and learning opportunities, and a critical evaluation of the theories selected as the basis for the development. (Nuutinen 2003.)

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## 5.2 Cultural approach to organisations and management of change

Teemu Reiman & Pia Oedewald

### 5.2.1 Introduction

The difficulties of managing complex organisations have received a lot of attention in connection with various organisational accidents (e.g. the Challenger space shuttle accident, see Vaughan [1996], Chernobyl nuclear accident or the Piper Alpha offshore platform accident, see Wright [1994] and Paté-Cornell [1993]). In Turner's (1978) terms these have been *disasters*. This means that the accidents have brought the previous approaches and assumptions about safety into question. A disaster is something that was not supposed to take place according to the existing framework of thinking, but it happened nevertheless. The event was thus in contradiction to the basic assumptions (cf. Schein 1985) about safety and the appropriate means for guaranteeing it (Turner 1978).

Organisational culture refers to the practices, principles and meanings that guide the daily work and decision making in the organisation. The culture has an influence on the overall safety, reliability and effectiveness of the operations. The elements of culture are often so self-evident or subconscious that they are not questioned until something critical happens. Modern industrial organisations are facing strong pressures for change due to competition and change of generation (both technology and people) and at the same time they should be able to ensure and prove their reliability and safety to the general public. Organisational culture has been proposed as a concept for tackling these issues. The current working practices, ideas, and conceptions might no longer be suitable in the new environment. Rigid organisational structures and narrow conceptions can inhibit change and be detrimental to the effectiveness of organisations.

The practical problems of organisational culture in complex organisations which we aim to address are:

- How to change working practices?

- How to identify and maintain organisational core competence?
- How well does the organisation utilise its technology?
- How to introduce new technological solutions into the organisation?
- How to anticipate the functioning of the organisation?

The concept of organisational culture – which is a combination of several important organisational dimensions – does not offer criteria for the assessment of the organisation or its specific tasks. For this reason, we have developed a methodology called Contextual Assessment of Organisation Culture (CAOC), which is described next.

## **5.2.2 Methodology for cultural assessment**

### **5.2.2.1 Basic principles**

The CAOC methodology utilises two concepts, organisational culture and organisational core task (OCT). Organisational culture refers to the practices, principles and meanings that guide the daily work and decision making in the organisation. The culture is formed over time and it has two functions: 1) to maintain the internal integrity of the group working in the company and 2) to create ways of responding to external expectations towards the company. The solutions have worked well enough to be taught to new members as the correct way to perceive, think, and feel in relation to those problems (Schein 1985).

Culture is a multilayered phenomenon (see Figure 23). The surface level of culture consists of artefacts that include the visible behaviour of the group and organisational processes, products and technology. The next level contains the embraced values that refer to conscious justifications to action. They predict what the people will say in a variety of situations, but if they are not congruent with the underlying assumptions, they do not necessarily predict what the people will actually do in different situations. These surface level phenomena are hard to decipher since they stem primarily from the subconscious assumptions and situational or individual variables. The deepest layer of organisational culture consists of shared tacit assumptions, conceptions and beliefs that have resulted from a joint learning process. (Schein 1985.)

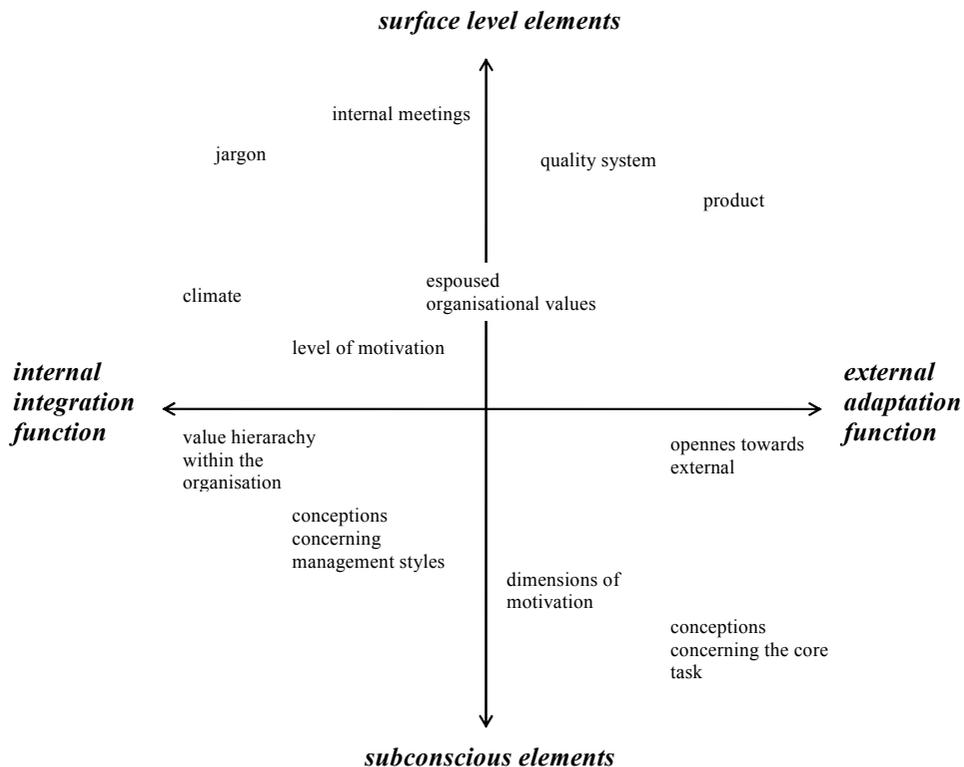


Figure 23. Examples of the cultural elements and of the functions that they are contributing to.

