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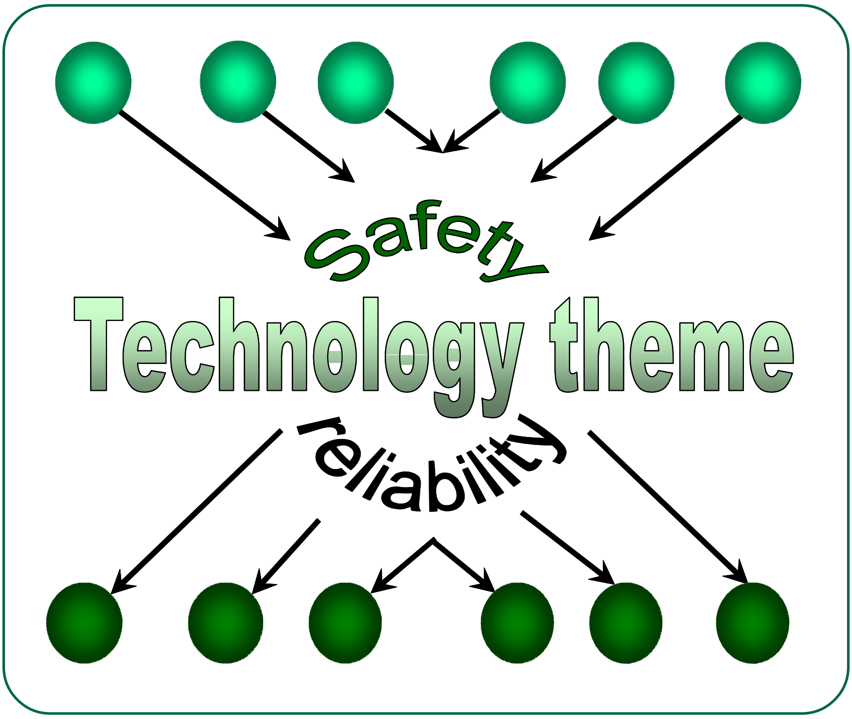

Veikko Rouhiainen (ed.)

Safety and reliability

Technology theme – Final report

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Abstract

"Safety and reliability" has been one of the four strategic technology themes of VTT during 2001–2005. Technology themes are research programmes initiated and financed by VTT. In this theme, technologies, system models, and measurement, modelling and estimation methods have been developed for the Finnish industry's needs. The results have been applied to the development of safety and the lifecycle management of socio-technical systems. In the theme, particularly the following expertise, and knowledge areas have been utilised and developed: safety engineering, risk management, system engineering, machine diagnostics and monitoring, psychology, microbiology and management of safety and dependability knowledge. The research in the theme has been focused on: methods for life cycle management of production systems, human-technology interaction (HTI) and safety, and new technologies and operating principles.

This report describes the research carried out and the main results obtained in the Safety and reliability technology theme.

Preface

“Safety and reliability” has been one of the four strategic technology themes of VTT during 2001–2005. The themes are multidisciplinary research programmes initiated by VTT, with aim to achieve significant scientific and technology improvements. The projects of these programmes represent a high international standard and are also expected to raise the level of VTT’s other projects – paving the way to technological breakthroughs and innovations. The projects of the technology themes reached the start-up phase at the end of the year 2001. Ambitious goals have been set for these projects over a period of several years. The aim of the themes is also to promote networking with the best partners and enhance synergetic co-operation within VTT.

The authors would like to thank the Scientific Advisory Board of the theme, and all the Steering Comittees of the projects. As an externally focused innovation organisation, VTT highly appreciates external support as a unique and invaluable source of obtaining new impulses, views and well-considered recommendations.

The original aim of the theme was to initiate new, challenging research at VTT. When the projects have now been running for around four years, this aim has been achieved, and the research can be continued in other projects. This report compiles the main results obtained in the projects of the Safety and reliability technology theme.

The authors would like to thank all the organisations and individuals who have taken part in the implementation of the projects of the Safety and reliability theme for their excellent co-operation.

Tampere 14.12.2005

Authors

Contents

Acronyms and abbreviations

ADAS	Advanced Driver Assistance System
AIDE	Adaptive Integrated Driver-vehicle InterfacE
AIS	Automatic Identification System
CAA	Cockpit Activity Assessment Module
CABIN	Project: New Interfaces in the Cabins of the Future in Movable Machines and Vehicles
CAN	Controller Area Network
CCP	Critical Control Points
CMM	Computerised Maintenance Management
CTA	Core Task Analysis
PCM	Dependability Control Model
DGGE	Denaturing Gradient Gel Electrophoresis
FI-TOOL	Project: Management of Safety and Reliability Knowledge during the Life Cycle of Working Machines
GMO	Genetically Modified Organism
GMP	Good Manufacturing Practise
GMORA	Project: Risk Assessment of Genetically Modified Plants
GOFREP	Gulf Of Finland REPorting system

HACCP	Hazard Analysis and Critical Control Points -analysis
HMI	Human-machine interaction
HTI	Human-technology interaction
ICT	Information and Communication Technology
IMO	International Maritime Organization
INID	International Network for Industrial Diagnostics
ITS	Intelligent Transport System
IVIS	In-Vehicle Information System
IWRIS®	Intelligent Water-borne Risk Indication System
KTA	Key Technology Action of VTT
LIIKKUDIA	Project: Monitoring and Diagnostics – Lifetime Management of Mobile Machinery
METODI	Project: Development of a Human-Centered Design Methodology for Human-Machine Systems
OHA	Operating Hazard Analysis
O&SHA	Operating and support hazard analysis
PCR	Polymerase Chain Reaction
PDM	Product Data Management
PHA	Preliminary Hazard Analysis
RAMS	Reliability, Availability, Maintainability, Safety

RFID	Radio-Frequency Identification
SCADA	Supervisory Control And Data Acquisition
SEFO-sensor	Seat foil sensor -sensor
SENSATION	Project: Advanced sensor development for attention, stress, vigilance & sleep/wakefulness monitoring
S-IVIS	Surrogate In-Vehicle Information Systems
SRB	Sulphate reducing bacteria
SYKE	Project: Unobtrusive Driver Monitoring Technologies
SYSTELI	Project: Systems Analysis in Management of Plant Lifetime and Production Safety
TRUST	Project: Trusted Software Technology
VTMIS	Vessel Traffic Management and Information Service
VTS	Project: Offshore VTS (Vessel Traffic Service) for the Gulf of Finland
VTT	Technical Research Centre of Finland

Executive summary

“Safety and reliability” has been one of the four strategic technology themes of VTT during 2001–2005. The **strategic technology themes** are multidisciplinary research programmes initiated by VTT. The themes are aiming at high level scientific and technology achievements. The projects of these programmes represent a high international standard and are also expected to raise the level of VTT’s other projects – paving the way to technological breakthroughs and innovations. The projects of the technology themes reached the start-up phase at the end of the year 2001. Ambitious goals have been set for these projects over a period of several years.

The vision of the **Safety and reliability theme** has been the suitable and safe interaction of humans and technology without unexpected disturbances and failures. In the Safety and reliability theme, technologies, system models, and measurement, modelling and estimation methods were developed for the Finnish industry’s needs. The results were aimed to be applicable in the development of safety and the lifecycle management of production systems.

The aim of the Safety and reliability theme was to systematically bring together VTT’s qualified research groups and high-level specialists in this field. The critical mass that comprised this focused network consisted of high-level experts in the fields of safety engineering, risk assessment, industrial mathematics, modelling, simulation, material science, mechanical engineering, software engineering, psychology and biotechnology. Networking with the best partners and enhancing synergetic co-operation both inside and outside of VTT was promoted in all projects.

Research carried out in the theme has empasised the sociotechnical point of view, and has been focused on three areas: life cycle management of production systems, human-technology interaction and safety, and new technologies and operating principles. The goals and objects of the focus areas were

- increase the profitability of production systems by improving their reliability during their life cycle

– implement human-technology interaction so that the user is taken into account already when planning the system

– develop frontier technologies and new operating principles for providing possibilities for new business concepts.

The research in the theme was conducted in various **projects**. The projects running in the focus area life cycle management were related to: systems analysis in the management of plant lifetime and production safety, management of safety and reliability knowledge during the life cycle of working machines, and failure monitoring and diagnostics of mobile machinery. Three projects running in the focus area human-technology interaction (HTI) and safety developed: a human-centered design methodology for human-machine systems, offshore Vessel Traffic Service (VTS) for the Gulf of Finland, and new interfaces in the cabins of the future in movable machines and vehicles. The third focus area was called new technologies and operating principles, and the projects developed unobtrusive driver monitoring technologies, software reliability, and risk assessment of genetically modified organisms (GMO).

The research aimed at a high international level. All projects have been highly ambitious, and the following research was thought to be **the most scientifically and technologically challenging:**

– Unobtrusive Driver Fatigue Monitoring is an area where a lot of research has been conducted, however applicable systems have not yet been developed.
– The new RAMS-concept is quite clear for the researchers, however, the problem involves many new practical tools, as well as persuading industry (machine manufacturers) of the value in utilising this kind of system and developing practical applications.
– Risk Assessment of GMO's is a very new area, and generally accepted methods are not available. The most difficult problem is that there is no practical data related to the risks available.

It is difficult to evaluate which of the **obtained results** are the most significant. The following results are expected to have a remarkable impact in the future:

- Systems analytic ageing management approach utilising various stochastic and decision analysis models.
- The research on microbiological production safety has produced results with clear industrial interest and immediate impact. A tool called Paperi Hygram® was built up for risk assessment and Hazard Analysis and Critical Control Points (HACCP) analyses for the pulp, paper and packaging industry, showing the results in clear charts and including a databank on risk analysis and problematic micro-organisms.
- A new RAMS-concept (Reliability, Availability, Maintainability, Safety), a new system for management of RAMS-knowledge at the conceptual level is currently in the testing phase.
- The Machine Diagnostic Centre has been created at VTT. It offers a platform for the development of remote diagnostics and prognostics within an international network.

For assuring the **maximum impact** of the theme, the most potential areas in technology and industry that offered potential safety and reliability improvements were evaluated, and compared with requirements and priorities in Finnish industry. The Scientific Advisory Board ranked the projects and the highest ranking was given to the projects related to the RAMS-concept and GMO-risks. The area to which the RAMS-concept can be exploited was deemed to be very wide, while GMO-risks are related to a very new area where not many tools are currently available.

Good examples of the valuable potential impacts can be expected to be found from the following research results:

- IWRIS®-technology, which will be improving maritime safety by alerting of a developing collision hazard in the monitored area, alerting of deviation in a vessel's typical motion path (grounding hazard), and alerting of a vessel which has no track record of navigation in the area.
- Methodology to recognise and to solve the challenges concerning human behaviour in complex, safety critical systems, and for supporting design of different kinds of human-technology systems.

- Bacteria identification methods have been developed for rapid screening of the presence of bacteria, resulting in a shortening of the time needed for obtaining the results from several days to one day. This is particularly important in the case of food packaging materials and bacteria causing food poisoning. Rapid detection of the bacteria reduces both the loss of production and the risks concerning product safety. The new methods are in use in projects and contracts with industry.
- Driver impairment monitoring system has been seen to offer possibilities for improving traffic safety. Results may have applicability also in monitoring areas other than road traffic.

The impact of the theme is mainly indirect, seeing that all projects do not themselves develop safer technology. The main focus of the theme has been on improved safety and reliability and this is being pursued by developing tools, methods and procedures that will help our customers when developing the safety and reliability of their technical systems. The work started in the theme will continue in other research projects and programmes, where the presented ideas will be further developed, and different kinds of applications utilising the results of the theme projects.

1. Introduction

1.1 Introduction to the Safety and reliability theme

1.1.1 Aim and pursued impacts of the theme

The purpose of the theme has been the reasonable and safe interaction of humans and technology without unexpected disturbances and failures. In the Safety and reliability theme, technologies, system models, and measurement, modelling and estimation methods have been developed for the Finnish industry's needs. The results are applied to the development of safety and the lifecycle management of socio-technical systems.

VTT is active in several fields of safety and reliability related scientific and technical competence, e.g. fatigue testing, reliability analysis, hazard analysis, human behaviour studies, safety analysis, condition monitoring, and reliability design. However, the research groups working in these fields have mainly developed their skills separate from each other. Improvements in the safety level will require the integration of these competencies, together with modern information technology, in order to meet the future needs and to generate new products for networked large companies and SMEs. Under the theme, VTT´s know-how has encompassed the fields of safety engineering, risk management, system engineering, machine diagnostics and monitoring, psychology, microbiology and management of safety and dependability knowledge.

1.1.2 Why this theme?

Safety and reliability has been an evident and justified area to be a technology theme because:

- It addresses major societal needs – to improve the safety and security in a society that is more and more dependant on products and procedures with ever increasing complexity, vulnerability and uncertainty.
- It is challenging both from a scientific and an implementation point of view.

– It is largely multidisciplinary and needs the critical mass from bringing together the high level research groups and industrial expertise.
– The challenging goal of improving safety can only be achieved through the efforts of a large, integrated and multidisciplinary action that contains research and technological development, as well as development of new operating procedures.

In today's society there are several trends and new features that increase the complexity, vulnerability and uncertainty in activities related to the society itself, industrial production, and peoples' use of new products and technologies. The **increasing complexity of technical systems** and products makes them more difficult to understand, monitor and control. They are thus more vulnerable to both internal failures and malfunctions as well as to external destructive attacks.

Financial losses from accidents, damages and unforeseen production interruption may be considerable. Unexpected hazards in technical systems may result in the loss of human life and environmental pollution in addition to impaired industrial competitiveness and image. There have recently been several large accidents in Europe such as the explosions, fires, transportation accidents, aircraft crashes at the airports, and railway accidents. The use of advanced new technologies has resulted in an extensive range of problems, e.g. in some new airports.

The **economic impact of accidents** is huge. The total costs of accidents in the EU is estimated to be about 170 billion Euro for the European societies, and 20 billion Euro of that is acciciated with labour accidents. From a ten year perspective, it has been estimated that 10% of these accidents could be avoided.

Major industrial **economic losses** are also due to disturbances and failures resulting in the **shutdown of the production and function.** The overall economical losses for lost production due to shutdown and malfunctions have been estimated to be 7% of the turnover. Examples of one day shutdown costs for different commercial functions include: paper plant 500 000 Euros, power plant (coal) 100 000 Euros, oil refinery 500 000 Euros, cargo ship 5 000 Euros, train 2 000 Euros, and design office with 100 employees 4 000 Euros. The overall losses due to lost profit as a result of shutdowns, decreased efficiency and quality (OEE Overall Equipment Efficiency is about 70–80%) in Europe are about 140 billion Euros annually.

1.2 Objectives for Safety and reliability technology theme

Research carried out in the theme has been focused on three areas: life cycle management, human-technology interaction and safety, and new technologies and operating principles. The research itself was conducted in projects. The goals and objects of the focus areas are:

- Increase the profitability of production systems by improving their reliability during their life cycle. The projects are related to the prevention of hazards and accidental disturbances in movable working machines, as well as in paper and energy production.
- Implement human-technology interaction so that the user is taken into account already when planning the system. The case areas include road and marine traffic, and the mining industry.
- Develop technologies and applications for monitoring the system and the operator. The aim is to utilise this information in operation and maintenance, and when assuring safety.

Referring to the status reports of the projects, the major goals have all been obtained. The projects have mainly continued from the start of the theme. Only one project has been suspended – the risk analysis of GMOs. In that case it became obvious that the international top level results could not be obtained with the available resources, and the project could not find industrial partners, customers, and public funding.

The theme did bring together VTT's research groups and specialists in the field of safety and reliability. The critical mass that comprised this focused network consisted of high-level experts in the fields of safety engineering, risk assessment, industrial mathematics, modelling, simulation, material science, mechanical engineering, software engineering, psychology and biotechnology. This group had a very wide international contact network, which supported the research carried out in the theme projects, and provided a good basis for increasing and cross-linking the international networking.

International networking was promoted and supported by procedures accepted and applied in the theme. The theme leader and researchers have visited several research institutes in Europe, USA and Japan. Results of these travels, contacts, discussions, ideas, proposals, etc. have been reported and distributed within the theme. Public results of research projects have been presented at several conferences and seminars.

As a result of international activities, for example, the following actions can be listed:

- Several European research initiatives have been proposed, and research has been started in several projects.
- Several reserchers and senior research scientist of VTT will join to other institutes for some period of time.
- Visiting students from other Research Institutes will join the projects of VTT.

Preparations and project proposals have been made to start the collaboration and researcher exchange with Japanese universities in the area of systems safety.

1.3 Structure of Safety and reliability technology theme

The following Section discusses the main aspects of the focus areas of the theme. The contents of some projects, and the main results have been discussed in more detail in Chapters 2, 3, and 4.

1.3.1 Methods for life cycle management

Three projects were running in this focus area:

- LIIKKUDIA – Monitoring and Diagnostics: Lifetime Management of Mobile Machinery
- SYSTELI – Systems Analysis in Management of Plant Lifetime and Production Safety
- FI-TOOL – Management of safety and reliability knowledge during the life cycle of working machines.

In SYSTELI, system technical methods have been developed to support safety and dependability studies. The methods combine historical data and measurements, and the predictions of probability-based failure and condition monitoring models. In FI-TOOL, a data management system embedded into the machines and devices has been developed for the management of safety and dependability knowledge. The system covers the entire life cycle of the devices and production systems. In LIIKKUDIA, the self-diagnostics of the work machines has been developed. The aim was that the machine will be able to diagnose its own condition and send the diagnosis, measurement data, and maintenance order to a remote supervision centre.

The most significant results obtained are the following:

- System analytical models and approaches have been developed and tested for multi-criteria decision making related to safety and reliability (SYSTELI).
- Related to microbiological production safety in pulp and paper industry, a bacteria identification method has been developed including the rapid screening for the presence of bacteria. This would result in a shortening of the time needed for obtaining the results from several days to only one day (SYSTELI).
- A knowledge management system at the conceptual level is currently in the testing phase (FI-TOOL).
- One employment invention concerning video monitoring of a production line using wireless technology has been made and accepted (FI-TOOL).
- The Machine Diagnostic Centre has been created at VTT. It offers a platform for the development of remote diagnostics and prognostics within an international network (LIIKKUDIA).

1.3.2 Human-technology interaction (HTI) and safety

Three projects were running in this focus area:

- METODI – Development of a human-centered design methodology for human-machine systems: Remote operation of mining machines as a case study
- VTS – Offshore VTS (Vessel Traffic Service) for the Gulf of Finland
- CABIN – New interfaces in the cabins of the future in movable machines and vehicles.

In METODI, a methodology for the evaluation of man-machine systems has been developed. The methodology includes the principles and criteria needed for the development of different types of man-machine systems. The new methodology was developed in the research on the remote use of mining machines. In VTS, the aim was to develop a training system utilising several simulators and virtual technology in order to support the implementation of the vessel traffic management and information service (VTMIS). In CABIN, a new generation of user interfaces of movable machines and vehicles, which utilise the newest information and communication technologies, has been developed.

The most significant results obtained are the following:

- Knowledge about available HTI research, as well as the applicability of existing and new methods used at VTT to different HTI problems has increased (METODI).
- A preliminary model, "human-technology interaction design process" for integrating HTI issues into the technical design process of automated mining has been developed (METODI).
- A Formal Safety Assessment (FSA) was conducted and submitted to the International Maritime Organization, IMO (VTS).
- A technology roadmap has been developed and the summary of the needs collected from the companies (CABIN).

1.3.3 New technologies and operating principles

Three projects were running in this focus area:

- SYKE – Unobtrusive Driver Monitoring Technologies
- TRUST – Trusted Software Technologies
- GMORA – Risk Assessment of Genetically Modified Plants.

In SYKE, unobtrusive monitoring methods for driver fatigue detection has been developed. They will be based on the integrated use of Emfit technology and other sensors. In TRUST, a knowledge management system that enhances the ability to utilise specific methods and techniques to design and demonstrate safety and reliability of software has been developed. In GMO, a framework for the risk assessment of genetically modified plants, that helps the plant developer to manage the risks during the plant's development cycle, was developed.

The most significant results obtained are the following:

- First feasibility tests have been carried out on a non-invasive sensor technology (SYKE).
- A common concept concerning the content and the way of realising the software reliability has been created (TRUST).
- Preliminary method for identification of safety critical requirements of a software has been developed (TRUST).
- New hazard identification and risk assessment method for GMOs has been published.

1.4 Strategic importance of the theme

1.4.1 Links to VTT's technology strategy

The Safety and reliability theme has had a central position in VTT's technology strategy. It has close connections to three focus areas of VTT's strategic research: safety and reliability, tools for information society, and industrial biotechnology. The theme will increase collaboration and links between these focus areas. For example, when developing the methodology for microbiological risk analysis for the paper industry, the expertise from reliability engineering has been complemented with expertise from the field of biotechnology.

VTT's technology strategy highlights certain Key Technology Actions (KTA). The theme has had the following close connections to these:

- human-technology interaction (HTI) KTA
- safety and security of the built environment KTA
- the asset management KTA.

The theme has had also many links to the focus areas of different Research Institutes of VTT. In VTT Industrial Systems, such strategic focus areas have been, for example, Life Cycle Management of Structures, Risk Management and Systems Safety, Human-Technology Interaction, and Factory of the Future. VTT's other research institutes have also the same kind of connections to this theme.

The amount of the financing and resources for the Safety and reliability theme may have been warranted, when taking into account that the theme does not cover all research carried out in the areas of safety, security and reliability. The total amount of the funding used in these areas is very difficult to estimate. Safety is a very broad area, and much research related to it is carried on outside the theme. This theme concentrates on three focus areas.

When considering the extent and volume of the theme, two questions arise:

- If the research carried on outside the theme would be conducted within the theme, would it be more effective? Should the theme have more focus areas?
- If more financing would be directed to the selected focus areas, would the research be more effective? In some areas the progress would proceed more rapidly, if the projects had more financing. However, the issue of the amount of available experienced resources might be raised, and this might also be problematic.

1.5 International level

All the projects in the theme aimed to achieve results of an international level. This was assured by visiting other international research institutes, attending conferences, and developing contacts with internationally high level researchers. The international contacts are presented later in the Section 1.7. It is noticeable that the theme projects have increased the amount of international contacts and internationality. The most active international networking were in the following projects:

- SYSTELI (thematic networks, researcher exchange to and from VTT)
- LIIKKUDIA (International Machine Diagnostic Centre)
- METODI (researcher exchange from VTT)
- VTS (fixed networking with Russia and Estonia)
- SYKE (two EU-funded Integrated Projects running).

One point which could be developed further is the cross-utilisation of this international contact network in all research projects. A lot of information is also available through the thematic networks, however, the problem is the lack of resources for disseminating and utilising all this information.

1.5.1 International technological breakthroughs

In the following areas, the research is very close to the international top level, and world-class results were expected in

- Driver Monitoring Techniques (participating in two European Integrated Projects)
- Offshore Vessel Traffic Service (VTS) system (IWRIS® Intelligent Water-borne Risk Indication System developed will be at the top-most level)
- Self-Diagnosis and Prognosis System of Machines (the international machine diagnostic centre has already started).

It is difficult to identify which areas possess the most potential for international technological breakthroughs. What is a breakthrough? How is it defined? And what are the criteria for it? At the moment the Driver Monitoring Techniques project has raised the most international interest and increasing international activity.

1.5.2 Scientific and technological challenges?

The following research areas are thought to be the most scientifically and technologically challenging:

- Unobtrusive Driver Fatigue Monitoring is an area where a lot of research has been conducted, however applicable systems have not yet been developed.
- In the FI-TOOL project the concept to be developed is quite clear for the researchers, however, the problem involves persuading industry (machine manufacturers) of the value in utilising this kind of system and developing practical applications.
- Risk Assessment of GMO's is a very new area, and generally accepted methods are not yet available. The most remarkable problem is that there is no practical data related to the risks available. A new methodology has been developed, but it is difficult to get international acceptance for this kind of new approach. A new approach and guidance for risk assessment of GMOs has been developed, published, and accepted into use in Finland.

The Scientific Advisory Board of the theme did rank the projects, and especially the projects SYSTELI (Systems Analysis in Management of Plant Lifetime and Production Safety) and METODI (Human-centered design methodology for human-machine systems) also received a high-level ranking for novelty and ambition (impact).

1.6 Impacts of the theme projects

When planning the theme a clarification was made about the areas, in which disturbances (unreliability) and accidents result in the largest losses. This is referred to in the introduction of this report. The aim was to start projects in those areas.

The Scientific Advisory Board has ranked the projects and in this issue the highest ranking was given to FI-TOOL and GMORA. In the FI-TOOL project, the area and field to which the results of the project can be exploited is deemed to be very wide, while GMORA is directed at a very new area where not many tools are currently available. A high ranking was also given to the SYSTELI and METODI projects.

Good examples of the impacts can be found from the results of the following research projects:

- The VTS project developed the IWRIS®-technology, which will improve maritime safety by alerting of a developing collision hazard in the monitored area, alerting of deviation in a vessel's typical motion path (grounding hazard), and alerting of a vessel which has no track record of navigation in the area.
- In the LIIKKUDIA project, the Machine Diagnostic Centre has been created. It offers a platform for the development of remote diagnostics and prognostics within an international network.
- In SYSTELI, a risk assessment model, Paperi Hygram®, for performing and maintaining Hazard Analysis and Critical Control Points (HACCP) analyses has been developed. It provides information on good manufacturing practise and HACCP specifically in paper and packaging industry, it guides the user through the whole risk assessment process and it serves at the same time as a documentation tool.
- The driver impairment monitoring system has been seen to offer possibilities for improving traffic safety. The results may have applicability also in monitoring areas other than road traffic.

