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Integration of User-Centred Design and Product Development Process within a Virtual Environment

Practical case KVALIVE

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Abstract

User-Centred Design (UCD) is an approach which aims to improve the management of human requirements in the Product Development Process (PDP). The main aim of this approach is to incorporate the users more closely into the development process already in very early phase, in order to obtain direct clarifications on the specification requirements and immediate feedback from them. A significant drawback observed in the application of this approach was that it had typically not been integrated into the companies' business processes.

The aim of this research study was to integrate a theoretical PDP and UCD within a Virtual Environment (VE). The integrated process was tested in one industrial case study – the cabin development of an underground loader. Feedback about the process and virtual simulator was gathered from engineers and loader drivers. Their feedback was mainly positive, however further research about the closer integration of UCD into the real PDP is required.

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Preface

This VTT Working Paper introduces results that are part of the research projects "KVALIVE – Qualitative methods in virtual design of machines" and "CoF – Cabin of the future". The KVALIVE project was funded by Tekes, VTT and VSF, and was part of MASI Modelling and Simulation 2005-2009 research programme. Coordinated by Lappeenranta University of Technology (LUT) over the period 2008–2009, the KVALIVE project included researchers from VTT and Tampere University of Technology (TUT). Launched in 2009, CoF is a VTT funded strategic research project, which aims to generate a next generation multi-sense cabin simulator, together with a human-machine system (HMS) development methodology.

The aim of the KVALIVE project was to propose novel methods and tools for the development of human operated mobile machines. The methods utilise tools such as real-time simulation, visualisation, haptics and motion platforms. The project attempted to take a significant step towards developing a system in which the test drivers are able to participate in the R&D process by operating dynamically adequate virtual prototypes through virtual interfaces that making use of haptic tools. The research work of VTT in the KVALIVE project was mainly focused on the integration of the User-Centred Design (UCD) approach in the Product Development Process (PDP) by utilising virtual environments (VEs) and simulators.

Future developments will involve the application of simulators and the UCD for design processes in both Fimecc's "Energy and life cycle cost efficient machines" (EFFIMA) programme in the LEFA (New Generation Human-Centered Design Simulators for Life Cycle Efficient Mobile Machines) project and in VTT's funded strategic research COFEX (Cabin of the Future – User Experience) project.

We would like to thank all the contributors, project members and steering group members of the KVALIVE and CoF projects.

Tampere, February 2010

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Appendix D: Virtual Environment System

1. Introduction

Human-Technology Interaction (HTI) and Human Factors (HF) (i.e. ergonomics) are presenting user-centred (human-centred) perspectives to technological innovation and development, especially to interactive system development (see Appendix A). User-Centred Design (UCD), usability, or safety, are not isolated issues of design in the Product Development Process[1] (PDP), because they have significant relevance and effect to the economic success of technical products and services (see Appendix B). Moreover, they actually have a close connection with the Information and Communication Technologies (ICTs), access and availability of information, and connections in people's everyday and working activities. Modern working machines' interfaces require increasing simultaneous functions, and a profound comprehension of working processes and work contexts. Tackling these situations seems to necessitate the involvement of actual users much earlier in the PDP (Norros *et al.* 2003, Määttä *et al.* 2005) with challenges:

- "How to improve communication between designers and users, and other involved and interested parties, in the product design development process?"
- "How to increase the exploitation of user knowledge?"
- "How to ensure, within the same concurrent development cycles and design tasks, the balanced product and the user-centred ways of thinking efficiently?"

Virtual Environments (VEs) have been used in PDPs as a supporting tool to accelerate and increase the efficiency of the product development. VE technology, human models and simulators provide an opportunity to use USD and participatory design to acknowl-

[1] Actually New Product Development process, but here used more general form of term because of about 75% of design is indeed redesign.

edge human needs and requirements already in early phase of the design process (Appendix C).

This study aimed to develop the UCD's procedural tasks (Helin *et al.* 2007) further for the cabin interfaces in movable machines and vehicles by implementing the UCD into the design process. The objective was to develop and evaluate the applicability of the VE in the different process steps and cycles between PDP and UCD.

A new instance of the UCD is introduced that aims to integrate the theoretical design methods in PDP and UCD, together with the practical use of VE facilities and applications. This study shows the means and ways for user input and the work process -related information to be used more efficiently in the development and design of user interfaces (UIs) in cabins of mobile working machines. The most crucial methods and data sources (from the user's point of view) in this particular application area are also presented. These points are highlighted with narrative storyboards in order to elucidate the findings.

2. Material and methods

The methods used for processing the industrial study case issues are introduced briefly in the context of the UCD in order to understand the integration of the two separate processes, namely the PDP and the UCD as a process. The introduced methods were selected for addressing the issues raised within the study case. As the most appropriate methods are dependent on the case at hand, the following methods can be seen to represent typical examples rather than a regular set.

2.1 User-Centred Design and Human Factors methods

The user-centred design (UCD) approach is a model in which human factors are of central concern within the design process. This design approach connects user requirements, user goals, and user tasks as early as possible into the design of a system, when the design is still relatively flexible and when changes can be made at less cost (Salvendy 2006). UCD highlights the needs, wants and limitations of users. A number of methods can be used in UCD – e.g. checklists and guidelines, observations, interviews, task analysis and physical and mental load assessments.

The standard "Human-centred design processes for interactive systems" (ISO 13407: 1999) introduces human factor design activities. There are four UCD activities (Figure 1) that should take place during all interactive systems development processes:

- understand and specify the context of use
- specify the user and organisational requirements
- produce design solutions
- evaluate designs against requirements.

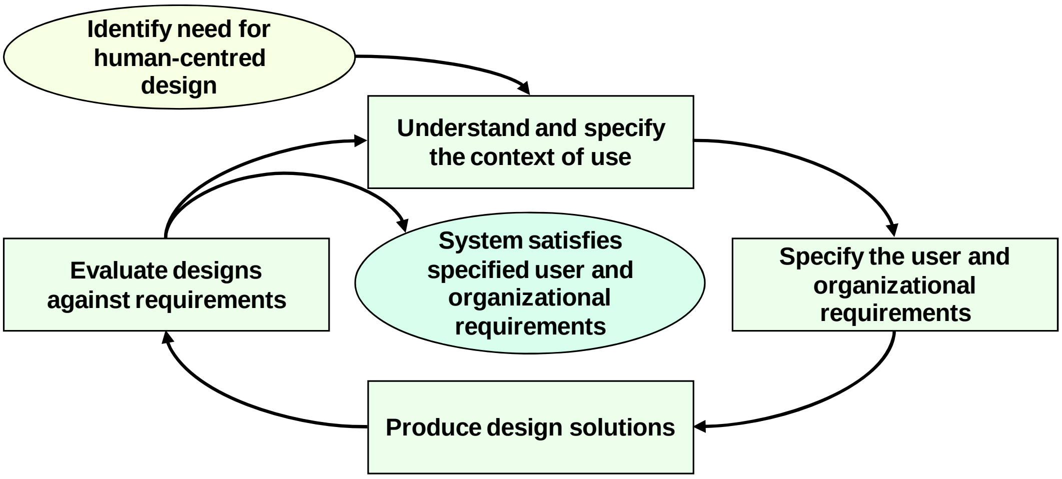

Figure 1. The interdependence of human-centred design activities. (ISO 13407:1999)

In HumanICT (Helin *et al.* 2007), the ISO 13407 standard was applied in vehicular working machine design with VEs. It highlighted the combination of these aspects (i.e. UCD, VR/VE systems, and the design process) and the synergistic possibilities they raise when used together. The use of a VR/VE system especially raises new possibilities to exploit UCD, and it can more easily be adapted to the traditional design process.

VR/VE systems, 3D models and simulations make it easier to identify and recognise human physical and cognitive needs in a working environment. Simulation also provides possibilities for investigating and developing UCD-based approaches. There are a variety of ways in which the set of usability, ergonomics, and human factors can be considered while the PDP is in progress. In this context there are also a set of methods that can confer a high priority to processing the needs, requirements, and specifications of the product. The users, however, definitely need to commit to the process. Example methods include:

- participatory approach in design and development
- problem solving
- user interviews, questionnaires and observation
- task analyses and planning
- motion and postural analyses
- usability and safety analyses.