The OCT-concept refers to the motivation of the activity of the organisation (Reiman & Oedewald submitted). The object of the work (e.g. particular power plant, manufacturing plant or offshore platform) and the environment (e.g. deregulated electricity market) set constraints and requirements for the fulfilment of the organisational core task (e.g. generating electricity safely and economically by a light boiling water nuclear reactor to the electricity market at a competitive price). The OCT concept frames the shared constraints and requirements that all the workers have to take into account in all their tasks. The OCT concept can be used in assessing the central dimensions of the organisational culture. The organisational practices, values and conceptions are evaluated against what the organisation is trying to accomplish and what demands it has to fulfil in order to survive. (Reiman & Oedewald submitted.)

The personnel’s conceptions of the core task are historically constructed and rooted in the culture of the organisation (Figure 24) and as stated, they are not inevitably uniform. The history of the organisation is physically present in the tools, practices and organisational structures. For example, outdated tools can maintain a false image of the present core task (see e.g. Hutchins 1995). Thus, changes in the operating environment and the new operational demands caused by the changes do not automatically lead to changes in the personnel’s understandings of their core task.

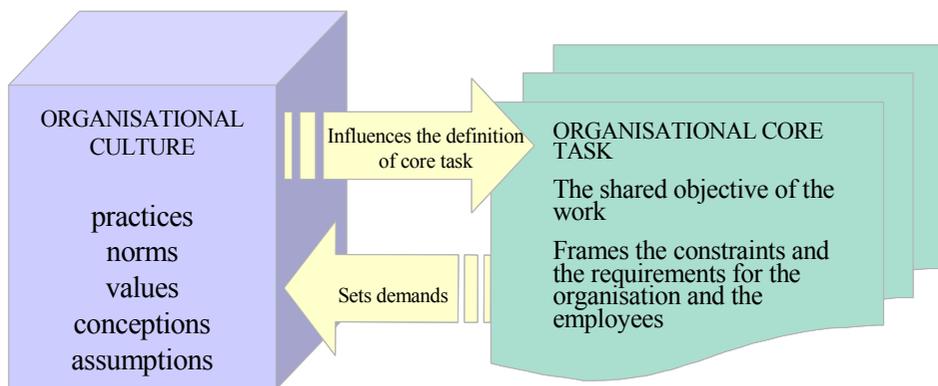


Figure 24. The basic concepts of CAOC methodology (Reiman & Oedewald 2002, submitted).

When studying organizational culture attention should be given also to the dysfunctional solutions, ambiguities, and discrepancies in the organisation, as well as to the attempts to solve or cover these (Martin 2002; Oedewald & Reiman 2003). Homogeneity of the culture (widely shared conceptions and assumptions) as such is not always a criterion for good culture. The demands of the OCT dictate whether certain cultural features (differences in opinion, emphasis on self-confidence) are good, bad or insignificant for the effectiveness of the organisation (Reiman & Oedewald submitted). For example, different opinions can facilitate discussion and be adaptive in fulfilling the demands of safety and reliability (Reiman et al. 2005).

### 5.2.2.2 Application

Assessment made in accordance with the principles of CAOC consists of three phases:

- modelling the organisational core task
- characterizing the culture of the organisation
- explaining the effect of the culture on the effectiveness of the organisation. (Reiman & Oedewald submitted.)

The methodology aims at conceptualising both the “objective” core task demands and the way they are understood in the culture. The aim of conceptualising the OCT is not to prescribe the structures or practices needed to accomplish the organisational core task. Instead, the aim is to explicate the demands that the organisation has to manage in its everyday activities. The demands can be fulfilled organisationally in many different ways. In this sense, our approach is formative rather than normative (see Vicente 1999, p. 110). The organising of the activity and the activity itself are assessed only on the basis of the requirements that they have to fulfil and the constraints that they have to take into account. (Reiman & Oedewald submitted.)

The focus of organisational assessment as we define it is thus on the OCT-related conceptions and assumptions in the given organisation. Poor practices and procedures combined with adequate conceptions of the OCT are better than the currently functioning procedures and practices combined with deficient or out-dated conceptions of the OCT. For example, this can mean a situation where the current practices maintain a false conception of the OCT since they work well enough in the normal daily work, but some critical aspect of the OCT tends to be ignored because it does not manifest itself daily (e.g. bypassing the radiation check at a NPP in a room where there has never been radiation), or its effects are long-term and difficult to perceive (e.g. monitoring the effect of corrosion on machinery), or it becomes relevant only in a case of exceptional conditions (e.g. the loss of electricity in a hospital). (Reiman & Oedewald submitted.)

### 5.2.2.3 Methods of CAOC

*CULTURE-questionnaire (Reiman & Oedewald 2004):*

The questionnaire consists of four different measuring instruments: measure of the perceived values, measure of the psychological work characteristics, measure of the personnel's conceptions of the organisational core task and measure of the ideal values of the organisation. The questionnaire consists of about 100 multiple choice questions and two open questions.