1.7 National and international networking

Safety and reliability can not be developed in the laboratory alone. The research has to be fixed to real operating systems or products. When planning the projects, the case and object areas were selected to represent of high international level. That way the pursued results should also be world-class.

In research, the first phase in networking occurred inside VTT, and this is naturally extended in the direction of Europe. Systems engineering and the HTI area have also started networking towards the USA and Canada. And the Machine Diagnostic Centre has started collaborating also with Canada and Australia. Collaboration with the University of Okayama in Japan has also been started.

The current active contact net, based on the all the researchers and the projects of the theme, includes many research institutes, thematic networks of the EU, and associations, etc. One good example of the extent of these networking activities is the ESReDA Seminar (European Safety and Reliability Association) – organised by VTT in Tampere 11–12 May 2004.

European research organisations have organised thematic networks for collecting together expert organisations in each area. The theme has had contacts in at least the following European networks:

- SAFERELNET, Thematic Network on Safety and Reliability of Industrial Products, Systems and Structures: http://mar.ist.utl.pt/saferelnet/
- S2S, a Network on Plant and Process Safety: http://www.s-2-s.org/
- RIMAP, Risk Based Inspection and Maintenance Procedures for European Industry: http://research.dnv.com/rimap/
- SAFETYNET, a Network on Process Safety: http://www.safetynet.de/
- HARSNET, a thematic network on Hazard Assessment of Highly Reactive Systems: http://www.harsnet.de/
- PRISM, Process Industries Safety Management: http://www.prism-network.org/

– INID, Research Organisations and Diagnostic Centres dedicated to developing and enhancing research on condition monitoring, diagnostics and prognostics
– HUMANIST, a network of excellence on human-centered design for Information Society Technologies.

Especially noteworthy is the fact that SYKE has been increasing networking with the automotive and other related industries. This occurred mainly as a result of two European Integrated Projects, AIDE and SENSATION.

1.8 Synergetic collaboration inside VTT

Collaboration with different research institutes of VTT had already been started while planning the theme. Three seminars were organised and researchers from all of VTT's research institutes participated. All of VTT's research institutes participated in the theme projects. A commonly accepted opinion among researchers is that the theme has increased the real collaboration between VTT's institutes in the focus areas of the theme.

Practical collaboration has also been made, for example, when Safety and reliability theme was joined preparing the VTT roadmaps, Human-Technology Interaction Research and Design, published in December 2003, and Security Research Roadmap, completed in October 2005.

The focus areas have increased the collaboration between the theme projects. In life cycle management, the systems engineering and probabilistic approaches developed in SYSTELI can also be utilised in LIIKKUDIA. The data management system developed in FI-TOOL can support the management of monitoring data needed by the tools developed in both LIIKKUDIA and SYSTELI.

Projects related to HTI and safety focus area also form a project cluster. The Core Task Analysis method was developed in METODI, and is utilised in mining machines. The same approach has been used when developing operating principles in the VTS system.

Methods and tools developed for assuring safety and reliability would be widely applicable in the projects of the other themes. The other themes are mainly focused on developing new technologies, whose reliability and safety could be assured with the tools developed in this theme.

1.9 Theme from the viewpoint of the customers

The results of the theme can be utilised in many application areas: large-scale systemic risks, occupational accidents, as well as production disturbances; in different kinds of industries: the process industry, metal industry, machine construction, energy production; and in transport infrastructures: marine transport, railway, automotive. New generic methods, tools and techniques for risk management are being developed, tested, and validated in several of those application areas. The applicability of the results is wide and the methods and knowledge can be transferred and utilised also in other application areas such as the food and construction industries.

While planning the theme, the needs of the customers were also taken into account. Four working groups were collected from the industry in order to define the goals of the theme. They represented the following industrial fields:

- working machines
- pulp and paper industry
- chemical industry
- transport and logistics.

These working groups had several meetings for defining the future needs and visions which affect, and which should be considered, when planning the theme and the theme's projects.

- Discussions with the customers have continued also after the start of the theme. Meetings have been organised also for different customer groups for the purpose of exchanging information about research results and customer needs.

2. Extended lifetime for production systems through controlled operation and maintenance

2.1 Topic description (Aino Helle)

The increasing complexity of machinery and production systems together with the growing demands on controlling costs, environmental risks and safety increases the importance of focusing research on safety and reliability of products, machines and production systems throughout their life cycle.

By systematic analytical approaches and multi-criteria decision making tools, planning of maintenance activities could be enhanced, the safety and reliability be improved and the economic lifetime of products and systems optimized. Information is produced at different points in time in different organisations during the life cycle of a machine or a production system. For life cycle management the continuous availability of information is essential, despite the diversity of the organisations producing and utilizing the information. Monitoring and diagnostic methods are needed for faults in machinery to be detected and predicted early enough to avoid serious damage and to allow for properly timed and focused maintenance actions with the shortest possible production interruptions. Advanced and generic diagnostic solutions are still lacking, the existing methods being in general relatively restricted and case specific. Besides good technical knowledge of equipment, production processes and failure modes and mechanisms, life cycle management requires a systematic approach and overall view. The focus area *Methods for life cycle management* within the Safety and reliability technology theme aimed to develop methods and tools for the above mentioned areas, in order to better control operation and maintenance and thereby to achieve extended lifetime of production systems.

2.1.1 Objectives and vision

The work was carried out in three concurrent projects with the objective that together they will provide a variety of novel tools and methods for optimization of the safety and reliability of products, machinery and industrial production plants throughout their life cycle, with simultaneous considerations of cost efficiency. The projects and their objectives and visions were as follows.

The objective of SYSTELI (Systems analysis in plant life management) was to develop a system analytical framework for the lifetime management of industrial systems, and tools and methods for component lifetime prediction and production safety. These include multi-criteria decision making tools, expert judgement in ageing management and microbiological production safety, as well as probabilistic models for residual lifetime prediction accounting for uncertain multi-source information.

The objective of FI-TOOL (Management of safety and reliability knowledge during the life cycle of machines) was to produce a concept for a comprehensive safety and reliability information management system. The system to be developed, being at the level of individual machine, was aimed to provide information for all persons in need over the entire life cycle of the machine from design to dismantling, utilizing unique identification of machines for linking all machine specific information.

The objective of LIIKKUDIA (Monitoring and Diagnostics – Lifetime Management of Mobile Machinery) was to provide mobile machinery the ability to self-diagnosis and prognosis, as well as to learning and communication. The challenge was to develop a generic self-learning diagnostic and prognostic system. A local online diagnostics system will be capable to specify needs for servicing and spare parts as well as to provide notifications to a remote supervision location.

2.1.2 Activities

The activities included industrial surveys and interviews for obtaining the necessary background information, generic and conceptual development work, modelling and simulation, experimental research as well as case studies for more application oriented parts and for application and demonstration of the models and methods both in laboratory and in industry.

The research in this focus area was widely multidisciplinary and combined resources from four research institutes of VTT, which had a very positive effect in increasing the interaction, knowledge sharing and co-operation between researchers from the different technological fields at VTT.

International networking was also at a very good level in the focus area. It was most prominent in SYSTELI, with connections to the European Safety, Reliability and Data Association (ESReDA). An ESReDA seminar with the topic of lifetime management of industrial systems was organized by VTT in Finland in May 2004. International research exchange was also realized in SYSTELI as a visiting student from the Troyes University in France joined the project for 6 months and a senior research scientist of VTT has worked as a visiting scientist at the Institute for Energy of the Joint Research Centre since the summer 2004. Co-operation was also built with Tallinn Technical University and Estonian dairy industry in the area of food safety. International networking was also active in LIIKKUDIA through the INID network involving 5 European universities and research organisations and the VTT Machine Diagnostic Centre. An initial business plan was created for the VTT Machine Diagnostic Centre in co-operation with researchers from the Berkeley University.

The activities in all three projects have also naturally included participation in international conferences and seminars. Co-operation and networking with Finnish industry and several national research projects has also been active in all the projects.

2.1.3 Approach

The research in the three projects was directed to different aspects of life cycle management, with different approaches. SYSTELI had a system analytical approach for the management of lifetime and production safety of industrial plants, including microbiological production safety. FI-TOOL focused in developing an information management concept covering the whole life cycle of a machine. LIIKKUDIA was focusing on monitoring and diagnostics of mobile machinery and developing methods and means for a machine to diagnose faults and its condition, estimate the remaining life time and to communicate with a remote supervision centre. The projects were both complementary and interrelated, providing data, requirement definitions and tools also for the use of each other.

2.1.4 Topic highlights

The main results of the projects are presented in the following Chapters describing the three projects as well as the part of SYSTELI relating to microbiological production safety. A number of scientific publications and conference papers have been produced in all the projects and they are listed in the end of this report.

Some of the results of the projects showing clear impacts or industrial relevance and interest are shown below.

SYSTELI

– Life-time management of industrial systems involves decision making in all organisational levels under uncertainty and multiple, often contradictory objectives. A system analytical approach framework was developed for life-time management and some of the models were demonstrated in several theoretical and practical case studies. The phases of the approach include identification of decision objectives and constraints, identification of ageing phenomena (both materials and technological), identification of factors having impact on the ageing processes, modelling the ageing processes, identification and modelling of the life-time management decision problem, solution of the decision problem and implementation of the decision and monitoring the performance. Stochastic dynamic programming model was applied in a case study for identifying the optimal maintenance policies regarding the measures to be taken in case of ageing degradation damaging of a power plant component. Degradation processes considered included corrosion, oxidation as well as fatigue cracking. A stochastic filtering based model was constructed in a method developed for accounting imprecise condition monitoring information in life-time prediction concerning fatigue crack growth.

– The research on microbiological production safety has produced results with clear industrial interest and immediate impact. Based on an earlier tool developed for food industry, a tool called Paperi Hygram® was built up for risk assessment and Hazard Analysis and Critical Control Points (HACCP) analyses for pulp, paper and packaging industry, showing the results in clear charts and including a data bank on risk analysis and problematic micro-organisms. Bacteria identification methods have been developed for rapid screening of the presence of bacteria, resulting in that the time needed for obtaining the results has shortened from several days to one day. This is particularly important in case of food packaging materials and bacteria causing food poisoning. Rapid detection of the bacteria reduces loss of production and risks concerning product safety. The new methods are in use in projects and contracts with industry.

FI-TOOL

- A concept of safety and dependability information system was developed using conceptual modelling. The main parts of the concept include a system for locating and storing product specific information, a mobile system for utilization and updating of data in daily operations, and a background information system with data analysis, synthesis and management capabilities. Prototype devices for parts of the concept were developed and demonstrated on the Crossbow MOTE-KIT-2400 wireless sensor network.

- System safety concept for machinery has been developed into an expert service and its has been integrated as part of the automation development process in two world leading mobile machine manufacturers, one in the mining sector and the other in container terminal sector.

LIIKKUDIA

- The lubrication and hydraulic systems form a major focus for the development of diagnostics in mobile machinery. The results achieved include a stochastic model for lubricating film thickness in rolling contact, with application areas in estimation of oil film thickness in rolling bearings. A simulation model for faults in hydraulic machinery and a fault analysis demonstrator was developed. The model can produce data regarding electric faults, control valve jamming and system leaks. In addition, signal analysis tools were developed for fast discrete phenomena. The results will be used in several new research projects, including the diagnostics development project in the Technology program for the Finnish Defence Forces.

– Machine Diagnostic Centre has been created at VTT and it offers an international platform for development of remote diagnostics and prognostics. A basic idea for developing a first stage learning diagnostic system is based on utilization of the Machine Diagnostic Centre to create cumulative knowledge on faults in machinery.

2.1.5 Summary and conclusions

The focus area *Methods for life cycle management* within the Safety and reliability technology theme comprised of three concurrent projects in which tools and methods were developed for optimization of the safety and reliability of products, machinery and industrial production plants throughout their life cycle. The projects were directed to different aspects of life cycle management, with different approaches, ranging from a system analytical approach for life-time management and conceptual development of safety and reliability information management to development of monitoring and diagnostics of mobile machinery.

The focus area and the theme combine the expertise of different disciplines and bring researchers from various research areas and units in contact with each other, both in actual research work and at the meetings and seminars. This has an impact on lowering the threshold of cooperation between the research units. The results from the projects are expected to lead, and already have led to the start up of several new research projects utilizing the results and the cumulated knowledge and networks. The results are particularly applicable to process industry and users of mobile machinery as well as to the machine manufacturers and maintenance service providers though not restricted to only those sectors.

2.2 SYSTELI – Systems analysis in plant life management (Urho Pulkkinen)

2.2.1 Objectives

The objective of SYSTELI-project (Systems analysis in plant life management) was to develop system analytical methods for life management of industrial systems. The methods aim at better focusing of maintenance activities, improvement of reliability, and optimisation of economical lifetime. Within the project, models and approaches are developed for multi-criteria decision making in focusing ageing analyses and in definition of maintenance tasks, for expert judgement in ageing management, and for prediction of residual lifetime of components, accounting for uncertain information from several sources. The approaches were applied to practical cases from power, chemical and paper industry.

One of the main objectives of the SYSTELI-project was the development a systems analytical framework for life time management. The framework was aimed at a holistic approach, which takes into account the uncertainties of ageing phenomena, the multiple goals of decision maker and the requirements of authorities. As based on the probabilistic thinking, the framework makes possible so called risks-informed decision making.

2.2.2 Methods used

The methodology of SYSTELI-project is systems analysis. Systems analysis is often interpreted as a synonym for operations research and decision analysis. In addition to systems analysis, the expertise and methodology of the application are essential.

In ageing management this application specific expertise includes the knowledge and models describing the ageing mechanisms and material properties of the studied industrial system. In addition to these, the methodologies to analyse the behaviour of the process and the environment of the system are needed. Depending on the system under analysis, the application specific methods may include fracture mechanics, process simulation, thermal fatigue analyses, and even microbiological measurement techniques.

The systems analysis approach is generic, and it includes probabilistic modelling of ageing mechanisms, statistical analysis of failure data, and the decision or optimisation models needed in selecting the appropriate ageing management actions. In the SYSTELI-project, the probabilistic models of ageing mechanisms where applied in updating the residual life prediction on basis of non-destructive condition monitoring measurements and in predicting the failure behaviour of a power plant component. In addition to these, the probabilistic failure models where applied in analysing the behaviour of oil film thickness in a rotating machine. The mathematical methods were based on stochastic filtering, Bayesian models and Markov processes.

The decision models based on multi-criteria value functions were used in evaluating the maintenance options of a power plant component. The dynamic optimisation of maintenance strategies of a power plant component was based on stochastic dynamic programming and Markov decision processes.

The ageing management requires data on component failure intensities and ageing mechanisms. In many cases experimental data is available. However, there are situations in which the analysis must be based on expert judgements; in the SYSTELI-project, methodologies for systematic use of expert judgement were developed and applied.

2.2.3 Main results

A systems analysis framework for ageing management

The ageing management of industrial systems includes the identification of systems feasible life-time with respect to many factors, such as economy, safety, occupational safety, systems availability and technology. The most important task in ageing management is to identify the means to maintain the systems performance over the life-time by appropriate maintenance policies and operational policies. Life-time management is decision making on all levels of organisation under uncertainty and multiple, often contradicting objectives.

In SYSTELI-project, a systems analysis point of view was applied to structure the decision making in life-time management. Basically this means the application of (mathematical) models to describe uncertainties, values and preferences, dependencies and control hierarchies of life time management. The phases of systems analytical approach framework developed in the project are in Figure 1.

The first phase of the approach is the identification of the general decision objectives and constraints of the decision. They are based on the strategy of the company or the regulations from the authorities. Usually the decision objectives are related to the safety and economy (life-time profits) of the system. Furthermore, some social and environmental objectives are taken into account. It has to be noted that these general level objectives are treated and measured in different way in different decision problems.

The second phase of the approach is the identification of ageing phenomena. It is important that all kinds of ageing are taken into account. In addition to materials ageing (e.g. corrosion, fatigue, erosion, wear) also obsolescence and technological ageing has to be accounted. Furthermore, the organisational issues may be of interest.

Many factors may affect of the ageing processes. They have to be identified in order to find out the appropriate ageing management activities (the third phase of the approach). Usually the most important factors are related to the process conditions: e.g thermal and other stresses, mechanical vibrations, chemical conditions can make the ageing process faster. Furthermore, the environmental factors and operational polices have an impact on ageing processes.

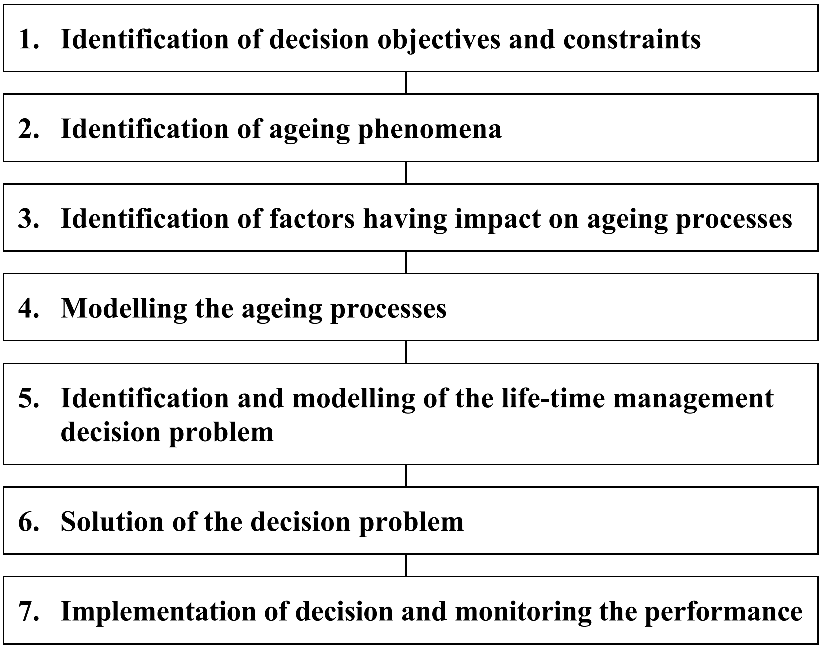

Figure 1. Phases of ageing management approach.

In order to evaluate the decision options quantitatively, the ageing process has to be modelled. This is the task of the fourth phase of the approach. Since the ageing mechanisms are not deterministic, it is essential to identify the uncertainties related to ageing phenomena. It is important to describe the nature of the uncertainties qualitatively. The uncertainties have to be modelled by using suitable stochastic models. Often the models are based on randomisation of traditional deterministic ageing models and in some cases Markovian cumulative damage models can be applied. When the ageing models are used, it is important to combine then with simulation of process and environmental conditions.

One of the most challenging tasks is to develop data for the models. For some phenomena there are data from experiments or operation experience. Sometimes data from condition monitoring can be used and combined with a priori predictions by using Bayesian statistical methods. Model simulations combined with expert judgements are also an important data source. The lack of data must not prevent the modelling: the aim of probability models is to describe what can be said about ageing by using existing data, independently on the amount of data.

The fifth phase of the ageing management approach is the identification and modelling of the life-time management decision problem. When developing a decision model, it is important to identify the time horizon of the problem. It may be a single decision on maintenance action or series of maintenance decisions or even a maintenance strategy over the planned life-time. This determines the decision options, which depend on the decision situation. The option may be the timing or type of preventive maintenance, the type of repair or renewal of a component. When the decision problem involves long term strategic decisions, the options may be for example, different outsourcing strategies for maintenance, different inspection policies, and different maintenance portfolios.

For making the decisions, the problem specific decision objectives have to be identified. Usually they are different types of costs e.g. costs of maintenance, cost of failures, costs of accidents. However, also non-monetary objectives such as safety culture, health effects, and environmental effects are important. Together with the identification of the decision objectives also the way of measuring the satisfaction of the objectives and the weights of different objectives have to be defined. For this purpose a decision model has to be constructed. Depending on the case, multi-objective value of utility functions of decision trees and decision tables can be applied.

The solution of the decision problem is the sixth phase of the management approach. In this phase, the decision options are evaluated by using the ageing process model, and the decision model. In this connection the sensitivity of the solution must be analysed e.g. with respect to preferences of the decision maker (weights of different objectives, value/utility functions).

The last phase of the approach is the implementation of the solution and monitoring of the performance of the solution.

In the SYSTELI-project, some of the models of the above system analytic ageing management approach were demonstrated in several theoretical and practical case studies.

A stochastic dynamic programming model for maintenance optimisation

One case study of the SYSTELI-project considered the use of stochastic dynamic programming for identifying optimal maintenance policies. The motivation for using stochastic models is the fact that in real operational environment, the fatigue cracks grow in a random way. The decisions concerning the maintenance of a system can be made on the basis of observations about the system's degradations state. The state is monitored periodically e.g. during the yearly overhauls. Given the observed state, and the history of the system, the decision maker can choose between certain options. When the profit of continued operation of the system, the costs of maintenance actions and possible failures are taken into account, it is possible to determine the optimal maintenance strategies e.g. by applying the dynamic programming algorithm.

In applying the dynamic programming principle, the following steps were performed:

1. identification of the states of the system
2. identification of the decisions
3. determination of transition probabilitiy matrices for each decision
4. identification of the costs of each decision and state
5. determination of optimal maintenance policy by applying the dynamic programming recursion
6. evaluation of the sensitivity of optimal policy with respect to relevant variables of ther model (e.g. the costs, transition probability matrices).

The problem considered in the case study was the measures to be taken concerning the ageing degradation damaging of a power plant component (steam drum). Primarily damage to the drum material is due to internal metal loss including corrosion and oxidation. Mechanical and thermal stresses can also create cracking in the drum. The following maintenance options were considered: 1) Do nothing, 2) Repair a by grinding off the cracks, 3) Replace the drum head, and, 4) Stop the operation.

The results obtained by the method are in Figure 2, in which the optimal decisions are presented for each decision time and each state. Due to the large cost of lost operation, it is optimal to repair the system in state 2 at time points 1–26 and in state 4 at time points 1–37. The replacement is optimal in states 5, 9 and 11 almost overt the whole 40 years operation horizon. It is never optimal to stop the system. It is evident that is the failure costs were larger, the stop of the system would be more optimal.

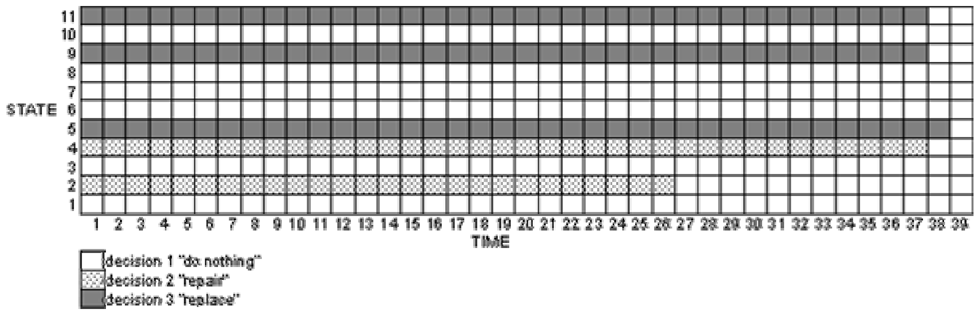

Figure 2. Determination of maintenance policies by applying dynamic programming.

Application of stochastic filtering for lifetime prediction

In the SYSTELI-project, a method for accounting imprecise condition monitoring information in life-time prediction was developed. The model is based on stochastic filtering.

The stochastic filtering approach requires three models. First, the systems degradation process and its relationship with the system lifetime must be described with a stochastic model. Secondly, the connection between the degradation and the condition monitoring measurement must be modeled in a probabilistic way. Finally, the residual lifetime must be predicted by using recursively the Bayes rule. The model was then specified more exactly in the case of fatigue crack growth prediction. First, the Paris-Erdogan model crack growth model was randomized and approximated with discrete time Markov chain model with finite state space. The condition monitoring measurements were described by a simple probability model. Finally, the stochastic filtering model was constructed by combining the crack growth model with a probabilistic condition monitoring model.

Other studies

Other studies made in the SYSTELI-project considered the use of multi-criteria decision making models in the case of steam drum maintenance, development of expert judgement approaches to utilisation and combination of maintenance information from several sources, and combination of process simulation with crack growth models. In addition to these, an integral software package for evaluating structural risks in various applications with consideration of the availability and reliability of necessary input data, was developed.

2.2.4 Potential impacts

The most important results of the project were the development of systems analytic ageing management approach and application of various stochastic and decision analytic models in some practical cases. These case studies demonstrated the applicability of the models and created a basis for large scale risk-informed ageing management studies. A package of approaches suitable for practical studies was made available for real practical maintenance management.

2.2.5 Conclusions

The ageing management framework, based on decision analytic and stochastic modelling techniques was developed in the project. The framework integrates several types of models from several areas of technologies, and combines expertise form several areas. In addition to this, the framework makes it possible to evaluate ageing management actions and policies with respect to several, and even contradicting objectives. Several stochastic models were demonstrated in practical and theoretical case studies.

