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INTEGRATION OF MANUAL WORK RELATED INFORMATION TO PLM

S. P. Leino, S. Lind, J. Heikkilä and O. Uuttu

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1. Introduction

Manual work relates to various work phases throughout a product's life cycle. For example, assembly, operation, maintenance, and recycling may require multiple, and various manual tasks. Such product features that affect on performing the manual work tasks can be managed most efficiently during the product's design phase. At that point, the designer can make changes that can greatly improve the possibilities to perform manual work tasks in a rapidquick, easy, safe, and cost-efficient way. However, gaining information from the various users has proved to be problematic, as the feedback information flows between the designer, and the user may be insufficient. Therefore, the designer may never receive any feedback from the operators, and other users along the life cycle. This can lead to unnecessary, and inintentional deficienies in product design, which can weaken product usability, and feasibility throughout the life cycle.

Virtual engineering tools, such as virtual reality, and virtual prototypes, provide the designers, and users a new media to communicate during product design, and use. They also enable analysis of product properties at an very early stage of design, so that the required, and unwanted properties can be identified. Although the tools have been proved to be effective in design process, the supportive process linking user feedback, and product design process has not been modelled for virtual engineering tools. This paper presents a proposal for such a supportive process. The paper aims to define, how information relating to manual work can be integrated to PLM. Focus is in system design view. In order to reach the aim, the following research questions are set:

- How virtual environments, and virtual prototypes can be utilized in capturing task related information?
- How relevant information can be captured to PLM?

The paper bases on two studies, of which the first focused on analysis, and development of maintenance tasks using virtual environments (Virvo study [Leino 2008], 2006 - 2009). The second study (Virtual Enterprise PLM Solutions, 2008 - 2009) aimed to define a process that describes product process information flow between the product designers, product users, and the other operations in company networks. The first project was coordinated by VTT, whereas the second study was company-driven by Eurostep. In this paper, "product" refers to any single system, or artefact that is designed solely. Respectively, "users" refer to the humans that are dealing with the product after the product has been designed, during its entire lifecycle. Thus, users include, among others, assembly personnel, operators ,and maintenance workers. Finally, "product data" includes the technical specifications of the product, specifications for development, manufacture, and maintain, and the types of materials that will be required to produce it.

2. Background

2.1 Manual work and Human Factors

Manual work is executed at many stages of product life cycle. For example in maintenance, manual work cannot be decreased substantially, as the tasks require basically always close human-system interaction. In every phase, manual work tasks should be possible to carry out safely, and effectively so that the required operation can be completed within the intended time frame. Therefore, required resources, such as time, workforce, and tools should be identified reliably. However, in many cases resource allocation can have several problems, which originate to poor task identification, or deficiencies in product data. Such deficincies can lead to unefficient use of resources, and work-related risks, as, for example, the work instructions may be improper, or even misleading, product maintainability can be poor, or the product is not used, or maintained in the intended way.

To avoid these kind of informational gaps, communication between the product designers, users, and work supervisors is essential. In the best case, the communication is active already during the desing phase, especially if a new product is being designed. Moreover, such communication is crucial in those cases when an existing model is updated.

In such communication, virtual engineering tools are proved to be effective (see e.g. [Laring et al. 1996, Määttä 2004]). They enable, for example, maintainability, and safety analyses, as well as a platform for task identification, and planning.

2.2 Virtual Environments

The virtual environment (VE) is a synthetic computer-generated representation of a physical system; a representation which allows a user to interact with the synthetic environment as if it were real [Kalawsky 1993]. For example CAD software enables just one-way interaction, i.e., it reacts to commands given by the user but it does not provide real feedback. VE aims to create artificial impressions, and sensations. VE techniques share common objectives, and characteristics such as interaction, autonomy, immersion, and determinism, and precision. A VE system consists of software, virtual models (e.g., geometry models, and digital humans), data communication, computers, display devices (monitors, immersive CAVEs), user interface devices, and other devices, and their drivers. Their installation depends on the application. [Mäkiranta 2009].