*The interview themes of CAOC are as follows:*

- own job (the content, motivating and demanding features, nature of expertise, changes in work)
- organisational core task (goals and critical demands)
- organising of activities (pros and cons of current organisational structure, co-operation between different technical fields)
- organisational culture (stories, climate, subcultures).

Furthermore, we use group working in order to facilitate the core task modelling and seminars for presenting and discussing the preliminary results with the personnel.

### 5.2.3 Conclusions

The CAOC-methodology has been applied in studying and developing the maintenance work at Loviisa, Olkiluoto and Forsmark nuclear power plants (Reiman & Oedewald 2002; Reiman et al. 2005; Oedewald & Reiman 2003). The aim of the case studies has been to assess how the maintenance culture supported perceiving and fulfilling the demands of the maintenance core task. The change of worker generation was one of the main concerns in these organisations. Cultural assessment gives information about e.g. the following aspects of organisations: what is considered as important among the personnel, how is the core task currently understood, do subcultures exist, how have the subcultures formed, what is the role of technology in the work, which

characteristics are associated with competent worker. Thus, the results of assessment can be utilised in designing the form and content of training and socialisation programmes. CAOC has also been applied in a study that focused on SME metal manufacturing companies. The purpose of the study was to explain how the organisational culture affected the quality of the production and the cooperation between suppliers and the main supplier.

CAOC provides important background information for development initiatives. A future challenge in terms of development of the CAOC methodology is to provide tools for implementing and assessing organisational changes. This is an especially important topic in safety critical organisations, where changes can endanger environmental or occupational safety. Problems common to all changes irrespective of the industry also manifest in safety critical organisations. These include increased uncertainty, unclear responsibilities and an initial decline in the performance after the change. The typical features of safety critical organisations such as organisational redundancies and thorough documentation of activities also set unique demands for the organisational change.

As stated by Woods and Cook (2002, p. 142), changes in complex systems are “opportunities to learn how the system actually functions”. A failure reveals something about the system’s functioning that was not known or adequately prepared for (cf. Turner 1978). The CAOC methodology aims to provide the means for anticipating the functioning of the system so that a system need not fail before its dynamics are understood (Reiman & Oedewald submitted). Critical reflection of the assumptions embedded in the artefacts and the current working practices of the organisation and the modelling of the organisational core task are central in this process.

Due to its contextual and participative nature, the CAOC-methodology acts as an intervention into the culture of the organization. Core task modelling prompts the personnel to discuss and make explicit the aspects taken for granted in their daily work. The approach strives to enhance the organisational capability to assess the current working practices and the meanings attached to them and compare these to the actual demands of the organisational core task and in that way change unadaptive practices.

It is imperative to acknowledge the nature of the organisational culture for effective change management. In order to maintain internal cohesion the culture forms routines, preconceptions and rules-of-thumb, and hence it inherently resists outside change. Furthermore, inputs from the outside are interpreted within the existing cultural framework of thinking. The organisational culture acts as much as a blindfold as an asset if not reflected upon actively. (Alvesson 2002; Kunda 1992.)

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## **5.3 Challenges of industrial expert services: assessment of a current service practice as a way to promote development**

Maaria Nuutinen

Expert services are a quite new service business on which high hopes are directed. Some of these expectations have already failed. Developing expert services into a profitable industrial service business is an important current challenge faced by the industry (BestServ 2003). However, implementation of the new service business has not been as successful as expected. This chapter aims to give some explanations for the difficulties in the implementation by studying one existing expert service business more closely.

### **5.3.1 A new service for pulp mills**

This study was a part of the *Technology Mediated Knowledge Services for Distributed Work Environments* (TechMedia) programme, aiming at a coherent view of the development needs of distributed knowledge management (from the technology point of view) and the future technological possibilities supporting it. The study summarised here aimed at explaining the difficulties in developing a new service business, finding major development challenges of the remote expert service and creating ideas for further information and communication technology (ICT) innovations. The study focused on a remote expert service business offering production support service for pulp mills (Nuutinen 2004; Nuutinen 2005).

The studied remote expert service was a part of an organisation which mainly designed and manufactured automation systems. The organisation also offers related expert services. The expert service business was quite a new activity but the organisation had already made relatively large investments on the technical devices supposed to support the experts' remote work. There was a direct remote connection to the customers' process and excellent video and web meeting possibilities were also available. A vision behind the technology development was a kind of "super process operator", who could remotely "save" the customer's process in a disturbance situation. Also, they had a new process

control software application which allows higher- level automated control of the pulping process. There had been considerable profit expectations concerning the expert service business in general in the organisation and these expectations had partly failed. The best situation was in the studied pulp mill service.

### **5.3.2 Data and assessment method**

The data of the study consisted of 11 recorded semistructured interviews, observations and contextual inquiries (Beyer & Holtzblatt 1998) in the mill control room, at an expert service office and at a remote expert service control room, general presentations of the organisations, four TechMedia workshops and different documents. The interviewees came from different hierarchical levels of the organisations, the service provider and the buyer. In the analysis of the data the method, Contextual Assessment of Working Practices (CAWP) (see e.g. Nuutinen 2005), based on the Core Task Analysis approach was applied (Norros 2004). The phases of analysis were: core task modelling; describing the current practices; assessing the practices; finding out explanations for the practices and recognition of the development challenges. Figure 25 presents the method used in assessing the current service practices (see in more details Nuutinen 2005).