2.3 Management of safety and reliability through the use of context dependent safety and reliability information (Risto Tiusanen)

2.3.1 Objectives

The important role of safety and reliability in modern industry is obvious. Management of safety and reliability of machines requires continuous and easy access to important safety and reliability information during the whole life cycle of machines. At the moment this information is not easily accessible because it is produced at different points in time in different organisations during the life cycle of machine (design-production-operation-maintenance-disposal).

The main objectives of this research were tools, methodologies and technologies that support safety and reliability management during the entire life cycle of machines. The project aimed for better availability and utilisation of safety and reliability information and thereby to enhance safety and reliability management. Thus, it supports decision making in daily operations in companies.

2.3.2 Methods used

Safety and reliability information management concept specification

A concept of safety and reliability information system was developed using conceptual modelling. The initial part of the conceptualisation process involved interviews with industrial partners from Finland. Safety and reliability information management practices were studied in mobile machine manufacturing companies and their subcontracting companies. 26 persons including managing directors, R&D managers and designers were interviewed. The interviews were supported by questionnaires that were delivered to the companies in advance. Each person was interviewed separately and the results were documented. The results of the interviews are summerised in Suutarinen et al. (2005).

Definition of the information content of the the safety and reliability information system

The definition of the information content was started by applying a scenario based specification method to identify the various uses of the safety and reliability information system. A parcel of scenarios were developed to cover various use situations and working conditions. Application of each scenario involved identification of the required functionalities and characteristics of the user interface of the system. One of the scenarios consisted of the following elements: Application of a checklist for starting up the machine, reading data wirelessly from the machine and getting information on how to handle an error reported by the machine's control system.

Safety and reliability information is used, for example, for safety and reliability assessment, planning and decision making purposes. Other uses include, for instance, acute situations where the information must be readily accessible when the need arises. Instructions on how to make sure whether a system that requires immediate repair is in a safe state for the job are an example of the latter. In order to get more insight to the acute situations, a dedicated study to identify work related hazards was carried out in a company belonging to the mining and manufacture of metals sector. The study included analysing accident records (accident and incident records of the company, and national records on severe occupational accidents), interviewing employees and carrying out detailed safety analyses of various tasks. This material was used to get a better understanding on acute context dependent safety information needs.

Wireless data transmission and user interface

The development of the technologies and procedures was done first at a conceptual level and completed by selecting the most relevant issues for further detailing. Preliminary tests were performed to investigate the technical feasibility of the of the machine ID element, a smart transponder for the identification of the machine. More specifically, the identification of a product with the ID element, the access process to the product specific information, and the availability of the information by using the ID element subsystem were investigated.

An assembly of the machine ID element and the user terminal were constructed for the test stage purposes. The test was arranged in a laboratory environment. A machine, similar to, e.g. a loader or a harvester having its own control system, was selected as a target, of which the product specific information was to be read. The target's control function, which communicates with other equipment on-board over a CAN-bus, was modelled in this test by using the CANALYZER software from Vector Informatik GmbH. The model produces the similar data and information packets that are transferred over a local CAN-bus.

2.3.3 Main results

Context dependent safety and reliability information management concept

The concept includes a system for locating and storing of product specific information, a mobile system for the utilisation and updating of safety and reliability knowledge in daily operations, and a background information system with data analysis, synthesis and management capabilities.

The concept provides a completely new means for the manufacturers to manage and for operators to utilise safety and dependability information.

Examples of recognised management systems are PDM (Product Data Management) systems, CMM (Computerized Maintenance Management) systems and safety information management systems. Typically, PDM systems include huge amounts of product related information. In addition to the basic/standard product descriptions and documents included are e.g. information relevant to configuration and maintenance management. Further items, that may be included, are supply chain management information and resource management information. In addition to information on maintenance events, CMM systems may contain functionalities that allow planning of maintenance tasks and keeping record on spare parts inventory. Safety management systems typically contain information on accidents, injuries, incidents, hazardous chemicals and other documents concerning occupational safety issues.

Successful management of safety and reliability of machines requires the continuous availability of safety and reliability information during the entire life cycle of machines. At the moment, this information is not easily accessible because it stems from various and diverse origins along the machine lifecycle. This information may also have dubious conformity and integrity of content. Figure 3 outlines a concept that seeks to solve these problems and challenges with respect to safety and reliability information exploitation. The concept aims for better availability and utilisation of safety and reliability information within and between organisations. Thereby, it will enhance the transfer of safety and reliability information and thus, supports decision making in daily operations in companies.

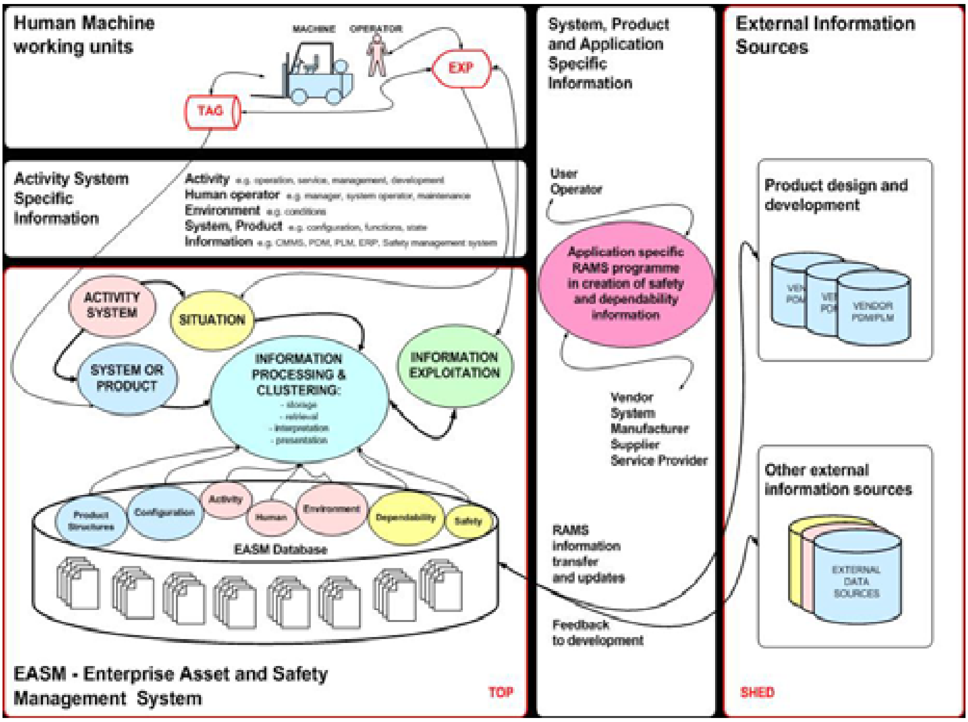

Figure 3. An outline of the concept to facilitate the exploitation of the safety and dependability information (Viitaniemi et al. 2004).

RAMS program for machinery applications

System life cycle is a sequence of phases covering the total life of a system from initial concept through to decommissioning and disposal. Companies increasingly use the life cycle concept for their investment projects to provide a structure for planning, managing, controlling and monitoring all aspects of the system, including reliability, availability, maintainability and safety (i.e., RAMS). Special attention is often given to RAMS aspects in order to make sure that the asset shall operate during the life cycle under every circumstance in relation to reliability, availability, maintainability and safety. The supplier is typically obliged to support the RAMS activities during the project phases. In order to be able to do this, the supplier is – according to e.g. the standard EN 50126 – advised to establish a specific RAMS program for the purposes of the delivery project. This program proceeds iteratively with the project as the system design develops. The RAMS programs of similar projects or system requirements of a supplier may yield a “standard RAMS program” (basic RAMS program) which establishes the RAMS baseline of a company.

Basic RAMS program outlines were developed to cover two application areas. These included a general model for mobile machine manufacturing companies and a model for a company that delivers automated high performance warehousing and distribution systems. The basic RAMS programme outlines consist of descriptions of the appropriate life cycle or project phases, the phase related RAMS tasks and responsibilities, results and deliverables of each RAMS program phase.

System safety concept for machine automation applications

As part of the RAMS program studies, a new safety engineering approach has been developed. This approach combines the base line hazard identification, task based hazard identification, system level HAZOP studies and risk assessment principles into a system safety concept (Tiusanen 2004). The approach is based on IEC 60300-3-9 and ISO 14121 standards that describe the general risk management process for machinery and other technical systems.

In complex machinery systems the risk analysis must be done at several levels to be able cover the entire machine system. Safety related control functions in highly automated machine systems include multi-dimensional aspects such as the operator’s actions, user interface communication protocols and machine onboard control signals. In such a context, safety aspects should be understood as an important part of systems engineering. The system operation and maintenance work tasks must be specified and designed taking in to account the new automation related hazards and potential safety risks.

The applied system level approach forces the consideration of new issues related to the work process such as production planning, maintenance planning, and work management. It additionally introduces new safety related aspects related to the co-operation between production and maintenance people and co-operation with machine suppliers and other subcontractors. These are system level topics that are not normally discussed when safety analysis is conducted at the machine level only.

Wireless data transmission and user interface

Different levels of the machine specific information transmission were identified. In its most simple form the machine is identified, and all the information is stored remotely in the background system. In this case, either barcode or RFID can be used to identify the machine. RFID allows also to store static data (e.g. design data). The second level is a separate device, which communicates wirelessly with a portable user terminal, e.g. using Bluetooth or WLAN. Information on the actual machine status can be obtained from sensors, which are connected over a serial link, e.g. by using the machine's CAN-bus, or from remote sensors, which are wirelessly connected to the device. If the machine has its own on-board computing facilities, the device can be integrated in the machine and provide a wireless communication link to the user terminal.

Two different demonstrators have been developed. The first demonstration device (Reunanen et al. 2004) was developed in 2003, and consisted of a board containing an ARM processor with 1MB FLASH and serial interfaces. The board communicates with a Symbian phone (Nokia 7650) over Bluetooth. The phone user-interface allows among other things viewing sensor data and updating the FLASH memory content.

The second demonstration device (BlueLinkZ) was designed to assess the wireless sensor network concept. The device, which was developed in 2004, was designed and implemented on the Crossbow's MOTE-KIT-2400 wireless sensor network (Figure 4). This system is used for communication systems development platform according to IEEE802.15.4 standard. BlueLinkZ connection has been designed to be able to add auxiliary sensor devices to the sensor network via the Bluetooth Serial Port Profile (SPP).

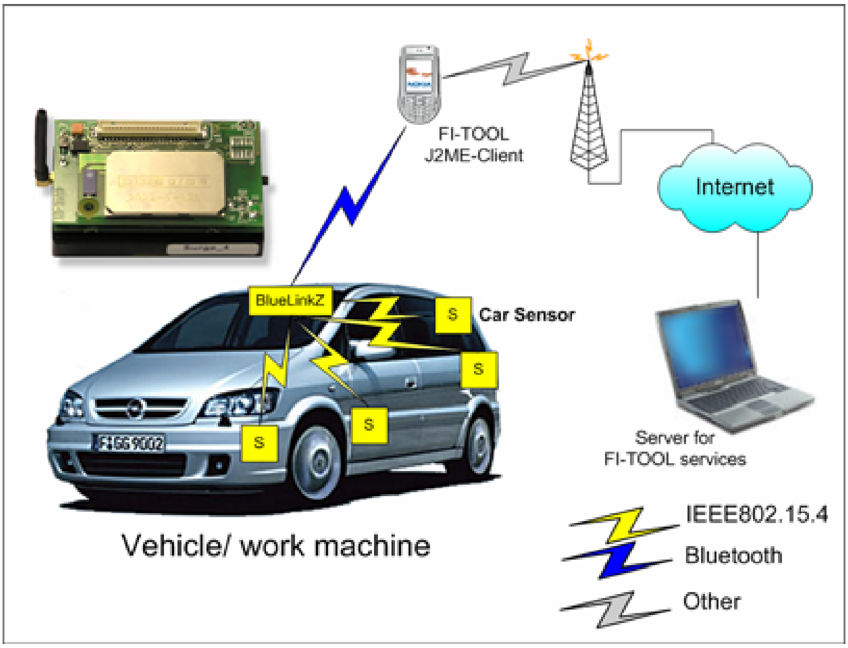

Figure 4. The improved demonstrator device that links the wireless sensor network to a portable user terminal.

2.3.4 Potential impacts

Concerning RAMS programs for machinery applications, an assignment (Reunanen 2005) has been completed in cooperation with AWA Advanced Warehouse Automation Oy, who are a leader in automated high performance warehousing and distribution systems serving industrial customers worldwide. To support its customer interface and engineering processes, AWA needed to define and implement a RAMS program applicable to their automated warehousing system delivery projects. A basic RAMS program which was integrated into AWA's product development process was established.

System safety concept for machinery has been developed into an expert service and it has been integrated to be part of the automation development processes of two world leading mobile machine manufacturers.

In mining sector the concept has been integrated with the Sandvik Tamrock Oy's customer project management process. The first target was an autonomous ore transportation system in a diamond mine in South Africa. This is the first ore transportation system in the world were autonomous trucks drive around the truck haulage loop. The automated truck system deep in the mine is controlled from the control centre located above ground level.

In container terminal sector the concept is being integrated with Kalmar Industries Ltd's automation development process. The first target is an automatic stacking crane system development project. Automatic stacking cranes are used for stacking and in-stack transportation in harbour container terminals. This is the first stacking crane application where there are three cranes operating simultaneously in the same stack. The automatic stacking cranes are monitored and operated from a control room. Loading and unloading of road trucks is done via teleoperation from the control room.

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2.4 Potential of monitoring and diagnostics – Lifetime management of mobile machinery (Jyrki Tervo)

2.4.1 Abstract

In LIIKKUDIA the self-diagnostics of mobile machinery has been studied. The goal was to develop methods which would enable the machine to diagnose its own condition and send the diagnosis, measurement data, and maintenance order to a remote supervision centre. The main achievements of the project were the Machine Diagnostic Centre, as well as modeling and simulation of hydraulic failures. The Machine Diagnostic Centre offers a platform for the development of remote diagnostics and prognostics within an international network.

2.4.2 Introduction

Friction and wear increase the cost of operation of a mobile machine by decreasing the lifetime of components and machinery. Savings can be achieved by increasing the maintenance and design efficiency by correctly diagnosing machinery faults. Reduction of downtime as well as maintenance and replacement costs constitutes the major part of savings. Savings can be achieved by better understanding and diagnosing the phenomena taking place in machinery and by correctly predicting the occurrence the final failure.

Methodologies to diagnose and forecast failures in mobile machinery are generic in such sense, that similar phenomena are taking place in industrial machinery as well. According to a recent survey among Finnish industry, estimated potential savings are biggest in pulp and paper industry, metal and steel production, manufacturing of metal products as well as in energy production. These sectors comprise 70% of the expenses of mechanical maintenance within the Finnish industry. By applying advanced diagnostic methods the cost can be decreased significantly.

At present, the most available diagnostic methods in general are relatively restricted case specific tools that apply strict rules for reasoning (Figure 5). In some cases the rules have been fuzzified. Some examples have been published that utilise neural network techniques. Stochastic methods and physical models have also been applied in failure modelling. Only some rule based reasoning have been implemented in mobile machinery self-diagnosis.

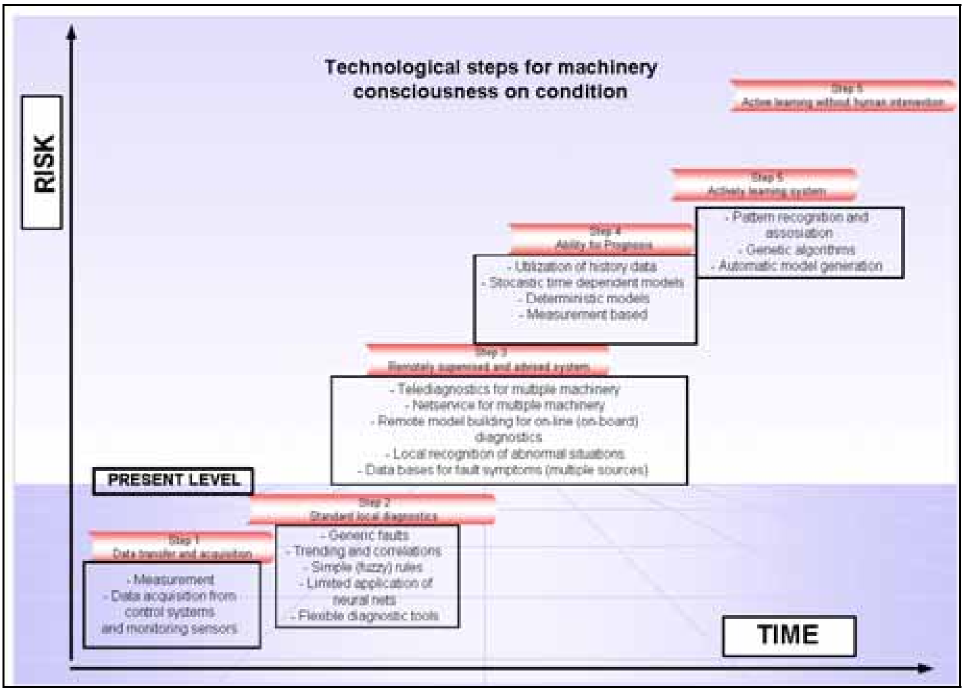

Figure 5. Vision of technology development in machinery diagnostics.

The key issue in machinery self-diagnostics is the intelligent agent capable for learning. In order to be applicable to multi-technical environment of a mobile machine, the solution needs also to be generic. The goal of the project was to develop methods by which machinery would have the ability of self-diagnosis and prognosis, as well as of learning and communication.

The new achievement is the identification and definition of the necessary means and methods to produce a generic, self-learning diagnostic and prognostic system. This kind of system does not yet exist. In order to fulfil the goal the system needs to be hybrid (uses multiple methods for problem solving), modular (to make it flexible in adding new features and measurements), distributed (to make it flexible in operation), integrated (capable to use data from control system as well) and able to communicate with different user levels. The methods and tools developed will enable a machine itself to diagnose its condition, estimate the remaining lifetime and, if needed, to transmit the necessary data and information to a remote supervision centre. The remote supervision centre also acts as a tutor for the system.

Implementation of the solutions developed will lead to a self-communicating machine able to specify its own servicing needs. A local online diagnostic system will be capable to specify needs for service actions and spare parts, as well as to provide notifications to a remote supervision location. A remote supervision centre provides higher intelligence to the local system. The system makes it possible to avoid imminent serious damage by allowing properly timed maintenance measures to be carried out. The way of operation results in the shortest possible production interruptions.

2.4.3 Main results

The work in the project was focussed on four main areas important with respect to monitoring and diagnostics of mobile machinery, i.e. lubrication, hydraulic system, automated fault diagnosis and remote monitoring and diagnostics.

Stochastic model for lubricating film thickness in rolling contact

Film thickness measurements were conducted in laboratory by means of optical interferometry. The multiple linear regression model includes parameters such as rolling speed, sliding ratio, loading, temperature and water content of oil. The model may be used for estimation of film thickness in rolling bearings. Application of the model in practice requires further research.

Simulation model for faults in hydraulic machinery

A simulation model for faults in hydraulic machinery was developed. The model can be used to simulate electric faults, control valve jamming and leaks in the system (Vidqvist & Tervo 2005). Faults can be examined on the basis of position, pressure and flow during different work phases of a cylinder. The simulated target was an existing industrial machine. Results of the simulations are to be used in diagnostics development.

Development of fault diagnosis methods

Data mining approach and classification methods have been used to design fault classifiers to detect different operational states of a machine from each other, based on a time series of measured data. The models were developed based on training data obtained by a simulation model of the machine. Classification algorithms have been prototyped in the Matlab environment. Some of the working algorithms have been translated to C++ using the Matlab Compiler toolbox. These algorithms have been integrated to a main memory database as trigger actions. The potential of fast database-based fault analysis of time series data has been demonstrated using Rapidbase (Hiirsalmi 2004). Learning classification algorithms has been discussed in (Hiirsalmi 2005).

Diagnostic Centre for further diagnostics utilisation and development

The VTT Machine Diagnostic Centre was established and it is available for use in remote monitoring and diagnostics applications (Figure 6). A project was launched to find possibilities to create business with remote diagnostics services. Utilisation of international networks (INID) was also investigated.

A basic idea for a 1st stage learning diagnostic system is based on the Machine Diagnostic Centre, which is used to create cumulative knowledge such as a database for faults in machinery. The fundamental challenge in creating a learning diagnostic system is obviously huge. Machine learning (emulation of intelligent behaviour) requires that certain fundamental conditions will be fulfilled. These include teaching and rules generated from experience, models to handle conflicting information, estimation of performance and feedback, analysis of causal errors in diagnosis, ability to find complementary ways for information analysis as well as constant training. The Machine Diagnostic Centre can be seen to serve some of these challenges.

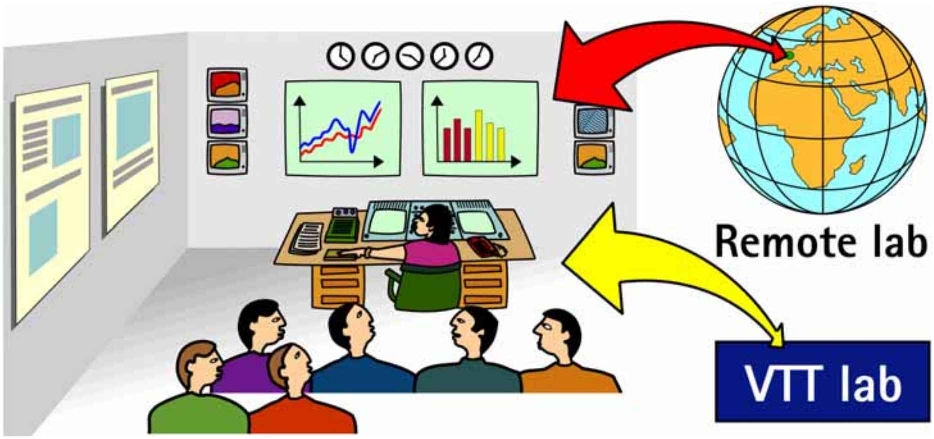

Figure 6. Principle of the VTT Machine Diagnostic Centre (artwork by Tuomo Hokkanen).

Synthesis

The ultimate goal of the project, i.e., the ability to self-diagnosis and prognosis as well as to learning and communication, requires modelling and simulation, advanced feature extraction methods as well as the facilities provided by a remote diagnostic centre. Model based diagnostics makes it possible to monitor technically complex machinery. Feature extraction tools (neural nets) need to be sensitive and accurate to produce reliable diagnoses. Supervision of the monitoring and diagnostic system is implemented by the diagnostic centre. Since only known failures can be diagnosed by feature extraction tools, the diagnostic centre is also needed for analyzing new phenomena.

2.4.4 Impacts

As an immediate impact of the research new ideas for industry related research projects have been created. The Machine Diagnostic Centre offers an international platform for the diagnostics and prognostics development. Anticipated further impact will be measured as an increase in industry-related research both in international and domestic development projects. Since the results are not directly applicable for industrial use, further development in joint projects with industry is required.

2.4.5 Future activities

The results of the project will be utilized in several new research projects. The Machine Diagnostic Centre will serve as one of the technological start points in the diagnostics development project in the Technology program for the Finnish Defence Forces.

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2.5 Tools for efficient risk management of product safety in process industry (Laura Raaska, Outi Priha & Gun Wirtanen)

2.5.1 Paperi Hygram® – a practical tool for paper and packaging industry

Objectives

Over the past decades incidents of food-related illnesses have acquired attention in the media, and awareness of food safety related issues has increased. Food suppliers are nowadays required to apply the principles of Hazard Analysis and Critical Control Points (HACCP) in order to ensure the hygiene and safety of their products (Codex 1997). The food supply system forms a chain from the farm to the table, and food packagings are a part of this chain. Hence manufacturers of packaging for food, and also other hygiene-sensitive packaging, are increasingly being required by their customers to conduct a HACCP study on their process. The requirement of HACCP can also be extended to raw material, e.g. pulp, suppliers.

The goal of HACCP is to recognize product safety threatening risks arising in the process and to prevent or reduce them to an acceptable level by establishing control procedures at carefully chosen Critical Control Points (CCPs) in the process. Part of identifiable hygiene risks are generic, that is to say they are not present at a specific process point, but can be present at any stage of the process (Ewartt 2000). Their control is part of the Good Manufacturing Practice (GMP), and GMP principles can be taken as the prerequisites HACCP. The regulation of European Union states that materials intended to come into contact with foodstuffs must be manufactured in compliance with good manufacturing practice (EC 1935/2004).

To conduct a HACCP analysis, a multidisciplinary HACCP team must be assembled, including representatives of all parts of the production plant: process, maintenance, quality control and management. GMP and HACCP can be performed without any specific tools, but it demands expertise on aspects of risk assessment. According to experience, the implementation of HACCP to practice can be hindered by lack of knowledge, time, funding or motivation.

To help in overcoming at least part of these problems the aim of this subproject was to develop a practical and easy-to-use tool for implementation and maintaining of GMP and HACCP principles to paper and packaging mills.

Description of the model

VTT, the National Veterinary and Food Research Institute of Finland (EELA) and the University of Helsinki have earlier developed a tool for implementing HACCP and GMP to food industry (Tuominen et al. 2003). Hygram® was used as a basis for building up Paperi Hygram®, a tool for performing and maintaining HACCP-analyses and GMP in the pulp, paper and packaging industry.