VE techniques are very potential in improving product processes. Many things can be designed, and tested without building expensive physical prototypes. In a virtual environment it is possible to arrange test programs which would be impossible with real system. For example dangerous situations can be simulated safely in VE. With using VE, it is also possible to gather feedback in early product lifecycle phase when it is still relatively easy to make changes in a system. Anyway, using VE in product development, and design process of a manufacturing company encounters several challenges. Firstly, VE is often a separated, and odd function without real connection to company's projects, and processes. VE is often also used by experts who are actually not involved in product development projects, and it is a function which is often outsourced to universities, or research institutes. Secondly, data flow from design, and engineering tools, like CAD, to VE systems is nowadays still often insufficient, as well as information flow related to usage, and exploiting of VE. This process including it's actors, tools, methods, and data/information is seldom well defined, and feedback information flow to PDM, and other systems is lacking.

2.3 Product Lifecycle Management

Product Lifecycle Management (PLM) is an integrated, information-driven approach comprised of people, processes/practices, and technology to all aspects of product's life, from its design through manufacture, deployment, and maintenance – culminating in the product's removal from service, and final disposal. [Grieves 2006] PLM is a holistic business activity addressing many components. Product data is just one component of PLM. Other components include the products themselves, organizational structure, working methods, processes, people, and information systems. Addressing

them together leads to better results than addressing them separately. The whole is greater than the sum of the parts [Stark 2006].
PLM is a paradigm, which can be seen as an enabler of efficient communication between actors (e.g. engineers, human factors experts, and workers) in complex product process, and VE is novel technology tool of PLM. PLM implementation needs practical guidelines how for instance human factors, manual work design, and VE can be integrated in company processes.

2.4 Requirements definition

This paper utilised a set of previously reported results (see Leino et al., 2008). The results based on interviews were conducted during the Virvo project between 2006 - 2009. The aim of the interviews was to determine the practices, and problems of service business, and maintenance work in the participating companies. The results from the interviews reported how manual work tasks are planned, documented, trained, and guided, as well as how the requirements of such work are taken into account in machine engineering, and design. In addition, the study delivered information on the needs, and requirements for improving planning, design, documentation, and guidance methods within the companies. In this paper, the findings from that study are used to determine the information flow between the users, and the designers.
According to the findings, the companies have expectations for better exploitation of the existing 3D models, and product data during the product life cycle, for example, in planning, training, and guiding maintenance tasks. Moreover, the requirements of end users, and maintenance workers must be observed in machine design, and engineering. Engineering disciplines, and system interfaces must communicate more effectively. There is also need for more automation in design process, life cycle management, and data/information management. Novel virtual engineering methods, and tools, such as digital human models, should be evaluated, adopted, and integrated into the design process, and product life cycle management. The requirements, and expectations discovered in company interviews can be grouped into three categories: 1) Product Lifecycle Management (PLM) philosophy adoption, communication, and product process development; 2) Product Data Management (PDM), and knowledge management development; 3) Technology utilisation of virtual engineering, etc.

3. Materials and Methods

The research method was based on industrial case study, where Virvo concept [Lind 2008], and process modelling with simulation games, were utilised.

3.1 VIRVO Concept

The approach to information flow modelling, and management, as presented in this paper, bases on the Virvo concept (see [Lind et al. 2008]). The concept connects product, and PLM data, and exploits user experiences. The concept includes task planning, and training in a virtual environment, which is updated through the database combining different types of data. The concept can be fulfilled with additional analyses, such as maintainability, risk, and task analyses. The usability, and feasibility for companies have been tested with industrial case studies [Lind 2008].
The Virvo concept is a description of how product lifecycle, product processes, product data, and product development, as well as product design can be managed. The procedures are descriptions of how manual maintenance work tasks can be modelled, planned, and evaluated using virtual engineering tools. The procedures consist also of instructions how to convert, and simplify 3D models, and how to use various supporting techniques in modelling, and building virtual environments, and simulators. Virtual engineering tools include, for example, computer software for virtual environments, and simulations. In the real world organisations, processes, and systems of enterprises are very different. In consequence, Virvo concept is a collection of common procedures, tools, and instructions, which must be customised for every company adoption. Thus, the Virvo concept is rather imprecise, and more detailed PLM process definitions are needed (see Figure 1).