2.1.1 Participatory approach in design and development

The participatory approach in design and development is a procedure in which the users, (workers of a production process or machine operation) are presented with an opportunity to influence to the content of design target. They are assumed to be motivated into participation and committed (will consider their own work now or in the future) to influence the design and development of a new product or process.

In the participatory approach, some or all of the workers who will work, for example, at a forthcoming plant, take part in a number of development and design sessions and meetings during the different design phases (Mumford 1989). The participatory approach "spans a rich diversity of theories, practices, analyses, and actions, with the goal of working directly with users (and other stakeholders) in design of social systems" (Muller & Kuhn 1993). According to Hirschheim (1989), participation increases: (1) quality of design results, (2) commitment, (3) work satisfaction, (4) efficiency of training, (5) efficiency of production, and (6) participation as a value in itself.

How to apply?

Participatory design can be used, for example, in the concept design phase to generate product concepts. In this case study, a VR/VE systems was employed to help the users visualise the product, in order to make it easier to discuss. Trials were also held in the VE to test different parameters of the targeted object. Moreover, users were encouraged to give feedback to the designers, and to have discussions together with designers and other experts about the product design concepts/solutions in order to support the designers as much as possible.

2.1.2 Problem solving

Problem-solving is an essential part of design, development and learning. It is a process usually introduced as a cycle of several phases starting from confronting an unsatisfactory condition, and systematically proceeding until the implementation of the solution. There are obvious similarities, and synergies, with development and learning process cycles (Experience-Evaluation-Comprehension-Application), or with a human action cycle, or seven stages model of activity (Goal formation-Execution-Evaluation). Problem-solving may be introduced as the following cycle phases (Norman 1988, Dekker 1995, Engström *et al.* 2005, Ellis & Levy 2008):

1. confront the need state of the established practice
2. shape and understand challenges and contradictions
3. frame and define the problem
4. collect and research information to hypothesise alternatives
5. synthesise and seek solutions
6. work out and refine solutions
7. test and evaluate solutions
8. implement, apply, regularise, and share the solutions.

Some of the problem-solving techniques that have been widely used in the different types of problem-solving cases follow:

- *Abstraction / Generalisation / Use of a model:* investigate and solve the problem in a model of the system and subsequently apply it to the real system.
- *Analogy / Map / Search / Research:* use solutions to analogous problems, employ existing ideas or adapt existing solutions to similar problems.
- *Brainstorming / Decomposing / Solve a simpler problem / Recombining:* groups of people suggest solutions or ideas, combine and develop them towards an optimum, or break down a problem into smaller, more well-defined problems.
- *Sub-goal / Means-ends analysis:* choose an action at each step to move closer to the goal.
- *Reduction / Pattern recognition, matching:* transform the problem into a problem that has solutions.
- *Hypothesis testing / Eliminate possibilities:* assume a possible explanation to the problem, then prove or disprove the assumption.
- *Root cause analysis:* eliminate the cause of the problem.
- *Lateral thinking:* approach solutions indirectly and creatively, using both reasoning and intuition for creating new ideas.
- *Method of focal objects:* synthesise clearly non-matching characteristics of different objects into something new.
- *Morphological analysis:* assess the output and interactions of an entire system.
- *Trial-and-error / Guess and check:* test possible solutions until a solution is found.

How to apply?

A prerequisite for problem-solving involves the formulation of a well-articulated problem statement that constitutes the basis for the work to solve it; thus problem finding and shaping, and framing necessitate revising a question so that the solution process can begin or continue. A well-articulated problem is the basis for development work to resolve the confronted unsatisfactory situations. This is typically done by using a participatory approach to share knowledge and skills, generally by applying the brainstorming and other related types of techniques. Problem-solving is commonly used by users when they are for the first time familiarising themselves with the interfaces in order to interact with machines. Thus, understanding the role of problem-solving and the different techniques that can be applied is important in designing interactions and interfaces for machines.

2.1.3 Interviews, questionnaires and observations

Questionnaire, interview and actual observations were among the methods used for collecting and compiling valuable information on different targeted subjects, objects, phenomena, and any other relevant issues.

Questionnaires: Questionnaires are a way to collect information quickly, inexpensively and from a broad area. When using questionnaires, the target groups should be known in order to be able to formulate relevant questions for each of the groups. Questions can either be in an open or closed form, depending on what kind of response is desired. In open questions, a respondent can freely write a response, while in closed questions the respondent needs to choose from a set of predefined options (e.g. a, b, c, or d). While closed questions can more easily be statistically analysed, open questions tend to provide more qualitative feedback.

Interviews: Interviews can be formulated in a variety of ways, either structured (closed questions) or quite freely formulated (open questions; themes), but it is important is to decide beforehand as to what issues are to be addressed and the desired outcome of the interview in order to maintain the focus throughout. Interviews can be executed with only one interviewee at each time, or instead with a group of interviewees. Examples of interviews include team interviews, focus groups, or puzzle interviews.

Observing: Observation is a method for data and information collection of human activities while they are working. There are a variety of observation approaches and it is important to be conscious of whether the observer may affect (disturb or change behaviour/activity) the subject (non-systematic, or systematic observing and indirect observing/self-reporting). Obviously the aim is not to manipulate the subject, or at least affect as little as possible, and observing is often also done while interviewing the target.

Contextual inquiry: Contextual inquiries are a good way to collect information in real time situations – it combines both interviews and observation. In contextual inquiries, the user is the expert and the interviewer is the student, who observes and asks questions. In this way it is easy to get knowledge about how the product is used, related problems and perhaps also development suggestions. It also reveals hidden work structure. (Beyer & Holtzblatt 1998.)

How to apply?

In the investigation of PDP, and specifically in the context of UCD, the use of questionnaires, interviews, contextual inquiries and observation provides valuable information. Such methods can be applied at different phases of the PDP in order to collect different kinds of information; not only in the planning and concept development phases, but also during all the later phases (e.g. system-level design, detailed design, etc.) depending on each development case's requirements and needs.

Examples of how they were applied in the study cases include: (1) context of use and user requirements can be collected with these methods in the very early phases of the PDP, especially in the concept design phase when identifying customer needs, (2) also user experience and use cases based information from previous product generations can be collected, and (3) while using VR/VE simulation, simulators, or mock-ups, the observation, interview, contextual inquiry and questionnaire methods were used for collecting and compiling the desired information.

2.1.4 Task analyses and planning

Task analysis covers techniques that are used by ergonomists, designers, operators and assessors to describe and evaluate human-machine and human-human interactions in systems, and to document the information and control facilities used to complete the task. Task analysis is therefore a methodology which, when supported by a number of techniques to collect, organise, and use information, enables various judgements or design decisions to be made. Task analysis approaches are used for integrating human elements into system design and operations in areas such as safety, productivity, availability, allocation of functions, person specification, staffing and job organisation, user interface, skills and knowledge acquisition, and performance assurance. Task analysis is especially used for system design and evaluation during the whole system life cycle, and also when a particular human-machine system (HMS) performance problem is to be analysed and resolved.

The purpose of task analysis is to describe a task's goals, disaggregate the task to describe the sub-tasks, provide an overview plan of how a task is accomplished, and to characterise the included activities, together with a description of what an operator is required to do to achieve the desired goal. One of the most common task analyses is Hierarchical Task Analysis (HTA). HTA decomposes tasks into subtasks and repeats this process until the desired level of subtasks has been reached. Relationships between a set of subtasks also generally exist, and they are typically governed by plans (e.g. complete sequentially, or if X then Y). (Salvendy 2006.)

Task analysis forms a basis for the task planning, which also is a desirable result for usage within the PDP phases.

How to apply?

Task analysis creates a basis for many of the other methods exploited in this study because the tasks in most of the methods were required to create the structure for categorising the specific details and their linkage to each other. HTA can be used in the early phase of the design process, e.g. in planning, to understand and specify the task and the context of its use. It yields information about the goal of task and details about the subtasks that need to be performed. It also is the basis for the user and task requirements. HTA can be furthermore be used later in design phase, e.g. when testing a product in a VR environment.

2.1.5 Motion and posture analyses

Motion and postural analyses are helpful for making assessing the user's motion (speed, acceleration, forces, etc.) in different positions of the motion. Postural analysis checks the physical stressing of the user in a specific posture. Links (visual, aural) between humans, and between humans and machines, in order maintain control over machines may be checked using link analysis.