Paperi Hygram® application was built on the Microsoft Windows 32bit environment using Borland Delphi as a development tool. Delphi utilises object oriented pascal programming language. Some open source expansions under Mozilla Public Licence (MPL) were used. Paperi Hygram® functions in Windows NT/XP/2000 operating systems, and the use of it does not require special computer skills. Paperi Hygram® exists both in Finnish and in English. The demo version of the model can be loaded freely from the internet (http://www.vtt.fi/virtual/paperihygram) from 15.12.2005 on. The complete version of the model can be purchased from VTT.

In the first part of Paperi Hygram®, Background information, general information of the mill, process and product(s) to be evaluated is gathered. The sheet includes a table of raw materials, where for instance a chemical list can be maintained (Figure 7).

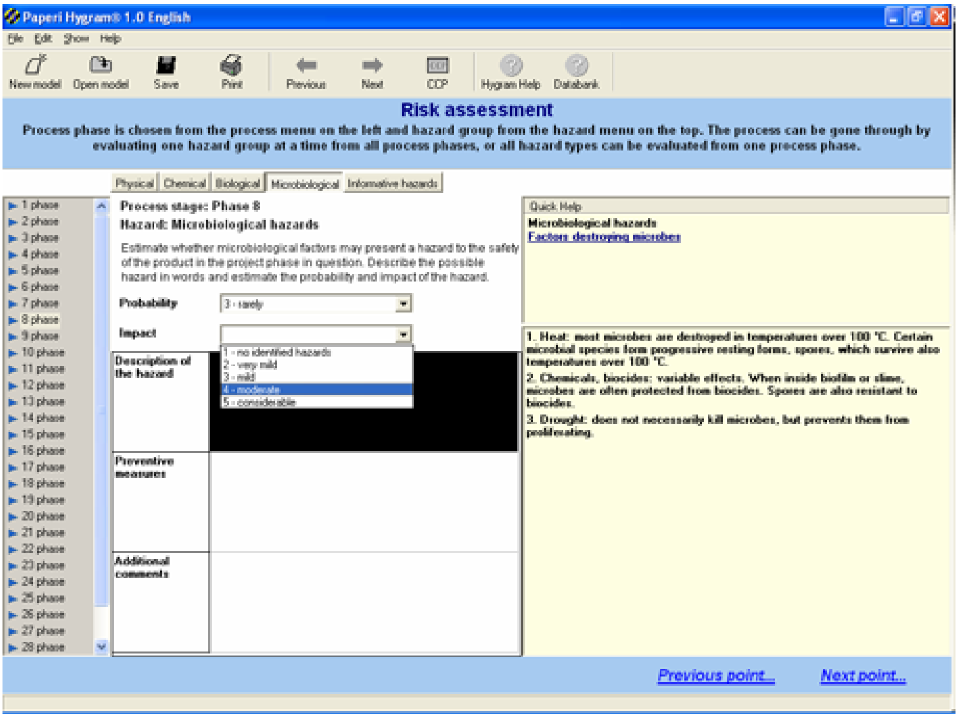

Figure 7. An example of a risk assessment page of the Paperi Hygram®.

The second part is a GMP checklist with 86 questions going through various aspects of Good Manufacturing Practice. The questions are based on regulations for both food and food packaging industry by suitable parts (Codex 1997). The risk assessment part consists of four separate parts. Firstly a flow diagram of the process is filled in as a list in a table. In the following sheet the user may choose the hazard groups (physical, chemical, biological, microbiological, informative, self-chosen) to be evaluated. In the risk assessment all process steps are gone through, considering all chosen hazard groups. The identified hazards and the possible existing preventive measures are described in words. For each hazard both the probability and the severity of the risk are determined on a scale from one to five, where value 1 means that no risk has been identified at the process stage in question. At all times quick instructions of each hazard group to be evaluated are shown. The results of the risk assessment will appear in a figure, where x-axis shows the probability of the risk and y-axis the severity. Different result tables can be created, for instance including all process steps, or only the steps which contain the highest risks.

Critical Control Points are chosen from the most severe and most probable risks. The model does not choose them automatically, since it is necessary that the CCPs are chosen critically by the HACCP team. The CCP table includes columns where limit values, monitoring way and frequency, responsible persons for each CCP, corrective actions and documentation methods can be described.

Paperi Hygram® also includes a databank, which contains information of risk analysis and of the problematic microorganisms in the pulp, paper, and packaging industry. It is based on scientific references, which are given in the databank. The databank provides help in understanding the general principles of GMP and HACCP, and also help in more specific questions which may arise at the risk assessment. A helpful vocabulary is also included. All necessary information can be documented in the model, and it is easily updated when changes occur in the process. The model offers software-assisted guidance through the procedure.

User experience

User experiences were gained by using Paperi Hygram® in HACCP analyses of two mills converting food-contact packaging materials. At the first mill one risk with both the highest probability and the highest severity (5,5), and fourteen risks with the highest probability and a high severity (5,4) were identified. Altogether eleven of the fifteen most serious risks identified by Paperi Hygram® were included in the CCP:s. The important process phases included in CCP:s contained the application of glue, drying stages, moistening and preparing moistening water and recycling pallets.

The results from the second mill showed that there were two risks with the highest probability and severity values (5,5 and 4,5), both of which were chosen to be CCP:s. In addition, three other CCP:s were chosen, with values 4,4 and 3,3 and 5,3 for risk probability and severity. The important process phases included in CCP:s contained the reception of granulates, reception of other supplies, lamination, intermediate storage and loading.

Potential impacts

Paperi Hygram® aids paper and packaging mills in implementing HACCP and own-checking systems, so that they are able to fulfil both legal and customer demands. Furthermore, establishing hygiene practices to a mill also serves as an advantage in the ever tightening international competition. By using the help of Paperi Hygram®, both time and money can be saved.

Conclusions

Paperi Hygram® proved to be a useful tool for implementing GMP and HACCP in mills producing packaging materials. It was fast and easy to use and made the progression of risk analysis fluent and illustrative. To our knowledge, corresponding tools aimed at paper and packaging industry do not exist. Paperi Hygram® is suitable tool for multinational as well as for medium and small sized enterprises. The advantages of Paperi Hygram® are that it provides information on GMP and HACCP specifically in paper and packaging industry, it guides the user through the whole risk assessment process and it serves at the same time as a documentation tool. Always when changes or amendments are made to the HACCP plan, a new version may be saved, keeping at the same time all older versions documented.

2.5.2 Development of diagnostics for harmful microorganisms

Objectives

Microorganisms grow under a wide variety of environmental conditions, and usually paper and board mills provide them excellent growth conditions. Bacterial endospores produced by e.g. *Bacillus* spp. and *Clostridium* spp. are capable of surviving the extreme conditions of the process, since they are dormant forms highly resistant to different environmental conditions like extreme temperatures, dehydration, or presence of biocides. Spores may thus end up in the end products of paper and packaging mills. This way the quality of end products can be reduced by microorganisms harmful to human health and their metabolic products (toxins) and microorganisms causing colour defects. In addition, microorganisms can cause smell or taste defects, such as the foulsmelling compounds produced during metabolism of anaerobic *Clostridium* spp. and sulphate-reducing bacteria (SRB). Furthermore, hydrogen sulphide produced by SRB increases biological corrosion and is explosive, along with hydrogen gas produced by *Clostridium* spp.

Traditionally microorganisms have been detected by culturing. The disadvantage of culturing is slowness, since microorganisms have to proliferate and form visible colonies, which takes from overnight until several days or even weeks depending on the species. Moreover, there are many bacterial species which do not grow at artificial laboratory media. The new molecular biological tools are based on studying the genotype of the microorganisms instead of the fenotype, which makes them faster than culturing and not dependent on the culturing conditions. When these methods are well optimised, they can be extremely specific and sensitive. Nevertheless, the drawback is the difficulty of applying these methods to different complicated sample matrices.

The aim of this subproject was the development of new tools for detection and identification of harmful microorganisms in the paper and packaging industry. The focus was in three bacterial groups. Firstly detecting *Bacillus cereus* group bacteria from cardboard and paper intended for food contact. *B. cereus* is pathogenic and causes two types of food-borne illnesses due to the toxins it produces, and is therefore particularly unwanted in end products coming into contact with food. The second target group of bacteria was anaerobic sulphate-reducing *Desulfovibrionales*-related bacteria, which are difficult to culture at artificial media and produce hydrogen sulphide, which causes corrosion and odour problems at the mills. The third target group was anaerobic spore-forming *Clostridium* genus, the species of which produce volatile fatty acids and H_2, causing odour problems at the mills and in end products. In addition some clostridia are pathogenic.

Methods used

The isolation of bacterial DNA straight from the paper mills samples was first optimised (Priha et al. 2004, Maukonen et al. 2005). For detection of *B. cereus* group bacteria from cardboard and paper a real-time quantitative PCR (polymerase chain reaction) was applied. In real-time PCR, amplification of target DNA is monitored continuously during the PCR reaction, which permits quantification of the target, based on the fact that the more target there is present, the earlier amplification starts.

A nested PCR-DGGE (denaturing gradient gel electrophoresis) method was developed for detecting *Desulfovibrionales*-related SRB from cultured samples or straight from process samples of paper mills. In DGGE the amplified PCR product is run in a linear denaturing gradient, which permits separation of products with different base composition and thus separation of different bacterial species or strains, in this case different species or strains of SRB. The DNA base composition was determined from the separated bands by sequencing in order to identify the strains.

PCR-DGGE and PCR are also under development for detection of *Clostridium* bacteria belonging to clusters I and VII, which are the most common clostridial groups found from the paper mills (Suihko et al. 2005). Cluster I includes some 60 clostridial species, many of which produce butyric acid, acetic acid or H_2, and some of which are also pathogenic. Cluster VII includes *Thermoanaerobacterium* species (formerly *Clostridium*), which grow at higher temperatures (around 55 °C), and many of which are also producers of odorous substances.

Main results

With the quantitative real-time PCR nine end products from paper mills were studied and the results were compared with culturing (Priha et al. 2004). Both methods gave the same results: three of the samples contained *B. cereus* spores, 100–4000 cfu (colony-forming units) g^{-2} paper. The difference in the methods was that culturing with additional verifications took over one week, whereas PCR results could be obtained in one day. The same quantitative PCR was also used for detecting *B. thuringiensis* spores, used as a model organism for *B. anthracis,* from air samples. PCR proved to be faster, more sensitive and more specific than culturing for studying air samples.

SRB were detected from paper mill process samples. Culturing was able to detect *Desulfovibrionales*-related bacteria from two different white waters, two different brokes, pulp, clay and slime. With PCR-DGGE an identical *Desulfovibrio* sequence was found from paper machine I (broke I, slime and pulp) and from paper machine II (broke II and white water II), suggesting an in-house contamination with the same strain. When PCR-DGGE was performed straight from the samples, *Desulfovibrionales*-related bacteria were found from the same samples as with culturing, and also from calcium carbonate. The DGGE profiles were more diverse than the ones obtained from cultured samples suggesting that not all of the strains were able to grow on artificial media.

Potential impacts

With the fast and specific molecular biological tools paper and packaging mills may obtain more specific information of the presence of harmful microorganisms in their process and products. By this means the safety and microbial management of their process is improved. The molecular biological tools developed for important harmful micro-organisms are in use both in research projects and contract-based research. These tools developed are also applicable to other matrices.

Conclusions

New molecular biological methods offer promising tools for helping paper and packaging mills to control and manage microbiological problems in their process. *B. cereus* -group bacteria, which cause food poisonings, may now be quickly and reliably determined from the end products. The detection and identification of SRB, which cause odour and corrosion problems, has also been notably improved. Method development for detection and identification of *Clostridium* spp. is also under way.

2.5.3 Process management

Objectives

The aim of this subproject was to build up cooperation with Tallinn Technical University and dairy industry in Estonia in area of food safety. Two bachelor students did their thesis at VTT that included microbiological sampling in three Estonian dairies. The other objective of this subproject was to compare and test the applicability and sensitivity of three different air sampling methods in food packaging materials producing plant.

Main results

Hygiene survey was performed in three Estonian dairies. Samples were collected from process environment, equipment, packaging material. Liquid and solid samples were taken from raw material, product from the process, final product, wastewater and water. Samples for detecting *Bacillus cereus, Listeria monocytogenes*, mycobacteria, total bacterial count, *Enterobacteriaceae* spp., coliforms, β-glucuronidase positive bacteria, yeast and mould were collected from all dairies and analyzed. Gauze tests, Rida Count and Hygicult tests were used for detecting bacteria from surfaces. Traditional cultivation techniques and DryCult test were used for liquid samples. Results were compared with each other.

Equipment samples were both food and non-contact, results showed that food contact samples were less contaminated than non-contact, therefore dairies pay more attention to cleaning process of food contact equipment. Two *Listeria monocytogenes* positive samples were found from two dairies, both were from raw milk samples, one *Listeria seeligeri/ivanovii* was found from food-contact equipment sample and 13 mycobacteria were found from all dairies, two of them were identified with DNA sequence method. One was either *Mycobacterium porcinum* or *Mycobacterium fortuitum* (both risk group 2), it was found from wastewater. Other was *Mycobacterium phlei* (risk group 1) and it was found from final product. One final product was "very contaminated" with aerobic bacteria and two raw material samples were "contaminated" according to Finnish law. Amounts of "clean", "contaminated" and "very contaminated" samples for each dairy were similar.

As contamination from non-contact places (environmental and equipment) may be carried to food contact places and from there to the process line, dairies should pay more attention to cleaning processes of these places. Carriers can be for example employees' hands. Biofilms are problems in food industry, because they are protective barrier for microorganisms against sanitizers, and due to it cleaning can be more complicated.

Disinfectant resistances of bacteria from three Estonian dairies (isolated in spring 2004), Finnish dairies and reference strains were investigated. Survival of bacteria after disinfection represents a potential spoilage or food safety problem for the food industry and consumer. Resistance of bacteria were determined to disinfectants that were used in Estonian dairies, in addition some disinfectants with similar mechanisms of action were tested. Resistance stability of four *Listeria* spp. were further examined to disinfectants that showed higher resistance than other bacteria.

Minimum inhibitory concentration (MIC) values for resistance and resistance stability were determined with the microdilution broth method at the optimum temperature of bacteria for *Listeria* spp., mycobacteria and *Bacillus cereus*. The MIC method has been used extensively to determine the resistance to antibiotics and disinfectants. This method gave variable results and may be therefore not so reliable.

Listeria monocytogenes was the most adapted strain investigated, while *Bacillus cereus* and mycobacteria were more sensitive to in-use concentrations of disinfectants. Only six antimicrobial agents were efficient in inhibiting all microbes tested, while seven agents were not so effective and had at least one strain that was not inhibited by the recommended concentration. Disinfectants based on sodium hypochlorite were the most ineffective, while other chlorine-based disinfectants, QACs and cationic tensides were efficient to every bacteria tested. Cleaning agents did not have microbicidal properties. Stability of resistance was not constant in some cases. Instead of decreasing it was surprisingly increasing. Only two *Listeria monocytogenes* strains showed smaller resistance after 10^{th} subcultivation than initial resistance to antimicrobial agent that contained sodium hypochlorite. Because results varied, they are not so reliable.

In conclusion dairies have to start using immediately bigger concentrations of ineffective agents or choose more effective disinfectant, because using sublethal concentrations of disinfectants leads to resistance formation. Before disinfection should be carried out effective cleaning procedure that removes biofilms and organic material and help disinfectants to reach their targets.

Three air sampling methods: sedimentation, impacting and filtration were compared in a food packaging materials producing factory. Sampling was performed four times during a year in three sampling places. The study showed that the results with all three methods used has similar trend. In general settle plates caught less microbes than other methods. The results for impacting and filtration methods were in many cases similar to each other. These methods were more sensitive than the method based on settle plates. A bigger sampling volume also used in filtration method did not increase the yield.

Potential impacts

Cooperation with Estonian dairies and technology transfer in food hygiene and safety have continued as contract-based research. In addition the concept tested in Estonia will be transferred also to other associated EU-countries. Microbiological air sampling and pre-treatment of samples is now used not only in solution-oriented process hygiene and end products safety questions but also in research focusing on fast and very sensitive field sampling of potential intentionally disseminated micro-organisms.

Conclusions

In the food industry, the settle plates and impacting-type samplers are the most commonly used air-sampling methods in routine monitoring. Our test showed that the results with all three methods used had similar trends. Impacting and filtration methods were more sensitive than settle plate method. Settle plate results also describe only a very limited, local area where particles happen to settle whereas air-sampling methods that actively collect air are more reliable to describe the air quality. Our results demonstrated that implication and filtration methods were very similar and both worked well in industry environment. A bigger sampling volume in filtration method did not increase the yield. The filtration method may not be optimal for counting vegetative cells due to the stress it places on cells through dehydration during sampling when prolonged sampling times are used. The use of one air sampling method suits for a routine air quality monitoring. However time to time it is recommended to check the situation with another method because no method is able to reflect the whole variation of air.

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3. Human technology interaction and safety

3.1 Topic description (Maaria Nuutinen)

3.1.1 Introduction

The increasing safety, reliability and economical demands in industry and transport emphasise the efficiency of human-technology interaction (HTI). As a part of the VTT Safety and reliability theme, *the HTI and safety focus area* emphasizes the importance of understanding the role of human practice and behaviour in the construction of safety and reliability of any technical system: In safety critical domains there are particular demands for designing and modifying HTI and assessing its safety effects.

Transport telematics or intelligent transport systems are under vivid development in all transport modes. They are proposed as possible solutions for reducing congestion and improving traffic safety and driver comfort in land transport. In-vehicle information systems represent one area of transport telematics, and using these systems while driving might have significant safety consequences. (See Section 3.4.) In the maritime field, the management of traffic and incidents is greatly based on the utilisation of information and communication technology (ICT). During the last decade this has been enhanced through the development of national maritime telematics architecture. Emphasis is now placed on the creation and implementation of an operation model for maritime incident management. A rather new but very significant player in this field is the Vessel Traffic Service (VTS) serving and co-operating with nearly all maritime stakeholders. The studies made have indicated that since the number of key actors in the maritime sector is so large compared with other transport modes a common operational model for incident management placing the VTS as an information hub, is needed. As in other transport modes, the reliable and effective use of maritime telematics for information management and exchange is valued as a necessity. (See Section 3.3.)

The development is also vivid in mines. New automated loading and transport systems in mines can include several autonomously tramming and teleoperated loading machines. 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. 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. (See Section 3.2.)

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. There is a growing interest in understanding what people actually do in their work or need in their everyday activities in order to better contribute to technology development. This emphasises the importance of conducting studies in the field and understanding human behaviour more comprehensively. Discovery of the real practices or behaviour, 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, the ability to predict the possible effects of changes caused e.g. by introduction of new technology poses a serious challenge for research. 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.

3.1.2 Objectives and vision

The general vision guided the HTI and Safety research was that the state and the focus of the technology development and related HTI research are different on different domains and thus we can learn from domain to domain *if* we become more aware of their characteristics from the point of view of human and the limits of knowledge applicability caused by a particular approach and method utilised in the study.

The main common aim of the focus area was to increase VTT readiness to fulfil HTI needs on safety critical domains, firstly, by conducting empirical case studies with carefully chosen topics on HTI on different safety critical domains. In all cases the objective was three-fold: to discover adequate practical solutions to the HTI related challenges of the case domain; to develop a new or supplementing method(s) capable of studying and taking into account that HTI related issue; and to increase knowledge of the applicability of the different theoretic frameworks, the empirical research based HTI knowledge and the particular methods from one domain to the other. The cases included in the focus area represented HTI on different interaction levels. Car driving was representing an example of a quite immediate interaction with an object, the car. The other example was remote control of an unoccupied machine or several machines in mining domain. The cases also included representatives of a highly mediated and distant interaction between vessel traffic service operators and several, occupied vessels. Secondly, the readiness was aimed to increase by bringing together results and experiences from the HTI projects (including also projects outside of the Safety and reliability theme), cooperating and sharing knowledge of HTI relevant issues on different domains.

3.1.3 Activities

The main activities were related to the conduction of the empirical case studies. In addition to the activities particularly connected to the conduction of the studies these include various activities such as numerous contacts with companies and getting acquainted with their HTI problems, current trends of technology development on different domains and the development state HTI policy and R&D activities at companies.

International activities had crucial role throughout the theme projects under the HTI and safety focus area. The international activities include: researcher exchanges, co-operation in EU activities HUMANIST network of excellence and Human machine interface and the safety of traffic in Europe -project, participation in numerous international conferences, visits on research institutes, contributing to the establishment of an international research co-operation group (Maritime Human Factors Group) and publishing on international scientific journals.

3.1.4 Approach

Human-technology interaction can be defined as denoting the activity of a distributed cooperative system that the users and the technology form together with their physical and social environment (Norros et al. 2003). The nature of HTI phenomenon is thus multilevel and it should be studied interdisciplinary from many different perspectives. This focus area shares some general premises, which were

- understanding of human practice, behaviour, motivations and needs in the particular context as the starting point for technology development
- importance of integrating domain, behaviour science and technology expertise
- importance of evaluating the applicability of the used theoretic framework, methods and results for the particular HTI issue and domain.

3.1.5 Topic highlights

The results of the particular cases are the highlights of the HTI and safety focus area. They are described in following Sections and the various publications (see in the end of the report). The integrating METODI-project resulted in a book "Human practice in the life cycle of complex systems". The new book is an attempt to open up the complex world of human-technology interaction for readers facing practical problems with complex systems. The 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. The book is a collection of the newest results and 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. (Nuutinen & Luoma 2005.)

However, there are also several general results of the focus area research activity that have been promoted readiness to tackle HTI & safety issues and are therefore worth mentioning here. The fact that different kinds of domains and levels of technology mediated interactions to the environments were well represented in the focus projects created good possibilities for comparisons highlighting both similarities and unique characters of the domains and for more general level discussions between specialists. This created an excellent prerequisite for development in several areas:

- increasing knowledge about available HTI research, human reliability and human centered design methods; similarities and differences of HTI on different domains; the applicability of the existing and new methods to different HTI problems
- understanding of HTI phenomena, what kind of shape the HTI problems can take in practice, how to manage HTI related risks
- increasing cooperation, information sharing and common project preparation over organisational boundaries
- developing and "transferring" competences. The project teams have members with different educational and occupational backgrounds and experience. The focus area activity has also promoted individual development of expertise (doctoral thesis work)
- increasing knowledge about VTT HTI expertise and international research partners
- increasing knowledge of HTI needs and future trends at industry
- communicating the importance of the user point of view and the behavioural science based ways of doing that. This communication has been directed towards public financier, industry customers and VTT engineers. The communication has also served marketing purposes
- learning from a domain to an other domain in order to avoid "the old mistakes" of the technology driven development.

3.1.6 Potential impact and conclusions

In summary, this focus area produced four kinds of results: methodical, knowledge based on empirical studies on field, knowledge of practical HTI needs and conditions, and promotion of co-operation and competence in this area.

The life cycle of the socio-technical systems can be divided into four parts each of which has their particular HTI challenges. The parts are design, validation and evaluation, implementation, and operation. This life cycle structure can be used to emphasise that even if the system had been designed optimally from the point of the user and the motivation of the system, there are many tasks left to the later phases of the system. It has been recognised for decades that the user-centered design of technical systems has many benefits, such as improved efficiency, productivity, quality, health, safety etc. Although user-centered 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-centered 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. Always, 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. For that purpose, the particular methods for validation and evaluation is needed.

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-centered 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.

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.

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3.2 Operating Hazard Identification in automated mining machine systems (Risto Tiusanen)

3.2.1 Introduction

In certain mining methods, like block caving, the efficient and continuous movement of large amounts of ore and the continuity of the material flow is essential. A material handling process for a daily production of over 100 000 tonnes, involving monitoring, real time process control and automation, can show full benefits and improve mine profitability (Puhakka & Soikkeli 2001). The added performance comes not only from the new technology, but also from the change of working procedures and better process control. Puhakka and Soikkeli (2001) claim 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 and originally specified for automated operation.

The system supplier or system integrator is responsible for the system functionality but the system operational performance and system safety are shared with the mining company and all the subcontractors. In this sense, mine automation projects do not differ from applications in the process or manufacturing industries. Semi-automatic loading and transport system can include several autonomously tramming trucks and loading machines. Each operator in the control room can handle several loaders and rock breakers from his control station. The machine operator has become a system controller (Figure 8) (Pulli 2003).

System operation and operating hazards are new issues to machine manufacturers. In the case of a manual machine, the manufacturer is responsible for the technical safety of the machine, according to machine safety directives and local regulations. The manufacturer gives the end-users practical training on how to use the machine, and after that, the operating company is responsible of the safe operation. In automated machinery systems, the system supplier is responsible that the entire automation system is safe to implement, test, commission, operate, maintain and modify. Commission and operation of a highly automated and autonomously operating machine fleet is totally different from driving manual machines.

The main objective of this study was to develop methods to identify operating hazards and assess risks in complex mining machinery systems by taking into account the operating situations underground, the system operation modes, and the operators' tasks and human factors.

Figure 8. One transportation process controller in an underground mine – an overall view (Pulli 2003).

3.2.2 Methods used

A 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 the process industry were applied to mobile machine system. The approach includes three different analysis methods that are used at different stages of the system life cycle. The methods are Preliminary Hazard Analysis (PHA), Operating Hazard Analysis (OHA) and subsystem Hazard and Operability Analysis (HAZOP) (Stephenson 2004).