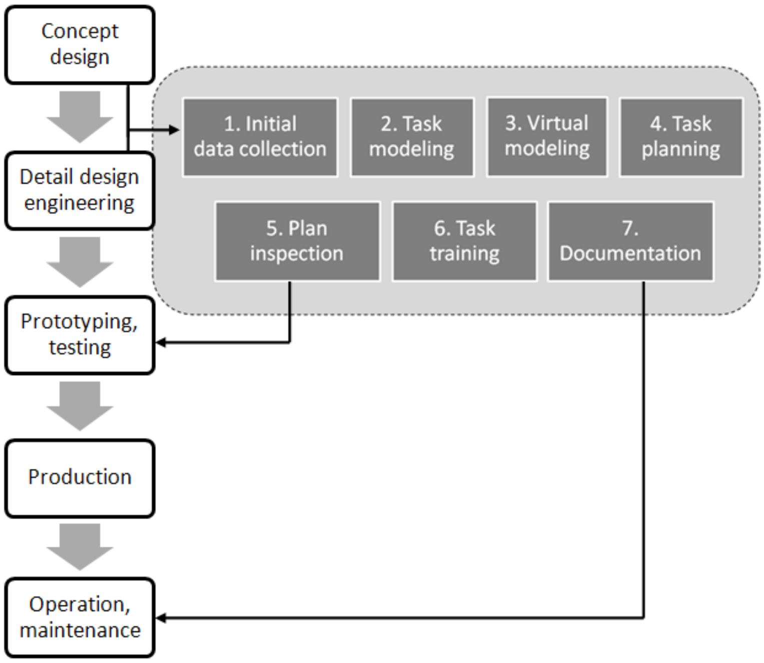

Figure 1. Illustration of the Virvo concept with seven steps and it's connection to simplified product process flow [Mäkiranta 2009]

3.2 Process modelling with simulation games

Simulation game sessions were used in modelling PLM processes which include parties from several organisations, departments, and functions. In this paper's context simulation game is defined as simulation of certain part of product lifecycle, and product process in order to model who are the parties, and functions involved, and what kind of data, and information is dealed between the parties. Simulation game sessions were played so that all needed parties of the modelled process were sitting around same table. Game sessions were led by a PLM expert, who also drew process flowcart simultaneously during the game. The modelled processes were related to using virtual environments in manual work task design, and the parties were engineers from a Company, and simulation experts as well as human factors experts from VTT. In simulation games, parties imagined how certain process would flow in reality, which function is the next actor, what kind of activities have to be done, and what data, and information should be stored after the activities. The purpose was not just to model the present processes, but to try to also define best possible processes for the future.

The PLM processes between different parties (users, designers) were modelled using Cross Functional Flowchart (CFF) of MS Vision software tool. CFF flowcharts show the relationship between a process, and the functional units (such as departments, or positions) responsible for that process. The functional units are represented by horizontal bands in the flowchart. Each shape representing a step in the process is placed in the band for the functional unit responsible for that step. In this paper CFF includes following elements: parties, process phases, process flow activities, information flow content, data storage, notifications, alternative flows, and decisions.

3.3 Industrial test case

Process modelling was done in a set of industrial test cases of the research study. The test cases were related to a Company's own product development project of a new generation mobile rock crusher (Figure 2). Aim of the industrial case and process modelling was to better adopt virtual engineering methods (VE, virtual prototyping) to product development and manual work planning processes, and to integrate them into PLM. During the product process, and product development project, virtual engineering methods are mainly utilized in so called review meetings. In those meetings development groups review current version of a product design, and give feedback for designers and engineers. The development groups consist of experts (e.g. designers, managers, ergonomics, workers) coming from

different disciplines and lifecycle stages. The feedback, and other results from a review meeting should be stored in PDM/PLM system.
Again, simulation games were carried out in test cases where a manual maintenance work tasks were planned during rock crusher engineering, and design. In the simulation games participants were three engineers from the Company together with two simulation, and one human factors experts from VTT. In the test case it was studied how virtual environment models can be built in VTT laboratory from CAD models from the company, and what data, and information related to maintenance work planning, and analysis have to be extracted.