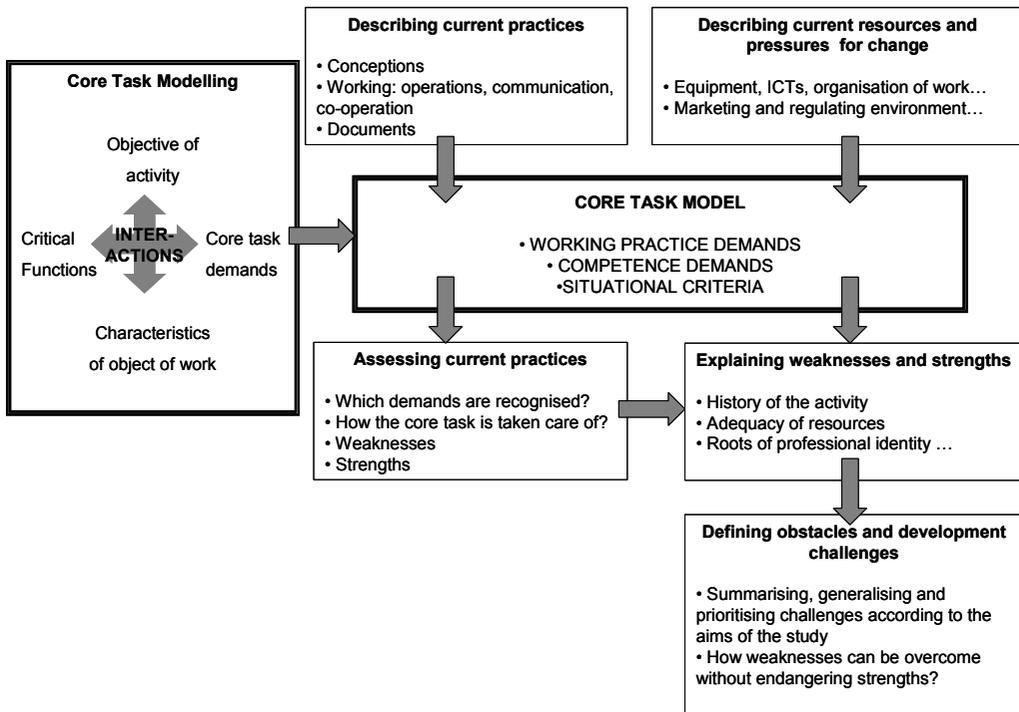


Figure 25. Contextual assessment of working practices (adopted from Nuutinen 2005).

### 5.3.3 A part of the service experts' core task model

On the basis of the core task modelling seven interrelated *critical functions or fields* of expert service business were recognised. These were:

1. customising and maintaining the software application functionality at the customer's mill
2. developing further parts for the application and other applications
3. creating customer partnerships
4. developing further the company's expert service business concept
5. finding solutions to the customers' various problems by offering products and services of the entire corporate group

6. training the customers to use the application and the service
7. continuous development of resources and competence in all the above areas.

All these were important when aiming towards a profitable expert service business. However, in practice no expert could tackle alone all the fields. Cooperation with all the main and local office experts is needed. The first critical function was assessed as the most important for the aims of the study (and possible to explore with the available resources), so it was analysed further. The current practices were assessed against the resulting model.

#### **5.3.4 Challenges for the development of profitable expert services**

Altogether 28 development challenges were recognised when assessing the current practices with the core task model concerning the function “Customising and maintaining the software application functionality at the customer’s mill”. With the previous results, these formed the main basis for creating development ideas for the ICTs.

When looking for explanations for the results, four critical cornerstones of the expert service business were recognized: 1) trust between the expert(s) and the customers, 2) context (local) knowledge of the mill, 3) expertise and 4) technical cornerstone based on the software application. The software was an important basis for the service because it provided the possibility to define concrete aims for the service and the price in the contracts, in the form of numerical boundaries for the process development. A major obstacle for handling the core task was that the development activities of the service had overemphasised the technical prerequisites for *remote* service and neglected, or not even recognised, the other prerequisites. For example, the context knowledge included also knowledge of the people working and the development activities at the mill, not only knowledge of the state of the pulping process. Also, the current service business was quite vulnerable. For example, trust between the local expert and the customer was essential. Trust between people is always quite sensitive and in this case it was built primarily between persons, not companies. Thus, if e.g. a local expert changes his job, the company might lose the customer as well. The

result of the overemphasis of one cornerstone and neglect of the others was that the future direction of the service business and the work of the experts was unclear, which involved unsolved tensions breaking up the development of the service. The challenges of the pulp expert service business were crystallised into seven tensions, which should be processed and solved in order to promote development. These were as follows:

- 1) Transforming services into products in order to increase efficiency – tailoring services to the customer’s special needs.
- 2) Limited definition of the expert service work in the service organisation – the seven critical fields of the work and the wide range of competence needed for accomplishing the work.
- 3) Building up “a super general expert identity”, experts are those who can cope with every problem on their own – specialist identity, experts are specialists who take advantage of expert networks.
- 4) The needed competence is all-around competence in order to get a general impression – special competence in order to be able to solve detailed problems.
- 5) Remote expert service is using technologies for mediating between an expert or experts and the customer – real presence at the mill and constructing trust between people in face to face communication and working together across organisational boundaries.
- 6) Offering technical services – the customer’s “soft” problems (such as e.g. personnel relationships and resistance to change).
- 7) Developing – loss of competence at the mill resulting from “the black box nature” of the software application (later) or taking the benefits of its ability to increase knowledge of the pulping process phenomena and its dependencies when the operators are closely involved in its development and trained in its secrets (former). (Nuutinen 2005.)