In this study, the potential hazards and dangerous situations of the entire semi-automatic loading and transporting system, including several production areas and several unmanned machines, were analysed using a PHA. Work tasks in a production area (set of tunnels) and control room were analysed with an OHA.

The aim in hazard identification in the PHA was to determine the automated system, its limits and interfaces, and identify all the potential hazards related to the machinery in all foreseeable operating situations. The intended use, related procedures and regular maintenance of the machine, as well as anticipated misuse of the machine was taken into consideration in the identification of risk factors.

The OHA, also called Operating and support hazard analysis (O&SHA), focuses on hazards resulting from tasks, activities, or operating system functions that occur as the system is used. The hazard is not necessary the result of a failure of a component or 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. The specific goals for OHA were stated as follows:

- 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
- identify existing controls
- develop alternative controls and/or procedures to eliminate or control the hazards.

The OHA in this study was divided into the following phases: daily routines carried out at the beginning of a work shift, daily work with the machinery, and daily maintenance and repair works. All the main work tasks in production areas and in the control room were analysed. These tasks include, e.g. area preparation, marking and teaching the routes for unmanned loaders, testing the control functions, operation (manual drive, teleoperation, autonomous drive), maintenance, troubleshooting, repair, works, etc.

Part of the analyses was conducted in traditional project team work meetings. Another way of working was a combination of safety expert work in the office and review meetings with the project team. In both cases the analysis was planned and the machinery system and its functions were specified in project team meetings.

3.2.3 Main results

The operator in a modern automated underground mine is like a process controller in a process plant. The roles and responsibilities of 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 like production control, tele-operation, safety system, etc.

A 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 results. The system level approach and OHA method raised new issues related to the work process such as operators' correct actions, clear communication, production planning, maintenance planning and work management. It additionally introduced new safety related aspects for co-operation inside the company between production and maintenance people and co-operation with machine suppliers and other subcontractors working in the automated production areas, topics that are not normally discussed when the safety analysis is conducted only at the machine level.

The OHA developed for automated mining machine systems considers system operation from three levels or viewpoints (Figure 9):

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

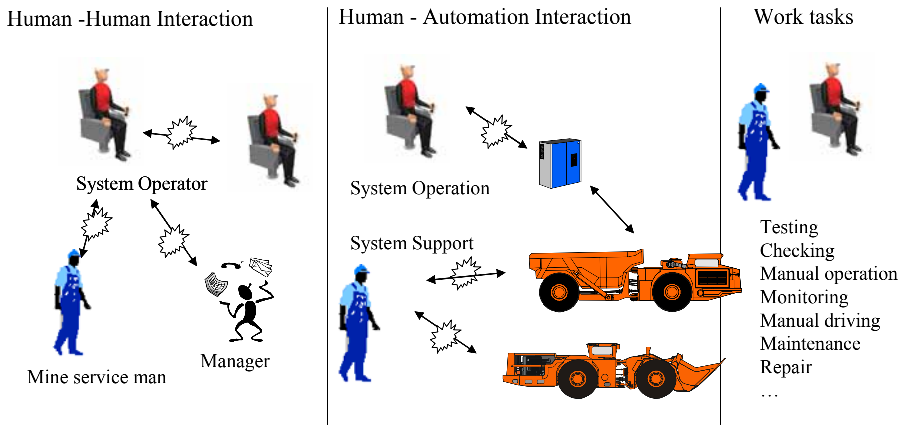

Figure 9. Three viewpoints used to identify possible human errors in system level OHA.

Practical experiences of case studies are that clear specifications of system operation use cases and maintenance work procedures are essential for operating hazard identification. Mining applications are always unique and procedures are dependent of the mine environment.

Procedures and tasks must be defined so in detailed that the system functions as well as interactions between operating or supporting crew can be understood and analysed. In a 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 modification management process. As in all system safety methods, team work is essential in OHA to ensure that all the application specific aspects are taken into consideration when analysing the operator's or serviceman's daily work tasks.

3.2.4 Potential impacts and conclusions

Automation has not only changed and improved the work conditions in the mine but also raised 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 in 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 a mine that has been working for a long time with manual machines means changes in mine daily practices like production control, maintenance management, shift chance procedures, communication practices, etc. Present practices are all developed for manual machine operations and need to be developed 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. Analyses and assessments must be synchronised 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. A systematic analysis also helps to understand sub-system functions and interrelations between different systems. Teamwork 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 behaviour and decision making. In that sense it is important to analyse operating and maintenance procedures to be able to identify possible automation related safety issues and new safety risks.

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3.3 Development of Vessel Traffic Service operators' work (Maaria Nuutinen, Paula Savioja & Sanna Sonninen) [1]

3.3.1 Introduction

This paper presents a concluding study the aim of which was to analyse the results of the four studies (conducted 2002–2005) focusing on different aspects of Vessel Traffic Service (VTS) in Finland. One of the studies, a VTS customer satisfaction survey was not conducted by VTT, but it serves as a complementary study and is thus perceived. The motivation of this paper is to raise a question of how to guide the development of a complex socio-technical system that is shaping up and defining itself. The results of the concluding study illustrate the complexity and the dynamic nature of the development. In the end of the paper we will discuss whether our conception of socio-technical systems should be more dynamic in general.

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[1] *Based on the article "Realising the Present, Acknowledging the Past, and Envisaging the Future: Challenges of Developing the Complex Socio-Technical System of VTS" by Maaria Nuutinen, Paula Savioja and Sanna Sonninen. Submitted to Applied Ergonomics.*

Vessel traffic service (VTS) is a service provided by the maritime authority or by another entity to enhance the safety at sea by online monitoring, information dissemination, and guidance from the shore-based VTS centres. The first vessel traffic surveillance systems were implemented already in the mid-twentieth century, but VTS operation as perceived today was truly granted its role during the 1980s and 1990s. In Finland, the first VTS centre started operation in 1996, and by 2002 all the Finnish merchant shipping fairways were included in the service. The increased risk of accidents at sea induced by the foreseen significant increase in the amount of vessel traffic was the trigger for the construction of a comprehensive national VTS system. A surveillance system reaching further to the monitoring of the open sea, a mandatory ship reporting system for the international waters of the Gulf of Finland (GOFREP) was implemented in 2004. The task of VTS in Finland is especially challenging because of the extensive coastline scattered with islands, shoals and rocks, which makes it particularly difficult to navigate safely.

VTS was approached as a complex socio-technical system, bound by constraints and enabled by possibilities (Vicente 1999) of the current and historical constituents of the activity system (Engeström 1999). We exploit three concepts in analysing the interactions within the VTS activity: Core task, working practices and expert identity (Nuutinen 2005a; Nuutinen 2005b). The concept of core task refers to the essential content of a particular work or activity. The core task concept and analytical approach have been developed at VTT in earlier process control studies (e.g. Hukki & Norros 1998; Klemola & Norros 1997), in organisational culture studies (e.g. Oedewald & Reiman 2003) and in accident investigation (e.g. Nuutinen & Norros 2001).

The research questions in this concluding study were: 1) What is the state of the VTS activity in terms of the service outcome, the operators' working practices, the conceptions of the core task and the sources of expert identity? 2) What are the explanations for that state in terms of the current state of the constituents and the history of the VTS activity? 3) What are the main challenges of the activity? 4) What are the first development steps in order to answer the challenges?

3.3.2 Methods

Data collection

This study is based on rich material collected in the four complementary studies, which all have their own particular practical aims expressed in the name of the studies. Table 1 summarises the different kinds of data and the data processing conducted in the original studies.

Data Analysis

The qualitative data was analysed following the principles for the analysis of fairly extensive data presented by Smith (1995, pp. 21–22). The quantitative data concerning e.g. the operative areas was organised by simple operations (percentages, time variations etc.) in order to allow comparisons between the centres. The outcome of the analysis expressed in Table 1 is limited to what is relevant in this concluding study. The steps conducted followed the Contextual Assessment of Working Practices method (see in details Nuutinen 2005a).

Table 1. Data and phases of analysis in relation to the main concepts and research questions. (IMO = International Maritime Organization, FMA = Finnish Maritime Administration; 1 In addition to posted forms, they were also available freely at offices of the interest groups. Thus it was not possible to calculated the hit rate.)

Data collection and data	Data treatment and main analysis method Focused constituents:	Outcome of analysis	The focused construct and time period (past, present, future) and the research question(s) of which the study contributes
Study 1: Development of VTS operator's work and work environment			
Recorded interviews: 12 (VTS operators) 2 (system designers) 5 (Supervisors of the centres)	Transcripts Qualitative All constituents	The operators' and supervisors' conceptions of their core task, available resources, themselves, the competence needed at the different VTS centres Sources of the operators' motivation and work stress Development history of VTS equipment and its future possibilities	Core task of VTS, present (1, 2, 3, 4) Working practices, present and past (1, 2, 3, 4) Expert identity, present (1, 2, 3, 4)

Videoed observations: 6 (change of shift situations)	Course of action description Qualitative All constituents	Description of practices at the different centres (on the level of main functions taken care of)	
Videoed contextual inquires (Beyer and Holtzblatt 1998): 12	Transcripts Qualitative Instrument, Subject, Object of work, Rules, Division of work	Description of tool usage practices, related competency and usability problems	
Videoed workshops: 1 (10 participants) Themes: The core task of VTS and debriefing of VTS training	Description of the results of the workshop and summary of discussion Qualitative Outcome, Community	General definition of the core task of VTS Challenges of defining the practices needed to fulfil the core task of VTS	
Working groups 3: (5 participants)	Description of the results and summary of discussion Qualitative Outcome, Community	Boundaries of the activity system and development	
Material concerning equipment and history of the centres produced by the district managers for the purposes of the study	Tables of available tools, descriptions of development histories of the centres Instruments (present) and all constituents from historical point of view	Comparisons between histories and available operation tools between the centres	
Documents: VTS master's guides, IMO and FMA materials, maps	Summaries, conclusions Document analysis Rules, Community, Outcome	Official definition of the system Boundaries of the system	
The operators' background information	Tables of the operators' educational background, work experience, sick days and turnover of workers Quantitative Subject, Outcome	Differences between the operators and the centres	
Vessel and weather statistics Digital maps of fairways	Amount and quality of the traffic, time frame of ice and combined mails of the monitored fairways Quantitative Object of work	Comparison between the centres according to the differences in the operative areas and traffic The working practice demands set by operative areas	

Study 2: Cost-benefit study of the centralisation of VTS services (operative analysis)			
Workshops: 1 (5 participants)	Description of the current state of the VTS centres done by the participants	Conceptions of the state of the VTS held within the activity system Differences between the centres	Core task of VTS, present and future (1, 3, 4) Working practices, present (1,4)
Expert assessment sessions: 2 A for VTS actors, 11 participants and B for VTS customers and associations, 10 participants	Individual assessment of current state of the VTS and possible consequences of the centralisation (54 assessment items in A and 13 in B) • Quantitative, graphical summaries of the assessments Summary of written comments and discussion • Qualitative All constituents	Conceptions of the state of the VTS held within VTS actors and their customers and associations Differences in conceptions of the core task of the VTS, its future and developmental possibilities	
Phone interviews: 3 (ship masters)	On-line notes Complements assessments of session B Outcome	Complements above results	
Study 3: Development of operational procedures for the Gulf of Finland Ship Reporting System			
Videoed wording groups: 3 (23 days of each, 17 participants from three countries)	Description of the process of working and arguments expressed Description of the joint operational procedures agreed by the participants Community, rules, Division of work, Outcome	International differences of the aimed control over vessel traffic, needed information boundaries of the development?	Core task of VTS, present and future (1, 4 Envisaging and the future system) Working practices, present and future (1, 4 Definition of concrete content of work by illustrating differences and similarities between SRS and VTS)
Videoed simulation exercises (14 scenarios)	Assessment of the adequacy of the procedure under development Rules, Instruments, Object of work, Outcome		
Study 4: Customer satisfaction survey			
Customer satisfaction survey conducted by FMA: 127 (returned)	Assessment of the outcome of the VTS regarding the customer expectations specified by the aims of the system, the group of customer, and the different centres Quantitative, graphical illustrations Outcome, Community, Object of work	Conceptions of service from outcome perspective, expectations of the customers, development challenges The available role "free" for VTS	Core task of VTS, present and future (1, 3, 4)

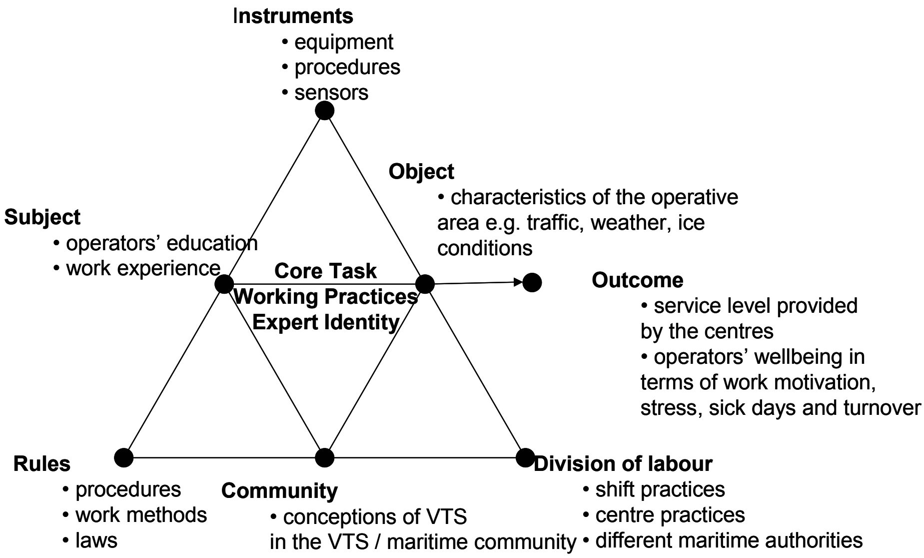

Figure 10. The model of an activity system (modified from Engeström 1999) and the objects of the analysis.

The data was analysed according to the research questions. First, the VTS actors' conceptions of the core task of VTS, adopted working practices, sources of operator identities and the produced outcome were identified and compared between persons and the centres (Figure 10). Guided by the activity system model (Figure 10) we then explored explanations for the state by searching for dependencies between the constituents and the historical roots of the current system. Next, we analysed the data in order to recognise pressures for change originating from the maritime community and society. Previous results were then studied from the point of view. The borders of the activity system (from one VTS centre to the maritime authority activity) and the following definitions of the other constituents and the focused time period (past, present, future) were changed according to the aims of the analysis. The previous analysis was concluded in the main challenges of the VTS activity and the steps for the development based on reflection of the past, the present and a possible future of the system.

3.3.3 Main results

The state of the VTS

The main result of the study is that all the 6 VTS centres in Finland are unique in nature. First of all the level of service (outcome) differs both between the centres and the operators of the same centre. The conceptions of the core task of VTS operations differed from centre to centre to such an extent that even the functions taken care of were different. This means that the sources of work motivation and operator identity were different among the operators. In practice, these differences in the foundations of the work have led to a centre-specific VTS practice. To the receivers of the service (i.e. vessels) this appears as ambiguous service.

The level of general work satisfaction among the VTS operators was quite high. The high work satisfaction was evident in interviews, almost non-existing turnover of the workers, and in the eagerness to contribute to the development of the system. A source of stress, shared by many operators from the different centres was also recognised: the varying workload originating e.g. from the unpredictable nature of the traffic density.

Explanations for the state

There are various explanations for the different ways of conducting VTS activities at the different centres. First, the operative areas (the object) were different with regard to traffic quality, flow and density, length and complexity of the routes and ice conditions. The operators' (subject) competencies and work experience varied largely. The available equipment (instruments) was similar in each centre but there were differences in the usage of the tools.

The absence of written procedures or commonly agreed work methods characterised the current system. For example, there were no commonly agreed methods (rules or tools) to handle the workload peaks and valleys. The centres also had their own ways to organise the work and shifts (division of labour).

The unsolved problem of the workload variability and the difficulties in noticing the impact of one's work (e.g. when monitoring traffic) explain the vagueness of the boundaries of the service. The operators had filled the quiet moments by taking on extra responsibilities. The extra tasks currently included in the core task in some centres offer feedback and social respect and thus compete with the tasks that are a part of the official definition of the service. The most problematic issue is monitoring the traffic, which might accidentally be “dropped” when burdened by other tasks (e.g. answering telephone calls and filling in forms). In this task, e.g. the time available for other tasks without losing the traffic situation image, is difficult to define. Also, there are centres where there is only one operator on duty at any one time. Thus the possibilities for managing the workload by sharing tasks are non-existent.

The centres have been established one by one and the responsibility for the development of the VTS activity has been on the local administration offices. This has resulted in fairly independent development processes. Each VTS centre has focused on the local needs and special circumstances.

The historical explanations for the developmental state of each centre are individual in each case. The development history of the VTS activity so far has been continuous change and the visions of the targeted system have evolved. Three phases of the development of the activity were recognised: The first phase was the national quite independent development of shore-based radar monitoring on a very limited sea area for local, mostly piloting needs. The second phase was implementation of VTS operations and extending them to cover all fairways used by the merchant shipping vessels and complying with international recommendations and guidelines. The third, on-going phase is characterised by enhancement of national VTS operations, extending of the national VTS-like operations to cover the international sea area adjacent to the national waters and enforcing the international cooperation in VTS activities.

There were several pressures for change evident in the data. The discrepancy between the available role, the service defined, and the actual service and the differences in the development potential was recognised as the main challenge of the VTS activity. There were indicators that at least a part of the maritime industry is ready to give or even expect a bigger role for the VTS in promoting maritime safety and efficiency. This discrepancy could also reflect on the future development of the system in terms of reducing respect from society and within the system in the long run.

Altogether eight development steps were identified and divided into acute and future-oriented steps. When trying to conclude the results to the development steps, we realised that there is an essential task still to do: to define what activities are included in good VTS operation, now and in the future.

3.3.4 Conclusions

The study aimed at contributing to the development of the VTS by describing the current state of the system, explaining it, recognising the main challenges and guiding further development. The results showed that there are differences between the outcome, practices, conceptions of the core task and the sources of the expert identity in the VTS centres, which can be explained by the current state of the constituents and the history of the activity system. Three qualitatively different development phases of the change were recognised. However, it was evident that the new, future- oriented definition of the VTS core task should be created. This was needed to frame the development actions – and for creating resources for the development.

At the first look, the state and the development history of the Finnish VTS might not seem like a success story. However, we consider it natural when establishing a new, complex socio-technical system. The VTS activity has become an essential part of the maritime industry. It fulfils the international demands of efficient and safe shipping. The definition of the general VTS activity has been made on an international level. However, the challenges of the Finnish VTS have been, and still are, the control of safety and efficiency in our navigationally very demanding archipelago and creating the kind of activity that can manage this task on a concrete level. Quite open boundaries for the development and focus on the local needs were the ways to learn the possibilities and constrains of the emerging system.

This study also contributed to the development of the CTA methodology. The nature of the VTS as an evolving activity guided us to broaden our time perspective. Defining the core task can usually be based on the analysis of the possibilities and constraints offered by the constituents of the activity system. This definition can then be used as a frame of assessment. In this case, most of the boundaries of the system are a matter of definition, that is, what we say the VTS is or should be and produce as outcome (i.e. safety at sea). In addition, dynamics seem to be an essential characteristic of the studied system. The continuous change, the different phases expressing in some respect qualitatively different systems and the pressures coming from the change in social, political and technical environment all support this conclusion.

We suggest a more dynamic and self-constructing view of the socio-technical systems and using methods that can take this into account. When the work is rapidly changing in many domains, the danger of ergonomic analysis is that when finished it is already outdated (Nuutinen 2005a). The main claim of this paper is that the only way we can keep up with the changes of work is to include the future of the system into our analysis (see also Engeström 2004, pp. 11–13). A future oriented way is to contribute more to design of the systems as suggested by many authors. This study was an example of how the two roles of ergonomics, retrospective analysis of the problems and future-oriented contribution to the design (Wilson 2000; MacLeod 2003; Clegg 2000), are interrelated. We suggest that also more open, visionary, definitions of the future system are needed in order to create frames and a desire for development within the system. In this process good interactions between human factors and ergonomic specialists and others are, of course, essential (Kirwan 2000).

In summary, this paper presented a concluding study of a complex socio-technical system, VTS, which is an example of a relatively young, developing system. We conclude that it is important to know not only the present, but also the past and the future of the system in order to discover, if not the optimal, at least the adequate development track. The results of ergonomic studies can help in self-reflecting and envisaging but the persons within the system create the will to develop and find their way towards the development horizon.

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3.4 Traffic safety (Virpi Anttila & Juha Luoma)

3.4.1 Introduction

Transport Telematics or Intelligent Transport Systems (ITS) have been proposed as possible solutions for reducing congestion and improving traffic safety and driver comfort. In-vehicle information 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.

It has been argued that allowing the drivers to interact with devices while driving may be unsafe. However, assessing the safety implications of information provision is still problematic. The European project HASTE (Human machine interface and the safety of traffic in Europe) aimed to develop methodologies and guidelines for the assessment of IVIS. VTT participated in that project and the work was conducted in the framework of strategic technology theme Safety and reliability. In the following, the principal findings of the study are summarised.

The field study was designed to investigate and compare the potential or sensitivity of the selected assessment methods to reflect the effects of different S-IVIS on driver behaviour in rural and in urban environment. More specifically, (1) the data were collected in real traffic, (2) the drivers included so-called average as well as elderly drivers, (3) the effects of increasing the demand of the visual task and of the cognitive task on driver performance were quantified, and (4) evaluations were based on vehicle data, observations and drivers' reports.

3.4.2 Method

Drivers had two surrogate in-vehicle devices (S-IVIS), the visual task and the cognitive task. A group of arrows were displayed on a touch-screen LCD mounted in the vehicle. The requirement of the driver was to make a manual yes/no response via the touch-screen if a "target" arrow (one pointing directly upwards) was present (Figure 11). The auditory task required drivers to maintain a count of their "target" sound, heard randomly amongst a sequence of non-target presentations. Both tasks had three difficulty levels, which drivers had to perform in urban and rural traffic environments. The test route was driven three times, with the visual task, with the cognitive task, and as a baseline (normal driving).

The VTT instrumented vehicle used in the experiment was equipped with an unobtrusive PC-based measuring system, differential GPS receiver and a video recording system. The visual task was presented on a monitor located on the right side of the steering wheel.

Drivers were informed that the aim of the study was to investigate what kind of task drivers can safely perform while driving. Particularly, the drivers were instructed to drive safely through the test route and perform the S-IVIS task when it was presented to them. In total, the data of 48 drivers were included in final analyses. Twenty-four of these were aged between 25 and 59 and twenty-four were aged 65 years or older. An experimenter sat in the front passenger position, where there was an extra brake pedal. He gave directions in order to maintain the correct route. An observer sat in the back.

In the rural route, speed limit information and the driver's speed behaviour was recorded. Only free-flow traffic situations were included in the speed analyses. In order to study mistakes in lateral position of the vehicle, also rapid steering-wheel turns were computed. In the urban route, speed behaviour in straight road sections was recorded. Special attention was directed to areas before zebra crossings.

Figure 11. The touch screen used for the visual task mounted in the instrumented car.

In addition to measured driver behaviour, the observer coded the driver's performance and the traffic situations with respect to

- presence of vehicle in front
- presence of oncoming vehicles
- interaction with vehicles in front
- lane keeping behaviour
- speed choice and adaptation
- yielding behaviour
- interaction with pedestrians
- stopping and signalling behaviour at intersections.

Driver's self-reported driving quality was asked after each S-IVIS block and at the same locations during the baseline run. Overall, the effects of S-IVIS type, S-IVIS difficulty and age group were analysed. However, the obtained differences should be viewed only as possible trends as only a few effects could be tested statistically.

3.4.3 Main results

For both secondary tasks, the percentage of correct responses was highest for the static situation, followed by rural and urban environments. Also the percentage of correct responses decreased with increasing task difficulty and the proportion of correct responses was somewhat higher among average than elderly drivers, indicating that the elderly drivers had more problems in performing the task. These results suggest that the use of an IVIS should always be evaluated when driving, not in static circumstances. In addition, an IVIS can not be evaluated only by the effects on driving, but the effects on performance of secondary tasks should be considered and evaluated as well.

The observations showed that each secondary task increased inappropriate speed behaviour in free-flow traffic situations (extremely fast, speeding up, varying speed, slowing down or extremely slow) in both environments. Compared to average drivers, elderly drivers were more often observed to have changes in their speed behaviour. When the difficulty of the secondary task increased, a greater proportion of drivers was generally observed to have inappropriate speed behaviour. In a rural environment, the secondary task increased the proportions of high and low speed compared to the posted speed limit for each age group and secondary task, except for average drivers performing the visual task. In urban intersections, the secondary task tended to increase speed before the intersection, especially when there was some interaction with pedestrians (Figure 12).