RULA: The Rapid Upper Limb Assessment (RULA) developed by McAtamney and Corlett (1993) is method for estimating the risks of work-related upper limb disorders. The method evaluates people's exposures to postures, forces and muscle activities that have been shown to contribute to repetitive strain injuries. It was developed to detect risk factors to the worker that deserve further attention. (McAtamney & Corlett 1993.)

REBA: Rapid Entire Body Assessment (REBA) was proposed by Hignett and McAtamney as a means to assess posture for risks associated with work-related musculoskeletal disorders. REBA has been developed to be especially sensitive to the type of unpredictable working postures found in health care and other service industries. (Hignett & McAtamney 2000.)

OWAS: Ovako Working posture Analysis System (OWAS) is a method for the evaluation of postural load during work. The OWAS method is based on a simple and systematic classification of work postures combined with observations of work tasks. The method can be applied, for example, in the following areas: (1) development of a workplace or a work method, to reduce its musculoskeletal load and to make it safer and more productive, (2) planning of a new workplace or work method, (3) ergonomic surveys, (4) occupational health surveys, and (5) research and development. (Karhu *et al.* 1977.)

Link analysis: Link analysis is a method for developing an arrangement of objects in relation to each other – humans, between humans, between machines, or between humans and machines – and identifying the best configuration. The criteria can be the minimum distance, fewest movements, or any better link between two points. The link is used here to refer to any connection (e.g. talk, visibility, or messages) i.e. talk links, visual links, control links. The link should possess some desired level of quality in order for the system to function/operate efficiently – the link value can be estimated by multiplying the frequency rating by the importance rating (Woodson 1981).

How to apply?

Posture analysis can be used in many phases of concept design: to identify customer needs, generate product concepts and test product concepts. The use of posture analysis can generate human requirements for the product (e.g. seat must be able to rotate). When generating product concepts, posture analyses can be used for comparing different design solutions in VR, for example, with human models. When testing the product concept, it is beneficial to analyse the users in simulators to evaluate their posture while they complete the required tasks.

Link analysis provides information concerning the visibility of targeted work objects – i.e. such objects within galleries in a mine, for example, for which interface elements, and other controlling devices may be needed.

2.1.6 Usability and safety methods

The usability of the target is evaluated by testing it on real users, and is usually carried out during development phases and for approvals. Usability inspection actually involves a set of methods, and involves an evaluator inspecting the target – it is generally used early in the development process to evaluate system prototypes or specifications.

Pluralistic walkthrough: The pluralistic walkthrough is a usability test method for conducting an early design evaluation. A group of users, developers, and human factors engineers typically meet in order to step through a set of tasks, by discussing and evaluating the usability of a system. The method does not require a working prototype, so the designers normally obtain early performance and satisfaction data directly from the users before any functional prototype is available. For the current investigation the system was an existing machine, and the purpose for the design was to improve the visibility from the cabin. Instead of studying paper printouts, VE modelling was used to introduce and assess new means to improve the coverage of visibility.

A group, consisting of representative users and system designers, together evaluate new design ideas by performing a series of tasks that represent the proposed system use. Usability practitioners(/human factors engineers) facilitate the work as walkthrough administrators and guide users through simulated tasks. Developers and other members of the product team address concerns or questions about the interface, thereby allowing system designers to obtain valuable information about the users' tasks in addition to the comments on the introduced design ideas. (Bias 1994, Riihiaho 2002.)

Heuristic evaluation: Heuristic evaluation is best used as a design phase evaluation technique because it is easier to address many of the usability problems that arise at that time. The evaluation requires that some kind of system description is at hand, e.g. from something like a set of storyboards that provide a quick overview of the system, to a fully functioning system that is in use in the field.

Heuristic evaluation is a method for structuring the critique of a system using a set of relatively simple and general heuristics. It aims to identify any problems associated with the design of UIs. A heuristic is a guideline, or general principle, or rule of thumb that can guide a design decision, or be used to critique a decision that has already been made. The approach demands that several independently working evaluators evaluate a system against potential usability problems. Nielsen's experience indicates that around 5 evaluators usually results in about 75% of the overall usability problems being discovered. (Nielsen 1994.)

Work Safety Analysis: In work safety analysis, the work under surveillance is broken down into a sequence of steps, after which the hazards and their causative factors in each phase are identified. Finally, proposals for improvements are made in order to eliminate or to reduce the hazards. The use and achievable results of the work safety analysis are illustrated through an example of a maintenance task at a paper machine. The most significant advantage of work safety analysis is that the hazards can be identified before the occurrence of any accidents. Moreover, the work safety analysis provides a general view of immediate accident risks related to the object being scrutinised. As one limitation, it can be mentioned that hazards that arise from a complicated sequences of events, and by operator errors in controlling tasks, are not systematically covered by the work safety analysis – other methods of safety analysis would be needed. However, if these limitations are recognised, the work safety analysis can form a firm basis for planning safety improvements.

How to apply?

Usability methods are used to analyse the different usability properties of a cabin interface. The information is used to support the selection and development of these solutions with the aim to eliminate the identified problems. Safety analysis provides basis for developing cabin safety issues and, for example, on how to safely use the loader in different mining environments.

2.2 Product Development Process (PDP)

PDP is the term used to describe the process of bringing new products to market. It may include phases of market surveys, idea and concept generation, system engineering, detailed design, and also preparation for production. The report of the Konemasina project (Lehtonen *et al.* 2006) introduced summing-up of known product development methodologies, as well as the challenges of adopting them to a companies' business: The first actual methodology for product development was published by Hansen (Hansen 1965). In this methodology, the product development project was divided into clear and distinct phases. In the 1980's, several design process models were presented (e.g.

Andreasen & Hein 1987, Pahl & Beitz 1977, Hubka 1987). These methods presented the product development as an algorithm, in which the goal was generally to improve product development.

In the 1990's design process models were extended to cover production, quality and economic issues (e.g. Pugh 1991, Pugh 1996, Ulrich & Eppinger 1995). The applicability of design process models has been criticised because a universally applicable PDP is deemed not to exist. Instead, the theoretical models can be used as reference models which can be adapted to a company's business (Andreasen & Hein 1987). The PDP, however, requires modifications and optimisation when novel CAE tools (like VEs) are integrated to it.

This paper introduces a way of integrating UCD into a generic PDP, and how VEs and simulators can best be utilised. The generic PDP (Figure 2) of Ulrich and Eppinger (Ulrich & Eppinger 2004) was chosen to be the generic model as the basis for the integration, because of its relatively wide familiarity in Finnish mechanical engineering.

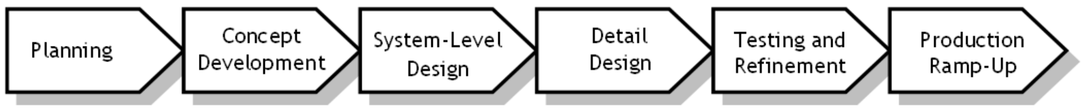

Figure 2. The generic PDP (Ulrich & Eppinger 2004).

The six phases of the generic PDP (Ulrich & Eppinger 2005) are:

Planning: Precedes the project approval and launch of the actual PDP. This phase begins with corporate strategy and includes assessment of technology developments and market objectives. The output of the planning phase is the project mission statement, which specifies the target market for the product, business goals, key assumptions, and constraints.

Concept Development: In the concept development phase, the needs of the target market are identified, alternative product concepts are generated and evaluated, and one or more concepts are selected for further development and testing. A concept is a description of the form, function, and features of a product and is usually accompanied by a set of specifications, an analysis of competitive products, and an economic justification of the project.

System-Level Design: The system-level design phase includes the definition of the product architecture and the decomposition of the product into subsystems and components.

Detailed Design: The detailed design phase includes the complete specification of the geometry, materials, and tolerances of all of the unique parts in the product, and the identification of all of the standard parts to be purchased from suppliers.

Testing and Refinement: The testing and refinement phase involves the construction and evaluation of multiple preproduction versions (prototypes) of the product.

Production Ramp-up: In the production ramp-up phase, the product is made using the intended production system. The purpose of the ramp-up is to train the workforce and to identify any remaining problems in the production processes.