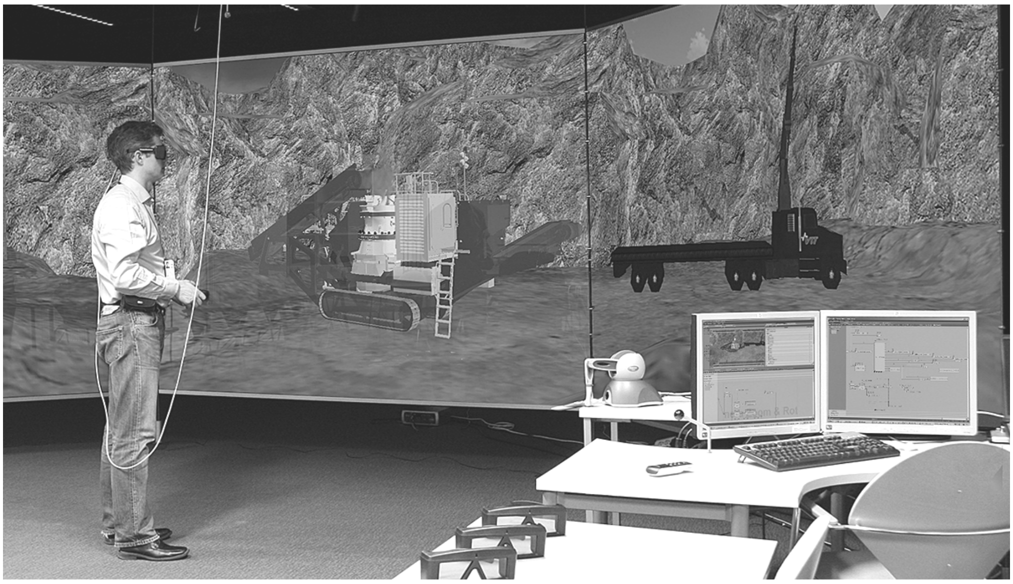

Figure 2. Virtual Environment model of the maintainability design test case

In the test case simulation game, and CFF modelling were applied in several phases of Virvo concept: 1. Initial data collection, 2. Task modeling, 3. Virtual modeling, 4. Task planning, 5. Plan inspection, and 7. Documentation. (Figure 3). The results data coming from simulation games and process modelling were reviewed and assessed by senior experts and managers of the Company.

4. Results

Simulation games, and CFF produced a PLM model which include 1) parties and processes between them, 2) tools and methods used in processes, and 3) output of processes i.e. stored models, analysis results, and other data and documentation. Figure 3 also defines how Virvo concept, and developed PLM model are integrated to a generic product process. Manual work task as part of machine system can be modelled in VE, and tested and reviewed virtually in prototyping phase (virtual prototyping). CFF model example (Figure 4) defines the parties of PLM process as well as stored data, and information in horizontal functional bands. It defines also how simulation process flows from start of the certain simulation process between parties, and what kind of process flow activities, notifications, and decisions happen during the process.
Figure 4 shows an example of CFF model which defines a collaborative networked PLM process of a simulation project. In this simple example, the parties are a Company, and VTT Simulation, and they use a networked PLM Database in order to share data, and information. Actually, inside those parties, there are several functions, and persons involved in this process. In the PLM process model, there is a process with input as specifications, and initial data of the project.
Based on the specifications, and initial data, VTT requests simulation data (e.g. 3D geometry models) from the Company. The Company delivers requested data into common database for testing its usability in building simulation models. When the data is acceptable, process continues to use case definitions carried out by the Company, and stored in the common database. When use case is ready, and in acceptable accuracy, it will be defined as a scheme model by VTT, and stored in the database.

When the scheme is accepted together, the actual simulation model building work begins. This model building is a iterative process, and it is reviewed many times together with VTT, and the Company, until the simulation model (virtual environment) is accepted by the Company. As a output, and result of this project process, a virtual environment simulation model together with needed documentation, and other data are stored in the common PLM database. The simulation model can be used for various purposes, for instance in manual work analysis process.