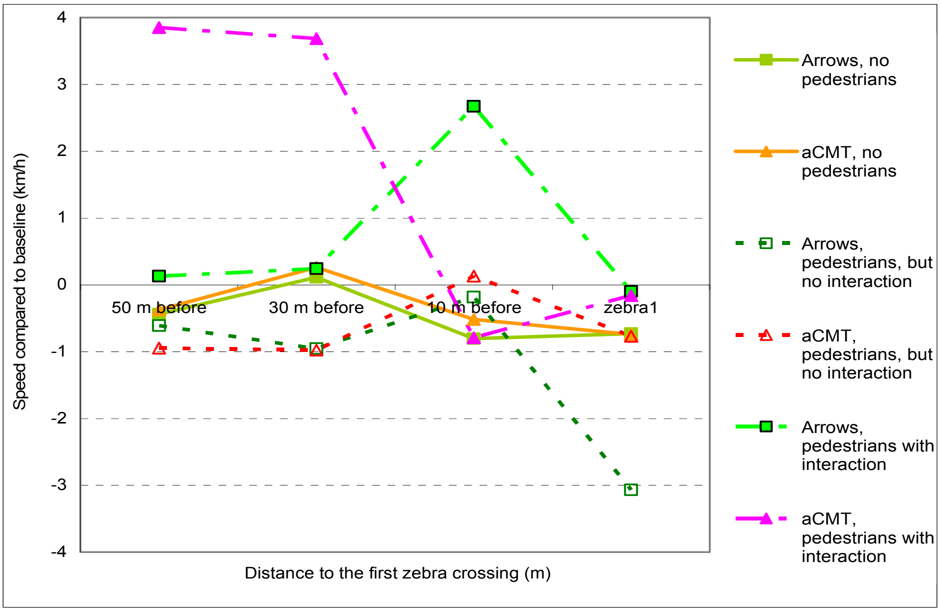

Figure 12. Approach speed (compared to baseline drive) to intersections by S-IVIS type and by interaction with pedestrians.

The visual task increased the frequency of rapid steering-wheel turnings substantially in a rural environment, and the frequency increased with the difficulty level. In addition, the measure was more sensitive for elderly drivers than for average drivers. Also observed lane keeping tended to be a sensitive measure for the visual secondary task in both environments and especially for elderly drivers. However, the cognitive task had no effect on rapid steering-wheel turnings.

In rural environment the observed headway distance in car-following situations seemed to be a rather sensitive measure for both secondary tasks. In urban environment, the interaction with other vehicles in yielding situation changed somewhat when conducting the secondary task compared to normal driving. Both S-IVIS tasks tended to decrease the proportion of proper yielding of the right-of-way to other vehicles at urban intersections. The visual task caused substantial unnecessary waiting when there was no other vehicle present or no crossing paths with other vehicles at the intersection. In addition, the proportion of short gap acceptance and potentially dangerous situations (sudden braking etc.) were more frequent when engaged in the visual task. The cognitive task increased the proportion of unnecessary waiting and dangerous situations to some degree.

The interaction with pedestrians was affected by secondary task performance as well. Overall, the cognitive task seemed more frequently to cause observed inappropriate behaviour towards pedestrians at urban intersections than the visual task. At the first zebra crossing before the turn, the cognitive task seemed to cause inappropriate behaviour towards pedestrians much more frequently than the visual task. In addition, pedestrians more frequently seemed to give the right-of-way to drivers when the driver was engaged in the cognitive task than in the visual task or no secondary task. Also the percentage of cases where a pedestrian was forced to stop to avoid conflict was higher when drivers had the cognitive task than when they had the visual task or no secondary task at all. At the second zebra crossing after the turn, inappropriate behaviour towards pedestrians seemed to be frequent in all three conditions and pedestrians frequently seemed to give the right-of-way to drivers. However, when the driver was engaged in the visual task, pedestrians were forced to wait even more often than in other trial conditions.

Drivers rated their driving performance best in baseline conditions, as worse when the difficulty of the secondary task increased, and elderly drivers rated their driving performance lower than average drivers for both environments and tasks. However, self-reported assessments of secondary tasks suggested that drivers mostly underestimated the effects of the secondary tasks. In addition, the differences were relatively small and therefore self-reported assessments of own driving cannot be assessed as sensitive measures.

3.4.4 Potential impacts

Overall, the results of this study confirmed that there are some concerns with secondary tasks that either divide visual attention, but also increase cognitive load while driving. The distraction resulting from an IVIS may lead to degraded driving, where the driver not only poses a risk to him/herself, but also endangers other people. Pedestrians are a particular hazard on urban roads since the separation of different road user groups (vehicles vs. pedestrians) is very hard and therefore pedestrians are to a large degree dependent upon the behaviour of motor vehicles towards them. Consequently, these systems should be designed so that the users will be able to cope with other users in a safe manner (e.g. not too high workload, no availability of in-vehicle information while driving etc.).

Furthermore, the results suggest that driving with a secondary task caused some changes in driving behaviour and these changes were observed more often with elderly drivers and they were often also more severe with elderly drivers. Therefore some special attention should be given to increasing amount of IVIS and elderly drivers in future traffic. In addition, research is required to establish the best methods by which information can be relayed to the older driver in a dynamic environment, without any adverse effects on the driving task (Merat et al. 2005).

From the methodological point of view, our studies demonstrated that the field experiments (in addition to the studies conducted in driving simulators) are a necessary tool for the impact evaluation of IVIS. Most simulators are not capable of capturing driving situations in which driving becomes highly cognitively demanding. In those situations the driver has to make a substantial effort to understand the information received from the environment, decide what to do during the following seconds and execute appropriate responses. Specifically, the benefits of our field experiments were most evident while assessing the interaction of drivers and pedestrians (Anttila & Luoma 2005).

3.4.5 Conclusions

For both S-IVIS tasks, the percentage of correct responses was affected by condition (static, rural and urban environment), secondary task difficulty and drivers' age. These results suggest that the use of an IVIS should always be evaluated when driving, not in static circumstances. In addition, an IVIS can not be evaluated only by the effects on driving, but the effects on performance of secondary tasks should be considered and evaluated as well.

In general, the results suggest that driving with a secondary task caused some changes in driving behaviour. These changes were observed more often with elderly drivers and they were often also more severe with elderly drivers. Therefore some special attention should be given to increasing amount of IVIS and elderly drivers in future traffic.

Although the drivers rated their driving performance worse when performing secondary task, the differences were relatively small and therefore self-reported assessments were not found sensitive measures in this study. Therefore some other measures are needed to assess the effects on an IVIS on driving performance and traffic safety.

The results suggested that lateral position (visual secondary task) and proper speed choice (both secondary tasks) were sensitive measures in rural environment. In urban environment proper interaction with other road users suffered when the driver had a secondary task and was therefore somewhat sensitive measure. The fact that both secondary tasks and the cognitive task in particular produced poorer behaviour towards pedestrians is important. This impairment in driving may be attributable to reduced mental processing available when under cognitive load. Overall, the results of this study confirmed that there are some concerns with secondary tasks that either divide visual attention, but also increase cognitive load while driving.

The distraction resulting from an IVIS may lead to degraded driving, where the driver not only poses a risk to him/herself, but also endangers other people. Pedestrians are a particular hazard on urban roads since the separation of different road user groups (vehicles vs. pedestrians) is very hard and therefore pedestrians are to a large degree dependent upon the behaviour of motor vehicles towards them. Thus, the possible distraction provided by an IVIS might be magnified in the risk that is handed down to these road users. Therefore more research is needed to confirm, specify and eliminate the possible severe problems in interaction with other road users when conducting a secondary task in an urban environment. The above results provide a good basis for future research.

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3.5 IWRIS® – Intelligent Water-borne Risk Indication System (Tony Rosqvist, Tapio Nyman & Robin Berglund)

3.5.1 Introduction

The ship traffic, although being partly scheduled has an unpredictable nature as regards to its density at the sea area. This has an effect to the workload of the Vessel Traffic Service (VTS) operators who are monitoring the sea area. During workload peaks, when the attentiveness is often directed to a certain part of the monitored sea area another threatening situation elsewhere may have completely escaped the operator's attention. On the other hand during quiet moments, the operators often take on extra responsibilities, and the core task, traffic monitoring, may stay in the background. For this kind of situations a system is needed alerting the operators to the possible developing hazard. The automatic identification system AIS developed for the ship traffic offers a valuable data source for the technology which identifies the hazardous situations and alarms about them. After the principles of such risk indication and alarming system technology were determined an IWRIS® registered trademark for the system was applied.

3.5.2 AIS (Ship-borne Automatic Identification System)

In 1997 the International Maritime Organization (IMO) drafted performance recommendations for a worldwide Automatic Identification System (AIS) (IMO 1998). Before that VTT took part in a project (POSEIDON) where a prototype system was tested in the Baltic in 1996. Now most ships in international traffic are required to have the Ship-borne AIS installed.

The information available through AIS is static, dynamic and voyage related. Static information is manually entered on installation and seldom changed. The static information consists of IMO number, call sign, name, length, beam and type of the vessel as well as the location of the position fixing antenna. Dynamic information is automatically entered from ship sensors consisting of vessels position, UTC-time, course and speed over ground, heading, navigational status and the rate of turn of the vessel. The voyage related information is manually entered and updated as appropriate consisting of vessel's draft, type of hazardous cargo if any, destination port as well as estimated time of arrival.

As a component of the Information system for the icebreakers – IBNet – VTT has implemented an application that can be connected to an on board transponder or to a network server that provides AIS information from all base stations in the Finnish AIS network.

To study the possibilities to use AIS data for traffic analysis, a prototype application with a graphical user interface, was developed (see Figure 13) (by Heli Orelma, Helsinki University of Technology). The experiences gained from this prototype are valuable for evaluating the usefulness of the AIS data. Possible problems that must be taken into account when using AIS data for traffic studies are both technical and legislative. The amount of data is large and thus the analysis requires special applications that can cope with the data volume. The quality of the data is not very high for some types of data (the voyage related information), thus requiring extra validation routines. The area covered by the AIS base stations is not 100% of the whole sea area. It must also be kept in mind that the use of the data must conform to the restrictions stipulated by the authorities, which should not be a serious problem as long as the data is used for research and statistical purposes only.

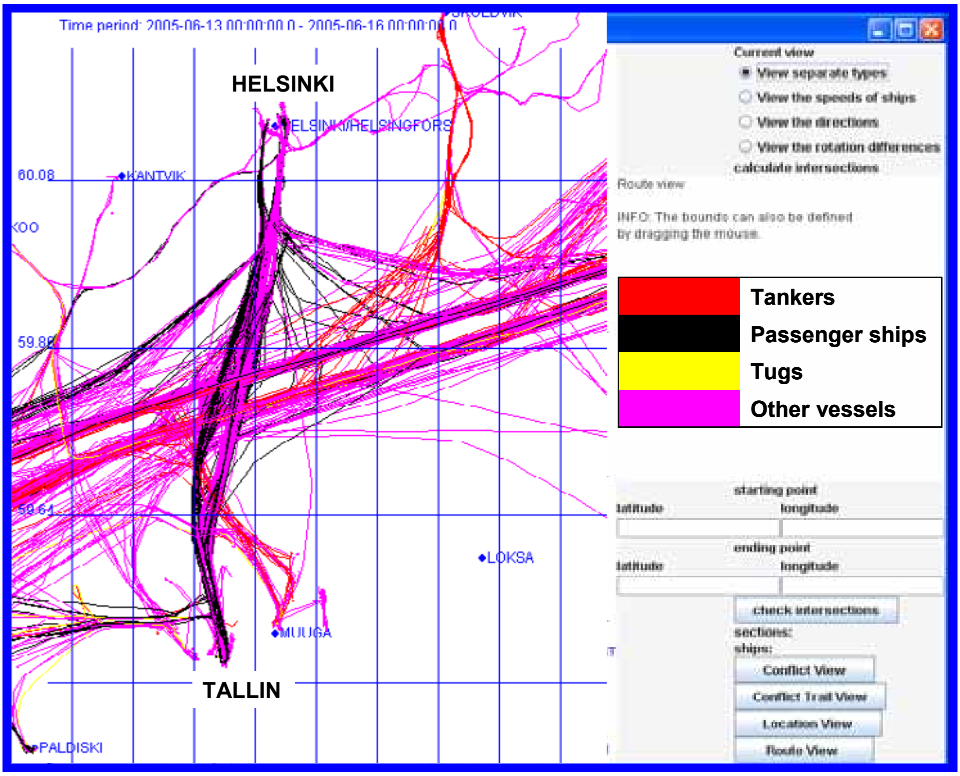


Figure 13. An example of the display of the AIS analysis tool. The coastlines are missing from the map in this version.

3.5.3 Objectives of the research

The objective of the research is to develop a technology, based on real-time position data of vessels (AIS-data), to support operative decision-making of VTS-operators. The core of the technology is a data model that takes as input AIS-data and provides in its output risk estimates that are used to alert VTS-operators of possible hazards that are developing in the monitored traffic area.

The long-term objective of IWRIS® R&D effort should be a product that possesses properties of an intelligent product:

- observation (understands and processes telematic information in real-time)

- adaptability (understanding structural changes in the environment)
- learning (giving better predictions as observations accumulate from repetition)
- communication (alerting operators in a meaningful way)
- feedback (operators can affect the functionality).

3.5.4 Methods used in the research

For IWRIS® to be a successfully implemented decision aid for VTS operators, three different methodological aspects have to be taken into consideration and integrated: user–centered design, bayesian statistics, and user interface technology. The overall methodological frame work of IWRIS® is depicted by Figure 14.

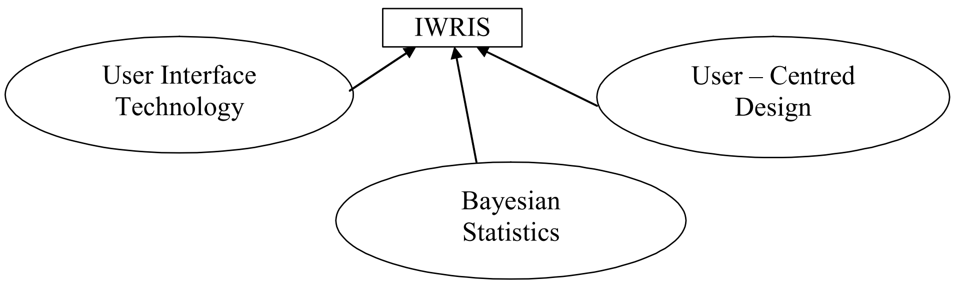


Figure 14. The methodological framework for IWRIS®.

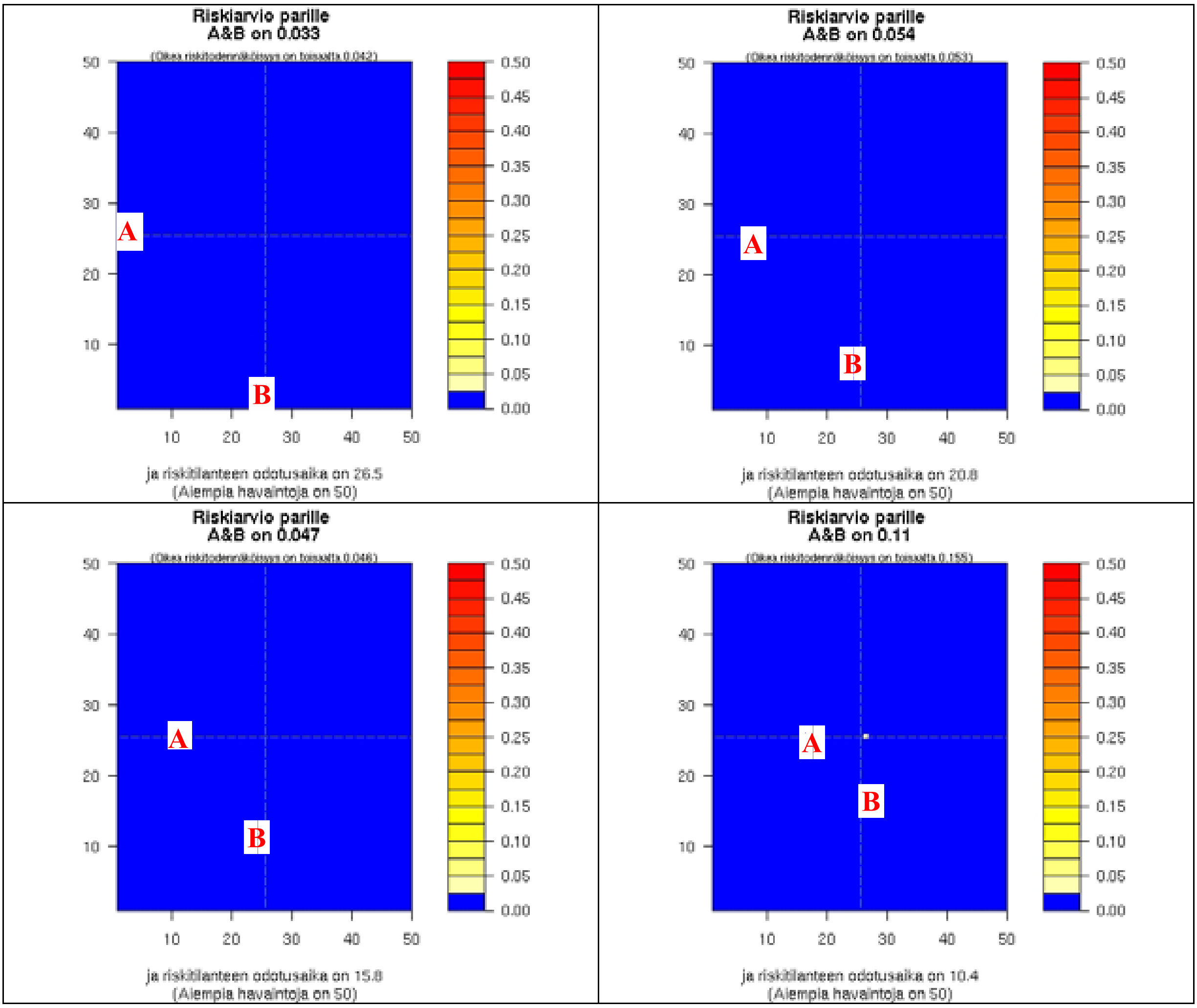
In this phase focus has been on the Bayesian mathematical formulation of the IWRIS® technology as well as on the development of the AIS analysis application.

In accordance with the Bayesian statistical approach, the risk computation of IWRIS® is two-phased: First, the parameters of the data model are updated by observed AIS-data that has been collected over a certain period, say, one year. Second, the updated data model is utilised to compute risk estimates of grounding and collision. In general, IWRIS® can be used to indicate deviations in the motion path of a vessel.

3.5.5 Main results

In the first development phase of IWRIS® the following tasks have been accomplished:

1. Trajectories of vessels over a two-dimensional grid have been produced by computer simulation of Markov chains (special work by Lassi Similä, Helsinki University of Technology). The aim of this task is to produce stochastic position data of crossing trajectories that can be used as input data to the data model. Markov chains of the first and second order have been used in the simulations.
2. A Bayesian updating algorithm, where transition probabilities are estimated dynamically, as observations on trajectories become available, was defined and implemented (special work by Sampo Etelävuori, Helsinki University). The Bayesian approach supports learning from observations, resolving initial (prior) uncertainties related to the transition of vessels through a grid, superpositioned on the monitored sea area.
3. A graphical display to show simulated traffic with risk indication based on a coloured probability scale has been developed (Figure 15).


Riskiarvio parille
A&B on 0.033
(Oikea riskitodennäköisyys on toisaalta 0.042)
A
B
ja riskitilanteen odotusaika on 26.5
(Alempia havaintoja on 50)
Riskiarvio parille
A&B on 0.054
(Oikea riskitodennäköisyys on toisaalta 0.053)
A
B
ja riskitilanteen odotusaika on 20.8
(Alempia havaintoja on 50)
Riskiarvio parille
A&B on 0.047
(Oikea riskitodennäköisyys on toisaalta 0.046)
A
B
ja riskitilanteen odotusaika on 15.8
(Alempia havaintoja on 50)
Riskiarvio parille
A&B on 0.11
(Oikea riskitodennäköisyys on toisaalta 0.155)
A
B
ja riskitilanteen odotusaika on 10.4
(Alempia havaintoja on 50)

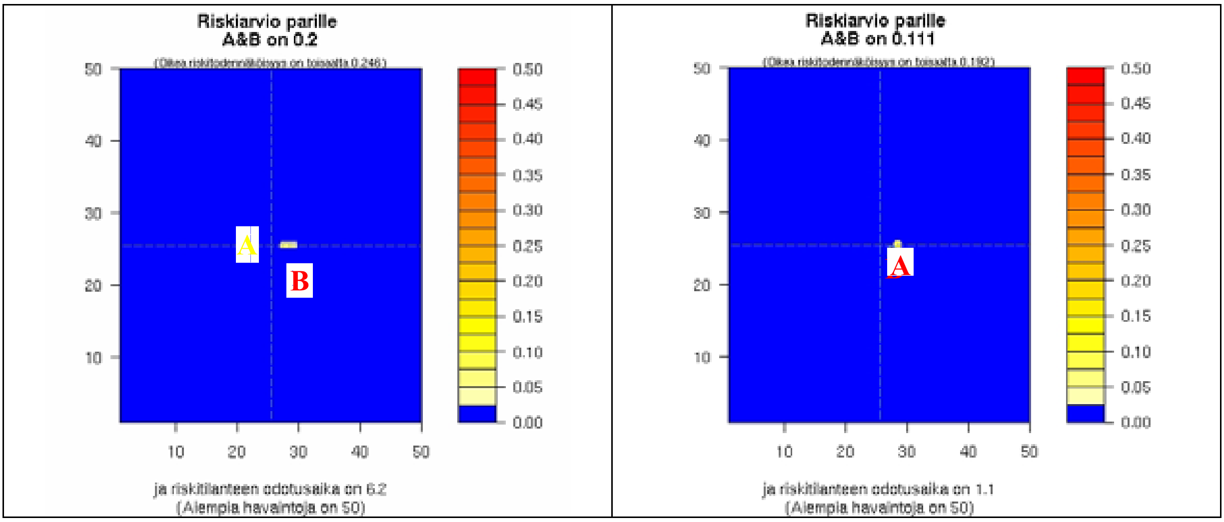


Figure 15. The six figures show an escalation of a collision situation between vessels A and B. The risk levels shown at the top are estimated by the IWRIS computational core (the risk levels within the brackets show the analytical results for comparison) and the numbers below the figures denote the expected time of arrival to the area of crossing paths. The Bayesian data model is estimated based on 50 observations.

3.5.6 Potential impacts

The potential impact of the IWRIS®-technology are the 1) timely alerting of a developing collision hazard in the monitored area, 2) alerting of deviation in a vessel's typical motion path (grounding hazard) and 3) alerting of a vessel which has no track record of navigation in the area to support VTS-operators in operative decision–making. Generally speaking, the impact of IWRIS® is the improvement of maritime safety by prevention.

As modifications of IWRIS®-technology, a real-time operative tool for oil combating operations can be created for accidental oil spills if some existing oil spreading model is connected to the system and a tool for designing new fairways and planning of oil combating strategies can be obtained if the system is used in off line mode.

In development of the AIS analysis tool, a wide variety of other targets of application for fairway analysis were identified for the tool. For example it can calculate the utilisation rate of existing fairways (also divided to light and dark times making the optimisation of lighting in the aids of navigation) and also the tool can identify the difficult fairway sections by recognizing the crossings of fairway area border lines.

3.5.7 Conclusions

In the work performed, on-line risk indication technology has been developed in the form of a data flow diagram, a multinomial data model with Bayesian updating of its parameters, software code for computer simulation of position data and real-time risk indication, and a demonstration presentation. As an additional output of the project an analysis tool for the AIS-data has been developed. For developing the IWRIS®-technology to a prototype level plans for wider national and international cooperation have been started.

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4. New technologies and operating principles

4.1 Topic description – Executive summary (Tapani Mäkinen)

The three projects, Risk Assessment of Genetically Modified Organisms (GMO), Unobtrusive Driver Monitoring Technologies (SYKE) and Trusted Software Technologies (TRUST) represent very different fields under Safety and reliability technology theme's new technologies focus area. The objectives of GMO were to develop a framework for the risk assessment of genetically modified plants (GMO) that helps the plant developer manage the risks during plant's development cycle. The objectives of SYKE is to develop unobtrusive sensors and related algorithms for monitoring driver behaviour, especially drowsiness while driving. The task of TRUST is to increase reliability, safety and security of software. The projects are also in different stages of their development and networking. While GMO was a very focused national project and has already been terminated, whereas SYKE joined two large EC funded Integrated Projects (IP) and has started its main activities early this year. TRUST as a conglomeration of six independent projects with specific objectives and structures is presently active in three of its subprojects. The GMO project developed a new hazard identification and risk assessment method for GMOs contained use. These methods will be further developed in later projects. SYKE main activities have started in January 2004 and new sensor applications for monitoring driver impairment is expected to be tested by major European car manufactures in four years time. In TRUST the work is underway and the expected outcome of the project is the methodological framework to support any given organisation in the selection of specific knowledge (methods, techniques and skills) to design, demonstrate and meassure safety, reliability and security of software.

4.1.1 Background and objectives of the projects

The three projects SYKE, TRUST, and GMO represent very different fields under Safety and reliability technology theme's new technologies focus area.