### 5.3.5 Conclusions

The expert service for pulp mills was an example of a new industrial service business, on which high hopes are currently placed. It raised a serious question concerning the use of the technology push as the main development strategy. Overemphasis of the technical cornerstone of the service business has resulted in a situation where the experts tried to cope with seven tensions. This endangered both the wellbeing of the experts and the development of the service into a profitable business. The inability to realise the other cornerstones was understandable when we examine the history of the organisation. After all, their core businesses had first been in manufacturing paper machines, then in developing automation technology and now they should learn to serve. However, it can be claimed that the (over)emphasis of technology when aiming to enhance efficiency is not only an occasional finding, but a major trend in the industrially developed countries.

The study also showed that the official definitions and visions of a particular activity and the actual content of the work and the practices fulfilling it can differ quite remarkably. Then, also the knowledge of the competence and the needed resources could be insufficient. This is, of course, not a good basis for development actions and supports the idea that the development actions should be based on the analysis of the current state of the activity with methods like CAWP.

The methodological challenges for work analysis and the development methods concluded from the realisation of this technology push are either to accept the situation and develop methods to cope with it or fight for a change, thus developing methods for interrelated design and development of the technology and the human part. The study summarised here aimed to illustrate the benefits of assessment when aiming at efficient guiding of development activities. It also tried to demonstrate the benefits of actually studying what the real content of the activity is or could be, instead of grounding development actions on the visions.

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## **5.4 Learning from accidents: how to handle the human contribution to accidents?**

Maaria Nuutinen, Leena Norros & Juha Luoma

### **5.4.1 The aims of accident investigation**

Different research groups at VTT have participated in incident and accident investigation bids e.g. in domains like road traffic, railway, maritime (Nuutinen & Norros 2001; Nuutinen & Norros in press; Norros et al. 2004), air traffic control (Norros & Nuutinen 1999) and nuclear power production. The methods and practices of investigation are different in different domains. One reason for these differences is that the frequency of accidents is not similar. Specifically, road accidents and even fatal road accidents occur relatively frequently, whereas accidents including other modes of transport or accidents in nuclear power plants are less frequent. Consequently, different approaches and procedures are needed.

In Finland, there is a standardised, multidisciplinary, in-depth road accident investigation method, according to which experts (a police officer, a road, a vehicle and a railway specialist, a physician and a psychologist) investigate accidents at the crash site and based on the information collected, thereby promote road safety (Finnish Motor Insurers' Centre / VALT 2004). More specifically, information about the accidents is collected at the crash site on specific forms that concern the parties involved, the events and the circumstances. The information collected forms the basis for the event description and analysis, and creation of an accident database. In the accident reconstruction, the course of the event and calculations to avoid the incident are examined. Reconstruction gives essential information for the analyses and for computer-based accident records. In the analysis of the accident, the key events and risk factors are identified and suggestions for safety measures are considered.

In contrast, in the maritime investigation for example, more systematic investigation methods especially concerning the human role in accidents are under development. The marine transport system is an example of complex socio-technological systems (CSTS). The development of CSTS as a whole is

very difficult. Single attempts to improve some parts of of a CSTS can actually increase the problems of the overall systems (by e.g. increasing tight coupling or complexity; Perrow 1984). However, the need for learning from experience is inherent in CSTSs. Individual workers and work groups have to cope with dynamic, complex and uncertain situations (DCU situations, Norros 2004) by adopting their actions to situational demands and resources. Changes in economic pressures and the political climate, technical developments, etc., continuously modify the surrounding conditions of the whole organisation and work within it, its demands and resources. Consequently, the ways for achieving efficiency of the socio-technical systems efficiency (safety, productivity and health, see Vicente 1999) also change.

Vincent Gauthereau (2003) has recently summarised the role of adaptation in the safety of complex systems: “Performance is adaptive. Safety builds on dynamic adjustments of performance. Practice is by nature changing over time... and this evolution is the backbone of safety, ...but adjustment are sometimes the *chink in safety armour*.” (P. 13.) A main challenge of developing safety critical work is how to lead or keep the situational adaptivity of individual behaviour as well as the evolution of the work practice on a safe(r) route. Accident investigation can have an important role in this, but first we have to overcome some of its current challenges.