How to apply?

In the practical study case KVALIVE, the focus was on the two first phases (Planning, and Concept Development) of the Ulrich & Eppinger's (2004) theoretical general PDP.

2.3 Virtual Environment Systems

In this study, a VE system for cabin design was established. The VE system (Figure 3) consists of several subsystems:

- visualisation
- user interface devices
- audio system
- physics simulation
- recording system.

The calculation of the physics, visualisation and device management were distributed over three computers. Communication between subsystems was handled throughout by the Virtual Reality Peripheral Network (VRPN). Also real devices were connected via the VRPN to this VE system. These devices included:

- motion platform
- tracking system
- input devices like joysticks
- steering wheel
- pedal
- buttons
- haptic devices
- data gloves, etc. (Aromaa *et al.* 2009).

Figure 3. Virtual Environment system for Cabin design used onsite at VTT.

The fundamental idea behind the established VE system was that it was relatively low cost, easily re-configurable, and the immersion level was reasonable enough for, for example, designing a cabin. A more detailed description is provided in Appendix C and D.

In the research study, the VE system was utilised for three main purposes:

1. adopting users into the UCD process of the HMSs
2. gathering qualitative feedback from the users in order to enhance UIs
3. getting real human control commands for virtual prototyping.

2.4 Study case KVALIVE technical material

The case study material centred around the creation of the VE for representing the actual usage of the Sandvik Toro 7 ™ underground loader at the test mine (located in Tampere, Finland). In order to create the virtual representation of the environment, a 3D model of the test mine was first needed. This initial model was preliminarily used in the physics simulation engine, from where it was subsequently converted and retextured for use in the VE software. The physics engine utilised a reduced model of the mine and rock particles, while the visualisation was performed with high detail 3D objects. This material included the mine itself and the rock particles with which the underground loader works.

The preparation of the "Toro 7" material included conversion and retexturing of the original working machine CAD models. In order to ensure that VE software axis difference was taken into account, the conversion process involved additional coordinate system changes. The "Toro 7" simulation model consisted of 20 separate components – for controlling the physics simulation of the underground loader, and visualisation. Outside of physics calculation was visualization of the cabin of the loader, what was imported from Sandvik CAD system. The cabin model was abridged accordingly in order to comply with the VE system's visualisation capabilities – certain hierarchical changes and groupings were performed to form interface resources. These interface resources were used as a component library to generate possibilities for cabin layout design changes.

After the 3D environment with complete loader was imported to the virtual environment, the physics engine had to be connected in order to reposition all the loader components according to the position and orientation data. The process was performed by 3 custom Building Blocks in Virtools 4.1 ™ that communicated with the simulation machine through the VRPN. The communication included a separate interface for the rock particles, the loader, and for sending control data to the physics engine. Other functionalities of the VE were also created on the Virtools side – including a digital human model addition for visibility and reaching estimations, and a user activity log for recording the user's head position for further analysis of the loading activities.

3. Results

The focus in this study was on the planning and concept development phases of the product process introduced by Ulrich & Eppinger (2004). The practical study case KVALIVE targeted only the very early phases of design, because of limited resources. It is important to note that the practical forms of application and implementation of the introduced theoretical product process may differ widely depending on the specific company. Therefore, further research into the integration of UCD and PDP should be conducted in order to confirm the validity of the findings.

3.1 Concept for the integration of Product Development and User centred Design Processes in practice

The main result of the work centred on the concept for the integration the UCD and the PDP, in practice, within a VE. The standard ISO 13407 (1999) (Figure 1) and Ulrich & Eppinger's (2004) PDP (Figure 2) were used as the basis for the integration of UCD and PDP. The approach behind UCD is based on an iterative process and it can be used in different phases of the PDP. However, the current company situation and its needs must be considered when applying the approach, as the use can vary widely between companies. Figures 4 & 5 show examples of how UCD and PDP can be integrated. The generic PDP is described at the top of the figures, followed by an expansion of the detailed planning phase (Figure 5) or concept development phase (Figure 6). The UCD's four steps are then related to the expanded component description, indicating how those steps can be connected to the PDP, along with examples of HF methods that can be used in those phases. Describing this integration associates tools to acknowledge ergonomics and user requirements, for designers, and it also suggests what kind of methods could be used in certain phases.

Figure 5 shows how the planning phase and UCD can be integrated. The planning phase has similarities and similar needs to UCD's first two steps (understanding and specifying the context of use, and specifying the user's and organisational requirements).

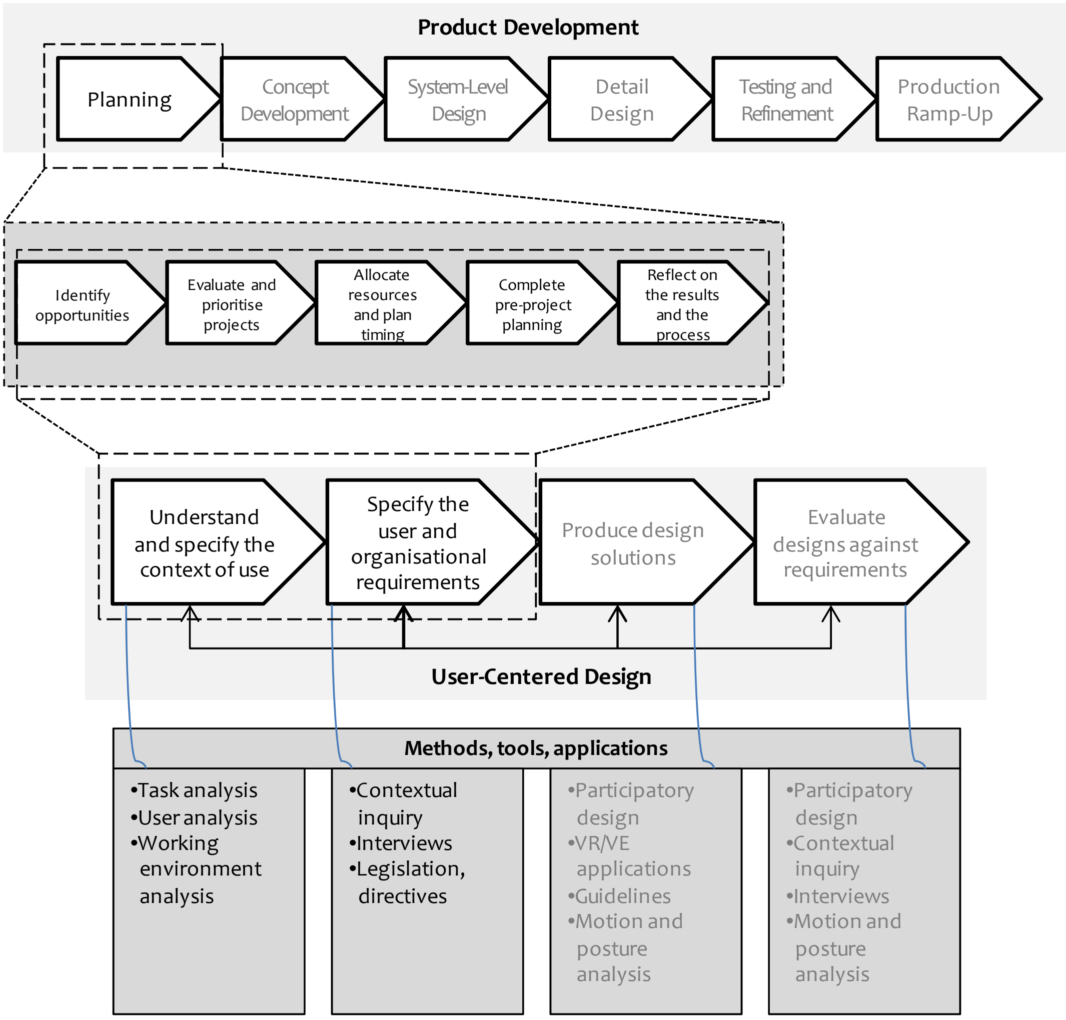

Figure 4. Diagram of integration of UCD and planning phase of PDP tasks.