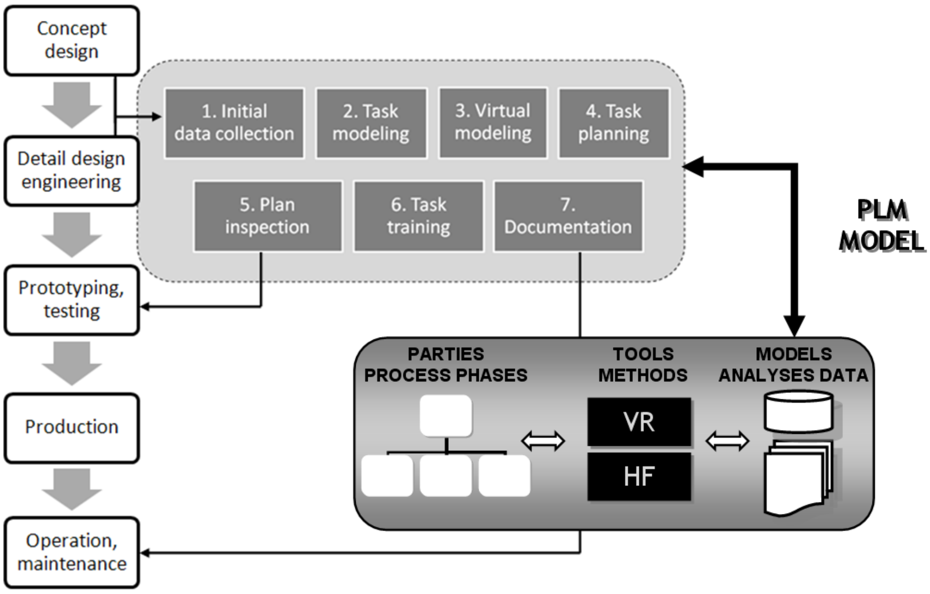

Figure 3. PLM model connection to Virvo concept and product process

Figure 5 defines a collaborative PLM process of manual work task analysis project. Virtual environment simulation model can be utilized in this analysis process. However, in some cases analysis process can be carried out without virtual environment, as well. In this analysis process, the parties are VTT Analysis, and the Company, and the used database is same as in previous simulation building process (Figure 4). This process also starts with project specifications, and initial data gathering.

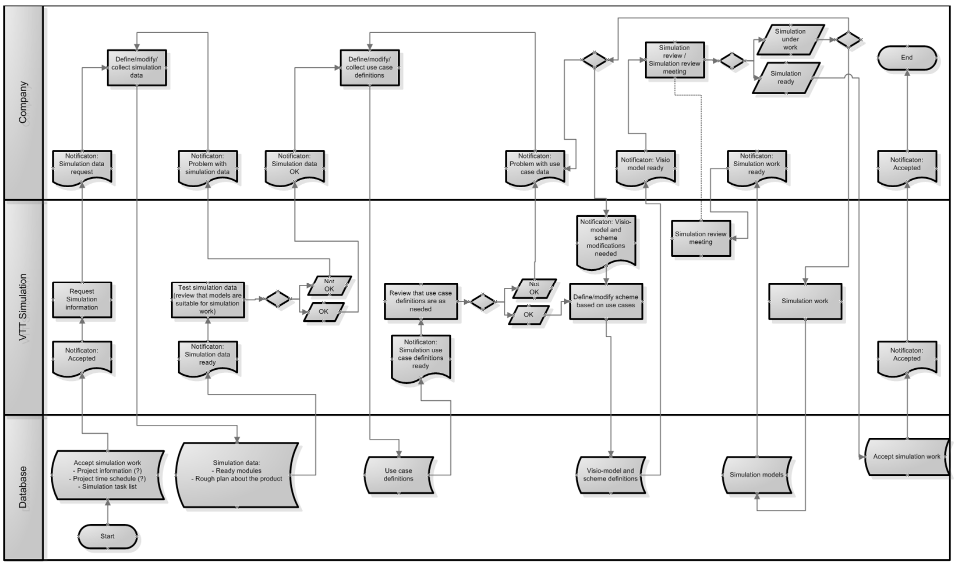

Figure 4. An example of CFF model which defines a collaborative PLM process of a virtual environment simulation model building project

Then VTT requests information for manual work analysis from the Company. This information contains use case, and task procedure descriptions which are stored in a common database. Based on these descriptions, VTT builds schemes to define exact model of work tasks, and they will be reviewed by the Company.

In the next phase it will be defined what actual analyses will be needed. Analyses can be, for instance, safety analyses, risk assessments, maintainability analyses, reliability analyses, etc. These analyses can be carried out using virtual environment simulation models which are stored in the database. After analysis work, review meetings, and iterations, all analysis results data, and information, as well as recommended actions are stored in the common PLM database, and linked to VE model. When improving manual work, the recommendations may include, for example actions for decreasing safety risks in the system, or change requests for better design for maintainability. This feedback can be delivered using the common PLM system.