Reason (1998) notes that accident investigators are required not only to establish the causes of an event but also to recommend measures to fix the problems. It may, unfortunately, sometimes turn out that these very same measures and “fixes” play a major part in causing some subsequent accident (Reason 1998, p. 52; see also Perrow 1984). This is dependent on what we think the aim of the accident investigation is. Is it (only) to create defences, barriers and safeguards? Because of the need of adaptation, safety cannot be achieved only by strict proceduralisation or any other form of standardisation in complex systems (Norros & Nuutinen 2002). We suggest that the aim of accident investigation is, to reflect the current normal practices and find out in which direction the evolution of the practice should be encouraged and by which means, through explaining the particular accident (Nuutinen & Norros submitted). In this way, reflection and development of the system’s normal functionality (including the safety goals) is emphasised, in addition to accident prevention.

The aim of this chapter is to shortly describe the problem of analysing the human participation in accidents. Some suggestions in order to improve learning from accidents are concluded by summarising the new method for accident investigation.

#### **5.4.2 The role of humans in accidents and different accident models**

Erik Hollnagel (2002) describes a paradox of optimal performance at the individual level: “If anything is unreasonable, it is the requirement to be both efficient and thorough at the same time – or rather to be thorough when in hindsight it was wrong to be efficient.” (Hollnagel 2002, p. 6.) As Woods (1994) earlier and Dekker (2002) recently pointed out, “From the perspective of the outside and hindsight (typically the investigator’s perspective), the entire sequence of events is exposed – the triggering conditions, the various twist and turns, the outcome, and the true nature of circumstances surrounding the route of trouble. This contrasts fundamentally with the point of view of the people who were inside the situation as it unfolded around them. They contributed to the direction of the sequence of events on the basis of what they saw and understood to be the case inside the evolving situation. For the investigators, however, it is very difficult to attain this perspective” (p. 374). This is a major challenge for the investigators and investigation methods concerning the human role in accidents.

Human behaviour can be conceptualised in different ways depending on the basic methodological assumptions. As a consequence, also the models for explaining accidents differ. Hollnagel (2002) overviews the development of accident analysis and the used accident models that are “a set of assumptions of what the underlying “mechanisms” are”. He distinguishes three types of accident models. These are sequential, epidemiological and systemic accident models. Within these models, the role of the human in accidents is also handled differently. In the sequential and the epidemiological accident models, human activity is usually connected with the notion of “human error”. Notwithstanding its evident explanatory power in everyday practice or in describing a particular course of action, *human error* is a difficult construct when applied to the analysis of the intentional dynamics of human performance (Rasmussen 1996; Woods 1994).

The “belief that there always will be variability in the system and that the best option therefore is to monitor the system’s performance so that uncontrollable

variability can be caught on” (Hollnagel 2002, p. 1–3) lies behind systemic models. In the systemic models, human performance variability is seen as necessary for a user to learn and a system to develop (Hollnagel 2002). Monitoring, or reflectivity as we rather call it, is needed in order to keep system adaptation on a safe route.

A systemic approach to accident investigation is promising, but some further developments are needed in order to avoid the loop holes of investigation, especially concerning the role of humans in the construction of accidents. In systemic models of accidents it is important to understand how and why human actions vary and how safety and efficiency come about (Hollnagel 2002); in other words, how to distinguish “good” adaptability from “bad” adaptability.

Our main claim is that descriptive research and situational analysis are essential for creating this understanding, but in order to learn from accidents more generic, formative analysis (see Vicente 1999) is also needed. In the following we will shortly present the approach based on Core Task Analysis (CTA) developed for accident investigation (see in more detail e.g. Nuutinen & Norros submitted; Norros et al. 2004; Norros & Nuutinen 1999).

### **5.4.3 Core task analysis approach to investigation**

The term core task indicates the essential content of a particular kind of work; the tasks that the workers or organisations should take care of in order to “survive” in the long run in their (physical, occupational, social, political and economic) environment. The core task comprises the objective and the aimed outcomes, the intrinsic constraints of work and the psychological work demands that are to be fulfilled by the operator (or organisation) for efficient performance of the system. Due to internal and external pressures for change in the dynamic socio-technical systems, the core tasks tend to change. As a result, the actual working practices that fulfil the core task may become invalid. Working practices are the ways in which the workers cope with the work demands by using the available resources. The aim of the approach is to promote the development of practices through explaining and evaluating them by the adequate criteria.

The conceptual structure of the approach has three parts: creating contextual criteria for good practices; assessing the practices with these criteria and explaining the strengths and weaknesses of the practices. The first part consists of modelling the work objective, context and domain, and the second part consists of analysing the current practices (or culture) represented as courses of actions and the workers' conceptions of the work, its meaning and of themselves as workers. In domain modelling, activity-system analysis of the developmental tensions (Engeström 1987) and the modelling of intrinsic constraints (Rasmussen 1996; Vicente 1999) are carried out. The conceptions of the actors of their work, its objective and demands are used both in the modelling and analysing practices. The practices are analysed from the perspective of the cultural-historical activity theory (Leontjev 1978) and we are particularly interested in explaining the situated courses of action (Hutchins 1995; Suchman 1987). (See Figure 26.) On a more general level, these first two parts make it possible to define the intrinsic constraints of work and the psychological work demands, the criteria for appropriate practices (which are interpreted as situational criteria) and the description of current practices. In the third part of the analysis, explanations for the practices are searched in order to define adequate development suggestions. The path of the investigation and questions to be answered are presented in Figure 27.