In the concept development phase, all four steps of UCD can be incorporated into the PDP quite easily. The first step of UCD (i.e. "understand and specify the context of use") is perhaps simply more of a planning phase in PDP, but it may also be needed in the concept phase. The other three steps of UCD are quite similar to the steps in PDP, but they always highlight the user approach.

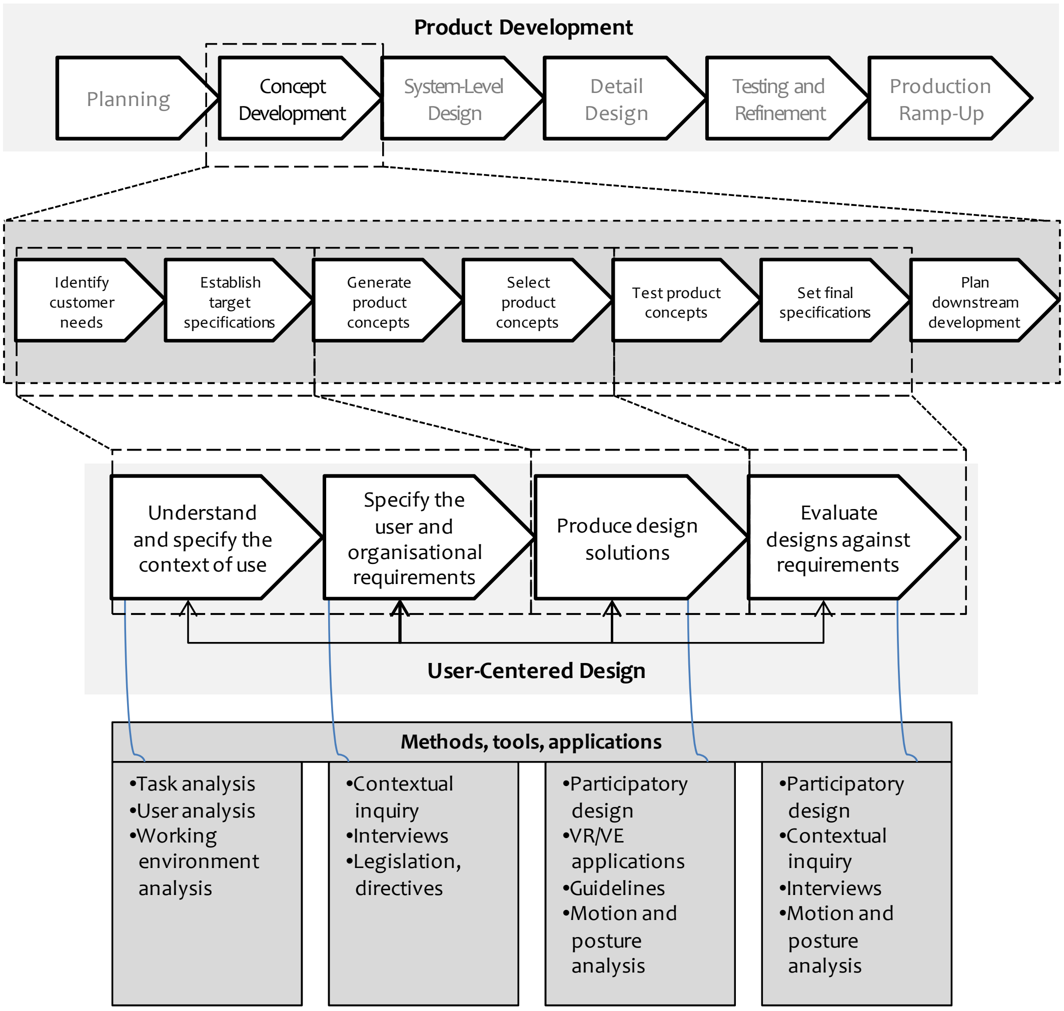

Figure 5. Diagram of integration of UCD and concept design phase of PDP tasks.

In order to show this integration in practise, a storyboard approach has been used. Storyboards provide a reader with concept of the immersion into developing and testing situations by exploiting UCD approach integrated with the PDP, and usage of VEs. The purpose is to help raise the understanding, and more specifically provide the means to improve the comprehension of the phenomena, events, and main findings that will take place during these situations.

Product development often fails to communicate the context of how the product will be used. Users in different situations will tend to use products in different ways and from different starting points. It is important to keep in mind that these storyboards are only examples and that there are many other important scenarios and paths that these examples do not address.

3.2 Storyboard of case study: Planning phase

The following storyboard introduces how the planning of the cabin development project progressed; i.e. its tasks and the people who participated during the workshop session and meetings. This is an example of how to integrate the planning phase of product development with UCD.

PDP tasks:

planning the targeted development project

UCD tasks:

understand (and specify) the context of use and specify user and organisational requirements

People involved:

Manager, Chief Engineer, Designer(s), Expert(s) on Safety, Expert(s) on Health Care, User(s)

VE models and functionalities:

use of existing CAD models/drawings of the cabin and the entire machine (and similar VE models of other machines)

Methods used:

Interview, Contextual Inquiry, Task analysis, Participation, Problem-solving, CAD, existing VE models.

<table>
<tr><th colspan="2">Chain of events – situations and their constituent parts:</th></tr>
<tr><td rowspan="2">

Figure 6. Negotiation for establishing the cabin development project to solve the confronted problems.</td><td>1. Establish assigned development project.
a. Manager determines a project based on the chief engineer's introduced usability and HF-problems, and the estimated cost for development of a solution.</td></tr>
<tr><td>2. Because of the clear UCD-link identified, the chief engineer reserves resources and contacts, and selects people for design and development groups (Participation).
a. Chief Engineer calls experienced users, and experts on safety and health care into the development group.</td></tr>
</table>

	b. Chief Engineer calls (industrial) designers from the cabin design team and designers from chassis design team into the design group.
	3. Work out facts (Interviews, Contextual Inquiries, Task analysis). a. Both groups work under the supervision of the chief engineer. b. Groups meet a few times during the week to obtain the necessary facts on the problems in order to define the project goals.
Figure 7. Work out facts for the definition of targeted goals by using interviews and carrying out contextual inquiry in the real use environment.  	4. Visualise the problems and their impacts using cabin design models (Interviews, Contextual Inquiries, Task analysis, VE, CAD). a. User illustrates the problematic visibility while loading, driving and unloading tasks. b. Designer makes a presentation of the visibility problem.
Figure 8. Visualise the problems and their impacts using cabin design models.	5. Define targeted goals for project (Participation, Problem-solving, VE, CAD). a. Visibility is not sufficient for achieving the required work efficiency.

Outcomes and conclusions:

Development project was successfully established to solve the visibility problem of the cabin.

Integration of UCD to the PDP:

There are common tasks which can be solved concurrently taking into account both UCD and PDP points of view.

3.3 Storyboard of case study: Concept development phase

The following storyboard introduces how the concept development phase of the cabin development project proceeded; i.e. its tasks and the people who participated in the workshop session and meetings. This is an example of how to integrate the concept development phase of product development with UCD.

PDP tasks:

Concept Development.

UCD tasks:

Understand and specify the context of use, and specify the user and organisational requirements to produce design solutions and evaluate the designs against the requirements.

People involved:

Manager, Chief Engineer, Designer(s), Expert(s) on Safety, Expert(s) on Health Care, User(s) (Note: the user can also be a maintenance worker).

VE models and functionalities:

Use existing CAD models/drawings of the cabin and the entire machine (and similar VE models of other machines).

Methods used:

Interview, Contextual Inquiry, Task analysis, Participation, Problem-solving, CAD, existing VE models.