The first mentioned of the projects SYKE aims at developing driver monitoring technologies to address the pressing safety needs of driver impairment accounting for most road traffic accidents today. The research on driver impairment monitoring has made great progress during the past ten years. However, currently there are no systems on the market that can reliably detect driver fatigue. Such a system can not be foreseen on a mass production car until 5 to 6 years from now. The most potential systems are existing as prototypes, and they are still beset by too many false alarms. It is possible that driver fatigue detection systems will not be introduced alone but as a complementary function of an overall driver impairment monitoring system. For this reason, continuous work on sensor optimisation and refinement of data fusion algorithms is needed. SYKE project will bring new unobtrusive sensor technologies for driver impairment monitoring.

TRUST project aims at developing methods to improve software dependability that has been an important research field at VTT for a number of years. Originally, this field was started in the late seventies when the development of programmable instrumentation and control systems made evident a need for high reliability applications such as safety systems at nuclear power plants. Later, development of software-based systems has brought in also other aspects of software dependability that will be addressed in the project. The objective of the main task of the TRUST is to develop a methodological framework which enhances organisational ability to take in use specific methods and techniques to design and demonstrate reliability, safety and security of software. In addition, by the methodological framework organisation is able to educate software developers about software reliability.

GMO project dealt with creating the framework for the risk assessment of genetically modified organisms (GMO) that helps the plant developer manage the risks during plant's development cycle. The other aim was to improve the ecological risk assessment process. The effects that might occur through the use of genetically modified organisms can actualise directly but also through indirect ecological processes. Not infrequently, the potential effects are difficult to determine since there is no earlier operational experience on the use of organisms. Current tools to assess the GMOs risks are based on regulatory lists and they are not designed concerning risk management aspects.

4.1.2 Expected impacts

SYKE

- increased knowledge of non-invasive sensor technologies
- improved networking of VTT with other major European players in the field
- possibility to improved traffic safety by means of advanced driver monitoring technologies
- improved market possibilities for Finnish SME's in sensor development area
- project results may have applicability also in other monitoring areas than road traffic only
- negotiations with automotive industry partners for other cooperation in sensor development.

TRUST

- The methodological framework of the TRUST will be a great support for an organisation in selection of specific knowledge (methods, techniques and skills) to design, demonstrate and measaure safety, reliability and security of software.
- The integration of the different expertise related to software development process will become easier, resulting to better design solutions.
- Expected impacts for manufacturers of programmable medical devices are
  - systematic and cost efficiency design process
  - better documentation throughout software engineering process
  - better verification and validation activities during software development
  - better software maintenance and management of modification
  - effective and traceability system requirement phase
  - less inadequate or inappropriate software requirements.

Dedicated devices and systems with embedded software are used in several more or less critical fields (for example, smart sensors and transmitters in nuclear plants and conventional industry, users of mobiles, medical device community). The results of the subproject will support manufacturers and purchasers of these dedicated devices in their effort of qualifying software safety and reliability.

GMO

- Guidance notes to perform the risk assessment for the use of genetically modified plants in contained environment. The paper is recommended and delivered by the Finnish board of gene technology.
- The results and "know-how" gained during the project has been was employed in later projects as in the current Academy funded research project "Assessment and Regulation of Ecological Effects of GMOs in Boreal Environment". The aim is to produce "standardised" procedures for the industry and regulative authorities.
- The industry is interested in comprehensive risk assessment since they can better manage the risks the new technology might pose. However negative public acceptance of GMOs have frozen the research and commercialisation activities in the Europe.

4.2 Operator monitoring systems (Matti Kutila, Juha Kortelainen & Tapani Mäkinen)

4.2.1 AIDE

Objectives

The overall objectives of the project are to develop technologies for driver and operator distraction and vigilance monitoring. Human-machine interaction (HMI) integration is needed to handle the rapid functional growth in today's vehicles. There are currently a rapidly increasing number of systems that interact with the driver in different ways, including Active safety systems, Advanced Driver Assistance Systems (ADAS) and In-vehicle Information Systems (IVIS).

HMI integration is needed to prevent interference between the different systems, but also to exploit potential synergies. Today there are good technological possibilities to monitor the driver/operator, the vehicle and the environment in real time. This can then be used to adapt different aspects of the HMI in order to optimize driver-system interaction to the current situation. Examples include locking out or postponing non-critical information in demanding situations or adapting the timing or intensity of safety warnings e.g. warn earlier when the driver is inattentive for what ever reason. The two projects, AIDE and SENSATION of the programme address these issues. The projects are a part of EU funded 6th framework programme activities and will continue even after this technology theme.

Methods used

For driver distraction monitoring a Cockpit Activity Assessment Module (CAA) was developed. The objective of the CAA module is to determine what the driver is doing inside the cockpit. Mounted in front of the driver, measuring the momentary position and rotation of the driver's head and eyes providing the most important input. Using this input and others (e.g. vehicle control measures, driver speech detection) the level of distraction due to secondary tasks (e.g. phone conversations, radio operation) is estimated, and the driver's direction of visual attention is continuously measured to detect what regions of the exterior or the interior he or she is focusing on. Typical uses for such information are warning adaptation and information filtering. A forward collision warning may for example be given earlier if the driver is distracted by a secondary task or if the driver is checking a mirror when having a secondary task.

The CAA architecture is presented in Figure 16.

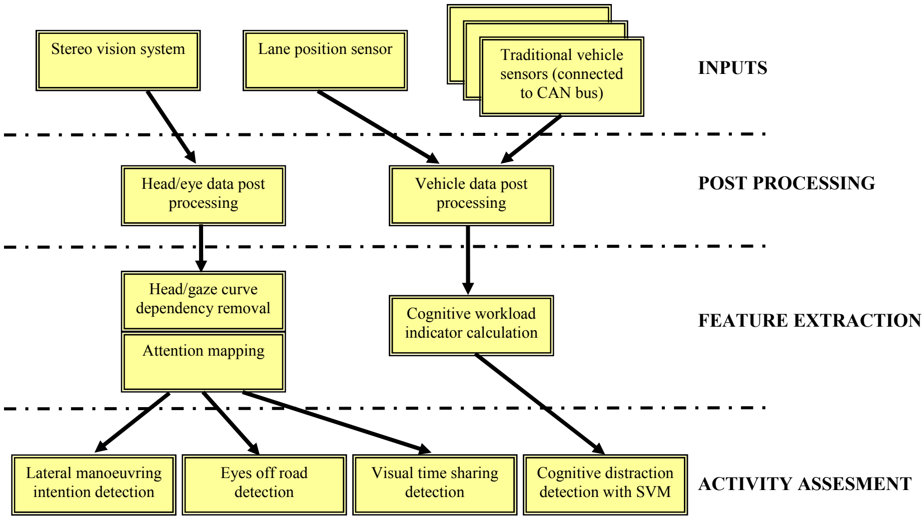

Figure 16. Cockpit Activity Assessment Module (CAA) architecture.

The visually distracted driver is recognised using the head and gaze rotation data. Signal enhancement and clustering algorithms were applied on the raw data to get a mapping to a momentary real-world point of attention. In the simplest case, it is then detected whenever the driver's attention is not on the road ahead. More elaborate metrics, detecting time sharing behaviours (i.e. when the driver divides his visual attention between the road ahead and some other region) were also envisioned.

CAA was used to measure so called cognitive distraction of the driver. Cognitive distraction while driving is typically caused by phone conversations or daydreaming or heavy thinking. It causes long glance fixations with small variations in direction, increased high-frequency steering wheel movements and smaller lane position variations. Reliable recognition of cognitive distraction is a complicated task. Due to the large number of input features a syntactic classifier would be insufficient and a more advanced method is needed. Support vector machine gives an "optimal" separation of clusters in the multidimensional feature space.

Main results and conclusions

The first version of the CAA module implements preliminary algorithms for detection of "eyes-off-road" visual distraction and cognitive distraction, using a stereo camera based head and eye tracker as main input. The algorithms have been created using, and tested on, real distracted driving data from an experiment with twelve professional truck drivers, also conducted within this AIDE task. Algorithm development environments have been set up that permit replay of recorded driving data offline. Algorithm results are encouraging, although future work is required. The mapping from gaze angles to real world object of interest, based on a static, manual offline definition of attention target boundaries, needs improvement mainly when it comes to mirror check detection. The cognitive distraction detection, a support vector machine classifier taking a set of "cognitive distraction indicators" as input, produce fair classification results in medium and high speed environments (motorway, rural, suburban), but online tests are probably needed to fully assess whether or not the current algorithm is good enough. Before releasing the final version of the module, algorithms for detection of visual time sharing and lateral manoeuvring intent will be implemented, and various improvements to the already developed algorithms will be attempted. Since the current version of the module is developed using truck driving data, an adaptation to the city car demonstrator will also be needed for some of the algorithms.

Potential impacts

After the R&D work of the project has been successfully completed, some time is needed for the commercialisation of the product. It goes without saying that in future vehicles cockpit information management and driver monitoring is needed. Due to the increasing number of Active Safety and ADAS applications, their HMI needs to be coordinated and prioritized according to traffic situation. Since driver distraction is a relatively common principal cause in traffic accidents, the safety benefits of driver monitoring and cockpit information management systems can be expected to be considerable.

4.2.2 SENSATION

Objectives

The objective of SENSATION project is to develop wearable sensors for driver and operator or patient vigilance, drowsiness and sleep monitoring. The current prototype specifications and preliminary results for the developed "Wearable sensors" is presented. Electret foil sensors with Emfit technology that is used for measuring spatial pressure profiles with high sensitivity are described. Shape of the foil electrodes are designed for different sensing areas and multiple elements. Novel electronics has given several benefits. Electret foil sensors include a prototype called SEFO (Seat Foil Sensor), applying the Emfit technology, which is developed for car seat and driver monitoring application.

Methods used

The electret foil Emfit is selected for development of pressure sensitive foil sensors in the SENSATION project. It is based on low cost polypropylene material, and enables both high sensitivity for large area electrodes and low power consuming electronics. Surface electrodes can be printed with different shapes, e.g. to create matrix type multi electrode sensor foils to measure 2D image of spatial pressure distribution for person lying in bed or sitting on a bench. The main objective for pressure sensitive foil sensors in the SENSATION project is to measure posture and movements of person. Second objective is to measure physiological indicators of heart beat and respiration. High dynamics of Emfit foil enables measurement of these both, although the weak physiological signals suffer from strong artefacts of any movements or environmental vibration.

Sensor development for the seat sensor is carried out by VTT in co-operation with the Emfit sensor manufacturer[2] and Siemens VDO. The new design is compact and cost efficient for pressure matrix with tens of electrodes. The previous technology would be to combine independent sensor foils with external wires. An additional layer for signal conductors is laminated in between the

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[2] Emfit corp., subcontractor in SENSATION IP.

electrode layer and the upper shield layer. The minimum width for each signal conductor is about 1 mm when using silver pasting technology on the smooth plastic foil surface. The lead-in connection between conductors and electrodes is done by laser beam through the insulating layer.

Additional insulation layer increases the thickness and reduces the flexibility, which was found to be problem especially for seat application. To increase the flexibility of sensor foil, the electrodes has been mechanically separated by laser cutting large holes for the foil. Electrodes are connected to each other with narrow foil stripes having curved shape.

The new design was developed firstly for SEFO sensor and with some modifications for Matsense sensor which is shown in the Figure 17. The previous design with continuous foil suffered from artefacts and crosstalk between the signal channels, which were quite complex in nature, as being caused by the tension forces on a large rigid foil pressed against soft tissue. A compromise is needed between foil flexibility and thickness of the additional insulation layers. Too thin insulating layers would increase the capacitance of electrodes, thus affecting the signal dynamics.

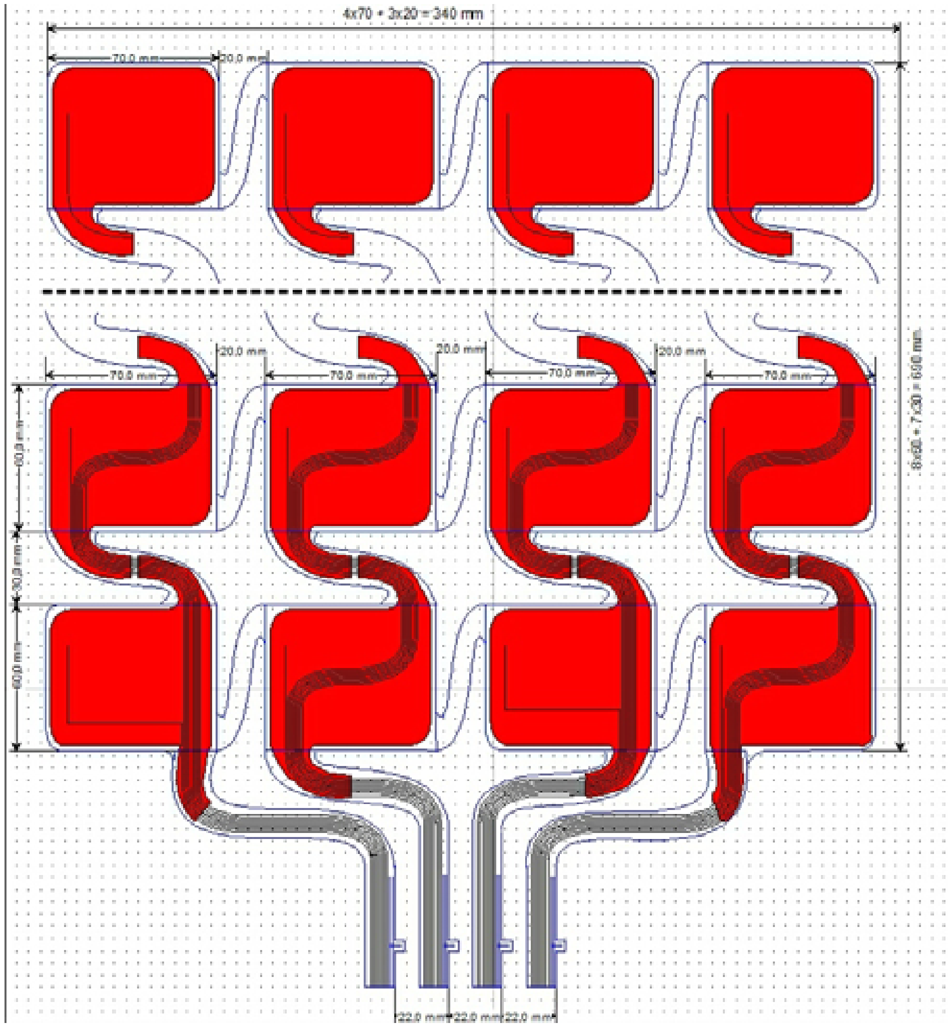

Figure 17. Schema for Matsense foil sensor design.

The electrodes are covering about 50% of the total area. When installed for bed or seat, the effective covering area increases as the pressing forces are spatially distributed in soft tissue. For a point-like pressing force located in between the electrodes, the soft tissue distributes part of the force for the neighbourhood electrodes.

Main results and conclusions

The SENSATION project has resulted into a new way to measure the Emfit charge signals, by using the switched integrator amplifier. This was realized with commercial IC chips, for example IVC102 or DDC112 from Texas Instruments. These are normally used as charge integrators of photo sensors, and no previous publication of using these for electret foil sensors has been found. The electronics is shown in details in the end of this Chapter under sensor specifications.

New design with switched integrator gives four major benefits for the Emfit application:

1) The highest possible level for input impedance is achieved with the analog switches, thus enabling the best low frequency dynamics.
2) Compact design for multichannel measurements is possible by using analog multiplexer before the switched integrator.
3) Integration cycle with exact time period yields advantage by introducing a notch type lowpass filter, which can be used efficiently to reduce a priori known interference, e.g. the mains 50 Hz.
4) Input stage can be supplied with only one sided voltage source, although the signal varies around zero.

The first one improves the measurement sensitivity in low frequency applications. The 2)…4) altogether enable to use compact electronics for multi channel measurements.

Pressure sensitive foil sensors with Emfit technology was developed for bed, seat and wearable application scenarios. The bed and seat application includes measurement of the spatial pressure profile to indicate the posture and movements of person. The Emfit foil structure has been modified to these applications to include an additional conductor layer to enable matrix like design. To improve the flexibility, large holes are cut by a laser into the foil. New electronics for the multi channel measurement uses switched integrator amplifier connected with analog multiplexers, which has proved several benefits for sensitivity and compact design.

The main benefit for the selected Emfit technology is high dynamic range and sensitivity compared to the alternative pressure sensitive foil principles. The drawback is the lack of static pressure in the measurement, which was partly overcome by the signal processing of the dynamic pressure signal. The preliminary tests for bed and wearable applications show good indication for the spatial pressure distribution and movements, including respiratory functions. The heart pulse can be measured with sharp details from the best positions, to be used even for estimation of pulse transit time and further blood pressure variation. The measurement of physiological signals by pressure sensitive foil is easiest to use as applicable over thin textiles, but also most sensitive for artefacts of any movements and thus can be reliable only for still postures, like in sleeping studies.

4.3 Trusted software technology (Hannu Harju, Seppo Hänninen, Ilpo Pöyhönen & Reijo Savola)

Trusted Software Technology, TRUST, is a collection of subprojects from three research institutes: VTT Electronics, VTT Industrial Systems, and VTT Processes. The TRUST project aimed at developing a knowledge management system that enhances the ability to utilise specific methods and techniques to design and demonstrate the safety and reliability of software.

In addition to the knowledge management system, subprojects have special research objectives under the strategy of the appropriate research institute. For instance, interest of VTT Electronics in TRUST is in software security based on architectural level, VTT Processes on the impact of software on electricity distributed reliability, and VTT Industrial Systems on the evaluation of software reliability and safety on the industrial fields on instrumentation and control of nuclear power plants and safety related software of medical devices. Results of the subprojects are collected together as so called fundamental principles that are utilized in knowledge management system, to which we give a name Dependability Control Model, DCM.

The objective of the subproject “Software security metrics” was to define security metrics to be used during software development process to monitor the security performance of a product. The objective of the subproject “Software dependability in complex systems” was to develop methods that consider issues of reliability in a systematic manner when dealing with software development within electricity distribution.

The objective of the subproject “Dedicated devices with embedded software” is to reduce qualification costs of small but safety critical software. One of this kind of software is embedded software of smart devices that possess several functions, and ability to be dublicated for decreasing hardware based faults, but not for decreasing functional failures based on software faults. The idea of this co-operation project with Swedish party was to study possibilities to reducing potential common cause failures caused by functional faults occurring.

Medical device regulations place restrictions on the software development process. Can these requirements be satisfied if developing according to agile development method? Agile methods are lightweight software development methodology which departs significantly from traditionally development practices, included of safety related system. A great benefit of agile methods is their ability to maintain a short development process and fast competence to market which sometimes takes place to the exclusion of safety. The objective of subproject “Connecting safety requirements for agile software” was to apply agile methods to safety related software development so that an enterprise can competitively maintain its commercial targets.

The idea behind developing frameworks of DCM is that the fields of computer science, IT, system engineering, and software engineering do not emphasise sufficiently the fundamental knowledge needed by practioners. DCM will give a practical insight into computing taken care specific factors that affect on dependability, that is, reliability, availability, maintainability, safety and security of software.

Before making any strategy for selecting methods and techniques for specific application domain or system environment, rules and laws should be studied, so that we know what is important in designing dependable software. In TRUST, we focus the selection of rules and laws to the field of information technology, system engineering, and software engineering. Laws and rules are easier to remember than a plurality of features which present everything precisly and covers all posssible aspects of the subject. In TRUST, we call those laws and rules by Fundamental Principles. The idea in presenting fundamental principles is not to bring in sight something totally new, but important.

4.3.1 Software security metrics

In today's information technology world, there is a growing need for security solutions: the information systems are more and more vulnerable because of increased complexity and interconnection of insecure networks. In any development process, security should be taken into account from the very first steps through its lifetime – not to think it as "add-on" which can be plugged into product at some stage of the life cycle.

Security is still an evolving discipline, and a precise definition does not currently exist. Even though appropriate security approaches can be found, the resulting security level often remains unknown in industry. It is a widely accepted principle that an activity cannot be managed well if it cannot be measured. *Security metrics* can be used to monitor the security performance of a process, product or system.

What kind of security metrics are then needed? Security failures in products might be fatal for business. Therefore the metrics should provide a security performance view for business managers, as a part of overall risk management process. On the other hand, security metrics are an important tool for system architecture designers. Security metrics form a basis for an overall security risk management process for IT product development.

In general, there is a need for metrics that are repeatable, manageable, objective and comparable. Additionally, the security level should be easily defined and presented in an understandable way. (Sademies & Savola 2004).

4.3.2 Software reliability of complicated electric systems

Electricity supply is increasingly dependent of devices and systems that include software. At every level from network operation and substation automation to individual components such as protection relays, software plays a crucial role nowadays. The task focused on the impact of software on electricity distribution reliability. The aim was to develop methods that consider issues of reliability in systematic manner when dealing with software development within electricity distribution. Computer systems and their main software that are central within electricity distribution and especially substation automation are described. The most important computer systems for distribution automation and network operation are the remote control system, better known as SCADA (Supervisory Control and data acquisition), the distribution management system, the network database system (AM/FM/GIS, automated mapping/facilities management/ geographic information system) and customer information system, see Figure 18.

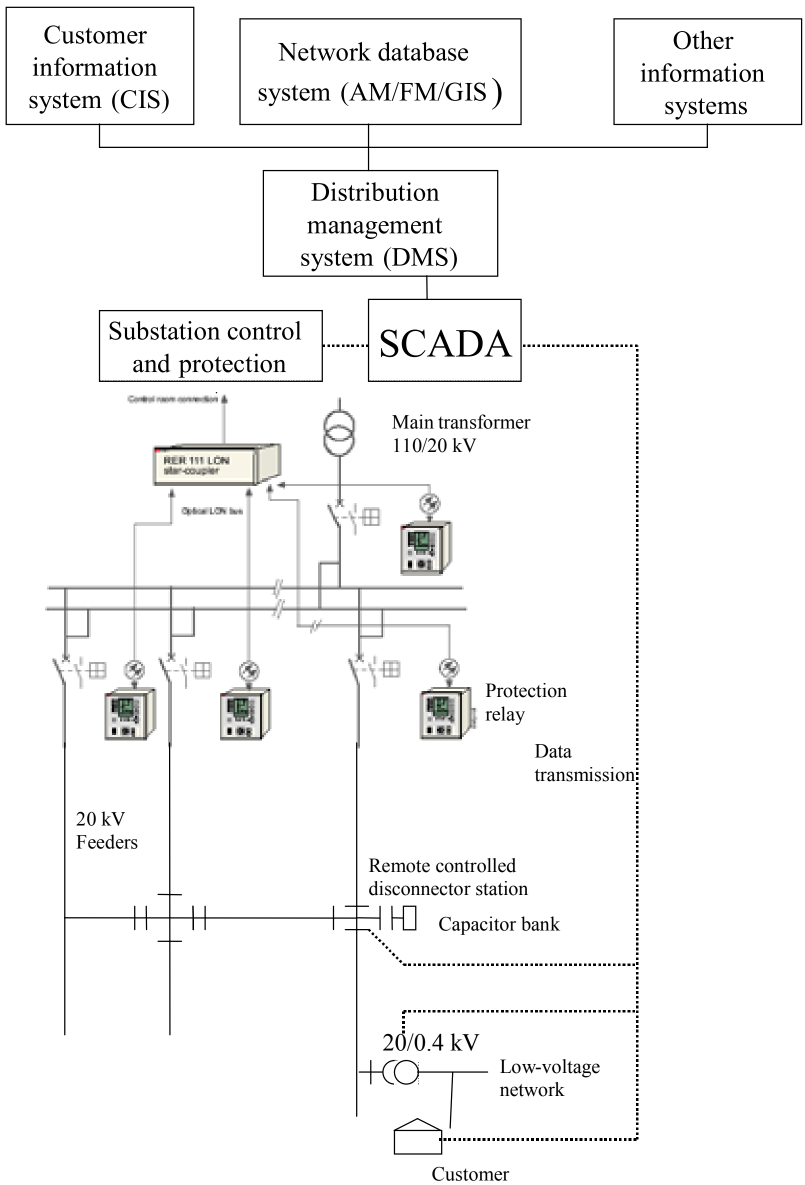

Figure 18. A general schema of a distribution with related automation and computer systems.

Distribution automation and control are recognised as ways for intelligently using appropriate technology to increase the reliability at reduced system operation cost. Automated operation and service restoration can eliminate the need to perform switching operations manually and can have a significant effect on reliability and power quality. The correct operation of the protection systems is of utmost importance for secure operation of automated power systems. In the event of a network failure the control sequences for fault isolation and service restoration are initiated by protection relays. In the reliability analysis of power systems the protection and control systems are generally assumed to be perfectly reliable. However, protection and control systems can fail in reality either by not responding when they should or by operating when they should not. The former type of failure is serious since it may result in isolation of larger sections of the network or it can be a potential hazard to personnel.

From the security and reliability point of view the most important systems are protection and control systems. The most important task of these systems is to protect major power system components from possible damage caused by abnormal voltages and currents. This can be achieved by isolating the fault from the network. The most important functions carried out by these systems are switchgear control, indications, synchronising, interlocking, auto-reclosure, protection and measurements. The four main critical actions that usually take place in the substation and to encompass all the individual functions involved in these actions are circuit breaker closure, circuit breaker opening, feeder reclosure, disconnector and earth switch operation. These mechanical actions are controlled and implemented by software.