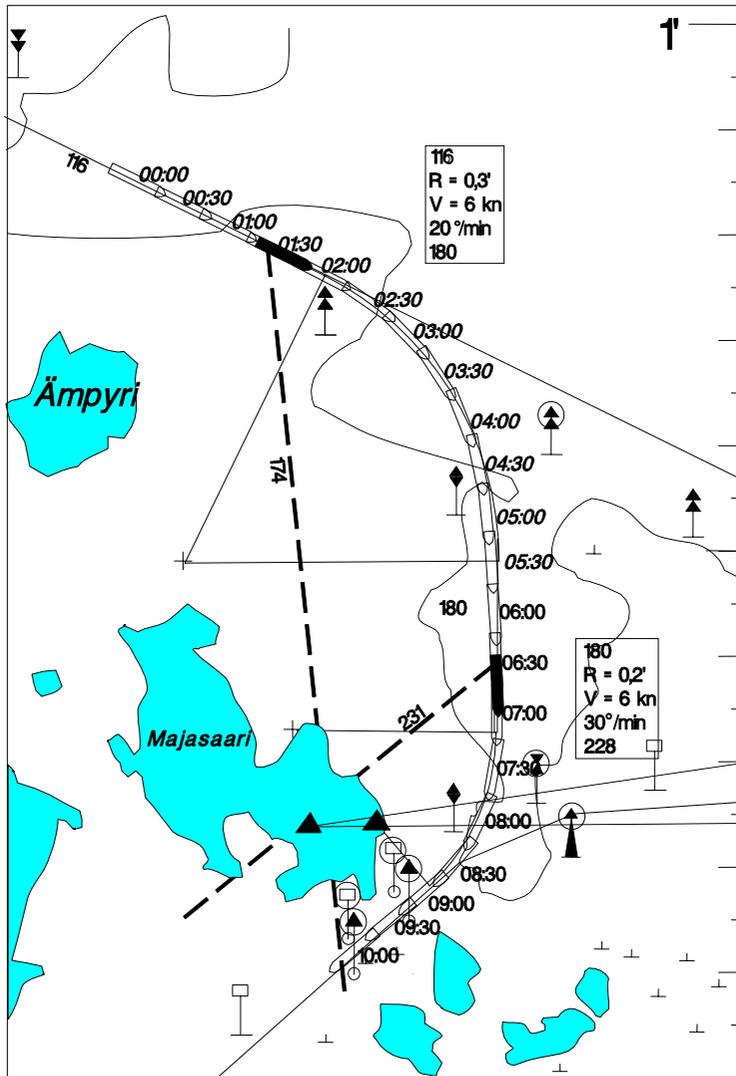


Figure 26. Assessment of situational demands: An example of simulator testing (AIB C 9/1998 M).

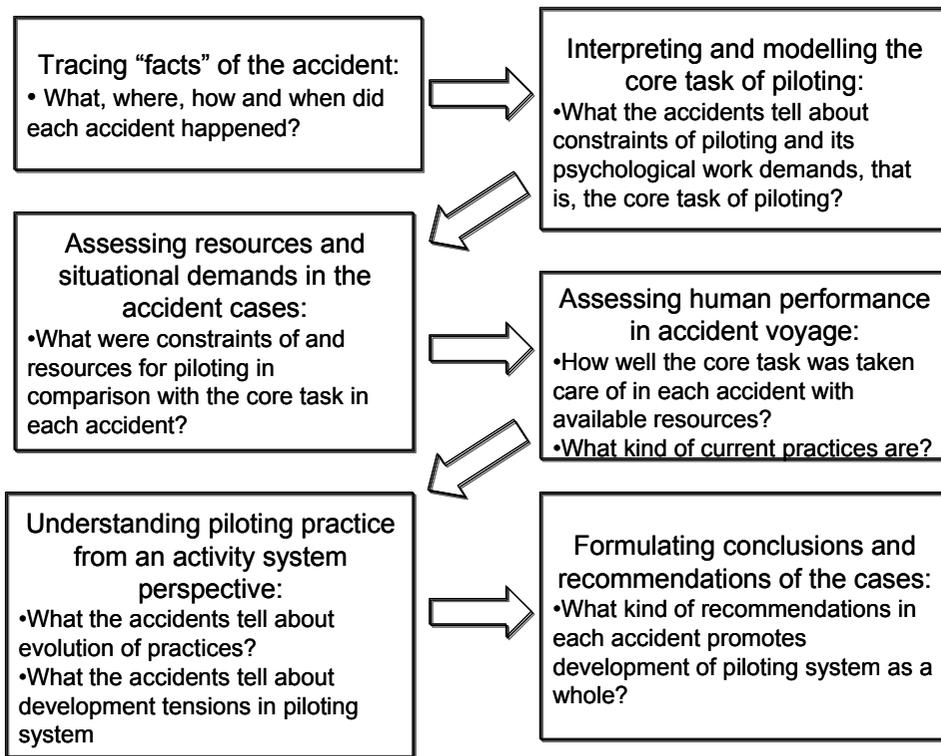


Figure 27. The path of investigation (adopted from Nuutinen & Norros in press). Based on the joint investigation of 10 accidents occurred during piloting (Norros et al. 2004).