<table>
<tr><th colspan="2">Chain of events – situations and their constituent parts:</th></tr>
<tr><td rowspan="2">
Figure 9. Discussions about context of use and requirements.</td><td>1. Context of use.
a. Environment where the loader is used has a significant impact on the visibility, illumination is limited, dust and water vapour may exist, any protruding object in the loader may easily be damaged.
b. Workshops, discussions and task analysis (HTA) are used for determining the task to be completed.</td></tr>
<tr><td>2. Specify user requirements.
a. The user is the driver of the machine; they possess the required skills.</td></tr>
</table>

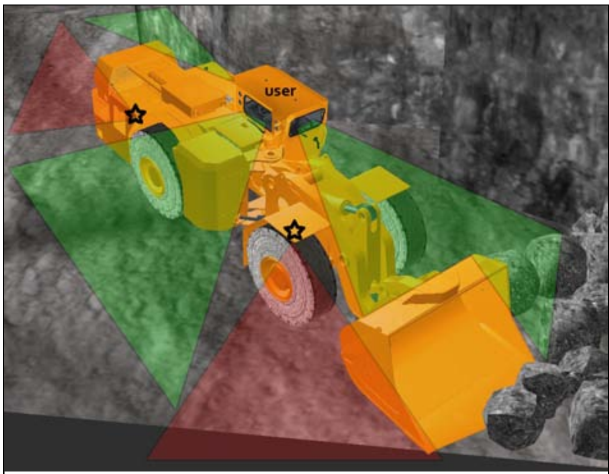

Figure 10. Visibility and blind spot areas.

b. Loading requires "seeing the rocks" going into the bucket, thus the user needs to see the bucket alignment wrt the ground when driving up to the pile of rocks. Visibility and blind spots in CAD model.
c. HTA provides information about the task; what is necessary to see and how often. These requirements come from the user and the task.

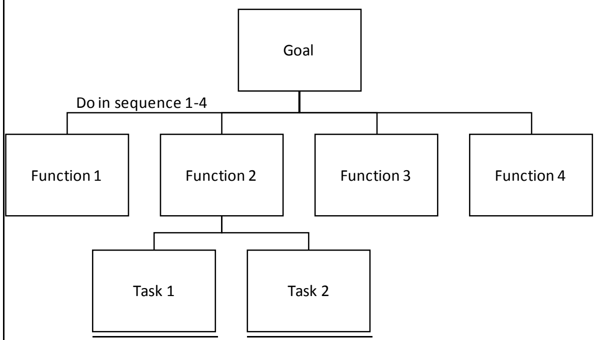

Figure 11. HTA table is helping defining requirements and needs.

3. Specify possible product and organisational requirements (e.g. in workshops).
   a. Loader's structural requirements wrt safety and maintainability regulations must be acceptable.
   b. Visibility system must be realisable without any unwanted side-effects.

Figure 12. Participatory design in VE.

4. Generate product concepts and select product concepts (Produce design solutions).
   a. Use CAD, VR/VE application tools to produce design solutions.
   b. Use participatory design to get important information from users and other specialists about the visibility (feedback from users).

Figure 13. Test and evaluate product concepts.

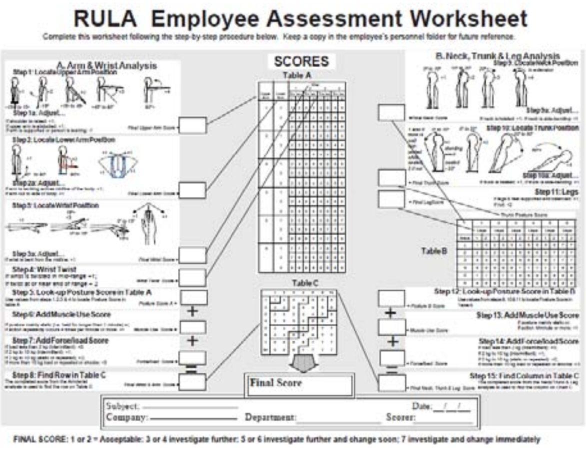

Figure 14. Analyse against requirements, e.g. with RULA-posture analyses.

5. Test product concepts and set final specifications (evaluate designs against requirements).
   a. Use VR to test and evaluate cabin design and visibility.
   b. The VE makes it easier to conduct trials, discuss, and to test different parameters of the targeted object.
   c. Use motion and posture analysis (e.g. RULA) to estimate physical load.
   d. Use participatory design approach to get feedback from different specialist groups (e.g. users, safety experts, designers, maintenance workers).

Outcomes and conclusions:

Development project established to solve defined problems of the cabin

Integration of UCD to the PDP:

There are common tasks which can be solved concurrently taking into account both UCD and PDP points of view.

3.4 Findings regarding the integration of the processes

There are many similar aspects (e.g. requirements) to consider in both processes (UCD and PDP), but usually the objects of the requirements differ (i.e. machine requirements and user requirements). Although there are similarities, the usual approach to PDP is still dominated by the technical aspects and human engineering will mostly be considered as supplementary. Unfortunately, this will mean that the integration is not intrinsic, but rather more through intervention. Moreover the continuity of the cooperation is uncertain and is highly dependent on the people who own the processes; their experiences and basic skills especially concerning human science expertise.

However this lack of cooperation might be partially overdriven, if establishing a kind of participatory planning process where both elements would be considered equally and at the same time to improve the quality of design process and the final product. Above all, it means that there are experienced, skilful (industrial) designers who have acquired education, information and knowledge about UCD, human factors, and usability and safety issues regarding the product development. Occasionally (design) managers also need to decide on requirements, design solutions and other such issues for which compromises are necessary.

A demand for common technical means also exists with regards as to how to share each participants' ideas and alternative proposals for solutions to make a shareable comprehension. VE is one of the most illustrative ways to share information between designers, industrial designers, users, and other involved personnel. Although the model or functional simulations or simulator facilities may not be perfect in all regards, such details do not necessarily matter as much as one could imagine. The users are mostly skilful persons and can use their experience to complete and consider such features which are not well developed or at a sufficiently high level. They typically provide strong feedback on such flaws and errors, but this comes with the territory and is indeed needed to direct the associated discussion and to attain the suitable level of knowledge sharing. Moreover, it is often even better that the first iteration intentionally has a low level of features in order to obtain feedback from the users on the really important (required and demanded) features. The focus of the design and development may then be more easily revealed.

The usage of VE is needed because it is common that designers are not able to get in real touch with their target product because of a lack (or low numbers) of prototypes or actual products for their usability testing. Moreover, it is important that designers are able to trial the product in an environment that is realistic, or similar, to the final intended use. It is also important to have the possibility to obtain feedback in a multimodal way by using all senses.

The most significant is, however, that VE provides a cost-efficient way to boost the knowledge creation and sharing simply by expanding the learning process with regard to the PDP's user-centred aspects.

4. Conclusions

Integration of UCD and PDP is important, because it is one way to ensure that Human Factors are acknowledged already in the early phase of design, which is critical for the development of ergonomic and usable products. The UCD and PDP integration described in this study is generic, as it is based on Ulrich & Eppinger's (2004) theoretical PDP. Only when the integration is actually done in the companies' design processes will the real problems and opportunities of integration be revealed.

Although the process integration was only on a theoretical level, the UCD approach and HF methods were used in one practical company case: Sandvik Toro loader cabin development. The integration and used methods were illustrated with storyboards – which successfully showed how integration was conducted on the practical level.

The integration study revealed that that there are similar kinds of elements to consider in both PDP and UCD. The reason why these two processes have been integrated is to highlight the user requirements and human factors in the design process. The PDP approach has conventionally been more technology and product -oriented. In the future, rather than having separate processes that need to be integrated, just one process would exist, i.e. a participatory planning process that incorporates all the relevant affecting elements (e.g. user, technology, and lifecycle).

5. Summary

Already since the mid-20th century numerous methods for modelling and developing the product developing process have been published (e.g. Hansen 1965, Andreasen & Hein 1987, Pahl & Beitz 1977, Hubka 1987, Pugh 1991, Pugh 1996, Ulrich & Eppinger 1995). It is commonly understood, that these methods and models are kinds of reference models, which need to be tailored and adapted for every company and value network that implements them in their product processes and product lifecycle management. Those methods and models are now relatively old, and obviously they do not therefore take into account progress in, for instance, novel virtual engineering tools, like virtual reality.

UCD is a approach which aims to improve the management of human requirements in the PDP. The main aim of these methods is to incorporate the users of the developed products or systems more closely into the development process already in very early phase, in order to obtain direct clarifications on the specification requirements and immediate feedback from them. A significant drawback observed in the application of these methods was that they had typically not been integrated into the companies' business processes.