The purpose of this project was also to discuss how the reliability of the software are taken into account in development and testing phase of the distribution control and protection system. In the following is a brief summary of the observations:

- In the design phase of the software, the programmer uses only simple basic guides and engineering methods in order to write reliable programs.
- Systematic reliability analysis methods in design phase are not in use, for example risk analyses.
- Testing with digital simulator is only way to guarantee the reliability of the software in protection and control system.

- So far it is impossible to test simultaneously the whole protection and control system installed on substation.
- Tests are limited due to the fact that it is impossible to simulate all possible events occurring in the network.
- Testing is performed mainly with simulated data and only limited testing with real case data (if at all).
- Lack of reliability data of software in real relays and SCADA systems.
- In the modern, integrated protection and control systems, failure of a single device or software is more likely to cause loss of several functions.

In the future, the local generation will become more general in the distribution level. In that case the protection of the distribution network may be very challenging. The software of the feeder relays in the substation must be planned so that relays are able to adaptively change their settings in consequence of that the local production is connected or not.

4.3.3 Dedicated devices with embedded software

A fault in a single version software of multiple processors is an important source of common cause failures. Isolation of safety and non-safety functions, functional diversity, independent verification and validation, and good practice are the most effective means for preventing and tolerating software common cause failures.

In this subproject, the concentration is in fault tolerance of a single version software of a dedicated device. A procedure for providing evidence of fault tolerance is presented, and the characteristics of software faults, errors and failures is discussed. The scope of the presentation and discussion in subproject is in safety integrity.

A key to successful evaluation of embedded software of dedicated device is in simplicity. The complexity of the functions, and the extent of interfaces and interactions must be limited so as to allow a thorough functional coverage by tests.

If the complexity increases, additional methods are needed to fulfill deficiency of tests. Especially, the use of fault tolerance techniques is high level evidence in addition to the external risk reduction techniques for the assessment how effectively the software safety has been achieved.

The ability of a system to tolerate faults begins with the detection of errors. In fact, the techniques of error detection are crucial for the success of fault tolerant systems. In addition to some error detection techniques, the fault tolerance methods such as forward error recovery, backward error recovery, process pairs, and data diversity are presented.

4.3.4 Connecting safety requirements for agile software

Agile methods have become common discipline in software development. There are many agile software developments methods, for instance, Extreme Progamming, Dynamic System Development Method, Adaptive Software Development, and Scrum. Some commonalities exist amongs them, all methods are based on agility, simplicity, change, planning, communication and learning. All of which are also recommended characteristics for development of safety critical software.

This subproject of TRUST considered agile methods and safety related software. Approaches to this examinations becomes from answering to following two questions: Are agile methods convenience for safety related software development environment? Can we learn something realted to safety in practicing the agile methods? The first question search answers from the following directions: fulfilment of safety requirements of medical device regulations and standards, and convenience for embedded software.

Agile methods are best known of good communication between team members, but the basic problem of it is that communication is mainly face-to-face discussions without written documentation. In research, we observed that there is not any restrains for documentation from agile methods side, but organisations afraid that their performance and economical bases will decrease if documentation increases. So, we did survey the mandatory documentation for software life cycle phases and took a notice of those documents that can be prepared by automatic tools. The conclusion from this research is that for almost all software that is related to safety, what ever the level of safety integrity of them is, must have written specifications for requirements and architecture. When the level of safety integrity increases, also need for documentation increases, but in those cases, there does not exist a big problem compared with low safety integrity software. This is because the software in high levels is simple, and organisation can establish basic procedures, processes and design solutions for those software. These basic methods will be heritated from project to project.

Lack of documentation is not the only problem in fulfilment of requirements. The most significant differences compared with safety regulations and standards are development cycle and design methods. Agile methods uses an evolutionary approach suited for vague and changing requirements, and the system is developed in small increments. Safety standards, on the other hand, assumes that every requirement is defined in the beginning of the development. In practice, writing requirements afterwoods is very frustrating for anyone. The development of safety related software need additional levels of skill in addition to those needed by other types of systems. Especially, in higher levels of safety integrity, additional time, effort and special knowledge and experience are needed.

Agile methods apply to embedded systems software development relatively good. Especially beneficial for safety development are the features of continuality: “continous refactoring”, “continous communication within the development team”, “continous measuring and planning”, and “continous testing”. However, “continual and extensive communication with customers” is not in convenience with safety related development.

4.3.5 Development of risk-informed requirements specification process of software

Requirements specification is the most fundamental phase of software design. Therefore, the development of the requirements specification process is considered to contribute significantly to the quality of software. The report examines aspects related to developing the requirements specification process of safety-critical software. The consideration is made both from technical and expert interaction point of view.

The choice of the objects to be developed and the evaluation of the applicability of the harmonized standards to the company's activities require critical and thorough consideration. The report introduces procedures which help in developing the company-specific risk-informed requirements specification. The focus is on procedures which are based on the support provided by standards and risk management. These procedures make it possible to improve the traceability of requirements specification and to facilitate the identification of those requirements which are critical from the safety point of view. The suggested procedures are the application of the harmonized standards to the design process and to requirements specification, and, in addition, the integration of quality management system and risk management as part of the design process.

The requirements specification process is considered also from the viewpoint of different parties' interaction, see Figure 19. The requirements are formed as the outcome of the experts' interaction. Therefore, the knowledge transfer between the experts, representing different disciplines, influences prominently the success of the specification process. The report examines the significance of knowledge transfer in the formation of software safety. In addition, procedures are introduced which help in enhancing the experts' mutual understanding. Enhanced mutual comprehension facilitates the integration of multidisciplinary expertise in the requirements specification projects and in the risk management of software engineering.

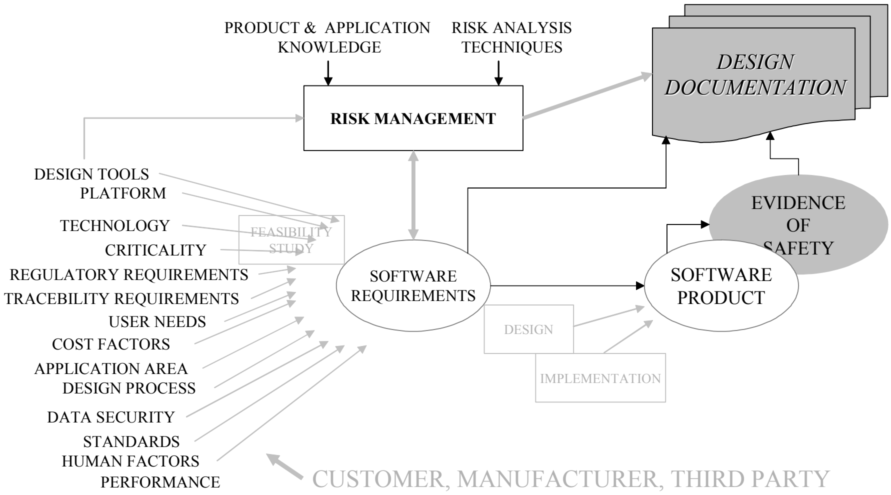

Figure 19. The requirements specification of the software depends on several factors.

4.3.6 Dependability Control Model

In practice the balance between adding new functionality and focusing quality assurance is determined by feedback. To limit the growth of complexity is one of the main objectives to build Dependability Control Model, DCM.

The main reason to changing software is to increase functionality. The functional growth is related to satisfaction of stakeholders. Changing environment gives feedback pressures to change application software features. The software must be adjusted to its application environment after changing its requirements specification. Changing can affect functionality, performance or correctness during every phases of software development. The basic idea of this fundamental principle is that the feedback pressures cause inconsistency between the software and its operational domain making the software proned to errors. The need for continuing adjustment and progress is fundamental to application and embedded software. The progress is achieved in a feedback driven and controlled maintenance process. If the adjustment to the new situation is not satisfactorily succeeded, the software in execution declines with time.

The software development team operates in an organisation, which goals are beyond the completion of the software to be developed. The organisation has to ensure by checking that operational rules are followed and goals are met. These checkings give positive and negative feedback controls that can be utilised in assessing growth and stabilisation mechanisms. Parameters of the stabilising control dynamics are the concequences of a large number of managerial and development decisions. After a while this control system directs the growth and development characteristics of the evolving software.

Although assessment of software reliability has been researched for many years, and several methods and techniques have been developed, software developers are not interested in reliability in practical software development projects. In spite of assessing reliability, they develop the software and test it so long time that it will apparently have no errors. This distinctly means that the used approaches for developing reliability estimation models and methods are not the correct approaches, and for corresponding to increasing complexity of software new approaches are needed. Models and methods should be of that kind that they lie on the background of software development projects. With the support of the models and methods, it should be possible for software developers to assess at early phases of development project that the plans of the project are sufficient to achieve the reliability target of the software.

Dependability Control Model (DCM) is a system theoretical model based on control state-space descriptions of software development, see Figure 20. The objective of DCM is to model such kind of system equations with which developers and quality assurances are able to predict stability, controllability and observability of software system. The idea behind this is the selection of the right methods that are appropriate exactly for special environment. The modelling is based mainly on evaluation results of software processes and in addition on special information about the available software artefacts.

We reviewed the state of the art of some new theories and practices included software stability, concept of software testability as attributes controllability and observability. The theme of “software stability” is a new subject that has been under research for a couple of years. The main principle of it is to devide software development to multi-level portions according to the permanence of the software (business, application, etc.).

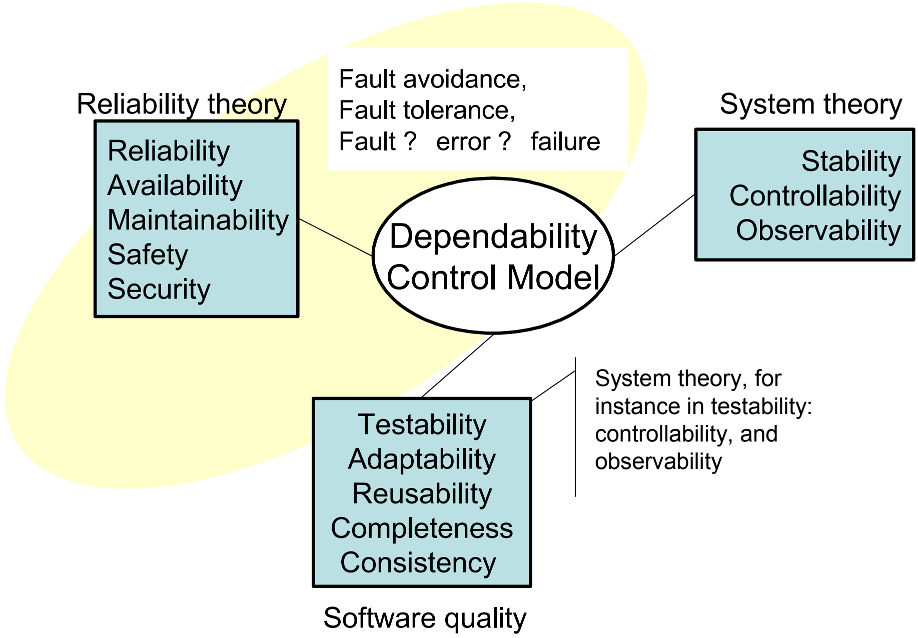

Figure 20. The idea of Dependability Control Model.

4.3.7 Conclusions

The research carried out in the Safety and reliability -technology theme showed that there is today increasing industrial interest and need to find better tools for improving safety and reliability of products and production systems. However, the area is difficult, because often the problems can not be solved by developing technology alone. Different kinds of aspects should be taken into account. Systems approach including human-technology interaction is needed. Developing safety and reliability requires usually interdisciplinary approaches and solutions.

When starting the theme the most potential areas in technology and industry that offered potential safety and reliability improvements were evaluated, and compared with requirements and priorities in Finnish industry. This formed the basis for R&D project generation. Tree utilization areas were identified: machines and equipment, processes, and transport and logistics. Research carried out has been focused on three areas: life cycle management of production systems, human-technology interaction and safety, and new technologies and operating principles. The research groups that comprised the theme network consisted of high-level experts in the fields of safety engineering, risk assessment, industrial mathematics, modelling, simulation, material science, mechanical engineering, software engineering, psychology and biotechnology.

The theme developed general methdologies and approaches to improving safety and reliability in industry. In some selected areas new methods and tools were both developed and demonstrated. The new technological research results were applied to plants, machinery, equipments and procedures in energy production, pulp and paper industry, mining industry, and road and marine traffic. It was very clear from the beginning of the theme, that it is necessary to study the whole sociotechnical system if we want to accomplish a remarkable enhancement to the safety and reliability of industrial systems.

Aim of the theme was to bring together VTT's qualified research groups and high-level specialists in this field. From the very beginning this was seen very important benefit. Various research groups had been doing similar kind of research in different research institutes of VTT. Bringing researchers from various research areas and units in contact with each other, both in actual research work and at the meetings and seminars has an impact on lowering the threshold of cooperation between the research units. This has increased mutual understanding, and even caused an enthusiastic atmosphere already when planning the projects in several workshops and think tanks. However, obtaining the level of a real synergetic collaboration requires a high personal regard for each other and a strong appreciation of the imprortance of the networking. Networking with the best partners and enhancing co-operation out of VTT was promoted in all projects, but even more effort is needed before the acceptable level has been reached.

For many of the participating companies the theme did give an impulse to focus more on safety and reliability. The results of the projects have already led to the start up of several new research projects utilizing the results and the cumulated knowledge and networks. For example, the development of the self-diagnostics of machine systems will be continued in the technology program for the Finnish Defence Forces. Many results are particularly applicable to process industry, and users of mobile machinery as well as to the machine manufacturers and maintenance service providers though not restricted to only those sectors.

Some projects increased the general awareness of the importance of these aspects and existing technical possibilities. Understanding of the limitations of the drivers in road traffic supports the designing of the traffic systems. Research on the work of the vessel traffic service operator showed that taking the human operator into account when planning the operating procedures and surroundings can increase the safety and reliability of the whole system.

Several examples show, that the level of controlling reliability and measuring safety is not yet at the level that users and society require. Industry is needing more comprehensive safety metrics. Some recent examples in Finland show that even many systems of the critical infrastructure do not satisfy the requirements of the consumers. Many unsolved problems and unusual potential technical possibilities remain to be utilized for mprovements in safety and reliability.

It is clear that this topic needs to be continued as a joint research and industrial R&D activity due to its important socioeconomic impact on safety, reliability and availability both enterprise and society levels. Suitable areas for future research work would include, for example, measuring safety, controling system reliability, implementation of reliability in organiszations, diagnostics and prognostics, human impact on safety and reliability, and reliability data collection.

During the latest years increased empasis is directed to public safety and aspects of security. Several very large and complicated systems of society might be vulnerable in security sense. This kind of systems are, for example, telecommunication systems, electricity networks, and energy systems.

References

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4.4 Risk assessment of Genetically Modified Organisms (Raija Koivisto & Antti Alavuotunki)

4.4.1 Objectives

The overall objective of the project was to develop a "Continuous risk assessment" framework for the risk assessment of genetically modified plants to help the plant developer to manage the risks during the whole development cycle of the plant. This includes the development of risk assessment tools for different stages of the genetically modified plant's development cycle and for the ecological risk assessment.

4.4.2 Methods used

The risk assessment process is comprised of the following steps:

- goal definition
- hazard identification
- incident/accident modelling (scenario identification)
- consequence & probability assessment
- risk estimation
- risk assessment.

From the results quality point of view, the hazard and scenario identification are crucial: if a hazard, which may contribute heavily to the total risk, is being ignored, the entire resulting risk assessment may be worthless. New technologies pose a special challenge for hazard identification in general.

The approach in this study was based on the fact that risk assessment always is a case-based study. Systematic hazard identification methods were developed to check all the possible interactions of the genetically modified organisms with the environment (people, nature, equipment, etc.) in each phase of the plant breeding. The identification is made by applying the developed search pattern into the developed model of the case. The possible scenarios were then developed and a rough classification system was developed to rank the consequent risks.

4.4.3 Main results

The main result of the work was the idea of "continuous" or "evolving" risk assessment procedure, which should be applied when developing new organisms, or new technologies in general. In the case of genetically modified plants, the evolving assessment can be demonstrated by Figure 21.

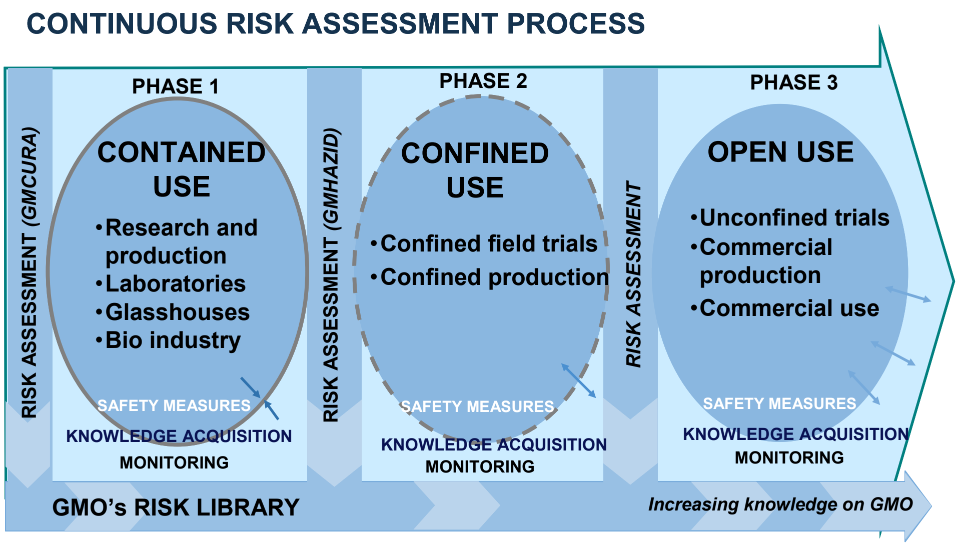

Figure 21. Evolving risk assessment of genetically modified organisms.

There clearly are three different phases in the plant breeding cycle:

1. contained use, which may be in a laboratory or in a green house
2. limited use, may be a field trial or a controlled industrial production
3. open use on the field or in the industrial production.

A hazard identification and risk assessment method called GMCURA was developed to assess the risks in the contained use. GMCURA has two important points of view: the possible interactions between the GMO and the surrounding specific environment, and the possibilities for the GMO material to escape from the confined space. When analysing the interactions there often are questions, which can not be answered using the currently available knowledge. Hence, the important result of the analysis is the identification of the knowledge, which will be needed for the reliable risk analysis of the GMO under testing. The lacking knowledge should be obtained during the breeding phase before the plant can be used openly on the field. The same principle should be applied to the development of any new technology: before spreading the product in the market, the risks should be properly assessed.

The GMCURA method was published on the website of the Finnish Advisory Board of Gene Technology operating under the Ministry of Social Affairs and Health. The Ministry of Social Affairs bases its guidelines on the GMCURA method when giving instructions on how to perform the risk assessment for the applications for the confined use of GMOs.

The risk assessment for field trials, the GMHAZID method, was developed by VTT already earlier and published by Koivisto et al. in 2002. The open use risk assessment (for plants) may be an application of the GMHAZID method developed for field trials.

4.4.4 Potential impacts

The GMCURA method is already being used as the basis in the guidelines of the Ministry of Social Affairs for stakeholders who are preparing an application to the competent authority for the confined use of GMOs. Moreover, an application of GMCURA for the confined use of genetically modified micro-organisms was prepared as well and used as the basis for the corresponding guidelines.

In the more general context, the developed evolving or continuous risk assessment approach is relevant in case of all new developments, may they be new technologies or new services.

4.4.5 Conclusions

There has been a lot of debate on the risks due to the novel gene technology during the past ten years. However, little has been done to develop proper risk assessment methods. Mostly these developments have been based on a global (not on a case based) view, which makes the problem unsolvable. The case-based approach, which limits the width of the problem, is a practical start to gain information and, moreover, to identify the required but lacking knowledge. The developed evolving risk assessment approach offers systematics to analyse the case.

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5. Conclusions

The research carried out in the Safety and reliability -technology theme showed that there is today increasing industrial interest and need to find better tools for improving safety and reliability of products and production systems. However, the area is difficult, because often the problems can not be solved by developing technology alone. Different kinds of aspects should be taken into account. Systems approach including human-technology interaction is needed. Developing safety and reliability requires usually interdisciplinary approaches and solutions.

When starting the theme the most potential areas in technology and industry that offered potential safety and reliability improvements were evaluated, and compared with requirements and priorities in Finnish industry. This formed the basis for R&D project generation. Tree utilization areas were identified: machines and equipment, processes, and transport and logistics. Research carried out has been focused on three areas: life cycle management of production systems, human-technology interaction and safety, and new technologies and operating principles. The research groups that comprised the theme network consisted of high-level experts in the fields of safety engineering, risk assessment, industrial mathematics, modelling, simulation, material science, mechanical engineering, software engineering, psychology and biotechnology.

The theme developed general methdologies and approaches to improving safety and reliability in industry. In some selected areas new methods and tools were both developed and demonstrated. The new technological research results were applied to plants, machinery, equipments and procedures in energy production, pulp and paper industry, mining industry, and road and marine traffic. It was very clear from the beginning of the theme, that it is necessary to study the whole sociotechnical system if we want to accomplish a remarkable enhancement to the safety and reliability of industrial systems.

Aim of the theme was to bring together VTT's qualified research groups and high-level specialists in this field. From the very beginning this was seen very important benefit. Various research groups had been doing similar kind of research in different research institutes of VTT. Bringing researchers from various research areas and units in contact with each other, both in actual research work and at the meetings and seminars has an impact on lowering the threshold of cooperation between the research units. This has increased mutual understanding, and even caused an enthusiastic atmosphere already when planning the projects in several workshops and think tanks. However, obtaining the level of a real synergetic collaboration requires a high personal regard for each other and a strong appreciation of the imprortance of the networking. Networking with the best partners and enhancing co-operation out of VTT was promoted in all projects, but even more effort is needed before the acceptable level has been reached.

For many of the participating companies the theme did give an impulse to focus more on safety and reliability. The results of the projects have already led to the start up of several new research projects utilizing the results and the cumulated knowledge and networks. For example, the development of the self-diagnostics of machine systems will be continued in the technology program for the Finnish Defence Forces. Many results are particularly applicable to process industry, and users of mobile machinery as well as to the machine manufacturers and maintenance service providers though not restricted to only those sectors.

Some projects increased the general awareness of the importance of these aspects and existing technical possibilities. Understanding of the limitations of the drivers in road traffic supports the designing of the traffic systems. Research on the work of the vessel traffic service operator showed that taking the human operator into account when planning the operating procedures and surroundings can increase the safety and reliability of the whole system.

Several examples show, that the level of controlling reliability and measuring safety is not yet at the level that users and society require. Industry is needing more comprehensive safety metrics. Some recent examples in Finland show that even many systems of the critical infrastructure do not satisfy the requirements of the consumers. Many unsolved problems and unusual potential technical possibilities remain to be utilized for mprovements in safety and reliability.

It is clear that this topic needs to be continued as a joint research and industrial R&D activity due to its important socioeconomic impact on safety, reliability and availability both enterprise and society levels. Suitable areas for future research work would include, for example, measuring safety, controling system reliability, implementation of reliability in organiszations, diagnostics and prognostics, human impact on safety and reliability, and reliability data collection.

During the latest years increased empasis is directed to public safety and aspects of security. Several very large and complicated systems of society might be vulnerable in security sense. This kind of systems are, for example, telecommunication systems, electricity networks, and energy systems.

Appendix 1: Research projects in the theme

Research projects, project managers, and their contact information

1. Focus area: life time management of production systems

Systems analysis in management of plant lifetime and production safety (SYSTELI)

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Management of safety and reliability knowledge during the life cycle of mobile work machines (FI-TOOL)

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Monitoring and diagnostics – Lifetime management of mobiloe machinery (LIIKKUDIA)

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2. Focus area: human-technology interaction (HTI) and safety

Development of a human-centered design methodology for human-machine systems (METODI)

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Offshore VTS for the Gulf of Finland (VTS)

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New human-centered method for the design of mobile work machine user inerface (CABIN) (year 2004)

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3. Focus area: New technologies and operating principles

Driver vigilance monitoring with minimum obtrusiveness by means of machine vision and EMFi and other technologies (SYKE)

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Trusted Software Technology (TRUST) (years 2004–2005)
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Risk asesssment of genetically modified plants (GMORA) (years 2002–2003)
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4. Coordination

Coordination project
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Appendix 2: Publications prepared in the theme-projects

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Journal articles

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Abstract

"Safety and reliability" has been one of the four strategic technology themes of VTT during 2001–2005. Technology themes are research programmes initiated and financed by VTT. In this theme, technologies, system models, and measurement, modelling and estimation methods have been developed for the Finnish industry's needs. The results have been applied to the development of safety and the lifecycle management of socio-technical systems. In the theme, particularly the following expertise, and knowledge areas have been utilised and developed: safety engineering, risk management, system engineering, machine diagnostics and monitoring, psychology, microbiology and management of safety and dependability knowledge. The research in the theme has been focused on: methods for life cycle management of production systems, human-technology interaction (HTI) and safety, and new technologies and operating principles.

This report describes the research carried out and the main results obtained in the Safety and reliability technology theme.

Keywords
reliability, safety engineering, risk management, system engineering, machine diagnostics, life cycle assessment, human factors, microbiologial safety, safety management, dependability

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