#### 5.4.4 Conclusions

Understanding the evolution of the practise (Gauthereau 2003) is important not only to improve safety, but also in order to keep a system functioning on its current level in a changing world. Reflective learning from experience can be seen as a way by which a system can adapt to changes and prepare for future demands. Thus learning from experience also gives an opportunity to improve system functionality. As already noted, the challenge for accident investigation is how to support leading or keeping the situational adaptivity of individual behaviour as well as the evolution of the work practice on a safe(r) route.

We suggest that the aim of accident investigation should be to reflect the current normal practices and find out in which direction the evolution of the practice should be encouraged and by which means, through explaining the particular accident(s). In this way, reflection and development of the system's normal functionality (including the safety goals) is emphasised instead of the prevention of (similar) accidents. Accident investigation is always like a snapshot of the current practices, but not necessarily of bad practices. The accident situation is a sample of normal practice which in most cases produces safety and efficiency of the system. When aiming at deep understanding of the human role in accidents we should also use other sources of normal practice available. For example, data and results of studies on normal situations and surveys conducted for different purposes are important sources for deepening understanding.

The models of accident investigation also have an impact on safety research. Safety research tends to focus on the causes to which accidents are attributed (Gauthereau 2003). When accidents were attributed to human error then the research also focused on this component, and the focus changed when organisational factors were emphasised as important causes of an accident. Practice-oriented safety research is emerging but in accident investigation practical methods are needed. Even with willingness to give up the old view of human error reconstruction of the past human performance and its role in an accident is difficult (Dekker 2002). We also need to understand the history of the practices and have an idea about the challenges of the future. Still incidents and minor accidents give us and the practitioners an opportunity to gear system evolution towards a safer route. A way of doing this was presented in this chapter: to recognise the result critical functions of the system and give the practitioners the resources to take care of them. That is, to promote core task-oriented working practices and develop tools supporting the core task.

In final remark, as e.g. Hollnagel (2002) had noticed, humans do play a role in systems, in their failure and in their recovery, and thus the role of humans in accidents must be considered at all levels of the system. However, even excellent accident investigation methods can lose their power if the investigators do not have full access to all material considering the accident and the possibility to interview participants or related groups. A crucial challenge for the entire society is to prevent the financial or juridical consequences from blocking the profound analysis of human role in accidents.

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Title <b>Human practice in the life cycle of complex systems Challenges and methods</b>			
Abstract This book describes the current and near future challenges in work and traffic environments in light of the rapid technology development. It focuses on the following domains: road and vessel traffic, nuclear power production, automatic mining, steel factory and the pulp and paper industry. Each example concerns complex technical systems where human practice and behaviour has an important role for the safety, efficiency and productivity of the system.  The articles illustrate the enormous field of human-related research when considering the design, validation, implementation, operation and maintenance of complex socio-technical systems. Nevertheless, these 14 chapters are only examples of the range of questions related to the issue. The authors of the book are VTT experts in work or traffic psychology and research, system usability, risk and safety analysis, virtual environments and they have experience in studying different domains.  This book is an attempt to open up the complex world of human-technology interaction for readers facing practical problems with complex systems. It is aimed to help a technical or organisational designer, a policy-maker, an expert or “a user”, the one who works or lives within the technology.			
Keywords complex systems, human-technology interaction, human practices, safety critical systems, traffic information services, user-centered design, nuclear power, mining, steel industry, pulp and paper industry			
Activity unit VTT Industrial Systems, Tekniikantie 12, P.O.Box 1301, FI-02044 VTT, Finland			
ISBN 951-38-6675-0 (soft back ed.) 951-38-6676-9 (URL: <a href="http://www.vtt.fi/inf/pdf/">http://www.vtt.fi/inf/pdf/</a> )		Project number G2SU00035	
Date December 2005	Language English	Pages 147 p.	Price C
Name of project T4Koord-ris		Commissioned by VTT teknologiateema Turvallisuus ja käyttövarmuus	
Series title and ISSN VTT Publications 1235-0621 (soft back ed.) 1455-0849 (URL: <a href="http://www.vtt.fi/inf/pdf/">http://www.vtt.fi/inf/pdf/</a> )		Sold by VTT Information Service P.O.Box 2000, FI-02044 VTT, Finland Phone internat. +358 20 722 4404 Fax +358 20 722 4374	

This book describes the current and near future challenges in different work and traffic environments in light of the rapid technology development. The book is directed to readers who are interested in the complex world of human-technology interaction, especially in safety critical domains. The 14 chapters illustrate the enormous field of human-related research when considering the design, validation, implementation, operation and maintenance of complex socio-technical systems. The various approaches, methods and frameworks are shortly described in the context of different practical problems – and the reader can follow the references to the sources of more detailed writings. The authors of the book are VTT experts in work or traffic psychology and research, system usability, risk and safety analysis, virtual environments and they have experience in studying different domains.

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Tätä julkaisua myy  
VTT TIETOPALVELU  
PL 2000  
02044 VTT  
Puh. 020 722 4404  
Faksi 020 722 4374

Denna publikation säljs av  
VTT INFORMATIONSTJÄNST  
PB 2000  
02044 VTT  
Tel. 020 722 4404  
Fax 020 722 4374

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