The aim of this research study was to integrate a theoretical PDP (Ulrich & Eppinger 2004) and UCD method with the aid of VEs. The integrated process was tested in one industrial case study – for the Sandvik Toro loader cabin development. Feedback about the process and virtual simulator was gathered from engineers and loader drivers. Their feedback was mainly positive, although closer integration into the real product development process was understandably seen to be required, because only theoretical methods and processes principles were tested. The feedback concerning the technology maturity and the utilisation of the virtual simulator and VEs was encouraging. It was easy to see that virtual simulators and environments have a lot of money and time saving potential, because they enable the rapid testing of ideas and concepts and allow for more comprehensive decision making earlier in the product development phase.

The modelling of real companies' product processes, and the subsequent integration of UCD and VE into those processes, will be a promising research area in the future.

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Appendix A: Human-Technology Interaction (HTI), a challenge to design

HTI focuses on ways in which technologies mediate the interaction between the human actor and their environment. Norros *et al.* (2003) have defined HTI as follows: (a) HTI denotes the activity of a distributed cooperative system that the users and the technology form together with their physical and social environment; (b) The product aspect of HTI deals with artefacts for human-environment interaction; (c) The design aspect of HTI deals with ways of accomplishing the products.

Knowledge of good practices is known to help avoid most common design errors. The designer should be aware of the issues of importance to the user and the machine (a joint cognitive system), and should understand their needs and any usability problems they may experience. HTI design is mostly focused on the trouble-free operation of systems and services; while human factors seeks to "maximise safety, efficiency and comfort by shaping the design and operation of the technology to the physical and technological capabilities and social needs of the user". (Barnes 1968, Rasmussen 1986, Hollnagel & Woods 2005, Leikas 2009.)

Design process is still often technology-centric (i.e. done in terms of technology) although in some cases the users' points of views are taken into account; users are considered as 'users' of technology. Designers therefore determine what the users should be able to do at different phases when using systems, products and services. The right ways and the correct operations to be carried out in order to fulfil the tasks and to achieve the goals are thus determined by the technology; the usage of technology is also assessed in such terms as efficiency and accuracy. (Barnes 1968, Rasmussen 1986, Reason 1990, Hollnagel & Woods 2005, Leikas 2009.)

Technologies obtain their role in the context of our everyday life and work; to reach our goals, to progress more easily in life, or to carry out things that would otherwise be impossible. Technologies increasingly mediate the interaction in life and work, and thus become more difficult to design with regards to easy access and control. Technologies have intensified the demands on the development of interfaces in order to make interaction more functional, usable and meaningful for people. (Norros *et al.* 2003, Leikas 2009.)

The core issues that HTI may introduce to design are concepts of: (a) design, (b) user activity, i.e. user model, and (c) interaction between the design and use. Overwhelmingly, design is a piecemeal, specific, partial, iterative practice that must involve users. Hence, integration of the core issues into the PDP of HMSs is significant to provide correct navigation, meaning assignment and task accomplishment, and to prevent declination or missing of affordance in making use of the machine's functionalities intuitively in a proper and efficient way. (Norros *et al.* 2003.)

The core issue of HTI is to improve the usability and appropriateness of tools to be embedded meaningfully throughout the cognitive system. Thus HTI seeks to understand and support humans in their interaction with and through technology. (Norros *et al.* 2003.)

Appendix B: User-Centred Design introduces a new way of thinking

UCD is a multi-disciplinary activity which incorporates human factors and ergonomics knowledge and techniques. It demands a variety of skills and multidisciplinary teaming with roles such as: user, purchaser, manager of user, application domain specialist, business analyst, systems analyst, systems engineer, programmer, marketer, salesperson, UI designer, visual designer, human factors and ergonomics expert, human-computer interaction specialist, technical author, trainer and support personnel (ISO 13407:1999). UCD should become embedded in the organisation's culture and happens naturally as a part of any design process (Norros *et al.* 2003) – reasoning the decisions made, the alternatives considered and the reasons for accepting or rejecting them. The reasoning capability is part of the knowledge of any company.

It is important that the user companies, i.e. users have a clear goal and wish to participate as that will guide the producers and manufacturers development process. Specific user requirements should drive development, and the processes of identifying user needs. Thus, technologies and methods (in providing requirements specification, technical development and evaluation) should include not only user involvement, but also the designers' own ways of thinking and working, leaning to infer what this information means for design (Beyer & Holzblatt 1998, Savioja 2003). This contextual design approach offers means to comprehend and define user practices, and in order to improve the understanding of usage demand, far more comprehensive studies should be done in real situations.

The results of user testing should feed back into the design and technical development. The cycle of iterative development will help to facilitate the design of effective, usable, user-centred interaction concepts and interaction devices. There are many issues to be taken into account even when creating UIs in design processes (Helin *et al.* 2007). An iterative design and evaluation process is the key to the success of the end product. Although it is important to take guidance on technical, task and user constraints into account, the design process must also allow flexibility and facilitate creativity.

UCDs focus specifically on making systems usable (ISO 13407:1999); meaning the extent to which goals are achieved with usability measures: effectiveness, efficiency and satisfaction. The application of human factors and ergonomics to interactive systems design enhances effectiveness and efficiency, improves human working conditions, and counteracts possible adverse effects of use on human health, safety and performance. Applying UCDs to the product development of systems involves taking account of human capabilities, skills, limitations and needs (Savioja 2003, Helin *et al.* 2007).

Appendix C: Virtual Environments in New Product Development

Primarily to meet HMS goals needs user and technical apparatus to be compatible, thus first a user was modelled by a simple generic linear processing of information from perception to action (Norman 1988). Introducing CAD and VR/VE systems highlighted digital human models possibilities to handle foreseeable user-centred issues in the working environment (Järvinen *et al.* 1994, Viitaniemi *et al.* 1997). It was important to under-stand human variation in many circumstances. However, the lack of real interactions made these functionality based approaches inadequate when manual control is required. A real human's contribution and the real interaction seemed to be a prerequisite.

The effect of user participation seems to be, however, mainly indirect: (a) providing the possibility to participation, (b) improving the quality of requirements, and (c) thus enhancing the system quality. At the same time the effects of product development on the economic efficiency and time effectiveness were found to be contradictory. Major difficulties appeared in: (a) communication between designers and users, and (b) the exploitation of user knowledge in the design process. Consequently, far more comprehensive studies should be carried out in real situations, in order to improve the understanding of the demands of usage, and to facilitate the understanding of user practices. (Lanzi & Marti 2002.)

Simulators, and simulation-based models have for some time been quite common element in the context of VEs, and are applicable in the design process of mobile working machine cabins (Leino *et al.* 2002, Lehtonen *et al.* 2006). Simulators have been widely used to investigate the safety effects and driving abilities of drivers (Smith 2001, Bullinger & Dangelmaier 2003, Lee *et al.* 2003). The results have been found to be fairly consistent with the results obtained in real vehicles according to research (Santos *et al.* 2005, Engström *et al.* 2005) and thus can be justified; ensuring the safety of the subjects in high-risk conditions or environments (Bullinger & Dangelmaier 2003).

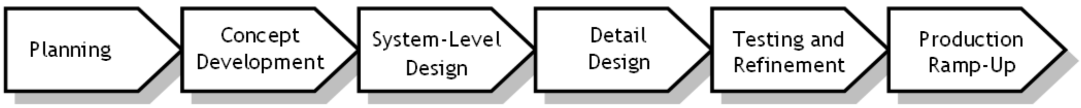

Figure C1. The generic new PDP (Ulrich & Eppinger 2004).

However, the practical new product development (NPD) process (similar to Figure C1) in companies should have specific links to process phases, functions, resources, etc. to accommodate user participation. Thus, NPDs should ensure that there are relevant channels in place to communicate problems that the users meet to the designers, in order to be able to improve future designs; i.e. participatory involvement virtual environment (VE).