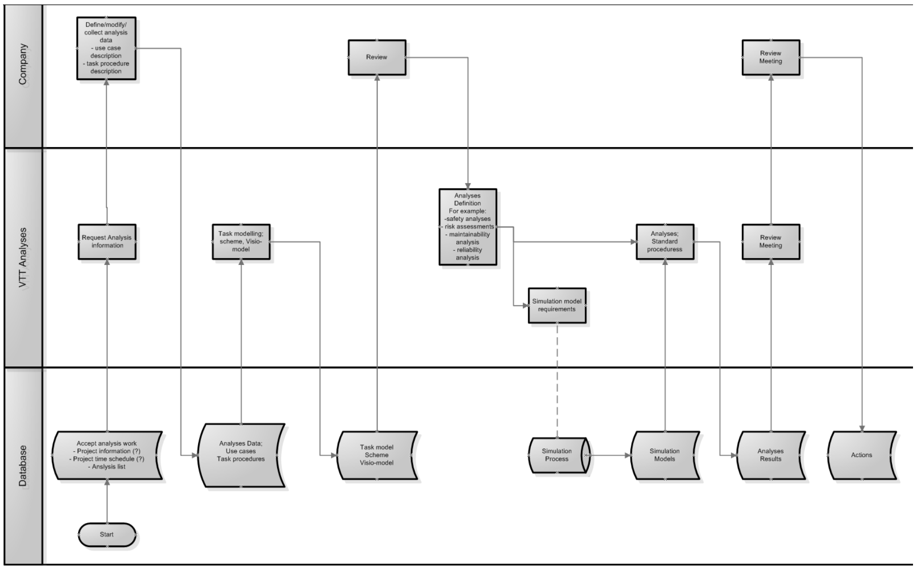

Figure 5. An example of CFF model which defines a collaborative PLM process of manual work task analysis project

5. Discussion and conclusions

Virtual environments (VE) are often seen as potential means for improving efficiency of product process, and decreasing amount of spent time, and money. VE's have also proved to be effective product development, and analysis tools. However, adopting a VE to a company's product processes, and PDM/PLM is a challenge [Stark 2006, Talaba 2008]. This paper aimed to propose how human factors and manual work design supported by novel VE tools and methods can be integrated into company product process and PLM. The paper based on results from two parallel studies, which focused on 1) applying virtual environments for analysis, and development of maintenance tasks, and 2) promoting use of PLM data in product design, and development.

As an outcome, this paper defined an example of information relating to how manual work task planning, and human factors can be integrated to PLM. In order to support industrial companies, the results propose a new procedure for planning, and analysing manual work tasks exploiting virtual environments. In addition, it paid attention also to definition, and modelling PLM processes in a systematic and practical way for building virtual environments, and extracting information for manual work development. The proposed procedure enable better information flow between product lifecycle stages, e.g. feedback from a maintenance worker to design engineers. It is enabled by using virtual prototyping, VE, participatory design of development groups, and PLM workflow processes as communication media. PLM processes were modelled using CFFs. The process modelling was based on present company processes, which were developed and modified in order to better meet requirements of applying virtual environments. Some preliminary demonstrations of realization

processes in PDM system were carried out. According to the experiences, and company feedback from senior experts and managers, this kind of approach could be beneficial in product development process. It could also help the companies to systemically identify, and define information that is required for product design, and task planning from the viewpoint of manual work.
The developed PLM model, and procedure were only applied in case studies of one company, but the model is generic, and potentially well applicable also for other companies', and organisation networks' processes. Of course, every companies' processes have to be modelled and PLM implementation tailored individually. These will be studied in the next research projects. Future work work will also focus on spreading this kind of PLM process modelling to other functions, and organisational networks, and value chains in full scale PLM implementation with process automation. In future projects, change management, and version management of CAD, and VE models will be interesting work. Another interesting topic is delivering different product information views, and product structures for various parties of networked PLM. Also the information flows between users, and designers regarding manual work will be enhanced so that relevant information can be identified, and extracted very early, and utilized in product design.

Acknowledgement

The contribution of the Virvo and Veps project members is greatly appreciated.

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Simo-Pekka Leino
Researcher
VTT Technical Research Centre of Finland, Systems Engineering
Tekniikankatu 1, 33101 Tampere, Finland
Telephone: +358407377184
Telefax: +358207223365
Email: simo-pekka.leino@vtt.fi
URL: http://www.vtt.fi