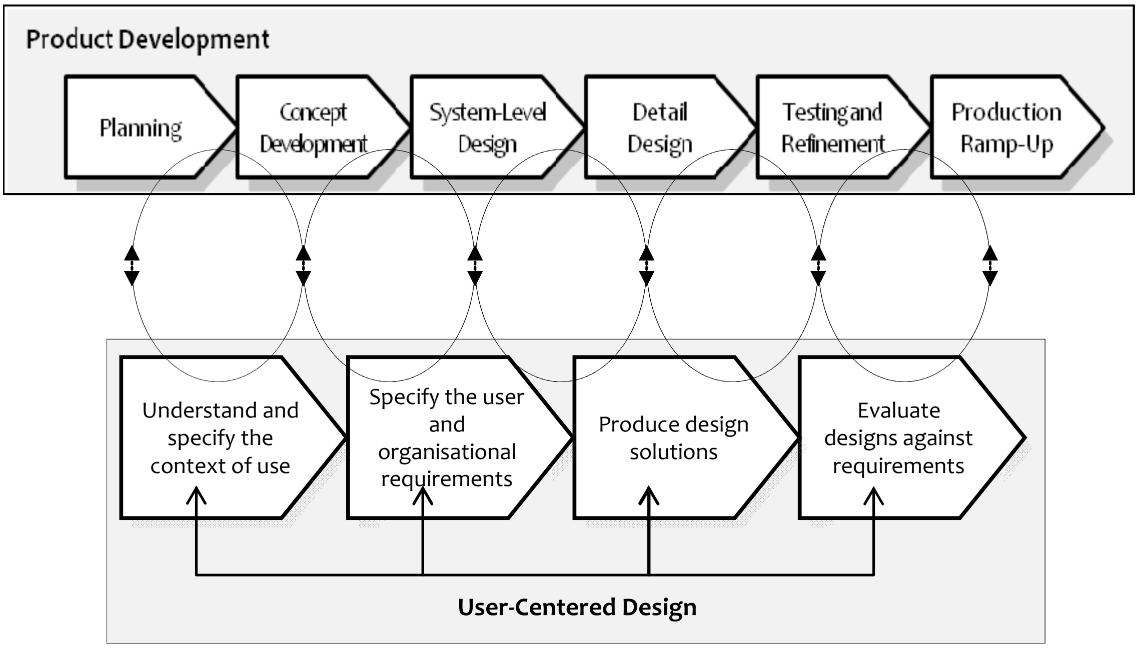

Figure C2. Links and channels between processes tasks should be continuous and regulated, working from a cyclic iterative basis.

It is generally agreed that the use of VR/VE systems can lead to a competitive advantage by accelerating and increasing the efficiency of the product development cycle (Määttä *et al.* 2003, Lind *et al.* 2008). Early user participation and VEs have had a positive impact on the user and customer satisfaction of different development or design cases (Helin *et al.* 2008). User participation and VEs in the early phases of NPD ensures that dynamic, ambiguities, and unpredictable matters are more likely taken into account, decreasing systemic usability problems in the final product or process (Viitaniemi *et al.* 2006).

Appendix D: Virtual Environment System

The visualisation system includes three 2.7 x 2.05 metre screens, three video-projectors and shutter glasses. The system enables a stereographic view to be portrayed in all three screens. Electromagnetic motion tracking enables the calculation of movements of the user's head and the correct viewing angle in the VE, as well as the control of the movements of the digital human model, which can be utilised in various HF analyses. The UI configuration is flexible, i.e. it is possible to connect different type of UI devices into the system. The devices can be real control instruments of mobile machines, or they can be, for example, gaming devices. Haptic UI devices enable the "touching" of virtual UIs. Also 5DT's data gloves can be used with this system. The calculation of physics, visualisation and device management are distributed in three computers. The functions and physics of the mobile machine can be simulated in real-time. The simulation models include mechanics, hydraulics, control systems, and the UIs of the machine. Some actions of the users can be recorded in order to analyse human factors.

Two main the cabin design simulator structures were tested in the project. For both structures, the user input was handled via the VRPN server. The user input can be via joysticks, pedals, steering wheels, a data glove or other input devices. Figure D1 presents the simulator structure where machines dynamics simulation has been calculated in Virtools. In this structure, the dynamics of the machine is not accurate enough for design purposes. Figure D2 presents a simulator structure where the machine's dynamics simulation has been calculated with an external PC and the simulation results have been transferred to Virtools via the VRPN. Also the user input to dynamic simulator has been handled via the VRPN. In this structure, the dynamics of the machine is accurate enough for design purposes.

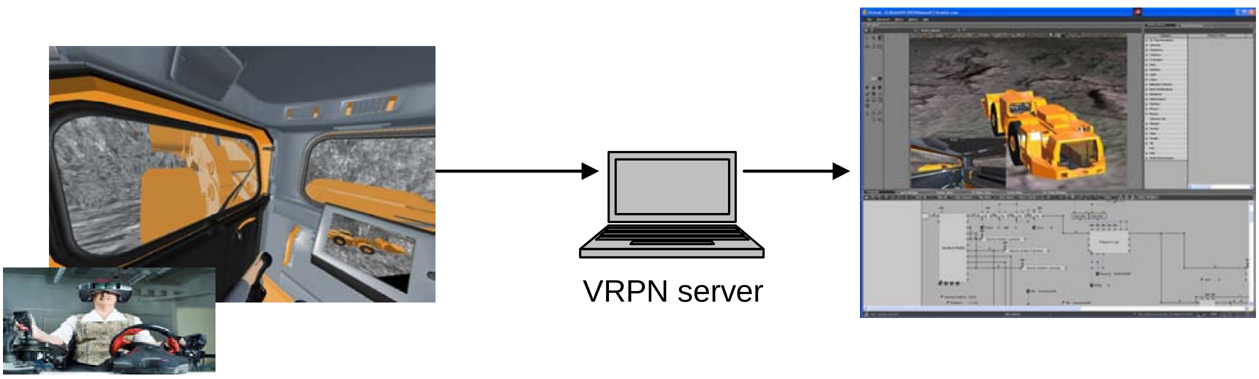

Figure D1. Cabin design simulator structure with Virtools dynamics simulation.

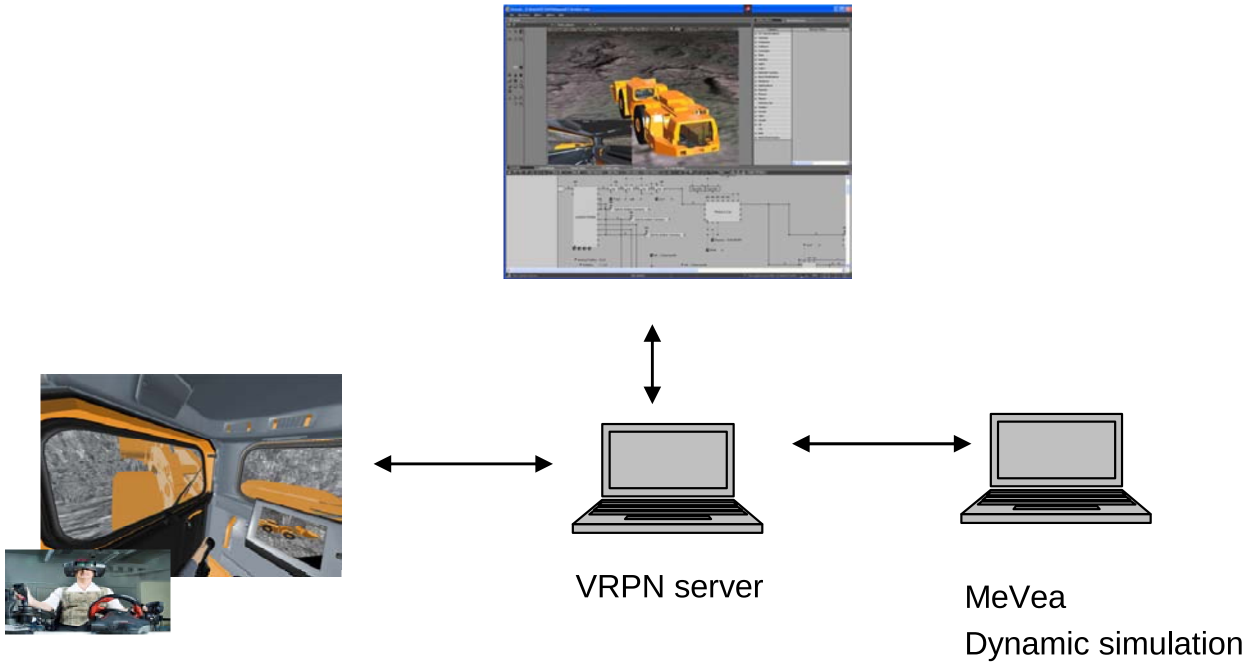

Figure D2. Cabin design simulator structure with external dynamics simulation server.

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